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Data quality assessment of pig movements in the Norwegian Livestock Register reveals challenges for outbreak preparedness

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Abstract

Background Animal movements are an important pathway for the spread of pig diseases. Traceability systems provide data for the competent authorities to prevent and manage infectious disease outbreaks. In Norway, batch-level pig movements are documented in the Norwegian Livestock Register. The purpose of our study was to evaluate the quality of pig movement data in the Norwegian Livestock Register for 2022. We assessed the quality in terms of accuracy, completeness and timeliness for the purpose of outbreak preparedness. We used secondary governmental and industry registers for external validation.

Results The Norwegian Livestock Register contained all the variables needed for tracing pig movements between farms and to slaughterhouses. The register had high accuracy for individual records of between farm movements, however, it lacked completeness. By comparing movements between farms to the Register for Carcass Deliveries, we found that 41% of sending farms lacked registrations in the Norwegian Livestock Register. Similarly, a quarter of all finisher farms did not report receiving any pigs for 2022. Using indicator farms, we show that three slaughterhouses did not correctly report live animal movements between farms on behalf of owners. Lastly, we found that 41% of records were registered after the deadline of seven days.

Conclusions The competent authorities need accurate, complete, and timely data on livestock movements to control rapidly spreading diseases. Based on our assessment, we found that pig movement data in the Norwegian Livestock Register lacked sufficient quality to serve this purpose. Instead, we recommend that movement data are additionally obtained through traditional epidemiological methods during outbreaks, such as from primary records on farms. Reporting from slaughterhouses and farms in sow pools should be targeted for improving the completeness and timeliness of the register data. Finally, the measures presented here should be used to develop real-time monitoring of the data quality.

Keywords Register evaluation, Animal health data, Quality monitoring, Surveillance, Traceability, Networks

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Background

Animal movements are an important pathway for the spread of swine diseases, such as classical swine fever [1], African swine fever [2], and foot-and-mouth disease [3]. Since the establishment of free trade amongst Member States in the 1990s, the European Union has enacted and strengthened legislation requiring the identification and traceability of livestock [4–6]. The competent authorities of the Member States are responsible for the operation of their animal traceability systems [7]. As a member of the European Economic Area, Norway is bound to the same legislation. In Norway, movements of cattle, pigs, and other small ruminants are recorded in the Norwegian Livestock Register, which is managed by the Norwegian Food Safety Authority [8, 9]. The primary purpose of the traceability systems is to ensure that the competent authorities have information to prevent and control the spread of diseases in livestock [7].

In addition to outbreak management, data from these registers have been used extensively for research on domestic and international pig trade in Europe. For example, the spatial and temporal characteristics of pig movements have been described for Austria [10], Belgium [11], Bulgaria [12], Denmark [13, 14], France [12, 15, 16], Germany [17, 18], Italy [12, 19, 20], North Macedonia [21], Spain [12], Sweden [22], Switzerland [23], and the United Kingdom [24–26]. Register data have also been used to study live pig trade between European countries in order to identify risks of transboundary spread [27]. Research on swine movements based on European registers has produced important insights for planning risk-based surveillance and control strategies [10, 12–15, 19, 21–25, 27].

Despite the importance of animal movement data for research and preparedness, only a few studies have investigated the data quality of these registers. Green and Kao (2007) assessed the quality of the Cattle Tracing System in the United Kingdom for 1996–2005 [28]. They found that there was variation in the amount of missing data between holding types, suggesting systematic biases in the data [28]. Similarly, Birkegård et al. (2018) investigated the quality of the Danish pig movement register for 2014–2015 [29]. They found that a large proportion of farms (27.3–53.9%) had either too many or too few ingoing and outgoing movements [29]. An earlier study of pig trade in Denmark for 2006–2015 also found movements between slaughterhouses and incorrectly registered movements, leading them to exclude about 0.01% of their data, although this still constituted tens of thousands movements [13]. Collectively, these studies show that animal movement registers can be prone to significant data quality issues, despite their widespread use.

The purpose of this study was to evaluate the quality of pig movement data in the Norwegian Livestock Register for risk assessment and outbreak response. Using data from 2022, we performed a quantitative assessment of the following attributes: accuracy, completeness, and timeliness. Finally, we identified several measures that can be used for continuous data quality monitoring.

Methods

Following the workflow presented in Birkegård et al. (2018), we began with a description of the Norwegian Livestock Register, including the objective, maintainer, data generators, supporting legislation, relevant variables, and optimal population coverage and timeliness [29]. We requested a data extract for the study from the Norwegian Food Safety Authority with the following variables: record identification number, sender and receiver information (name, three identification numbers (e.g., main organization number, business entity organization number, company number and producer number), producer activity (e.g., farm, live animal trader, slaughterhouse), event date, batch size, type of movement, and registration date. A batch was defined as a group of pigs moved between a sender and receiver on the same day and registered on the same record. There could be multiple batches sent between the same sender and receiver on the same day. We defined our study period as 01 January to 31 December 2022.

We merged aggregated farm-level data from the Norwegian Livestock Register with two other governmental registers, the Register for Production Subsidies and the Register for Carcass Deliveries, and one industry register, HelseGris. Table 1 provides an overview of these registers.

The Register for Production Subsidies is owned by the Norwegian Agricultural Agency and includes biannual counts of pigs in different production categories (piglets (< 20 kg), sows, boars, fattening pigs, gilts, and young boars) that are submitted voluntarily by farmers. The farmers have a financial incentive to report because the applications are necessary to obtain production subsidies and the reported numbers can be audited.

The Register for Carcass Deliveries is also owned by Norwegian Agricultural Agency and mainly records deliveries of carcasses for slaughter. The register contains information about each animal, including the delivery date, weight, type and slaughterhouse. Additionally, the register includes live pigs delivered for transport to other farms, if that transport is mediated by a slaughterhouse company. This is a common practice in Norway because the slaughterhouse companies have vehicles suited for animal transport. It is important to note that trades are only registered to the sending farm. Data in the register is reported by slaughterhouse companies for all pigs they receive and is tied to their payment systems. Yearly aggregated data for the number of slaughtered pigs are

Table 1 Overview of the registers used in this study

Register	Owner	Description	Purpose for this study
Norwegian Livestock Register	Norwegian Food Safety Authority	Information about pig movements (batches) between agricultural holdings and to slaughter. Each record includes the date, sender, receiver, number of pigs, and the purpose of movement. Reports are sent by receiving farms or slaughterhouses.	Number, type, and direction of pig movements per farm
Register for Production Subsidies	Norwegian Agricultural Agency	Information from voluntary applications for production grants to agricultural holdings. For each holding, the register includes the name, report date, and number animals per category. Counts for pigs are reported twice per year.	Number of pigs per farm
Register for Carcass Deliveries	Norwegian Agricultural Agency	Deliveries of livestock for trade, slaughter and wool from agricultural holdings. For each holding, the register includes the name, date, municipality, number traded or slaughtered, and animal information (weight, type). Pig reports are at the individual-level.	Number of traded and slaughtered pigs per farm
HelseGris	Animalia	Industry-owned documentation system for health, welfare, and biosecurity for pig farms.	Production category for farms

controlled by Statistics Norway, the national statistical institute and producer of official statistics.

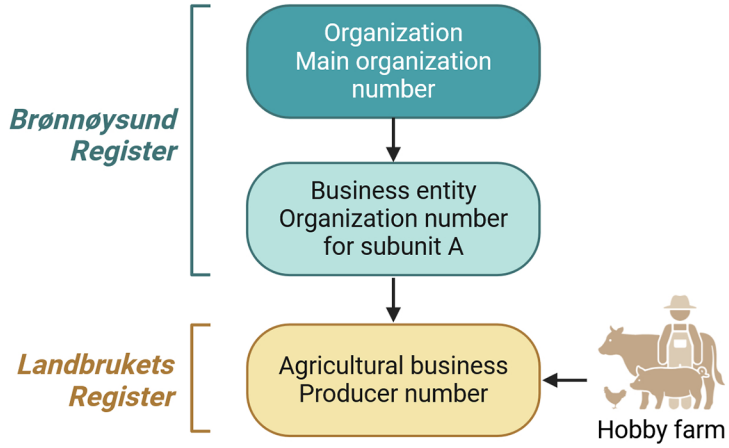
Animalia provided data on farm categories from their reporting system called HelseGris. Animalia AS is an independent industry organization that provides Norwegian farmers and the meat and egg industry with support through livestock monitoring, animal health services, research and educational projects. HelseGris is their documentation system for health, welfare, and biosecurity monitoring of pig farms. The system is also used to record veterinary visits that are required for all Norwegian pig farms one to three times per year, meaning that the data should cover the entire population.

In Norway, farms can be identified by different registration numbers related to business and producer databases: main organization number ('foretaksnummer'), business entity organization number ('bedriftsnummer'), and producer number ('produsentnummer') (Fig. 1). Slaughterhouses, excluding live animal trade activities, do not have producer numbers. By contrast, non-commercial/hobby farms can have producer numbers but may not have organization numbers. To merge the data for individual farms, we used the first eight digits of the producer number, which represents a single production site.

For the data assessment, we identified accuracy, completeness, and timeliness as the most relevant attributes for preparedness (Table 2). We defined accuracy as the plausibility that the registered data for individual variables were correct [30]. As a measure of accuracy, we calculated the percentage of missing data for the following variables: event and registration dates, number of pigs, sending owner information (organization number(s)/producer number, purpose (i.e., holding/live animal trade/slaughter)), receiving owner information (organization number(s)/producer number, purpose), and type of movement. To verify the farm identification numbers in the Norwegian Livestock Register, we compared them to identification numbers used in the Register for Production Subsidies and/or the Register for Carcass Deliveries. We considered records with batch sizes less than 1 or greater than 500 pigs as low quality; this is because transport vehicles in Norway do not move more than 500 pigs at one time. We used the Register for Production Subsidies and the Register of Carcass Deliveries to verify farm identification numbers.

Finally, we calculated the percentage of records where the direction of animal flow between farm categories was unlikely. Pig production in Norway is comprised of independent farms that are organized in a pyramidal structure, with unidirectional animal flow. In addition, there are specialized sow herds, where sows are inseminated and kept in central units through gestation and transported to satellite herds before farrowing. The sows are then sent back to the central unit after weaning. Using HelseGris, national register data, and expert knowledge, we assigned one of the following general production categories to each farm: nucleus, multiplier, commercial sow herd, sow pool central unit, sow pool satellite, finisher, non-commercial farm, and other (test/boar stud station). We considered the following unlikely movements as poor quality: non-nucleus herds to nucleus herds, non-nucleus herds to multipliers, non-nucleus or non-boar station to boar station, commercial sow herd to sow pool central units, finisher or small herds to other farms, or when the sender and receiver is the same. Although these may not necessarily be incorrect registrations, they are unlikely enough to warrant further investigation.

We defined completeness as the extent to which all movements were present in the register, equivalent to the optimal coverage [30]. For movements to slaughterhouses, we used the Register for Carcass Deliveries to cross-validate the yearly number of animals sent to slaughterhouses nationally and per farm. We lacked a secondary register to cross-validate movements between farms, also referred to here as 'live animal movements'. Instead, we used proxy measures to assess completeness for three subsets of the data: senders that traded pigs using transport from slaughterhouse companies,



Organization	Business entity	Agricultural business
• "Hovedenhet" in Norwegian • Registered in Brønnøysund • Represents a company, sole proprietership, association, cooperation, etc. • Identified by a 9-digit organization number • Also referred to as a "foretaksnummer"	• "Underenhet" in Norwegian • Registered in Brønnøysundregistrene • Represents an activity (e.g., animal husbandry) and place (i.e., municipality) • Identified by a 9-digit organization number • Also referred to as a "bedriftsnummer" or "virksomhetsnummer"	• Registered in Landbrukets (Agriculture) register • Represents an agricultural business connected to property(-ies) or a hobby farm • Identified by a 10-digit producer number, the last two digits are a serial number and a control number

Fig. 1 Identification numbers used by the competent authorities for businesses and producers in Norwegian swine production. Created in BioRender. Dean, K. (2025) BioRender.com/f21j417

movements within sow pool systems, and balance within finisher farms.

With the assumption that most pigs were transported between farms by slaughterhouse companies [31], we used live animal registrations in the Register for Carcass Deliveries to validate outgoing live animal movements. The number of live pig transports in the Register for Carcass Deliveries represents a lower bound for the total number of live pig movements for sending farms in the Livestock Register.

As another measure of completeness, we manually checked for regular movements between the central units and satellites in sow pools. Specifically, we expected to see movements between the central units and satellites in sow pools occurring on a regular basis following the batch-production pattern of the sow pool system, with movements occurring from the central unit three weeks prior to expected farrowing and sows being moved back from the satellites at weaning five weeks after farrowing.

Lastly, finisher farms should receive and slaughter approximately the same number of pigs in a given year, and, at minimum, they should not be filled more than once without being emptied and vice versa. For farms that reported information about the number of pigs to the Register for Production Subsidies, we calculated the yearly balance of in-going and out-going movements for finisher farms as [29]:

$$Balance = \frac{Received\,pigs - Slaughtered\,pigs}{Registered\,number\,of\,pigs}$$

We expected finisher farms to have a balance value between – 1 and 1 [29].

We considered slaughterhouse affiliation as a potential source of bias in farms with poor quality movement data. To investigate this, we first compared the yearly number of slaughtered pigs in the Register for Carcass Deliveries and the Norwegian Livestock Register for each slaughterhouse. We did not have information from the Norwegian Livestock Register to indicate when slaughterhouses had reported live animal movements on behalf of farm owners. Consequently, we could not directly compare the two registers. Instead, we selected indicator farms that delivered pigs to only one slaughterhouse and sent live pigs to other farms. We used the indicator farms to summarize the reporting of both slaughtered and live pigs for a subset of the slaughterhouses that had mediated live animal movements.

The final attribute we considered was timeliness, which we defined as the difference between the event date and

Table 2 Attributes and measures used for assessing data quality for pig movements in the Norwegian Livestock Register for 2022

Attribute	Measure description	Subset	Level	Method
Accuracy	Missing data	All	Record	Checking for missing values
	Inactive farm identifier	Farms	Farm	Cross-validation between Register for Carcass Deliveries and Register for Production Subsidies
	Invalid batch size	All	Record	Checking for unexpected values
	Unlikely movements between farm categories	Live animal movements	Record	Checking for movements against expected animal flow
Completeness	Registration of slaughter movements	All	Farm, National	Cross-validation with Register for Carcass Deliveries
	Registration of outgoing live animal movements mediated by slaughterhouses	Producers sending live pigs to other producers	Farm	Cross-validation with Register for Carcass Deliveries
	Balance of in-going and out-going movements in commercial finishers	Commercial finishers with population data	Farm	Checking for expected balance
	Regular movements within sow pools	Sow pools	Farm	Checking for regular movements between central units and satellites
Timeliness	Compliance with registration of movements within 7 days	All	Farm, Slaughterhouse	Calculated time between movement event and registration date

Table 3 Overview of the Norwegian Livestock Register for pigs

Norwegian Livestock Register for pigs	
Start year	2002
Maintainer	Norwegian Food Safety Authority
Objective	Traceability of animal movements
Legislation	FOR-2022-04-07-637 [32]
Data senders	Receiving farm/live animal trader/slaughterhouse, Slaughterhouses (on behalf of the receiving owners)
Optimal population coverage	All movements of live pigs between farms and to slaughterhouses.
Mandated timeliness	7 days
Data variables	• Record identification number • Sender information • Receiver information • Event date • Total number of animals • Type of movement (Movement between farms, movement to slaughterhouse, Other type of movement) • Registration date
Level of registration	• Batches (group of pigs moved between a sender and a receiver on the same day)

the registration date. We first calculated the overall timeliness of the register for all records. As slaughterhouses submit the majority of records to the Norwegian Livestock Register, we also compared the timeliness between slaughterhouses using only the records for movements of pigs to slaughter.

Results

Description

We received the movement data as a CSV file on 09 February 2023 that was extracted from the official database at the NFSA. From the complete dataset, we filtered the data to include only movements for pigs in 2022. Our resulting dataset had 41,615 registrations. Table 3 provides a description of the Norwegian Livestock Register for pigs and the variables included in the extract used for this study.

Accuracy

Missing data for registrations

We first measured accuracy as the amount of missing data for individual variables. Overall, we found that records had high accuracy for the variables we considered (Table 4).

Farm identification numbers

Next, we checked the accuracy of the reported farm identification numbers. We found that less than 1% of records in the data had missing information for all three numbers (organization id, business entity id, and producer id) for either the sender or the receiver. After removing slaughterhouses, we found 2,320 unique combinations of

Table 4 Results for the attributes and measures used to quantitatively assess the data quality of pig movements in the Norwegian Livestock Register for 2022. For each measure, we specify the level (record, farm, or slaughterhouse), number and percentage of low-quality data

Attribute	Measure	Level	Number low quality	Percent low quality
Accuracy	Missing sender information (organization number(s)/ producer number)	Record	4	< 0.01%
	Missing sender type (farm/live animal trader/ slaughterhouse)	Record	1	< 0.01%
	Missing receiver information (organization number(s)/ producer number)	Record	3	< 0.01%
	Missing receiver type (farm/live animal trader/ slaughterhouse)	Record	3	< 0.01%
	Missing batch size	Record	0	0%
	Missing movement type (Between farms/To slaughter/Other)	Record	0	0%
	Missing dates recorded in the register	Record	7	0.02%
	Inactive farm identifier	Farm	49	2.14%
	Batch size less than 0 or greater than 500	Record	79	0.02%
	Unlikely movements between farm categories	Record	42	0.1%
Completeness	> 5% difference in the number of pigs slaughtered	Farm	411	18.4%
	Sending producers missing live pig movements	Farm	239	41%
	Commercial finishers lacking balance of ingoing and outgoing movements	Farm	273	35%
	Satellites and central units missing sow pool movements	Farm	122	99%
Timeliness	Records delayed > 7 days	Record	16,873	40.6%
	Slaughterhouses with median timeliness > 7 days	Slaughterhouse	10	45.5%

identifiers (organization id, business entity id, and producer id). Of these, 2,212 (95%) had information for all three identification numbers.

Prior to merging the data, we found that the data in the Norwegian Livestock Register lacked producer numbers for 57 (2.5%) of the id combinations. For these combinations, we were able to add producer numbers for 53 producers using one of the other identification numbers. The final dataset had 2,279 farms represented by unique eight-digit producer numbers. Of these, 49 (2%) producer numbers could not be linked to data in either the Register for Production Subsidies or the Register for Carcass Deliveries for 2022. We found that 41 (84%) of these were classified as non-commercial farms.

Batch sizes

All records included information on the number of pigs (batch size) moved. The batch sizes ranged from 1 to 752, median 42 (IQR: 11, 96). There were 79 (0.2%) records with more than 500 pigs.

Movements between producer categories

Finally, we checked for unlikely movements between categories as possible registration errors in the direction of the movements. There were 42 records (0.1%) with movements against the expected direction of animal flow. For fifteen of these, the sender and receiver were the same farm. Another seven were due to a farm changing production types during the year. Finally, the 20 remaining unlikely movements appeared to be registered in the wrong direction based on previous trading activity.

Completeness

Movements from farms to slaughterhouses

First, we assessed the completeness of movements to slaughterhouses by cross-validating the number of pigs moved with the Register for Carcass Deliveries, both nationally and per farm. According to the Register for Carcass Deliveries, there were 1,532,529 pigs slaughtered in 2022, while the Norwegian Livestock Register reported 1,972,790 pigs moved to slaughterhouses. This means the Norwegian Livestock Register over reported the number of pigs moved to slaughter by 440,261 or 29%. At the farm level, we found that the quality of reported movements to slaughter varied greatly. Of the 2,232 farms or live animal traders in both registers, 1,619 (73%) had perfect agreement and 1,821 (82%) had a difference of 5% or less in the total number of pigs sent to slaughter in 2022. Of those with a difference greater than 5%, the absolute difference ranged from 1 to 21,500 slaughtered pigs with a median of 195. 64% of these farms over-reported movements to slaughter.

Movements between farms

We found that 583 producers had registrations of sending live pigs in at least one of the registers. For these, we calculated the difference in the number of pigs in the Norwegian Livestock Register and the Register for Carcass Deliveries. We expected that the number of outgoing live pigs in the Livestock Register would be equal to or greater than those in the Register for Carcass Deliveries, because slaughterhouses do not mediate all movements. However, we found that 239 (41%) producers had fewer reported sent pigs in the Livestock Register and the difference per producer ranged from 1 to 21,486 pigs with a median of 233.

Balance of movements in finisher farms

We classified 872 farms in the Livestock Register as commercial finishers. Of these, 630 (72%) reported both ingoing and outgoing movements, while 6 (1%) had only ingoing movements and 236 (27%) had only movements to slaughterhouses.

We had farmer-reported information about the number of pigs in the Register for Production Subsidies for 785 (90%) of the finisher farms. From this subset of commercial finishers, we calculated the balance of ingoing and outgoing movements. We found that 512 (65%) of the farms had balanced ingoing and outgoing movements, while 273 (35%) were not balanced. Of the farms lacking balance, 229 (85%) had values below – 1, meaning they received fewer pigs than expected.

Movements within Sow pools

There were 123 farms classified as sow pool members in our dataset for 2022, 11 central units and 112 satellites. For 2022, we found that there were only eight batches of pigs moved from central units to satellites and only one batch moved from a satellite farm to a central unit.

Slaughterhouse biases

We investigated slaughterhouses as a source of bias for missing or incorrect data. We summarized yearly data for the number of pigs received from the Norwegian Livestock Register and the number of pigs slaughtered from the Register for Carcass Deliveries per slaughterhouse. There were 24 slaughterhouses associated with pigs in the Register for Carcass Deliveries; however, two did not report receiving any pigs to the Norwegian Livestock Register. Only one slaughterhouse had perfect agreement in the number of received and slaughtered pigs between the two registers. For eleven slaughterhouses, the yearly totals were within 3% of each other. These eleven slaughterhouses accounted for a little over half (53%) of the total pigs slaughtered in 2022. Of the remaining slaughterhouses, two underreported movements and nine over reported movements as compared to the number of pigs slaughtered.

We wanted to understand how slaughterhouse affiliation could affect the quality of movement data for single farms. To do this, we selected indicator farms that had registered live animal movements in any register and that had delivered pigs to only one slaughterhouse in 2022. The 208 indicator farms represented eight of the ten slaughterhouses that reported live animal movements in the Register for Carcass Deliveries. We summarized the data for the indicator farms per slaughterhouse (Fig. 2). We found that farms associated with three of the slaughterhouses (A, C, and D) had live animal movements that were misclassified as movements to slaughterhouses. Consequently, these farms lacked almost all data for live animal movements between farms. Together, these three slaughterhouses accounted for 280,430 (24.4%) of the live animal movements in the Register for Carcass Deliveries. Additionally, we found that farms associated with slaughterhouse E had live animal movements reported twice, once as between farm movements and once as movements to slaughterhouses.

Timeliness

To assess timeliness, we calculated the number of days for a pig movement to be registered. We found that 59% of movements were registered within 7 days and 95% of the reports were made within 141 days of the movement (Fig. 3). The median time for slaughterhouses to report pigs received for slaughter ranged from 2 to 153 days.

Discussion

We assessed data quality for the following attributes: accuracy, completeness, and timeliness. We found that the most significant problem with the pig data in the Norwegian Livestock Register was that it was incomplete. Here we estimated that more than one third of farms that sent pigs to other farms lacked data for live pig movements. At the same time, around one third of finisher farms lacked balance of ingoing and outgoing movements and a quarter did not report having received any pigs. Using indicator farms that supplied to a single slaughterhouse company, we showed that three slaughterhouses incorrectly reported live animal movements on behalf of recipients. Consequently, up to a quarter of all live pig movements were missing in the Norwegian Livestock Register for 2022 for this reason alone. Previous quality assessments in other countries indicate that missing data may be a common issue with livestock movement data [28, 29]. Moreover, we expect that incompleteness may be more difficult to detect in batch-level data for pigs, as compared to individual data for cattle, which are tracked through the production with unique identification numbers.

Since missing data were associated with certain slaughterhouses, the quality of data from some regions was disproportionally affected. Previous studies have shown that partial, but targeted, sampling of movement data may provide enough information to accurately predict network metrics [33] and epidemic sizes [34]. However, in our case the data were not missing at random. This is a concern because biased movement data can lead to incorrect estimates of network properties [35–37].

Late registrations were also a significant problem with data in the Norwegian Livestock Register. Although companies are obliged to send reports of movements within seven days, we found that 41% of pig movements were registered after this deadline for 2022. Nearly all slaughterhouse companies had a significant percentage of late

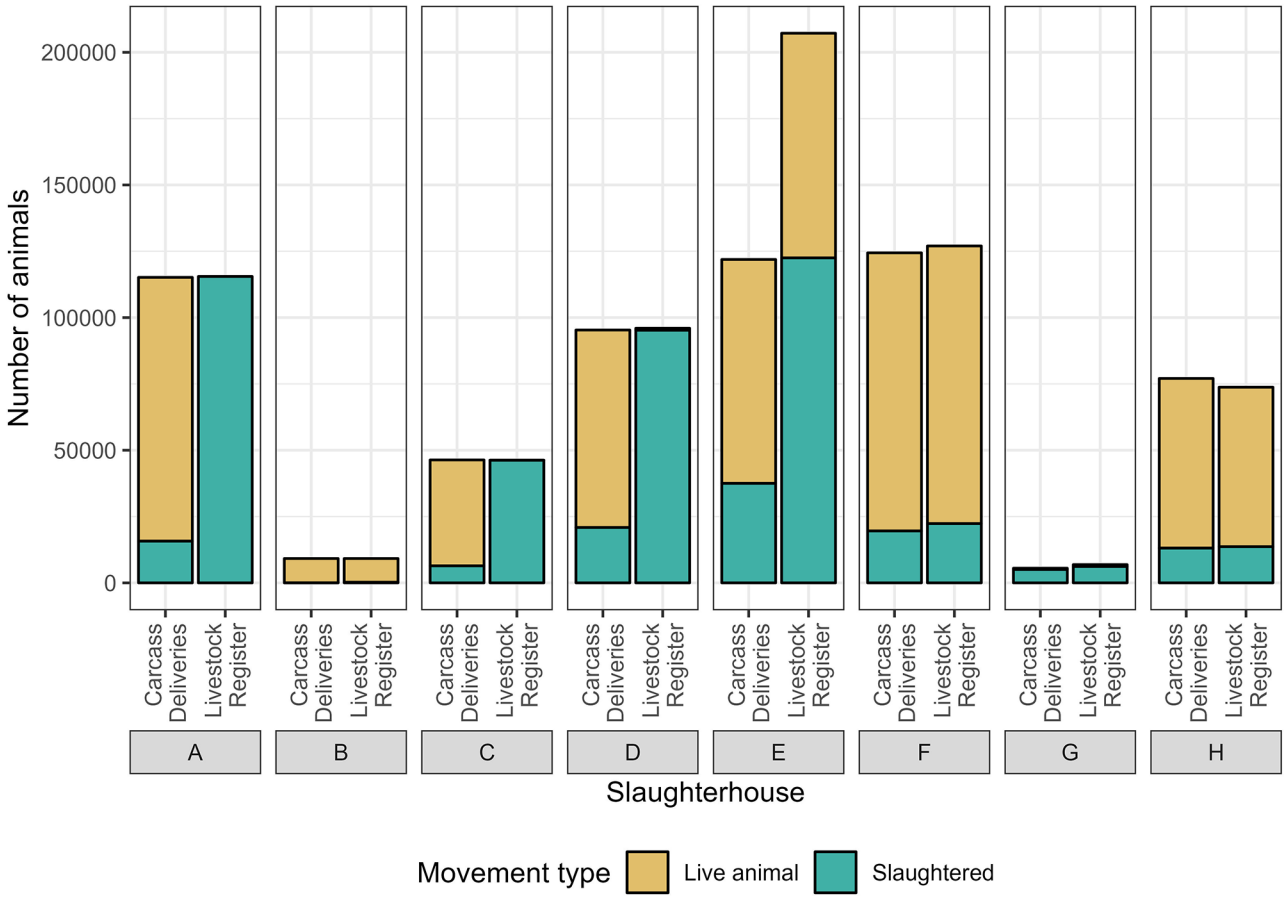


Fig. 2 Comparison of reported animal movements in the Register for Carcass Deliveries and the Norwegian Livestock Register for 204 indicator farms associated with eight slaughterhouses. The colors indicate the number of pigs moved between farms (yellow) and the number of pigs moved to slaughter (green). The indicator farms were distributed across slaughterhouses as follows: 27 for A, 3 for B, 14 for C, 37 for D, 45 for E, 51 for F, 6 for G, and 25 for H

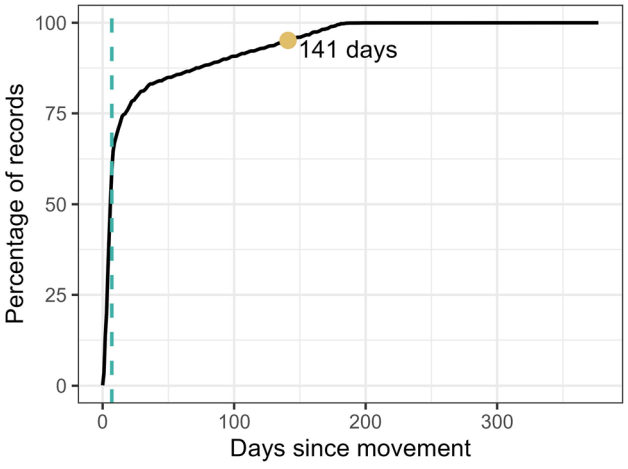


Fig. 3 Timeliness of pig movements records in the Norwegian Livestock Register for 2022. The green line indicates the optimal timeliness of 7 days, based on the legislation. The yellow point indicates when 95% of the records were received

reports for pigs they received for slaughter, although we could not estimate this for live pig movements without information about the report sender. Delayed reporting was also shown to be an issue with pig movement data in the Danish register [29]. At present, late reports in the Norwegian Livestock Register undermine the ability of the authorities to use this register during a disease outbreak investigation. Instead, we recommend that information about pig movements be verified or completed by contacting individual farms or slaughterhouse companies. However, this process can be time consuming and prone to other types of errors. We also recommend that the authorities monitor reporting delays and ensure compliance with the legislated deadlines.

Missing and delayed data on swine movements can be costly, especially during outbreaks of rapidly spreading diseases. Recently, the "Scientific and Technical Review of Animal Health data management" published by World Organisation for Animal Health identified high-quality animal movements as an important source of data for effective risk assessments during disease outbreaks [38]. As animal movements represent an important pathway

for disease transmission, a lack of data can lead to incorrect estimations of risk for farms/areas or overly conservative control measures that are costly for the livestock sector and individual producers. With access to production and animal registers, the authorities can prepare pipelines for data retrieval, cleaning, descriptive analyses, as well as advanced models for disease spread and the impacts of various control measures in peacetime [38].

Slaughterhouses generate a large amount of data in the Norwegian Livestock Register and these should be targeted for improving the register. It was clear from our analysis that data quality varied greatly between slaughterhouse companies. To improve quality, it is important to understand the data generation process and data transfer from the slaughterhouses to the register maintainer. We show that half of the slaughterhouses had very high agreement between registers for slaughtered pigs. The authorities should investigate how the processes at these companies differ from those with poorer data quality. This information can be used to make targeted recommendations for companies with poor quality to improve. To make it easier to identify the source of poor quality registrations, we recommend that the register includes a variable to indicate if reports are sent by slaughterhouses (on behalf of recipient farms) or recipient farms.

Here we presented several measures of quality that rely on data from secondary registers. Specifically, we used HelseGris to determine farm categories, the Register for Production Subsidies for farm sizes, and the Register for Carcass Deliveries to compare the number of live pig movements from sending farms and the movements of pigs to slaughter. We assumed that these registers had accurate and complete reporting. However, we acknowledge that secondary registers have their own limitations that could have affected our quality estimates. For example, reporting to the Register for Production Subsidies is voluntary by farmers and does not always reflect true farm sizes. Moreover, farms can change size and production category during the year, which can impact some of the measures. Ideally, primary data would be available for this purpose. However, the advantage of these secondary registers is that the data are available for the full farm population, and for continuous monitoring, without the need for additional data collection.

Monitoring data quality provides the authorities with the degree of confidence they can have that their decisions are based on data that reflects the state of the real world. The measures we presented here can be used to automate reporting on quality metrics for the Norwegian Livestock Register, which can directly inform targeted strategies to improve data quality. Although many metrics we used rely on integrating and comparing data from multiple secondary registers that are country specific, the principle of establishing metrics for routine quality monitoring can be applied widely to other registers. In the case of the Norwegian Livestock Register, even a simple comparison of the number of pigs slaughtered and the number of pigs sent to slaughter revealed significant discrepancies between the registers, signaling a data quality problem. With the consumption of increasingly large amounts of data related to animal health and production, we recommend that data owners and users incorporate quality checks into their workflows.

Conclusions

Our results showed that the pig movement data for 2022 in the Norwegian Livestock Register lacked sufficient quality to be used for risk assessment and outbreak management. By design, the Norwegian Livestock Register should include all batches of pigs moved between farms and from farms to slaughterhouses, recorded within seven days of the event. Apart from some exemptions, this is generally true for all of the European livestock movement registers to ensure animal traceability in case of a disease outbreak. Here our validation work provides clear indications of late reporting and missing registrations tied to specific slaughterhouses and sow pools. We recommend that slaughterhouses should be targeted for improving quality, as well as, continuous data quality monitoring and an additional variable for the data sender. These issues and recommendations have been reported to the register owner, and if resolved, the movement data can serve as a valuable foundation for risk assessments in the coming years.

Abbreviations

NFSA Norwegian Food Safety Authority
IQR Interquartile range

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Author contributions

KRD and PH conceived and designed the study. PH and CAG acquired the data. KRD analyzed the data. KRD, PH, CAG, HV and CW interpreted the results. KRD and CW drafted the work. All authors read and approved the manuscript.

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Data availability

The data that support the findings of this study are available from the Norwegian Food Safety Authority (Norwegian Livestock Register), the Norwegian Agricultural Agency (Register for Carcass Deliveries and the Register for Production Subsidies), and Animalia (HelseGris), but restrictions apply to the availability of these data, which were used under license for the current study, and so are not publicly available. Data are, however, available from the authors upon reasonable request and with permission the

Norwegian Food Safety Authority, the Norwegian Agricultural Agency, and Animalia.

Declarations

Ethics approval and consent to participate
Not applicable.

Consent for publication
Not applicable.

Competing interests
The authors declare no competing interests.

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