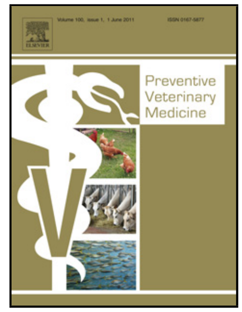
Accepted Manuscript



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Authors: I.M.G.A. Santman-Berends, A.J.G. De Bont-Smolenaars, L. Roos, A.G.J. Velthuis, G. van Schaik

PII:	S0167-5877(18)30194-6
DOI:	https://doi.org/10.1016/j.prevetmed.2018.05.013
Reference:	PREVET 4473
To appear in:	*PREVET*
Received date:	11-3-2018
Revised date:	18-5-2018
Accepted date:	24-5-2018

Please cite this article as: Santman-Berends IMGA, De Bont-Smolenaars AJG, Roos L, Velthuis AGJ, van Schaik G, Using routinely collected data to evaluate risk factors for mortality of veal calves, *Preventive Veterinary Medicine* (2018), https://doi.org/10.1016/j.prevetmed.2018.05.013

Using routinely collected data to evaluate risk factors for mortality of veal calves

I.M.G.A. Santman-Berends[a,*], A.J.G. De Bont-Smolenaars[a], L. Roos[a], A.G.J. Velthuis[a], G. van Schaik[a,b]

[a]GD Animal Health, PO box 9, 7400 AA Deventer, the Netherlands

[b]Department of Farm Animal Health, Faculty of Veterinary Medicine, Utrecht University, PO Box 80151, 3508 TD Utrecht, the Netherlands

[*]**Corresponding author:** Inge Santman-Berends

Department of Epidemiology, GD Animal Health, PO Box 9 7400 AA Deventer, the Netherlands

Tel.: +31570660546 ; Fax: +31570660354

E-mail: i.santman@gdanimalhealth.com

Abstract

From 2009 to 2012 a gradual increase in on-farm mortality of Dutch veal calves was observed. In 2012, the cattle industry decided that more information was needed on risk factors for mortality in both veal herds and herds of origin to enable implementation of risk mitigating measures. Routinely collected data were available from seven different data sources and contained information from 2.4 million white veal calves that were fattened in the period between 1 January 2011 and 30 June 2014. Survival analysis techniques (Kaplan-Meier), multilevel Poisson and multilevel Logistic regression models were applied to analyse the data. Two different models were assembled in which risk factors for veal calf mortality in respectively veal herds and herds of origin were identified. Univariable and multivariable regression techniques were used to detect risk factors significantly associated with mortality of veal calves during the fattening period. During the study period, the mean mortality was 4.9% per production cycle. The probability to die was highest during the first weeks after arrival in the veal herds and declined thereafter. Important risk factors included a veal herds with a higher use of antimicrobials, hair colour as proxy for breed, certain countries of origin, veal herd management with a limited amount of supplied feed and a not having an all-in / all-out system. A higher body weight at arrival in the veal herd was associated with lower mortality as well as veal calves that were fed an above median amount of milk, roughage and concentrates. From the calves that were fattened during the study period, observations of 1.1 million calves originated from the Netherlands and were available to study risk factors for veal calf mortality associated with the herd of origin. Important risk factors included purchase, herds with high mortality rates in the quarter in which the calf was born, fast growth in herd size, high cattle replacement rates and a higher antibiotic use in the quarter of birth. Calves that originated from herds that were certified BVD-free, Salmonella-unsuspected or Paratuberculosis-unsuspected, had a lower odds to die during the subsequent fattening period in a veal herd. Veal calf mortality was influenced by risk factors at the herd of origin as well as at veal herds. Adequate collaboration between the different industries is necessary to optimize veal calf management leading to a reduction in veal calf mortality during the fattening period.

Keywords: veal; dairy; calves; mortality; risk factors

1. Introduction

Annually, 5.8 million veal calves are fattened in Europe (Sans and De Fontguyon, 2009). With 1.6 million fattened veal calves per year, the Netherlands has one of the largest veal industries in Europe (Brscic et al., 2011; Sans and De Fontguyon, 2009). In this industry, surplus calves mostly born in dairy herds throughout Europe, are collected, fattened and eventually slaughtered. Given the fact that veal calves account for more than one-third of the total cattle population in the Netherlands, it is important to monitor their health. On population level, cattle health is monitored on a quarterly basis through the national cattle health surveillance system (CHSS) (Santman-Berends., 2016). One of the key-monitoring indicators in this system is mortality rate. Between 2009 and the end of 2012 a gradual increase in mortality rate of veal calves was observed in the CHSS. In the corresponding period, the policy with regard to antimicrobial use was altered, resulting in reduced possibilities to apply antibiotics in livestock followed by a tremendous decrease (>50%) in antimicrobial usage (SDa, 2014). It was hypothesized that this decrease in antibiotic use was associated with the increased mortality rate. Nevertheless, other potential causes were identified such as increased imports of calves persistently infected with BVDV, increased herd sizes and factors related to the herd from which the calves originated. Yet, even with all these potential conditions that might have led to an increased mortality in veal herds, the large between herd variation in veal calf mortality provided potential for improvement in herds with high mortality rates.

To enable the implementation of risk mitigating measures for veal calf mortality, more information was needed on risk factors associated with veal calf mortality. Although it is well known that diarrhoea and respiratory infections are the main causes of mortality among veal calves (Pardon et al., 2012; Hoet et al., 2003; Webster, 1990), the risk factors associated with occurrence of these disorders are ambiguous. Various studies describe pathogens as the cause of these problems such as Rotavirus, Coronavirus, BVDV and Cryptosporidium (Hoet et al., 2003; Bendali et al., 1999), but lack to describe management factors on which the farmer can intervene. There have been studies that described factors associated to either diarrhoea, respiratory syndromes or both. These factors include colostrum intake (Lorenz, 2006; Perez et al., 1990), BVDV (Pardon et al., 2013 and 2012), weight at arrival in the veal herd (Brscic et al., 2012), housing (Brscic et al., 2012; Lorenz, 2006) and type and amount of feed (Brscic et al., 2012). Nevertheless, it is unknown to which extent these risk factors for diarrhoea and respiratory syndromes are associated to veal calf mortality and whether these results are applicable to the white veal industry in the Netherlands. Additionally, this information does not provide insight in the combination of factors related to both the veal herd and the herd of origin that are associated to mortality.

Therefore, the aim of this study was to evaluate risk factors in veal herds and in the herd in which the calves were born that are associated with mortality of veal calves.

2. Material and Methods

A retrospective cohort study was carried out exclusively focusing on white veal calves in the Netherlands. White veal calves mainly consists of superfluous dairy calves (sometimes calves from suckler herds) that are transported to veal herds at an age of on average eighteen days. First, the calves are housed individually until an age of eight weeks after which they are held in group housing. Milk is the most important nutrition throughout the calves' life and at the age of approximately six months the white veal calves are slaughtered.

2.1 Study population

Data were available from all white veal calves that were fattened by four veal cooperations from 1 January 2011 to 30 June 2014. Cooperations were selected on the inclusion criteria that they had to digitally register data of their white veal herds and on an individual animal level during the complete study period. Additionally, they had to be willing to share their data for the study. Eventually, the delivered data consisted of records of 657 white veal herds, which represented around 70% of the total white veal herd population in the Netherlands.

2.2 Data

At onset, an inventory was conducted to evaluate which parameters were hypothesized to be of interest for inclusion in this study and were available in routinely collected datasets. Data were available on either individual level, level of the production cycle or at herd level. For this study, animal movement data (Identification and registration database) and data concerning the body weight at arrival in the veal herd were available on calf level. On the level of the production cycle, the amount of feed supplied, the veal herd system (all-in / all-out) and data about the amount of antibiotics that were supplied were provided. The production cycles were based on registrations of the veal industry that provided the production cycle number for each individual calf. The same production cycle number was given to a group of calves housed in either the same herd (all-in/ all-out) or in a barn in which all calves had approximately the same age.

At the herd, level information about the compliance to critical control points set by the veal branch organisation were accessed (Table 1). Additionally, information about the herd of origin was obtained for calves born in the Netherlands. This information consisted of the herd health status, mortality rates in the quarter of the year in which the calf was born and animal movement data in the herd of origin. For the calves that were imported, only the country of origin was available (Table 1). Additionally, information about the geographical location of the veal herds and meteorological records were available for the study period.

2.3 Data validation

To each data supplier anonymity was guaranteed and the delivered data were send to and encrypted by an external firm (IntoFocus Data Transformation Services (IDTS), Deventer). This firm encrypted all variables in the data that might link the data back to the original source, such as the Unique Herd Identification number (UHI) of the farm, number of the production cycle and the unique identification code of individual animals (Animal ID). The same encryption code was used for all datasets to ensure that data of the different data sources could be combined for analysis. Thereafter the data were send to the researchers for validation and analysis.

The level of detail of the data and the number of observations varied depending on the source of the data and the level of aggregation (Table 1). Software scripts in SAS 9.3® (SAS institute, 2010) were developed to combine the different datasets and to validate the data. Observations with non-existing animal identification numbers and records with unlikely values (such as starting weights of 0 kilograms or negative amounts of feeds) were set to removed.

The body weight of the calf at arrival was either estimated based on the difference in weight between the empty and full truck divided by the number of calves in that truck (95%) or known based on weighing each individual calf at arrival in the veal herd (5%). The amount of feed was provided as total amount of concentrates, roughage (sometimes further specified to, for example, amount of corn silage and straw) and milk powder in kilograms per production cycle. Based on this information the amount of feed per calf per day in that specific production cycle was calculated by dividing the total amount per type of feed by the number of calf-days in the herd. The latter was defined as the number of calves in the herd multiplied by the number of days that each calf was present.

Daily regional measures of humidity and temperature were obtained from the Royal Netherlands Meteorological Institute (KNMI, Zeist the Netherlands) during the study period. For each veal calf, the daily meteorological results from the month of birth from the nearest weather station (there are 50 weather stations in total) were downloaded from the national database (KNMI, 2016) and were averaged to a monthly measure that was used as an explanatory variable in the models.

2.4 Statistical analyses

For the analysis, Stata® version 14 (Stata Corporation, 2014) was used. Descriptive statistics were applied to present the data. An attempt was made to apply survival analysis techniques on the data. Survival time was defined as the time between entry in the veal herd and either death or the end of the follow up period i.e. the date of slaughter. White veal calves are slaughtered between 180 and 200 days of age thus the maximum study duration was set at 200 days. Observations of calves that outlived this period, were censored at 200 days. The Kaplan-Meier survival function in Stata (Stel et al., 2011; Kaplan and Meier, 1958) was used to determine the daily hazard rate, conditional on having survived until that specific day. Parameters such as mortality rates, probability of survival and the cumulative probability of dying were presented using life tables. Univariable associations between mortality rate and potential confounders were described using Kaplan-Meier survival curves. Cox proportional hazard frailty models were evaluated to test the association between potential risk factors and the time to survive, correcting for the hierarchical structure of the data. The attempt to correct for within herd clustering combined with the large number of observations lead to non-converging models and thus survival analyses seemed unfeasible for multivariable analysis of our data. Therefore multivariable regression techniques were applied for analysis of the data and it was decided to build two different models. The first model evaluated risk factors for veal calf mortality in veal herds and was conducted at the level of production cycle. The second model assessed risk factors for veal calf mortality associated with the herd of origin and was conducted on animal level. The latter was exclusively conducted on observations from veal calves originating from the Netherlands because information about the herd of origin was only available for Dutch calves.

2.4.1 Risk factors in veal herds

Multilevel Poisson regression models were used to determine the associations between veal herd risk factors and mortality at the level of production cycle. The number of deaths within each production cycle were included as dependent variable and the number of calves that entered the production cycle was incorporated as exposure. The UHI was included as random variable to correct for clustering within herds. First, all potential risk factors were univariably pre-screened and parameters which were significantly associated with the mortality rate (*P*-value < 0.05) entered the multivariable model. The final multivariable model was selected using a forward selection and elimination method in which every round the variable with the lowest *P*-value was added until all variables in the model were significantly (*P*-value<0.05) associated with the outcome and adding additional variables did not result in a significant improvement of the model (non-significant in the likelihood ratio test). Significance of relevant two-and three-way interaction terms and the amount of variance that was explained by the final multivariable model were assessed. Additionally, confounding was checked by evaluating the change in model coefficients after introduction of possible confounders (e.g. age at arrival as possible confounder for body weight at arrival). If the introduction of the confounder resulted in a substantial (>25%) change in coefficients of significantly associated variables, the variable was retained. Otherwise the variable was removed from the model. In the final model, the different classes of categorical variables were presented relative to the average of the complete study population.

2.4.2 Risk factors in the herd of origin

The risk factors in the herd of origin were evaluated on animal level because they were available for each calf individually. Again, the number of observations was too large for a Cox proportional hazard frailty model. Therefore, it was decided to use a logistic regression model in Stata® 14 in which mortality (yes/no) was included as dependent variable and potential risk factors as independent variables. In this model, we included the UHI from the veal herd as random variable to account for clustering of calves and for variability in mortality that was associated with the veal herd. Univariable pre-screening at P-value < 0.05 was conducted. The remaining variables were used to construct the final model using a forward selection procedure.

3. Results

After combing and validating the data, records of approximately 2.4 million veal calves that were fattened during the study period from 3,127 production cycles fattened in 657 different white veal herds where available for analysis. These calves represented more than 60% of the total white veal population in the Netherlands.

3.1 General description of the study population

From the population of 2.4 million calves that entered the veal herds from January 2011 to July 2014, 110,938 calves died before slaughter (Table 2). Corrected for censoring of calves that were removed from the herd before the moment they were slaughtered, resulted in a mean mortality rate of 4.9% per production cycle (Table 2). The median mortality rate was 4.3% per production cycle with an interquartile range (25^{th}-75^{th} percentile) ranging from 3.1% to 5.7%.

Veal calves that originated from Dutch cattle herds (58% of the study population) arrived in the veal herds at an average age of 17 days. Imported calves (42% of the study population) were on average 21 days old at arrival. The probability to die was highest during the first weeks after arrival in the veal herds, with a peak mortality rate between the first and second week and a declining rate thereafter (Table 2, Figure 1).

The probability to survive (1-mortality rate) the fattening period was highest in 2011 with 95.3% and lowest in 2012 with 94,9%. After 2012, the probability to survive the fattening period increased again (Figure 2). The difference in survival rate between 2011 and the following years arose in the first 60 days after arrival and remained stable during the remaining period. The higher survival rate in 2013 and 2014 compared to 2012 was observed in the second half of the fatting period (120 to 200 days) (Figure 2).

3.2 Risk factors in veal herds

In total, 83 potential risk factors for veal calf mortality that were related to the veal herd were evaluated. Out of these, 52 were significantly associated with calf mortality of which 30 variables were related to compliance (yes, no or not applicable) with critical control points defined by the branch organisation. Eleven variables were excluded from the multivariable model because of an insufficient number of observations (n<5) in one of the categories. Additionally, seven variables were highly correlated (r>0.6) with other variables and of those only the variables that were highest associated with the dependent variable were retained for inclusion in the initial multivariable model. From the 34 variables that entered the multivariable multilevel model selection process, 20 variables were significantly associated with the mortality rate. Additionally, the random herd-effect was significant. The final model included 2,236 production cycle observations from 567 veal herds and had a pseudo R^2 of 0.84.

The risk factors that were significantly associated with a higher mortality rate during the fattening period were a higher use of antimicrobials, hair colour as proxy for breed, country of origin, not having an all-in/all-out system, and the answer ‘not applicable’ at the critical control point “Medicines are stored in a closed cabinet or room separated from animals and feed” (Table 3). Veal calves that had a limited supply of feed had a higher mortality rate whereas being fed more than the median amount of milk and roughage was associated with a significantly lower mortality rate. Additionally, being born in the summer or autumn appeared to be associated with a higher mortality ratio (IRR=1.05 and 1.03, respectively), whereas born in winter and spring were associated with a lower risk (IRR=0.97 and 0.95, respectively) when corrected for temperature and humidity. Further, a higher body weight at arrival in the veal herd was associated with a lower mortality rate. Per kilogram increase in initial body weight, the incidence rate ratio was 0.98 (corresponds to 1.02 times lower mortality). Thus veal calves from a certain production cycle with an average weight at arrival of 48 kilograms had a 1.13 times lower mortality rate during the fattening period than calves from a cycle with an average weight at arrival of 42 kilograms. Finally, veal herds in which the predominant breed was Belgian Blue (based on the hair color), had a mortality rate of 0.77 compared to the population average.

3.3 Risk factors in the herd of origin

Observations of 1.1 million calves that were fattened during the study period and were born in the Netherlands were available for inclusion in the model. The majority of these calves originated from dairy herds (98%), followed by suckler cow herds (2%) and other herds (0.2%). In total 13 parameters were evaluated for their potential association with calf mortality. Twelve parameters and the random herd effect correcting for clustering within veal herds remained in the final model (Table

4). The final model included 852 thousand records from calves originating from more than 10 thousand different herds that were eventually fattened in 607 different veal herds.

The association between the size of the herd of origin and mortality was inconsistent. Purchase of cattle into the herd of origin on or prior to the date the calf was born was associated with a higher mortality odds during the subsequent fattening period (Table 4). Herds with high mortality rates in the quarter in which the calf was born (both in calves and older cattle), fast growth in herd size, high cattle replacement rates and a higher antibiotic use in the quarter of birth were also associated with a higher odds for mortality during the fattening period (Table 4).

Calves that originated from herds certified BVD-free, Salmonella-unsuspected or Paratuberculosis-unsuspected, had a lower odds to die during fattening compared to calves that originated from herds with an unknown status for these diseases. Originating from a herd that was certified IBR-free was associated with a higher odds to die during fattening (Table 4).

4. Discussion

In this study, many risk factors were identified for veal calf mortality during the fattening period, both related to the veal herd and the herd of origin. The mortality per production cycle varied between 4.7% and 5.1% during the study period and was in the same range as previous studies on mortality in veal calves. In an Italian study conducted by Brscic et al (2009), mortality rates per production cycle varied between 2.8 and 6.9%, and in Switzerland a mortality rate of 3.6% was found (Bähler et al., 2012). Furthermore, Pardon et al (2012) found that mortality rates were on average 4.9% per production cycle in Belgium veal herds. Additionally, we found that the gradual increase in mortality rate that was observed in the period before the initiation of this study, stabilized during the study period. The highest mortality rates in veal calves were observed in 2012 and declined thereafter. The decreased probability of mortality appeared to occur in the second half of the fattening period, indicating that the reduction was associated with veal calf management rather than management in the herd of origin.

Our study confirmed some risk factors already determined in previous studies, but also detected new risk factors. One of the most important factors in our model was the body weight of calves at arrival, with a higher starting weight being associated with a lower mortality. We checked whether the association between mortality and body weight would change when we corrected for age at arrival as confounder, but no change in association was observed. Our results were in agreement with the results of Brscic et al. (2012), who found that a lower weight at arrival was associated with an increased risk to develop respiratory infections, which is an important cause for mortality. Additionally, both Winder et al. (2016) and Brickell et al. (2009) found that a lower body weight at arrival in the veal herds was associated with an increased risk to die in the first six months. Veal calves of the Belgian Blue breed had a lower mortality risk than other breeds of calves in our study. Even though, these calves might have a higher body weight at arrival, the lower mortality risk was also observed when we corrected for weight at arrival as confounding factor. It was hypothesised that the lower mortality rate was due to the fact that Belgian Blue calves are very valuable resulting in application of additional care to maximise the probability of survival. This hypothesis was further supported by the fact that the veal cooperations stated that they only select specific farmers for fattening Belgian Blue calves.

Another known risk factor that was found in our study was purchase of cattle. Both in the herd of origin as in the subsequent veal herd (herds without an all-in/all-out system), purchase was a risk factor for a higher mortality rate. This finding was in accordance with previous studies of Pardon et al. (2012) and Gordon and Plummer (2010), who found that purchase resulted in a higher risk for respiratory infections during the fattening period, which consequentially may result in a higher mortality risk. The Kaplan-Meijer survival curve showed that the detrimental effect of purchase i.e. not having an all-in/all-out system, occurred from day 40 after arrival in the veal herd and onwards (results not presented). Generally, after this moment a new production round of calves enter the veal farm without all-in/all-out system resulting in an increased risk of introduction of infections and increasing the mortality risk. The significant association between veal calf mortality and number of calves in the specific production cycle that was found in this study was incoherent as both the smallest and largest veal herds were protective factors, whereas the size groups in between had a higher risk. Moreover, the association between veal calf mortality and the information from the critical control points was ambiguous. The answers could either be yes the farm complies with the demand, no the farm does not comply or not applicable. For most points, the answer “no” did not occur and the answer “not applicable” was significantly associated with the mortality rate. Nevertheless, information about the rationale behind this answer was not provided and might differ between farms.

In our study, a higher use of antibiotics in either the veal herd or the herd of origin was associated with a higher mortality rate. Both results indicate that health problems, either during the first weeks after birth or during the subsequent fattening period are associated with a higher probability to die during the fattening period. This finding is supported by earlier research of Jarrige et al. (2017) and Bähler et al. (2012), who both found that antibiotic treatment was associated with higher mortality. In the Netherlands, prophylactic use of antibiotics is forbidden and a higher use of antibiotics is thus an indication for increased health problems that result in a higher mortality rate. Moreover, a higher use of antibiotics might result in antibiotic resistance in time, which can deteriorate the possibility to treat infections and thus increase mortality (Hoet et al., 2003; Bos et al., 2012). Furthermore, we also observed that calves originating from herds with a higher health status for endemic diseases (i.e. BVDV, Salmonella, Paratbc), had a lower probability to die during their subsequent fattening period.

Providing a higher than median amount of either milk and roughage or all three types of feed (milk, roughage and concentrates), was associated with a lower mortality rate. Additionally, application of a lower than median amount of milk and roughage or all three types of feed was associated with higher mortality. Previous study already stressed the importance to provide sufficient amount of feed, especially when diarrhoea problems occur (Lorenz, 2006). In our study we were only able to distinguish concentrates and roughage and were unable to specify the feed on a more detailed level. Based on previous studies, not only the amount of feed but also the specific feed that is administered is indicated to be associated to health problems and mortality (Webb et al., 2013; Berends et al., 2012; Brscic et al., 2011). Although no comprehensive conclusion about the risk of certain types of feed can be drawn, it seems that a certain amount of roughage supports the development of the rumen and have a positive effect on calf health.

Unexpectedly, born in winter was not associated with an increased mortality while earlier studies found this birth season to be a risk (Bendali et al., 1999; Bscic et al., 2012; Winder et al., 2016). When we excluded the humidity and temperature from our model, we did find winter to be a risk factor. We therefore argue that it is not the season itself, but the weather conditions in that specific season that are associated with mortality.

To our knowledge, this study was the first that studied risk factors for veal calf mortality during fattening related to both the veal herd and the herd of origin. This approach offered additional insight compared to research that only evaluated risk factors during the fattening period. Nevertheless, there was still one factor missing in our study of which it is known that it influences health of veal calves, namely transport to the veal herd. We evaluated the possibilities to include such information, but at the time of the study, data of the transporter was not yet centrally registered. Nevertheless, given the strict regulations regarding transport on both European and national level (EC, 2005; IKB, 2008), we assumed that the variation in quality of transport was limited and thus that transported played a minor role compared to factors related to management in the herd of origin and the subsequent veal herd.

Ideally, both risk factors related to herds of origin and risk factors related to veal herds would be included in the same model. However, this was impossible due to a lack of background information from calves that were imported (in this study 42% of the veal calves). Additionally, while most of the information of the veal calves during the fattening period were available at the level of the production cycle, the information of the herd of origin (if born in the Netherlands) was available on individual level. This enabled more detailed evaluation of risk factors for veal calf mortality associated with the origin of the calves. For selection of the most appropriate model, both multilevel Poisson regression and negative binomial regression models were evaluated. Both regression models resulted in the same final model and because the model with the log-linear distribution showed the best fit to the data, it was decided to present those results in this paper.

For this analysis, only routinely collected data was available. The advantage of this type of data is the possibility to include a large number of observations resulting in a high analytical power. However, a drawback is that we could not include factors that are hypothesized to be important but that were not available from central databases. Such factors include for example quality and amount of colostrum received by the calves (Perez et al., 1990; Lorenz, 2006; Osorio and Drackley, 2010), housing (Lorenz, 2006; Brscic et al., 2012) and climate in the barn (Lorenz et al., 2011; Bähler et al., 2012). It is therefore commendable to collect additional management data to evaluate the importance of the factors that were observed in this study compared to management factors that are not present in generic big datasets.

5. Conclusion

The large dataset allowed detection of many risk factors associated with mortality of veal calves during the fattening period. Both factors in the herd of origin and the veal herds were found to influence mortality during the fattening period. Adequate collaboration between the different industries is necessary to optimize veal calf management leading to a maximal reduction in veal calf mortality during the fattening period.

Acknowledgements

This study was funded by the organisation of the Dutch dairy supply chain (ZuivelNL/DairyNL, the Hague the Netherlands) and the Dutch Calf Industry Association (Stichting Brancheorganisatie Kalversector (SBK), Nieuwegein). The authors would like to thank the data suppliers that delivered the data for this study and E. Damen for her participation in this study.

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Figures captions

Figure 1. Distribution of mortality age of white veal calves in the Netherlands. De vertical line represents the average age (in days) at which calves arrive in the veal herd.

Figure 2. Kaplan-Meier survival curve describing the probability (with 95% confidence interval) of survival for white veal calves during the 200 day fattening period per year, between January 2011 and July 2014 in the Netherlands.

Figure 1

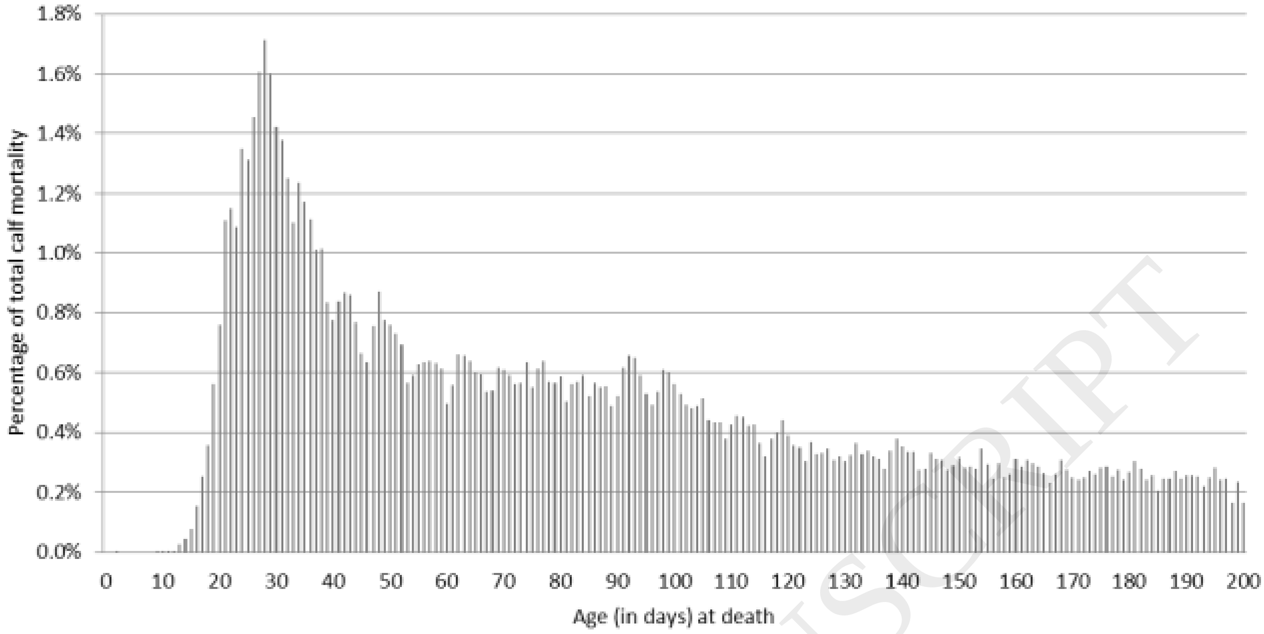
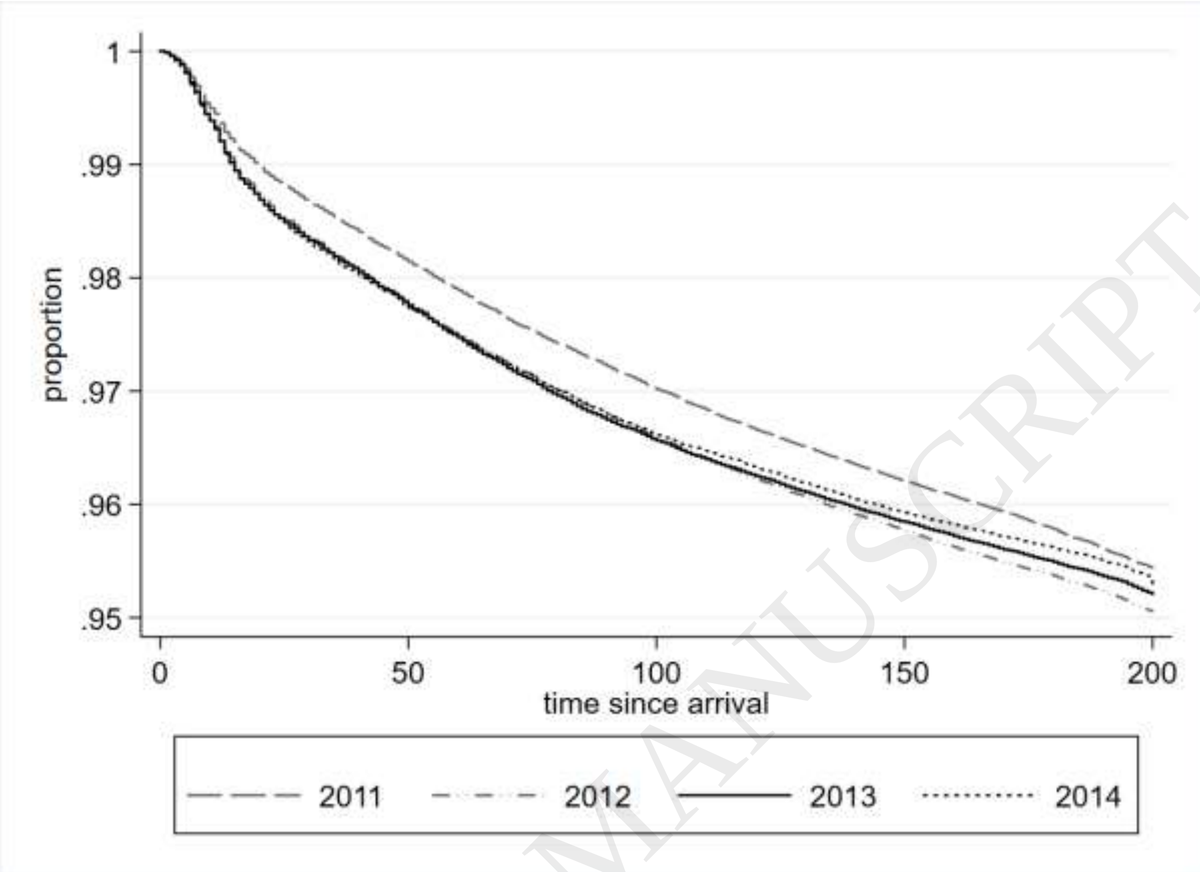

1.8%
1.6%
1.4%
1.2%
1.0%
0.8%
0.6%
0.4%
0.2%
0.0%
Percentage of total calf mortality
0 10 20 30 40 50 60 70 80 90 100 110 120 130 140 150 160 170 180 190 200
Age (in days) at death

Figure 2



1
.99
.98
.97
.96
.95
proportion
0
50
100
150
200
time since arrival
2011
2012
2013
2014

Tables

Table 1. Description of the study data, with the potential risk factors for mortality of white veal calves in the Netherlands between 1 January 2011 - 30 June 2014.

Potential risk factors	Data-set and source	Level of the data
Purchase, import, number of calves in the specific production cycle, origin of the calf, fur colour, age at moment of arrival, factors associated with the herd/ country of origin (e.g. mortality in period in which the calf was born, purchase, herd size, replacement, birth date)	Identification and registration data; Dutch enterprise agency (RVO), The Hague	Location per animal
Body weight at arrival, amount of feed fed during the fattening period (categorized into one of three groups: concentrates, roughage or milk powder), continuous arrival and removal of calves vs. all-in/ all-out	Multiple white veal cooperations, the Netherlands	Animal
Compliance to each of the critical control points that are agreed upon by the veal industry.	IKB Calf, Branche organisation veal calves (SBK), Nieuwegein	Herd per year
Production cylce number, start and end date of the production cycle, Daily Defined Doses of antibiotics supplied to veal calves fattened together and Daily Defined Doses of antibiotics supplied to the herd divided into three classes i.e. Antibiotics, last resort antibiotics and antibiotics critically important for human medicine according to van Hout et al., 2016.	InfoKalf, Nieuwegein and MediRund, The Hague	Production cycle and per delivery and date
Herd health status, based on GD Animal Health data, of herd of origin i.e. BVDV, IBR and Salmonella.	GD Animal Health, Deventer	Herd per quarter
Temperature and humidity (mean, minimum and maximum) in the postal code of birth in the month of birth	Meteorological data: Royal Dutch Meteorological Institute (KNMI), The Hague	Two-digit level per month
Location data	GD Animal Health, Deventer	Two-digit level per quarter

Table 2. Life table at month level to describe the survival of white veal calves in veal herds during the fattening period from January 2011 to July 2014 in the Netherlands

Time since arrival (months)	Number of calves at risk	Number of deaths	Number of censored calves	Probability of survival	Cumulative probability of mortality (presented as percentage)	Probability of mortality per month (presented as percentage)
0-1	2,402,510	38,051	21	0.984	1.6%	1.6%
1-2	2,364,438	19,865	52	0.976	2.4%	0.8%
2-3	2,344,521	17,424	384	0.969	3.1%	0.7%
3-4	2,326,713	12,623	1,318	0.963	3.7%	0.6%
4-5	2,312,772	10,237	7,813	0.959	4.1%	0.4%
5-6	2,294,722	9,195	418,321	0.955	4.5%	0.4%
>6	1,867,206	3,543	1,863,663	0.951	4.9%	0.4%

Table 3. Results of the multivariable multilevel Poisson regression model of the association between veal calf mortality during the fattening period and risk factors associated with the veal herd between January 2011 and July 2014 in 2,236 production cycles at 567 white veal herds with complete data in the Netherlands.

Parameter	Median and inter quartile range (continuous variables) or % of occurrence (categorical variables)	IRR	95% confidence interval	P-value (Z-test)
Antimicrobial usage in the specific production cycle				
Defined Daily Dose of antibiotic use [a]	22,0 (18-27)*	1.004	1.003-1.005	<0.001
Defined Daily Dose of use of last resort antibiotics	3,8 (0,6-8,3)*	1.012	1.010-1.014	<0.001
Defined Daily Dose of use of antibiotics critically important for human medicine	0 (0-0,2)*	1.022	1.012-1.032	<0.01
Mean temperature in birth month	10,6 (5,9-14,8)*	0.984	0.980-0.988	<0.001
Mean humidity in birth month	81,4% (77-86%)*	0.995	0.993-0.998	<0.001
Season at moment of birth [b]				
Winter	28,3%	0.97	0.95-1.00	0.06
Spring	27,3%	0.95	0.93-0.97	<0.001
Summer	23,0%	1.05	1.02-1.08	<0.001
Autumn	21,5%	1.03	1.01-1.05	0.01
Average body weight at arrival	46,2 (43-50)*	0.98	0.977-0.984	<0.001
Prominent hair colour [b]				
Belgian Blue	15,4%	0.77	0.73-0.81	<0.001
Other	1,0%	1.05	0.29-1.15	0.29
Red and white	11,4%	1.09	1.04-1.13	<0.001
Black and white	72,3%	1.14	1.10-1.18	<0.001
Predominant country of origin of the calves in the production cycle [b]				
The Netherlands	57,7%	0.99	0.96-1.02	0.48
Germany	22,8%	0.94	0.91-0.96	<0.001
Belgium	1,4%	1.11	1.02-1.20	0.01
Poland	6,3%	1.08	1.05-1.12	<0.001
Lithuania	3,8%	1.09	1.04-1.13	<0.001
Other	8,0%	0.83	0.80-0.86	<0.001
Feeding strategy [b,c]				
< median concentrates/milk/roughage	10,9%	1.09	1.06-1.12	<0.001
< median concentrates/ roughage, > milk	13,8%	0.99	0.96-1.01	0.39
< median milk/roughage, > concentrates	16,1%	1.02	1.00-1.05	0.03
< median milk/concentrates, > roughage	8,0%	0.99	0.96-1.02	0.56
< median roughage, > milk and concentrates	5,7%	0.98	0.95-1.01	0.31
< median concentrates, > milk and roughage	15,7%	1.00	0.97-1.02	0.75
< median milk, > concentrates and roughage	13,3%	0.98	0.95-1.00	0.05
> median milk, concentrates and roughage	8,8%	0.95	0.92-0.99	<0.01
Not included due to incomplete data because of an incomplete fattening period	7,8%			
System				
All-in/ all-out	89,9%	Ref.		
Continuous entry and removal of calves	10,1%	1.15	1.03-1.29	0.01

Number of nationalities per production cycle	2 (1-3)*	1.02	1.01-1.03	<0.01
Number of calves in the production cycle[b]				
<468 calves	24,9%	0.99	0.95-1.03	0.60
≥468 -<700 calves	25,0%	1.00	0.97-1.04	0.86
≥700 - <974 calves	25,0%	1.05	1.02-1.08	<0.01
≥974 calves	25,1%	0.95	0.92-0.98	<0.01
Critical control points				
Presence of a herd health plan [d]	No	0.92	0.88-0.96	<0.001
Part of the barn is equipped as resting area and is accommodated with a wooden slattered floor, or rubber/synthetic top layer [d]	N.A.	0.94	0.90-0.98	<0.01
Medicines are stored in a closed cabinet or room separated from animals and feed [d]	N.A.	1.25	1.11-1.40	<0.001
Surface per calf in the group housing meets the minimum requirements [d]	No or N.A.	0.98	0.97-0.99	<0.001
Cleaning and disinfectant products are stored in a closed cabinet or room separate from medicines, animals and feed [d]	No or N.A.	0.95	0.93-0.97	<0.001
Eventual abnormalities due to administering medicines are notified to the slaughterhouse [d]	N.A.	0.92	0.86-0.98	0.01
All feed originate from GMP+ certified feed suppliers [d]	N.A.	0.87	0.78-0.97	0.01
Cluster (UHI)		0.07	0.06-0.08	<0.001

[a] The Defined Daily Dose of antibiotic use is a standardized measure that is used to present the antibiotic use in a comparable way for all animal species and it refers to the number of days each calf is treated during a specific period (such as fattening period).
[b] The average of the complete study population is included as reference
[c] < median: the calves were fed less than the median amount of the specific type of feed per day, > median: the calves were fed more than the median amount of the specific type of feed per day. Median amount of product in kg per calf per day throughout the whole production cycle: concentrates 0,79; milk powder 1,70; roughage 0,14
[d] The answer category "Yes" is included as reference category
*Median and interquartile range

Table 4. Results of the multivariable multilevel logistic regression model of the association between veal calf mortality during the fattening period and risk factors associated with the herd of origin based on 852,462 Dutch veal calves that were fattened in the period between January 2011 and July 2014.

Parameter	Descriptive result	OR	95% confidence interval	P-value (Wald-test)
Number of cows (>2 years old) in herd of origin [a]				
Smallest herds (≤74 cows)	25%	1.02	1.00-1.04	0.10
Smaller herds (>74 - ≤ 102 cows)	25%	1.01	0.99-1.03	0.29
Larger herds (>102 - ≤ 140 cows)	25%	0.97	0.95-0.99	<0.001
Largest herds (> 140 cows)	26%	1.01	0.99-1.03	0.55
Purchase of cattle in the previous year				
No	49%	Reference		
Yes, 1 or 2 animals	13%	1.05	1.01-1.08	<0.001
Yes, more than 2 animals	38%	1.05	1.02-1.07	<0.001
Herd type				
Dairy	98%	Reference		
Suckler cow herd	2%	1.18	1.10-1.28	<0.001
Other	0.2%	1.36	1.11-1.67	<0.001
Mortality in cattle (>1 year) in herd of origin in the quarter of birth [a]				
None	46%	0.99	0.97-1.01	0.41
Low mortality ≤0.45%	4%	0.98	0.94-1.02	0.33
Higher mortality >0.45 - ≤1.08	25%	0.98	0.96-1.00	0.13
Highest mortality >1.08%	25%	1.04	1.02-1.07	<0.001
Mortality of ear tagged calves <1 year in the herd of origin in the quarter of birth [a]				
None	41%	0.95	0.93-0.96	<0.001
Low mortality ≤ 2%	9%	0.96	0.93-0.98	<0.001
Higher mortality >2 - ≤ 4.8%	25%	0.98	0.97-1.00	0.08
Highest mortality > 4.8%	25%	1.12	1.10-1.14	<0.001
BVDV status				
Unknown	75%	Reference		
Free	25%	0.93	0.91-0.96	<0.001
IBR status				
Unknown	76%	Reference		
Free	24%	1.03	1.00-1.05	0.04
Paratuberculosis				
Unfavourable (cows in herd have been tested positive)	25%	Reference		
Unsuspected	75%	0.97	0.94-0.99	0.01
Salmonellosis				
Unknown	67%	Reference		
Unsuspected	33%	0.96	0.94-0.98	<0.001
Annual cattle replacement rate [a]				
Lowest ≤20%	28%	0.95	0.93-0.96	<0.001

Lower >20% - ≤24%	26%	1.00	0.98-1.02	0.80
Higher >24% - ≤28%	24%	1.02	1.00-1.04	0.05
Highest >28%	22%	1.04	1.02-1.06	<0.001
Growth in herd size				
Lowest ≤ -1.7%	22%	0.99	0.97-1.01	0.32
Lower > -1.7% - ≤ 3.3%	24%	0.97	0.96-0.99	0.01
Higher > 3.3% - ≤ 8.7%	26%	1.00	0.99-1.02	0.71
Highest > 8.7%	27%	1.03	1.01-1.05	<0.001
Defined Daily Dose of antibiotic use in quarter of birth in calves <56 days	0 (0-0.04)*	1.05	1.03-1.08	<0.001
Cluster (UHI veal herd)		0.05	0.05-0.06	<0.001

[a]The average of the complete study population is included as reference,