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# A descriptive analysis of swine movements in Ontario (Canada) as a contributor to disease spread

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ABSTRACT

In recent times, considerable efforts have been made to develop infrastructure and processes of tracing livestock movements. One of common use of this type of data is to assess the potential for spread of infections in source populations. The objectives of this research were to describe Ontario pig movements in 2015, and to understand the potential for disease transmission through animal movement on a weekly and yearly basis. Swine shipments from January to December 2015 represented 224 production facilities and a total of 5398 unique animal movements. This one-mode directed network of animal movements was then analyzed using common descriptive network measures.

The maximum yearly ($_y$) weak component ($WC_y$) size and maximum weekly ($_w$) weak component size ($WC_w$) was 224 facilities, and 83 facilities, respectively. The maximum $WC_w$ did not change significantly ($p > 0.05$) over time. The maximum strong component (SC) consisted of two facilities both on a weekly, and on a yearly basis. The size of the maximum ingoing contact chain on a yearly basis ($ICC_y$) was 173 nodes with one abattoir as the end point, and the maximum $ICC_w$ consisted of 53 nodes. The size of the maximum outgoing contact chain ($OCC_y$) contained 79 nodes, with one sow herd as a starting point. The maximum $OCC_w$ was 6 nodes. Regression models resulted in significant quadratic associations between weekly count of finisher facilities with betweenness > 0 ($p = 0.02$) and weekly count of finisher facilities with in-degree and out-degree > 0 ($p = 0.01$) and week number. Higher weekly counts of nursery and finisher facilities with betweenness > 0 and in-degree and out-degree both > 0 values occurred during summer months.

All study facilities were connected when direction of animal movement was not taken into consideration in the yearly network. As such, yearly networks are potentially representative of infections with long incubation periods, subclinical infections, or endemic infections for which active control measures have not being taken. When the direction of animal movement was considered, such infection could still spread substantially and affect 35% of the study population (79/224).

In the study population, finisher sites were proportionally and consistently most represented in $WC_w$ (min = 51%, max = 78%), which reflects current Ontario herd demographics. However, abattoirs were over-represented when the number of facilities in the study population was taken into consideration. This, and the size of the maximum $ICC_w$ both suggest that abattoirs could be, at least for some infectious diseases, suitable establishments for targeted sampling.

## 1. Introduction

Improvements in livestock health management strategies over the past few decades have resulted in the elimination of certain swine diseases, however, despite these efforts the risk of emerging infections remains (Davies, 2012). In addition to ongoing disease challenges faced by swine populations, the movement of animals and animal by-products between countries has also increased. This increased movement has also increased the potential for disease transmission world wide (Ayudhya et al., 2012; Davies, 2012; Wernike et al., 2013). Globally, three new species of swine infectious agents per year were reported between 1985 and 2010 (Fournié et al., 2015). For emerging and for endemic swine diseases, various pathways of dissemination have been confirmed or suspected in different populations, with animal movement documented as an important contributor to transmission (Dee et al., 2004; Dubé et al., 2009; Guinat et al., 2016; Pasick et al., 2014). Network analysis has been utilized in studies to investigate how animal movements have contributed to disease spread (Bigras-Poulin et al.,

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2007; Dubé et al., 2008; Natale et al., 2009; Thakur et al., 2016). Such studies vary with respect to the completeness of the network, time periods over which the networks were constructed, and measures utilized to make recommendations.

In Canada, two recent studies utilized swine movement data to investigate network structure of swine populations (Dorjee et al., 2013; Thakur et al., 2016). In a study based on swine movements in four Canadian provinces, Thakur et al (2016) reported that swine farms showed high indirect connectivity via shared trucks. It has been argued that there is a high potential for disease transmission in swine populations due to its small-scale, and scale-free network topology (Dorjee et al., 2013). Despite useful information, the studies were conducted on data collected more than ten years ago. Significant disease events that recently occurred, and evolving nature of swine production systems could both have influenced the movement patterns over time. The primary objective of this study was to describe the contact structure, based on 2015 data collected from an Ontario swine data management company containing information on movements between individual farms and other production facilities located in Ontario. By addressing this objective, the potential for disease transmission through animal movement on a weekly and yearly level is hypothesized.

## 2. Materials and methods

### 2.1. Study population

The data was obtained from an Ontario swine data management company and included all animal movements between the facilities in the study population. The data analyzed consisted of animal movements associated with commercial swine production related facilities (nodes) located in southwestern Ontario, with some movements to locations in other provinces and exports to other countries in North America. These facilities were categorized by the stages of production of the animals shipped and received and were assigned to a facility type which is described below. The study period was between January 1$^{st}$ and December 31$^{st}$, 2015.

The raw data consisted of 5398 unique movements (edges) between the nodes, with 16 descriptive variables defining edge attributes. Nodes were categorized by facility type and included traditional facility designations: sow, nursery, finisher facilities, abattoir sites. These facility names are based on the typical production and life cycle of pigs within the Ontario swine production system. When abattoirs were referred to on an individual basis, the unique facility was assigned an arbitrary designation from A1-A10.The typical swine facility types in a three-site production system can be divided into the following: (i) a sow site houses breeding animals (sows) and their offspring until the 3–4 weeks of age, when they are moved to nursery facilities, (ii) nursery facility where animals are housed, typically for up to 8 weeks, after which period they are moved to finisher sites, and (iii) finisher sites where they grow until market weight, which in this source population, typically lasts for up to 16–17 weeks. More specific classification of herd types is possible, depending which production classes are located together on the same premises.

There were additional non-traditional facility classifications that were based on whether the node was a destination or a source that was external to the company's database. The non-traditional facilities were designated a unique identifier (UI) that represented business-related entities and these entities were further categorized as: Company Internal (CI), Company External (CE), and Company Export ($CE_X$). The details about the specific geographic locations of these entities were not part of the dataset, and consequently, each UI could represent one or more nodes grouped within it. The definitions of these three categories of entities were made based on the direction of animal movements over the period of the entire year and were then consistently applied for both yearly and weekly networks. Company Internal described nodes that are within Canada and are only a destination for movements of animals from unique facilities within the production system. Company Export was used to describe an identical type of destination for animal movement as CI, except that the destination was outside of Canada. Company External was used to describe entities that, over a period of the entire year, served as source of animals for nodes within the production system, but could also be destination for animals from the production system.

### 2.2. Data management

Data management and analysis was conducted with R version 3.3.2 (R Core Team, 2015). Packages *doBy* (Højsgaard and Halekoh, 2016) and *lubridate* (Grolemund and Wickham, 2011) were used for data aggregation and date organization.

One-mode networks were constructed from the movement data among all nodes using functionality available in the package *igraph* (Csardi and Nepusz, 2006), and were initially analyzed as a directed yearly network. Following this, weekly networks were constructed, and selected network and node characteristics were examined descriptively and analytically over time. S.Table 1 provides definitions of the descriptive network measures analyzed within this study (Dubé et al., 2009).

### 2.3. Descriptive network analysis

#### 2.3.1. Yearly network

A directed one-mode network was generated for 2015. Heatmaps were constructed to visualize the number of animal movements throughout the entire year between facility types. Accompanying dendrograms were constructed using hierarchical cluster analysis based on Euclidean distances between outgoing or ingoing number of movements and the Unweighted Pair Group with Arithmetic Mean (UPGMA) methods.

Network level measures of interest included the size of the strong ($SC_y$) and weak components ($WC_y$), density, diameter of the network, and the largest ingoing contact chain ($ICC_y$) and outgoing contact chain ($OCC_y$). The density measure was calculated based on a directed network. Contact chains are used to establish the temporal sequence of direct and indirect connections (i.e., animal movements) that were associated with the facility of interest (ingoing), or after the facility (outgoing) (Noremark et al., 2011); and were determined using functionality available in the package *EpiContactTrace* (Noemark and Widgren, 2014). Node centrality measures of interest were: in & out degree, and betweenness.

#### 2.3.2. Weekly network

Weekly network level measures considered were strong and weak components, order, density and diameter, and largest in- ($ICC_w$) and out-going contact chain, ($OCC_w$). Proportions of facility types within the weekly weak components ($WC_w$) were calculated, as well as the proportion of facility types in the entire study population that were observed in each $WC_w$.

Additionally, node centrality measures calculated were: in- and out-degree, and betweenness. Following the calculation of weekly node- and network-level measures; selected measures were further aggregated to a weekly level to evaluate any trends over time. Specifically, the size of the largest weak and strong components, demographic characteristics of the nodes involved in the largest weak components, number of nursery and finisher sites with the betweenness > 0, and number of finisher and nursery sites where both in-degree and out-degree were > 0 in a given week were determined.

## 3. Statistical analysis

Different types of regression were used to assess development of several measures indicative of network structure over time. Specifically,