Review of Syndromic Surveillance Systems Based on Livestock Abattoir Data

Writing Assignment

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One Health MSc

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Abstract

This review examines existing literature on veterinary syndromic surveillance (SyS) utilizing livestock abattoir data with the aim to consider its application in Thailand. A systematic search revealed seven studies employing SyS based on abattoir data. Time series analysis is the common approach on which all seven studies rely, but there is diversity in the modeling methods employed. The studies utilized either whole carcass condemnation (WCC) or partial carcass condemnation (PCC) recorded at abattoirs as their key indicators. Factors contributing to their baseline models and the modeling methods were described and compared in this study. Seasonal effects and time trends are assessed for their relationship with WCC and PCC in all these studies, along with other factors such as total number of cattle, price of meat, size of abattoir, etc., depending on their assumptions and designs. The comparison of detection algorithms is limited as only two studies validated outbreak detection algorithms with simulated outbreaks. Challenges of SyS with abattoir data are identified as the lack of timeliness and data standardization, while the benefit is good area coverage. The potential implementation of SyS with abattoir data in Thailand was discussed in the discussion part of this study. The abattoir data in Thailand is already centralized, so almost 100% data coverage can be achieved, but data standardization is a challenge in the country. Future studies are suggested to further explore outbreak detection and its performance, as well as finding methods or strategies to overcome challenges.

Layman's summary

Livestock products are essential as a food source for the human population. To ensure continuous production, it's crucial to prevent diseases in livestock. Veterinary surveillance systems were developed to detect diseases in animals, allowing for control measures to be implemented during outbreaks. Syndromic surveillance (SyS) emerged as a tool to detect outbreaks or diseases by analyzing digitized data, enabling earlier detection compared to traditional methods reliant solely on direct disease searching and discovery. This review focuses on SyS based on data from livestock abattoirs, which typically collect data from meat inspection results. The use of such SyS for Thailand is discussed

The methodology involved searching databases for articles related to veterinary SyS using abattoir data to examine existing research and identify patterns, gaps, and future research directions. Seven relevant studies were found, primarily analyzing Whole Carcass Condemnation (WCC) and Partial Carcass Condemnation (PCC) data, which are decision-making results in the meat inspection process indicating whether the meat is unfit for human consumption for the whole carcass, or for some part of it, respectively.

These studies employed various statistical models, utilizing diverse versions of time series analysis, to identify patterns and trends in the normal rates of WCC and PCC. Their findings show the significant effects of season on both WCC and PCC. Only two studies validated outbreak detection algorithms, showing promise for application in future outbreak detection efforts.

Utilizing abattoir data for SyS comes with challenges and benefits. Challenges include potential delays in outbreak alerts because the signals of outbreaks are detected only when animals are slaughtered, and subjective decision-making on condemnation and thus variation in the inspection process. However, the benefits of utilising abattoir data include wide area coverage. Additionally, when information about the origin of animals is available, detailed analysis of the outbreak locations becomes possible.

This study discusses the challenges and benefits of implementing SyS using abattoir data in Thailand. The country mandates abattoirs to collect and report WCC and PCC monthly, forming centralized data for potential analysis. However, the variability in practices among abattoirs poses challenges for standardization and reliability of the data.

In conclusion, while challenges exist in utilizing abattoir data for SyS, it presents valuable opportunities for improving disease surveillance in livestock populations. Addressing issues of promptness, data quality, and standardization is crucial for realizing the full potential of SyS in protecting animal health. Combining SyS utilizing abattoir data with other SyS methods and complementary surveillance systems is suggested to further enhance livestock disease control. Further research, including the development of outbreak detection algorithms and strategies to mitigate the effects of subjective data, is needed to overcome these challenges and implement effective SyS systems in veterinary medicine.

Table of content

Introduction

The agricultural sector including livestock production plays a crucial role in ensuring food security and supporting economies worldwide. The products of livestock serve as an important source of protein for the human population. However, livestock production poses unique challenges. Disease management is crucial for both production sustainability and food safety. Rapid and accurate detection of health anomalies in livestock populations is key point for preventing the spread of diseases, protecting public health, and maintaining the economic stability of the agricultural industry.

In recent years, the field of epidemiology has experienced a shift in disease monitoring and control strategies, increasingly turning towards innovative surveillance methods. Syndromic Surveillance (SyS) has emerged as a particularly powerful tool to utilise non-disease-specific data that is sensitive to changes in the health of animal populations, with the aim of enhancing the timeliness of detection, bringing it closer to the onset of disease outbreaks compared to traditional methods. This allows for early detection and rapid intervention.

This literature review focuses specifically on the application of SyS to data collected from livestock abattoirs, the intersection of public health, animal health and welfare, and economic considerations. Therefore, changes in data detected in abattoirs can provide underlying problems and diseases across multiple sectors. Moreover, SyS in abattoirs can be particularly effective in detecting certain diseases that manifest lesions on carcasses but may exhibit limited signs in live animals such as tuberculosis in cattle.

Digital transformation in modern livestock production has a noticeable trend toward the centralization of production data. The producers are increasingly adopting integrated data management systems that consolidate information from various stages of the production process including the data from abattoirs. This shift presents an opportunity for SyS to get access to these datasets for more accurate analyses. This review is directed to scientific publications that utilised centralized data of abattoir inspection of cattle and pigs with the aims to construct and enhance the effectiveness of SyS.

This review aims to provide a comprehensive overview of the existing research on veterinary SyS on livestock abattoir data for disease and animal welfare surveillance. By critically examining the methodologies, findings, and implications of these studies, we seek to identify patterns, gaps, and potential avenues for future research in this evolving field. Through this exploration, we aim to contribute to knowledge that informs policymakers, veterinarians, and researchers in enhancing surveillance systems with SyS on slaughter data for the benefit of both animal and human health. Finally, we discuss the feasibility of SyS on abattoir data for Thailand.

Methods

This literature review aimed to explore scientific literature addressing the current situation of implementing syndromic surveillance (SyS) in livestock production focussing on abattoir data from cattle, pigs, and small ruminants. The search procedure involved the utilization of two databases, namely ScienceDirect (NCBI) and PubMed. The search terms for gathering related articles are “veterinary” and “syndromic surveillance”. The setting of two searches was different by indicating article types in ScienceDirect as “review articles” and “research articles”, while not limited the results in PubMed.

The overall output consisted of 335 publications from the two databases, with 144 and 191 from PubMed and ScienceDirect, respectively. In total, 29 pairs of duplicated records were found and then remove one of each pair, coming up with 306 articles at the beginning of the screening process. Then, all articles were examined for the title, abstract, and contents whether they are related to animal disease surveillance at population level. The articles with clinical or individual disease detection and surveillance, and the other unrelated contents were excluded. And then, 137 articles remained and were further examined by focussing on SyS on livestock slaughter data, resulting in 7 articles directly related to the scope (see Table 1).

Table 1. Summary of Baseline Models in Syndromic Surveillance Studies Utilizing Abattoir Data

Reference	Animals; country	Variable in models		Distribution	Length of time series	Modeling methods
		Dependent (Indicator)	Independent (predictor)			
Alton *et al.*, 2010	Cattle; Canada	- Whole carcass condemnation (WCC) in monthly	- Seasonality (3-month interval) - Audit rating - Weeks open - Region	Negative binomial model	7 years	Generalized estimating equations Correcting for repeated measures for each abattoir by exchangeable correlation structure
Alton *et al.*, 2012	Cattle; Canada	- Lung consolidation - Hepatopathy in monthly	- Seasonality (3-month interval) - Year effect - Audit rating - Weeks open - Region - Cattle number	Poisson model	7 years	Multilevel Poisson penalized quasi-likelihood model with both 1st and 2nd order Taylor Series approximations (PQL-1 and PQL-2)
Alton *et al.*, 2015	Cattle; Canada	- Lung consolidation in monthly	- Seasonality (3-month interval) - Year effect[1] - Cattle number[2]	Negative binomial model	7 years	Multilevel negative binomial regression model with random intercept for each abattoir
Dupuy *et al.*, 2015	Cattle; France	- WCC in weekly	- Seasonality (4 sinusoidal trends) - Age-sex combined - Log Cattle number[2]	Negative binomial model	5 years	Sinusoidal negative binomial regression

1 Not explicitly stated to be included but presumed to be part of the model.

2 The dependent variables were utilized as offsets

Table 1. Summary of Baseline Models in Syndromic Surveillance Studies Utilizing Abattoir Data (continue)

Reference	Animals; country	Variable in models		Distribution	Length of time series	Modeling methods
Haredasht *et al*., 2018	Cattle; USA	- WCC with reason of condemnation in monthly	- Seasonality and time trends (Dynamic harmonic and autoregressive spectrum)	Gaussian distribution for model residuals	10 years	Dynamic harmonic regression with Autoregressive Spectrum Analysis and Random Walk models Subset by reason of condemnation
Vial & Reist, 2014	cattle, pig, small ruminants (goat and sheep); Switzerland	- WCC in monthly - n reason?	- Seasonality and time trends (Autoregressive Moving Average Model - ARMA)	-	6 years	Seasonal-trend decomposition with Generalised additive models and Autoregressive moving average Subset by normal and emergency slaughter
Vial, Thommen & Held, 2015	cattle, pig; Switzerland	- WCC in monthly	- Seasonality and time trends (endemic and autoregressive component)	Negative binomial model	6 years	Negative binomial time series decomposition with autoregressive and endemic components

Results

Data sources

Table 1 summarises the seven studies on SyS on livestock abattoir data.

All seven studies retrieved data from centralized databases. Five of these studies focused on cattle data, while one study included both cattle and pig data, and another study included cattle, pig, and small ruminant data. The length of time series data ranged from 5 to 10 years.

Dependent variables

Whole carcass condemnation (WCC)

WCC data can be used for monitoring animal diseases with unspecific etiologies. Ideally, WCC numbers should be collected and reported separately for each slaughter batch. A condemnation is the decision of the meat inspector, indicating that carcasses are unfit for human consumption. Another reason for condemnation may arise when an animal is suspected of infection with a highly contagious disease that could potentially spread to other livestock or wildlife.

Among the seven syndromic surveillance (SyS) studies conducted on livestock abattoir data, five studies utilized WCC as a key indicator (Alton *et al*., 2010; Dupuy *et al*., 2015; Haredasht *et al*., 2015; Vial & Reist, 2014; Vial, Thommen & Held, 2015). However, variations in data collection and reporting systems led to differences in the obtained WCC data. For instance, Alton *et al*. (2010) accessed only monthly WCC numbers, while Haredasht *et al*. (2018), Vial & Reist (2014), and Vial, Thommen & Held (2015) obtained them on a daily basis, and Dupuy *et al*. (2015) acquired the data with exact timestamps.

Despite the aim of SyS to achieve early detection, the analysis of WCC may face challenges in exploiting data as closely to the incidence as desired. A common limitation is the lagged time of the total number of processed carcasses, typically communicated at the end of the month (Alton *et al*., 2010; Haredasht *et al*., 2015; Vial & Reist, 2014; Vial, Thommen & Held, 2015). Moreover, many studies transformed WCC into proportions of condemned carcasses prior to analysis, necessitating the inclusion of the total number of processed carcasses as the denominator (Alton *et al*., 2010; Dupuy *et al*., 2015; Haredasht *et al*., 2015). Consequently, WCC in Alton *et al*. (2010), Haredasht *et al*. (2015), Vial & Reist (2014), and Vial, Thommen & Held (2015) had to be aggregated and analysed on a monthly basis, while Dupuy *et al*. (2015) chose a weekly analysis.

In the studies by Vial & Reist (2014) and Vial, Thommen & Held (2015), normal slaughtered livestock and emergency slaughtered livestock were analysed separately. However, it remains unclear whether other studies included emergency slaughtered animals in their analyses.

Partial carcass condemnation (PCC)

PCC was analysed by Alton *et al*. in their studies from 2012 and 2015. They specifically considered the number of partial condemnations, with a focus on lung consolidation and hepatopathy. Alton *et al*. (2012) identified two frequently reported PCCs, lung consolidation and hepatopathy. In contrast, Alton *et al*. (2015) concentrated solely on lung consolidation.

The definition of lung consolidation in their literature referred to "a previous localized and resolved antero-ventral pneumonia infection" (Alton *et al*., 2012). On the other hand, hepatopathy was described as any pathological lesions found on livers that were classified by meat inspectors as unfit for human consumption (Alton *et al*., 2012).

Similar to the approach taken with WCC, both Alton *et al*. (2012) and Alton *et al*. (2015) constructed their models using the proportion of the respective PCCs in the total number of processed cattle. It's noteworthy that, despite the potential for obtaining daily PCC numbers, there is an inevitable delay in data for constructing analytical models.

Independent variables

Seasonality

The SyS system depends on detecting incidents that exceed predefined thresholds deviated from a fluctuating baseline. The baseline patterns are usually examined with the presumption that seasons influence disease patterns. All seven studies included in this analysis explored the effects of seasonality in their models. However, the approaches to incorporating seasonality as a factor influencing disease indicators varied significantly.

The studies by Alton and colleagues in 2010 and 2012 informed their approach by grouping seasons into three-month intervals. Although not clearly mentioned, it can be assumed that Alton *et al*. (2015) used a similar methodology. In contrast, Dupuy *et al*. (2015) took a more complicated approach, inspecting seasonality through four sinusoidal trends including annually, biannually, quarterly, and monthly.

Vial & Reist (2014) adopted a decomposed function to extract its components, aiming to identify peak and trough months. Haredasht *et al*. (2018) utilized the autoregressive spectrum, while Vial, Thomman & Held (2015) decomposed the seasonal trend into an autoregressive component and an endemic component. This diversity in the treatment of seasonality underlines the complexity in understanding and modelling its impact on disease indicators in the SyS studies.

Other variables

Alton *et al*.'s studies in 2010, 2012, and 2015 used several unique independent variables for constructing their baseline models. They specifically examined the effects of years in studies where years were treated as categorical predictors. However, while the study in 2012 retained the year effect in the final model, the 2010 study excluded it, and the 2015 study did not clearly explain its inclusion.

Annual abattoir audit rating, the number of weeks operated in the year, and the region of the abattoir were analysed in Alton's studies in 2010 and 2012. Their final models incorporated these predictors, highlighting their impact on the dependent variables.

In contrast to other studies, Alton *et al*. included the numbers of processed cattle each year as independent variables in their models across all three years (2010, 2012, and 2015). Alton *et al*. (2010) excluded the number due to its statistical insignificance in their model of WCC. However, these numbers were proven to be significant in both models of consolidated lung and hepatopathy in the study of 2012, leading to their inclusion as an offset in Alton *et al*.'s (2015) consolidated lung model.

Similar to the numbers of processed cattle each year, the class of cattle is also incorporated in the models of Alton *et al*.'s studies in 2010, 2012, and 2015. In these studies, classes were defined by the animals' age and sex, with a specific focus on calves, cows, heifers, and steers. The studies conducted in 2010 and 2012 revealed associations between class and their respective dependent variables, also leading to their consideration as offsets in the study conducted in 2015.

Age, sex, and production types were exclusively examined in the models presented by Dupuy *et al*. in 2015. In this study, age classification was based on the age of the animal at the time of slaughter, categorizing them into groups of 8 to 24 months old, 2 to 5 years old, and over 5 years old. The analysis combined age and sex due to their correlation and potential interaction, revealing their associations in the models. Conversely, production types, including dairy, beef, and mixed categories, were intentionally excluded from the final models, with no explanation provided in the study.

On a different note, the price of meat for each animal class was examined in Alton *et al*.'s studies in 2010 and 2012, as well as in Vial & Reist's study in 2014. Despite the difference in their approaches, Alton analysed prices in binary categories based on whether they were less than or equal to the median yearly price of their respective animal classes, while Vial & Reist (2014) examined the monthly average price weighted by the number of working days. Notably, neither author group included these variables in any of their final models.

The effect of the size of abattoir on WCC was analysed by Vial & Reist (2014), grouping by whether the production volume was smaller or larger than the median volume over the year. In the study, it is not included in the model but the effect was determined. They found significant associations of abattoir size to WCC in emergency slaughtered cattle, pig, and small ruminants.

Vial & Reist (2014) examined the impact of abattoir size on whole carcass condemnation (WCC), categorizing abattoirs based on whether their production volume as smaller or larger than the median volume over the year. Although the abattoir size was not included directly in the model, its effect was determined. The study revealed a significant association between abattoir size and WCC, specifically in emergency slaughtered cattle, pigs, and small ruminants, although no significant association was observed in regular slaughter animals.

Statistical models

Time series analysis

All seven studies of SyS on livestock abattoir data in this review applied time series analysis with either month (Alton *et al*., 2010; Alton *et al*., 2012; Alton *et al*., 2015; Haredasht *et al*., 2015; Vial & Reist, 2014; Vial, Thomman & Held, 2015) or week (Dupuy *et al*., 2015) as the units of time.

Alton *et al*. (2010) employed a Generalized Estimating Equation (GEE) with Negative Binomial regression. The study used an exchangeable correlation structure for repeated measurements for abattoir effects. Wald test was conducted for testing the effects of covariates individually, and multivariate. Interactions were also inspected. Both Poisson and Negative Binomial models were considered, with various correlation structures such as exchangeable, first-order autoregressive, second-order autoregressive, non-stationary, and stationary. Model selection was based on the Quasi-log-likelihood under the independence model information criterion (QIC), and the best-fitting model identified was a multivariable negative binomial regression model using an exchangeable correlation structure. Significant variables included animal class, year, season, price, audit rating of abattoirs, and interaction between animal class and year category. The analysis was conducted using Stata 10.1.

In Alton *et al*. (2012), a Multilevel Poisson Regression Model was adopted for the analysis. They assessed linearity for covariates if they should be used in quadratic form or in categories. Covariates were tested individually, and then tested in multivariate model with Wald test. The removed covariates were assessed for possible confounding effect. Interactions of animal classes with region, year, and season were analysed. Multilevel Poisson penalized quasi-likelihood model with a 2nd order Taylor Series approximation (PQL-2) were selected for lung consolidate model, and a 1st order for hepatopathy model due to the convergence issues. The study further conducted a visual diagnostic analysis on the predicted random effects, and best linear unbiased predictors (BLUPs) were examined for the multilevel model. The software MLwiN 2.17 was utilized for the analysis.

Alton *et al*. (2015) chose a negative binomial model over a Poisson model based on the Akaike Information Criterion (AIC). The log-transformed number of slaughtered animals for a specific animal class was used in the offset. The study incorporated SyS with 3 conditional subset selection criteria, namely, the abattoirs which were open every week in the year, the abattoir with more than 6,500 processed cattle per year, and the multi-criteria with more than 44 weeks in operation per year and more than 499 processed cattle per year. The negative binomial model was used to assess the association of monthly condemnation rates of pneumonic lungs for each subset analysis with year, season, and animal class. All covariates underwent individual evaluation for statistical significance and were included in a multivariable multi-level negative binomial regression model with a random intercept for abattoir. The analysis was conducted using Stata 12.

In the study by Dupuy *et al*. (2015), a three-step approach was employed to create an outbreak-free WCC baseline, to simulate artificial outbreak, and to assess the model performance. Their first step was to construct the outbreak-free historical baseline through retrospective time-series analysis. This analysis used Poisson and negative binomial regression models with the weekly number of slaughtered cattle as an offset. The outcome of interest was the weekly proportion of whole carcass condemnation. The study investigated autocorrelation (within the same month of different years) and partial autocorrelation (across different months) to better understand temporal patterns. The models incorporated a combined age-sex variable, and interactions between all variables were investigated. Fit assessments were conducted using the analysis of residuals and Pearson goodness-of-fit test. Model comparisons were performed based on AIC. Their final model was the negative binomial with combined age-group categorical variable, annual sinusoidal effect, and the log number of slaughter cattle as an offset. To constructed the outbreak-free baseline, data points above the 95% confidence interval (CI) were replaced by the value of this CI. The study utilised the R environment for statistical analysis.

In Haredasht *et al*. (2018), the study employed Dynamic Harmonic Regression (DHR) to assess seasonality and trend of time series data of monthly carcass condemnations. The autoregressive spectrum to identify periodicity, with the order of the autoregressive spectrum determined using the Akaike Information Criterion (AIC). DHR model analysed the dynamic of WCC [Y(t)] deriving the numbers into trend [L(t)], cyclical [Q(t)], and residual [e(t)] components. The cyclical term, Q(t), was modelled as a sum of sinusoidal functions, and the stochastic time variable parameters [αi(t) and βi(t)] were estimated using Random Walk models. The trend component, L(t), was modelled as an Integrated Random Walk. The DHR algorithm employed the Kalman Filter for estimating time variable parameters. The models were then used to simulate and predict carcass condemnation rates for specific time periods. The evaluation of the resulting models was based on the coefficient of determination (R^2_t), indicating the goodness of fit between the simulated results and the observed rates of carcass condemnations. The Captain toolbox version 7.5 in Matlab was utilized for the analysis.

Vial & Reist (2014) adopted a time series decomposition method to analyze carcass condemnations. The time-series data [Y(t)] underwent decomposition into seasonal [S(t)], trend [T(t)], and irregular components [e(t)] using moving averages. The study utilized generalized additive models (GAM) with the formula Y(t) = T(t) + S(t) + e(t). Seasonality was identified by extracting the seasonal component, to identify peak and trough months. Prior to fitting models to investigate the trend effects and commodity prices, seasonality was removed from the time series. The analysis involved fitting a simple GAM model, assessing model residuals through autocorrelation and partial-autocorrelation plots. These plots informed the potential presence of an ARMA (p,q) process, where p and q represent auto-regressive and moving average parameters, respectively. The best fit p and q were selected by comparing AIC and residual visualisation of the GAMs incorporating ARMA. The analysis was initially conducted on the dataset from all abattoirs before being run separately for larger and smaller abattoirs. The study used the {mgcv} package in R for the GAM analysis.

Vial, Thommen & Held (2015) conducted a comprehensive analysis of four time-series for the combinations of slaughtering (regular and emergency slaughter) and animal type (cattle and pigs). Negative binomial distribution was adopted in their analysis because the overdispersion of the Poisson regression model in their pilot study. The time-series was decomposed into autoregressive and endemic components, represented as $\mu_t = \lambda_t y_t - 1 + \nu_t e_t$, where μ_t denotes the monthly incidence, and e_t serves as an offset adjusting for variations in the total number of slaughtered animals. The autoregressive component (λ_t) was designed to capture potential outbreaks and could include a seasonal pattern or a long-term trend. The endemic component (ν_t) modeled baseline counts, accommodating seasonality and trend, and was multiplied by the offset (e_t). Several trend types and seasonal patterns (sine-cosine function) in both autoregressive and endemic components were examined. Model selection was based on Bayesian Information Criterion (BIC). The best retrospective models were then utilized to simulate baseline time series spanning 72 months. The analysis was conducted in R environment with the 'surveillance' package.

Outbreak simulation, detection algorithm, and performance

Dupuy *et al*. (2015) conducted an extensive study beyond establishing the baseline of the proportion of WCC and identifying associated factors. After developing the final negative binomial model, they utilized 227 weeks of data to simulate a baseline covering 5,675 weeks. Artificial outbreaks were then introduced, with four different shapes and four levels of magnitudes considered for each age-sex category. In total, 40 scenarios were created, ranging from 274 to 421 outbreak injections for each scenario. Subsequently, they analysed four outbreak detection algorithms by optimizing their parameters and assessing their performance. The first algorithm examined the baseline through the weekly proportion of WCC, detecting outbreaks by establishing an upper control limit for each week (set at the standard deviation multiplied by a constant). The second algorithm analysed the baseline by the number of WCC, using a one-sided percentage of the confidence interval (CI) of the model as the threshold for each week. The third algorithm focused on the residuals of the baseline, employing an exponentially weighted moving average, settings a number of standard deviation of the residuals and a smoothing parameter. The last algorithm also analysed the residuals, utilizing the cumulative sum of residuals for each week, considering values exceeding 2 as the threshold. Model performance was evaluated based on sensitivity, specificity, and outbreak detection precocity in weeks.

The study of Vial, Thommen & Held in 2015 employed Farrington algorithm to detect outbreaks by log-linear quasi Poisson model for the historic baseline data. Three different sets of parameters were tested for detection effectiveness. The parameter set 1 tested the recent models while the parameter set 2 and 3 were to improve the probability of detection of small outbreaks. The alarm was set if the observed value exceeds the one-sided 97.5 percentile of normal distribution estimated. The algorithm was tested for performance by the probability of detection, false positive rate, mean time to detection in months, and the mean percentage of cases until detection.

Discussion

The finding of this review reveals the number of studies analysing livestock abattoir data using a syndromic surveillance (SyS) approach compared to other veterinary livestock data sources. Only seven studies were identified during the process, with five study focused on analysing the pattern of events (WCC, PCC), considering seasonality and relevant factors through fitting models. Two studies extended their researches by simulating baseline data, injecting artificial outbreaks, and implementing algorithms for outbreak detection. Subsequently, they assessed the performance of detection algorithms using various indicators.

The SyS studies examined in this analysis primarily focused on two key dependent variables, Whole Carcass Condemnation (WCC) and Partial Carcass Condemnation (PCC). WCC is questioned for its broad nature without specific causes, PCCs were assessed simultaneously with WCC to determine whether the number are similar or complementary for the surveillance system (Vial & Reist, 2015). Their findings suggested that these two numbers reflect different health events in animals, encouraging increased use of these data. In the same study, centralised WCC data and private PCCs data were used due to data system limitation from 2009 to 2010, but pointing out the promising further integration of PCCs into the same database (Vial & Reist, 2015).

The duration of baselines varied from 5 to 10 years across these studies. It is crucial to determine the optimal duration for fitting baseline models and prediction algorithms. Longer durations may not always yield better results for both aspects, as changes in trends due to advancements in breeding and rearing technology or the change in pattern of diseases could affect the predictive capability of long historical data. Therefore, regularly updating the baseline and adjusting its duration could enhance the effectiveness of the surveillance system.

Although various modeling approaches were applied in the seven studies, none of them compared these methods within the same population. Consequently, selecting a method for implementation or further study requires careful consideration of the limitations of each method and the availability of data. Similarly, the inclusion of time and seasonality effects in all SyS models in this study takes various forms. Comparing these forms for the best fit in each study or modelling method could aid selection for further studies.

Before concluding the review of primarily related studies in SyS with abattoir data, it is important to address the inadvertent exclusion of three additional studies employing veterinary SyS with abattoir data. Firstly, Dupuy *et al*. (2014) utilized a multivariate multinomial logistic regression model to analyse various factors such as age-sex variables, month, year, and abattoir, assessing their association with four condemnation categories (no condemnation, PCC of offal, PCC of carcass, and WCC). Secondly, Sanchez-Vazquez *et al*. (2012) conducted an analysis focusing on pigs, examining the incidence of epizootic pneumonia-like lesions, which appear as consolidated lung, serving as indicators. They employed a time series decomposition model to assess seasonality and trend, followed by the utilization of a generalized linear mixed-effects model to investigate the effects of other independent variables. Lastly, Thomas-Bachli *et al*. (2014) utilized a negative binomial model with random intercepts for each abattoir to analyse the association between WCC and non-disease factors. Initially, these studies were misunderstood by this review's author, who mistakenly believed that their scope was limited to determining the association of each predictor with indicators without constructing baseline models. Simultaneously, the study by Sanchez-Vanquez *et al*. (2012) was presumed to focus solely on a specific disease, later revealed to share similarities with Alton *et al*.'s studies in 2012 and 2015, which explore unspecific diseases. Furthermore, both the studies by Sanchez-Vanquez *et al*. (2012) and Thomas-Bachli *et al*. (2014) do not explicitly use the terms "syndromic surveillance" to describe their analyses. These factors, combined with a lack of understanding during the initial stages of this review analysis, led to the inadvertent exclusion of these studies.

In addition to the SyS studies analysed in this review, a study by Dupuy *et al*. in 2013 examined veterinary SyS systems, both active and in development, in European countries. Several projects have been undertaken to implement abattoir data, demonstrating the feasibility of their use in real-world applications. However, the comprehensive details of these systems were not provided in their study and are also difficult to access online. Dupuy collected information by sending surveys to individuals involved in the system.

While some independent variables were analysed for their significance in association with WCC or PCC, the results of these associations may not be generalisable. Using a list of variables as predictors in initial models and then excluding insignificants ones to improve model fitness could be more useful than solely relying on the final model from other studies.

One limitation of this study is the insufficient number of studies that inspected outbreak detection algorithms and assessed their performance. Only Dupuy's study in 2015 and Vial, Thommen & Held in 2015 performed these analyses. However, based on the methods demonstrated in these studies, following their algorithms in outbreak detection seems beneficial for SyS and other studies, and they may be relatively straightforward to implement.

However, in comparison with other SyS studies using different data sources, SyS utilizing abattoir data still lacks validation of prediction algorithms implemented on actual data, as demonstrated in Veldhuis et al.'s study in 2016 and Douglass et al.'s study in 2020, which utilized historical outbreaks to examine their outbreak detection algorithms using milk production data.

A major challenge in SyS is the lagged time of the data, possibly causing delays in early detection. The delays due to the monthly reporting of total slaughtered animal may not be the most important since the number is more relevant to the baseline construction step, not the outbreak detection. The primary concern could be the lagged time due to the fact that the data from livestock abattoir are from older animals that are ready to be slaughtered or they were decided to be replaced by the owners. This lag may result in outbreaks already occurring and spreading before detection from abattoir data.

Nevertheless, using abattoir data for surveillance purposes can offer advantages in certain scenarios. For instance, if a disease primarily manifests through lesions on carcasses and is less detectable in live animals, or if the disease has a high morbidity but low mortality rate, detecting outbreaks through abattoir data could prove beneficial. In such cases, monitoring data from abattoirs may provide information of the prevalence and spread of diseases that might otherwise go undetected until later stages.

SyS in the field of animal health has utilized a wide range of data sources beyond abattoir data. A review by Dórea and Vial in 2016 categorized the data sources for SyS, including production data, clinical data, laboratory data, mortality data, abattoir data, and media sources.

Production data can be collected with timeliness, as it is obtained while the animal is still on the farm where it is vulnerable to diseases. The decrease of milk production in dairy cattle farms were extensively used as indicator of SyS with production data. Madouasse *et al*. (2014) and Veldhuis *et al*. (2016) utilized linear mixed effects models with additional spatial data for prospective space-time scan statistics to capture the change in milk production. They used these statistics to analyse historical data, where outbreaks emerged in history. There were numerous delayed alerts in the event of the historic Bluetongue outbreak after suspicious cases were found. Conversely, Veldhuis *et al*. (2016) also retrospectively analysed the Schmallenberg virus (SBV) outbreak and found it effective for alerting in advance of the SBV epidemic incident in early 2012. Similarly, Douglass *et al*. (2020) conducted a linear mixed model with a cumulative summation algorithm for outbreak detection in the SBV historical outbreak in late 2012, using milk production data, which successfully notified the outbreak 4-6 weeks prior to the first laboratory confirmation case. However, Douglass *et al*. pointed out the promising prediction while raising questions about the possible unconfirmed case-effect relationship. Another study using production data is Bronner *et al*.'s study in 2015, using the number of reproductive events on a farm, which is the decrease in birth rate per number of cows, as an indicator of SyS.

Other interesting examples include the use of laboratory data, where Antunes *et al*. in 2016 performed a time series analysis without focusing on the specific targeted disease of the sample's submission. Similarly, two of Dórea *et al*.'s studies focused on fitting baseline models (Dórea *et al*., 2013a) and simulating outbreaks, then testing four algorithms (Dórea *et al*., 2013c), with three methods similar to those used by Dupuy *et al*. in 2015 with abattoir data and one additional method, namely Holt-Winters exponential smoothing generalization. Additionally, Dórea *et al*.'s series of studies combined the analysis with categorized syndromes and detection algorithms (Dórea *et al*., 2013b). In addition to the examples of SyS in other data source, Tongue *et al*. in 2020 utilized culling data in sheep farms, and Torres *et al*. in 2015 utilized mortality data in cattle farms for their SyS system' indicator.

While many studies utilized data to analyse baseline trends and detect outbreaks from data or from simulated data, some studies' main focuses were to solve their challenges, such as the translational issues in textual data collected from farmers (Conway, Dowling & Chapman, 2013; Pfeiffer *et al*., 2021) or veterinary necropsy reports (Bollig *et al*., 2020) whether they should fit into categories for their SyS indicators. Another study focused on assess the quality of data and the level of compliance of veterinary staff with their SyS system (Del Rocio Amezcua *et al*., 2010).

The use of abattoir data presents both advantages and disadvantages compared to the other source as also described the similar points in Dórea & Vial's review in 2016. A significant challenge is the lack of timeliness, as previously described, which limits the system's ability to provide real-time alert during outbreaks. Additionally, the wide range of abattoir practices raises concerns about data quality and standardisation, as inspections are subjectively conducted by different inspectors. However, if the bias were proven to be random, it would have no impact on the baseline model. Despite these challenges, SyS with abattoir data could provide good area coverage if the data were collected centrally. Moreover, with the location of abattoir and last location of holding area of animals prior to transportation, potential spatial analysis and the spatial details could be enabled in the event of outbreak detection. Given the disadvantages, combination of the SyS on abattoir data with SyS using other data source such as the production data and other approaches in veterinary surveillance will improve the overall effectiveness of animal diseases prevention system.

This study also aimed to discuss the feasibility of implementing SyS in Thailand, a country with over 2,000 abattoirs exhibiting diverse of operational practices. A reporting system for Whole Carcass Condemnation (WCC) and Partial Carcass Condemnation (PCC) along with reasons, has been established, requiring all abattoirs to submit monthly inspection forms for centralized data collection. While this presents a promising opportunity for SyS utilization, the validity of the collected data remains unassessed, particularly concerning small-scale abattoirs. Clustering or splitting data in the analysis process would facilitate the interpretation of trends and patterns within each subset, allowing for more targeted insights and informed decision-making based on unique characteristics of different groups or clusters within the data.

Conclusion

In conclusion, this study provides a comprehensive overview of veterinary syndromic surveillance (SyS) utilizing livestock abattoir data. Through a systematic review of existing literature, seven studies employing diverse methodologies for SyS were identified and analysed. While challenges such as timeliness and data standardization exist, the utilization of abattoir data presents valuable opportunities for improving disease surveillance in livestock populations. Further research directions include the implementation and validation of outbreak detection algorithms and strategies to mitigate the effects of subjective data. Implementing SyS systems with abattoir data requires addressing these challenges while the advantages of this system are promising to enhance the capacity to improve animal health protection and production sustainability. In Thailand, proposing a pilot study appears promising as the necessary data is already being collected. Conducting subset analyses in large or middle to large scale abattoirs may help address the challenge of data standardization. The expected results from these analyses may inform future data collection strategies and research directions.

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