MANAGEMENT AND PRODUCTION

Higher line speed in young chicken slaughter establishments does not predict increased *Salmonella* contamination risks

Louis Anthony Cox, Jr.[1]

Cox Associates and University of Colorado, Denver, CO, USA

ABSTRACT Do faster slaughter line speeds for young chickens increase risk of *Salmonella* contamination? We analyze data collected in 2018–2019 from 97 slaughter establishments processing young chickens to examine the extent to which differences in slaughter line speeds across establishments operating under the same inspection system explain observed differences in their microbial quality, specifically frequencies of positive *Salmonella* samples. A variety of off-the-shelf statistical and machine learning techniques applied to the data to identify and visualize correlations and potential causal relationships among variables showed that the presence of *Salmonella* or other indicators of process control, such as noncompliance records for regulations associated with process control and food safety, are not significantly increased in establishments with higher line speeds (e.g., above 140 birds per min) compared with establishments with lower line speeds when establishments are operating under the conditions present in this study. This included some establishments operating under specific criteria to obtain a waiver for line speed. A null hypothesis advanced over 30 yr ago by the National Research Council that increased line speeds result in a product that is not contaminated more often than before line speeds were increased, appears to be fully consistent with these recent data.

Key words: *Salmonella*, risk analysis, chicken, slaughter, line speed

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INTRODUCTION

In August 2014, the United States Department of Agriculture, Food Safety and Inspection Service (**FSIS**) established the New Poultry Inspection System (**NPIS**) as an additional inspection system for young chicken and all turkey slaughter establishments (U.S. Department of Agriculture, 2014). In poultry inspection systems other than the NPIS, online inspectors are positioned along the slaughter line and are responsible for identifying unacceptable carcasses and parts, examining carcasses for visual defects and directing establishment employees to take appropriate corrective actions if carcass defects can be corrected through trimming and processing. The maximum line speed authorized under these inspection systems reflects the time it takes for an inspector to effectively perform the online inspection procedures required for the system. The fastest line speed authorized for a non-NPIS young chicken inspection system is 140 bpm, which requires 4 online inspectors with each inspecting 35 bpm. The NPIS system, described next, enables more efficient inspection and faster line speeds in many establishments, raising the question of whether NPIS young chicken establishments can maintain process control at higher line speeds, keeping microbial hazards such as contamination of carcasses with *Salmonella* no greater than in establishments with lower line speeds. This article presents data and analyses to help answer that question.

Under the NPIS, establishment employees sort carcasses and remove unacceptable carcasses and parts before the birds are presented to a single online carcass inspector located at the end of the line just before the chiller (U.S. Department of Agriculture, 2014). Because the online inspector under the NPIS is presented with carcasses that have been sorted, washed, and trimmed by establishment employees and are thus much more likely to pass inspection, the inspector is able to conduct a more efficient and effective online inspection of each bird processed. The NPIS was informed by FSIS's experience under the Hazard Analysis and Critical Control Point–Based Inspection Models Project (**HIMP**) pilot study (U.S. Department of Agriculture, 2011a). Food Safety and Inspection Service's experience under the HIMP pilot showed that when presented with young chicken carcasses that have been sorted, washed, and trimmed by establishment employees, a single online inspector positioned at the end of the line is able to

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[1]Corresponding author: tcoxdenver@aol.com

conduct an effective online inspection of each carcass at line speeds of up to 175 bpm and that establishments participating in the HIMP pilot were able to maintain process control when operating at the line speeds authorized under HIMP (U.S. Department of Agriculture, 2014). Based on its experience under HIMP, FSIS initially proposed 175 bpm as the maximum line speed for young chicken establishments operating under the NPIS (U.S. Department of Agriculture, 2012). However, after considering public comments on the proposed NPIS, FSIS determined that it was important to assess young chicken establishments' ability to maintain process control as they implement changes to operate under the NPIS (U.S. Department of Agriculture, 2014). Therefore, FSIS established 140 bpm as the maximum line speed for young chicken establishments operating under the NPIS, instead of 175 bpm as was proposed, with an exception for the 20 young chicken establishments that had participated in the HIMP pilot (U.S. Department of Agriculture, 2014). The FSIS granted regulatory waivers under the Agency's *Salmonella* Initiative Program (SIP) to allow the 20 former HIMP establishments to continue to operate at line speeds up to 175 bpm because data from the HIMP pilot demonstrated that they were capable of consistently producing safe, wholesome, and unadulterated product and meeting *Salmonella* reduction performance standards at line speeds up to 175 bpm (U.S. Department of Agriculture, 2014).

Under FSIS's SIP, meat and poultry slaughter establishments receive waivers of regulatory requirements on condition that they will conduct regular microbial testing and share the resulting data with FSIS (U.S. Department of Agriculture, 2011b). The SIP benefits public health in that establishments operating under SIP waivers are required to conduct testing for microbial pathogens, which is a key feature of effective process control and to respond to testing results by taking steps, when necessary, to regain process control. The SIP establishments test for *Salmonella*, *Campylobacter* (if applicable), and generic *E. coli* or other indicator organism and share all sample results with FSIS (U.S. Department of Agriculture, 2011b).

When FSIS established 140 bpm as the maximum line speed for young chicken establishments under the NPIS, the Agency made clear that it would continue to consider line speeds at which establishments operating under NPIS are capable of producing safe, wholesome, and unadulterated product and are meeting pathogen reduction and other performance standards (U.S. Department of Agriculture, 2014). Therefore, in February 2018, after FSIS had at least a year's worth of demonstrated process control history for many young chicken establishments operating under the NPIS, the Agency announced that it had decided to consider requests for waivers from other young chicken establishments in addition to the 20 former HIMP establishments to operate at line speeds up to 175 bpm (U.S. Department of Agriculture, 2018a). The FSIS also determined that in addition to participating in the SIP, young chicken establishments would need to meet additional criteria to be eligible for a line speed waiver (U.S. Department of Agriculture, 2018a, 2018b). The FSIS required these additional criteria to ensure that establishments operating under line speed waivers incorporate measures into their food safety systems to maintain process control when operating at faster line speeds (U.S. Department of Agriculture, 2018b).

Specifically, in addition to participating in the SIP to be eligible for a new line speed waiver, an establishment

- Must have been operating under the NPIS for at least 1 yr;
- Must be in FSIS's *Salmonella* performance standard category 1 or 2 for young chicken carcasses. The FSIS continuously samples (up to 5 times per month) poultry establishments producing young chicken and turkey carcasses and raw chicken parts, so that it can more closely monitor an establishment's process control over time. The FSIS also continuously samples not-ready-to-eat comminuted chicken and turkey products for *Salmonella.* The FSIS uses these *Salmonella* sampling results to assess establishment performance during a reference period of one completed 52-week moving window based on a 3-category system. Establishments at or below half of the performance standard over the previous moving window are placed in Category 1, establishments that have a higher *Salmonella* positive rate required for Category 1 but that are at or below the standard in that period are placed in Category 2, and those that fail the standard in the previous moving window are placed in Category 3. To be categorized, establishments have to meet a minimum number of samples in the 52-week window (11 for broiler carcasses) not including follow-up sampling for positives. Additionally, FSIS sets the allowable positives for small sample numbers, so that smaller establishments are not at a disadvantage for having fewer collected samples;
- Must have a demonstrated history of regulatory compliance. For line speed waiver purposes, a demonstrated history of regulatory compliance means that the establishment has not received a public health regulation alert issued from FSIS's Public Health Information System (**PHIS**) for noncompliance with public health regulations in the last 120 d; has not had an enforcement action as a result of a Food Safety Assessment conducted in the last 120 d; has not been the subject of a public health related enforcement action in the last 120 d; and must not have had a noncompliance record for violation of FSIS's good commercial practices regulations (9 CFR 381.65(b)) in the last 120 d; and
- Must be able to demonstrate that the new equipment, technologies, or procedures that allow the establishment to operate at faster line speeds will maintain or improve food safety (U.S. Department of Agriculture, 2018a, 2018b).

In addition, instead of conducting weekly testing for indicator organisms and daily test for *Salmonella*, which had typically been required under the SIP, NPIS young chicken establishments that are granted new line speed waivers must conduct daily aerobic plate count testing and at least weekly testing for *Salmonella* and share the results with Sisals a condition of their waiver (U.S. Department of Agriculture, 2018b). All establishments granted line speed waivers are required to routinely operate at least 1 line above 140 bpm on average, but not higher than 175 bpm (U.S. Department of Agriculture, 2018b).

The FSIS decided to provide for additional line speed waivers so that the Agency could use data collected from establishments that were granted new waivers, along with data collected from the 20 former HIMP establishments currently operating under line speed waivers, to assess the ability of NPIS young chicken establishments to maintain process control at higher line speeds and to inform future rule-making, if supported (U.S. Department of Agriculture, 2018b). To ensure that the data collected from all NPIS establishments with line speed waivers were comparable, the former HIMP young chicken establishments were given 120 d to meet the additional criteria that the other NPIS establishments were required to meet to be eligible for a waiver (U.S. Department of Agriculture, 2018b). All but 2 of the 20 former HIMP establishments met these criteria and maintain their line speed waivers. (1 establishment was in Salmonella category 3, and the other was not using its waiver to operate faster than 140 bpm) (U.S. Department of Agriculture, 2018b).

As discussed next, data were collected from all young chicken slaughter establishments operating under the NPIS from July 2, 2018 to July 12, 2019, including those with line speed waivers. The data were used to determine how higher line speeds under the NPIS affect microbial safety outcomes, as measured by positive *Salmonella* samples and noncompliances related to food safety and process control. Because establishments must meet certain criteria to be eligible for a line speed waiver, the data collected from establishments operating at line speeds faster than 140 bpm reflect the joint effects of both line speed and any responses to the criteria specified in their waiver. The former is the primary focus of this analysis.

As discussed below, this study has compared the frequencies of *Salmonella* positives across NPIS young chicken establishments with varying line speeds. Although they were permitted to do so, not all establishments operating under line speed waivers chose to operate at the maximum line speed of 175 bpm. Establishments consider a number of factors to determine their line speed, including their equipment and facilities, bird size and flock condition, and their ability to maintain process control (i.e., adhere to the conditions of their waiver) when operating at a given line speed. In addition, establishments operating under the NPIS consider the number of employees that have been trained and are available to conduct carcass sorting when determining line speed.

MATERIALS AND METHODS

Data

The PHIS is a dynamic, comprehensive data analytic system used by FSIS to collect, consolidate, and analyze data to improve public health.[1]It can only be accessed by FSIS personnel and authorized industry users. The FSIS inspection personnel use PHIS to record activities related to ensuring that products are safe, wholesome, and correctly labeled and packaged. This includes routine activities (e.g., inspection tasks, slaughter totals and dispositions, and microbiological sampling information) and information collected through questionnaires sent by FSIS to establishments and provided to the author by FSIS for this study. These questionnaires are assigned to targeted establishments within the PHIS system to capture additional information about each establishment's products or processes that is not obtained through routine inspection. Data for this analysis were captured via PHIS from July 2, 2018 to July 12, 2019 (55 wk) and includes information on routine activities and answers to a questionnaire focused on slaughter line speeds (Appendix A).

The questionnaire was assigned weekly to all NPIS establishments that slaughtered young chickens between July 2, 2018 and July 7, 2019. Information was collected about number of slaughter lines operating, number of hours operating, and recorded line speeds for each line operating. The on-site veterinarian completed the questionnaire once per week per shift to coordinate with weekly routine microbiological samples taken by FSIS inspection personnel[2]. Occasionally, no questionnaires were completed in a week, or multiple questionnaires were completed in the same week because of confusion between temporary veterinarians filling in for a specific day or week. If there were multiple questionnaires completed in the same week, only the first was included in the data. The average number of completed questionnaires per establishment was 79.

Routine activities collected daily were aggregated by week and shift. Noncompliance records (**NR**) for key food safety and process control regulations were aggregated by week and shift as a total count and summarized by indicator variables for each regulation (Appendix B)[3]. Slaughter totals and dispositions were aggregated by week and shift. Routine microbiological testing by FSIS for *Salmonella* and *Campylobacter* occurred weekly with more frequent sampling if an establishment had a positive result. Therefore, samples were aggregated for

[1]More information about PHIS can be found here https://www.fsis.usda.gov/wps/portal/fsis/topics/inspection/phis.

[2]Establishments can operate 1 or 2 shifts per day. Establishments operating 1 shift would receive 1 questionnaire per week. Establishments operating 2 shifts would receive 2 questionnaires per week.

[3]Incidences in which the establishment fails to meet a regulation are documented as noncompliance records (NR).

each pathogen by week and shift to include any additional samples from positives.

Some establishments converted to NPIS during the data collection period, so the NPIS status of each establishment for each week is indicated by a binary variable, *npis*, with value 1 when an establishment was under the NPIS inspection system and 0 otherwise. The average value of this variable over all weeks of observation for an establishment indicates the fraction of the time that it was an NPIS establishment.

Establishments that converted to NPIS after July 2, 2018 had routine inspection information for weeks before their conversion but no questionnaire responses. An NPIS transition variable (denoted by *NPIStrans* in the following sections) was created, with values of 0, 1, and 2 indicating records before conversion, within 60 d of conversion and after conversion, respectively. Similarly, a line speed waiver indicator variable was also included (denoted by *Waiver*, with values of 0, 1, and 2), with 90 d for the transition period. A variable indicating that an establishment was part of the HIMP pilot program (denoted by *Himp*, with values of 1 for HIMP establishments and 0 otherwise) is also included because these establishments have been operating under the new inspection system and at higher line speeds longer than those recently converted to NPIS.

Except for the selection of the number of slaughter lines operating and whether the line was operating more than 5 bpm under the maximum (indicated by a variable *Slow* with value 1 for yes, 0 for no), the responses to the questionnaire were free text. This resulted in extraneous information in many of the responses. Responses to the questions about hours of operation and line speed were recoded to include only the numeric response. For example, "140 birds per minute" was recoded to "140". Additional recoding was needed to group responses that indicated "Other" for the reason why the line was operating at more than 5 bpm under the maximum. Data on positive *Salmonella* samples (denoted simply by *Salmonella* in the analyses and results that follow) were obtained from all 98 establishments in the population. Data on reported line speeds for at least 1 line were obtained from 97 of the 98 establishments. Only the line speed for Line 1 was used in the analysis for establishments that had more than 1 line. *Salmonella* samples could have been taken from any line operating at the time of collection, but only 1 establishment had significant differences in line speed when running multiple lines. One plant (ID 844) was dropped from further analyses because no line speed data were reported. The line speed variable is denoted simply as *speed* in the analyses and results that follow. There are missing data values because not every variable was measured for each establishment on each day of data collection. Most of our analyses aggregate data by establishment, with values of line speed and microbial outcomes being averaged over many sampling day, thus eliminating missing data. For example, a value of 0.04 for *Salmonella* for an establishment would be the average *Salmonella* positive samples detected over all samples from that establishment (i.e., the sum of positive *Salmonella* samples divided by the number of days of collection for each establishment). The analyses in the following section describe how the value of *Salmonella* varies across establishments with different values of *speed* (i.e., line speed in bpm) and other variables. In addition to these cross-sectional data on the population of establishments, data for individual establishments are used in longitudinal analyses to compare values of *Salmonella* before, during, and after implementation of line speed waivers.

Table 1 summarizes the main variables for which structured data were collected and analyzed for this study.

Data Analysis

We applied several multivariate statistical and machine learning methods (classification and regression trees, random forest ensembles, partial dependence plots, and Bayesian network learning algorithms) to

Table 1. Variables describing data elements collected and analyzed for this study.

Variable name	Meaning
Campy	Count of number of positive *Campylobacter* samples for carcasses from the sampled establishment, week, day, line, and shift
DOA	Total count of young chicken dead on arrival in week
Fecal_i	Indicates NR for 9 CFR 381.65(f)– Zero-tolerance for visible fecal material entering chiller (1 = yes, 0 = no)
Gcp_i	Indicates NR for 381.65(b)—Good commercial practices for poultry slaughter (1 = yes, 0 = no)
HeadCount	Total count of young chicken slaughtered in week
Himp	Indicates whether the establishment operated under HIMP (1 = yes, 0 = no)
Linespeed_i	Indicates NR for 9 CFR 381.69—maximum line speed rates under NPIS (1 = yes, 0 = no)
Npis	Indicates whether the establishment operated under NPIS (1 = yes, 0 = no)
Npistrans	Indicates whether the week is before, after, or during NPIS transition (0 = before, 1 = during, 2 = after)
NR	Count of NR in week (from regulation list see Appendix B)
PMCond	Total count of postmortem condemned young chicken in week
Rtever_i	Indicates NR for 9 CFR 381.76(b) (6) (ii) (D)—Ready-to-cook verification in NPIS (1 = yes, 0 = no)
Salmonella	Count of number of positive *Salmonella* samples for carcasses from the sampled establishment, week, day, line, and shift
Septox_i	Indicates NR for 9 CFR 381.76(b) (6) (ii) (C)—NPIS septicemia/toxemia (1 = yes, 0 = no)
Slow	1 if line currently operating more than 5 bpm below the allowed maximum, else0
speed	Line speed in birds per minute (bpm)
Waiver	Indicates whether the week is before, after, or during line speed waiver transition (0 = before, 1 = during, 2 = after)

seek statistically significant dependence relationships among variables and to study how the frequencies of positive *Salmonella* samples vary with line speed, given the values of other variables. We used the free in-browser Causal Analytics Toolkit analytics software (available at http://cox-associates.com:8899/), which includes on-line documentation for all statistical and machine learning packages used; all of the component packages and detailed documentation are provided in the CRAN repository (https://cran.r-project.org/).These methods are described further in Cox 2018 and the references therein and in Nagarajan et al., 2013. The scatter plot and regression lines in Figure 3 were produced with the *Statistica* statistical computing software (www.statsoft.de/en/statistica/statistica-software); any standard statistics software would produce similar results.

RESULTS

Nonparametric Partial Dependence Plots

To quantify how the conditional expected value of 1 variable (e.g., *Salmonella*, *Campylobacter*, or *NR*) varies with observed values of another (e.g., *speed*), a nonparametric machine learning alternative to regression modeling is the *partial dependence plot* (**PDP**), calculated by averaging predictions from hundreds of nonparametric models (classification and regression trees) for random samples of the data. Figure 1 shows a PDP for the dependence of *Salmonella* on *speed*, holding values of other variables fixed. This PDP suggests a slight negative relationship between higher line speeds (e.g., >135 bpm) and *Salmonella* contamination risk, holding values of other variables fixed. The Spearman's rank correlation coefficient between them is −0.6, significantly different from 0 ($P < 0.0001$), reflecting the fact that all of the lowest contamination risk occurs at the highest line speeds. Similar negative relationships are found in PDPs for *speed* and *NR* (and, more specifically, for *speed* and variable indicators of NR for visible fecal contamination and septicemia/toxemia) (not shown). They are not explained by differences in any of the other variables, as all their values are conditioned on in generating the PDP. The negative relationship is reassuring, in that lower *Salmonella* frequencies (and other adverse outcomes) are found in establishments with higher line speeds after conditioning (or matching) on other observed variables. This negative association (probably caused by other currently unidentified variables) is in the direction of protecting consumer health.

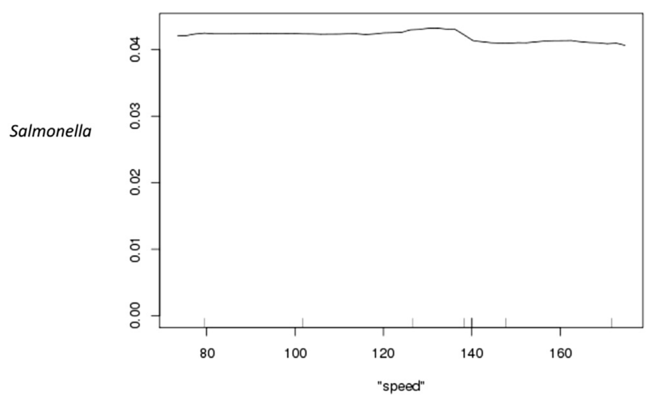

Figure 1. A partial dependence plot (PDP) for the dependence of *Salmonella* on *speed*. (This PDP was generated by the Causal Analytics Toolkit (CAT) software at http://cox-associates.com:8899/using the *randomForest* package in R.) Units are bpm for line speed and relative frequency for *Salmonella*.

Regression Models

Figure 2 shows relative frequency histograms of *speed* (upper left, with the tall spike near the middle at 140 bpm) and average frequency of positive *Salmonella* samples for the establishments (lower right, horizontal scale at top for legibility). The lower left panel shows a scatterplot of these 2 variables, with each point representing 1 establishment. A nonparametric regression curve (kernel density smoothing regression) is superimposed on it to indicate visually how average frequency of positive *Salmonella* samples vary with observed line speeds at each establishment (allowing other variables to change, unlike the PDP in Figure 1). This curve is approximately a flat horizontal line, although it is difficult to discern whether there might be a significant trend that is obscured by random variations. The upper right corner shows that the linear (Pearson's) correlation coefficient between line speed and *Salmonella* is 0.00 to 2 significant digits (0.0047 to 4 significant digits), and not statistically significantly different from 0.

Figure 3 shows an expanded view of this scatterplot and fits 3 parametric regression models—linear, quadratic, and cubic—and their 95% confidence bands to it. The best-fitting (ordinary least squares) regression line is approximately a horizontal line at height 0.04 positive *Salmonella* samples per establishment per day, that is, *Salmonella* appears to be independent of line speed (This is the red regression line in Figure 3). The best-fitting quadratic and cubic models (and also quartic and quintic polynomial regression models, not shown) lie nearly on top of each other and hence are visually indistinguishable in Figure 3. They all correspond to the solid curve, with wide, flat, peak at about 120 bpm. The null hypothesis of no relation (i.e., a flat horizontal line, slope = 0) cannot be rejected by these data and models, because a horizontal line at height of 0.04 positive counts per establishment-day fits between the upper and lower confidence bands for all models. (The narrowest pair of confidence bands, indicated by the pair of dashed curves that extends beyond the data points on the left and right, is for the linear model. The pair of confidence bands with the wide bulge at 100 bpm is for the cubic model. The remaining pair is for the quadratic model.) There is no significant departure from a zero slope (no statistical dependence) between *Salmonella* and line speed in

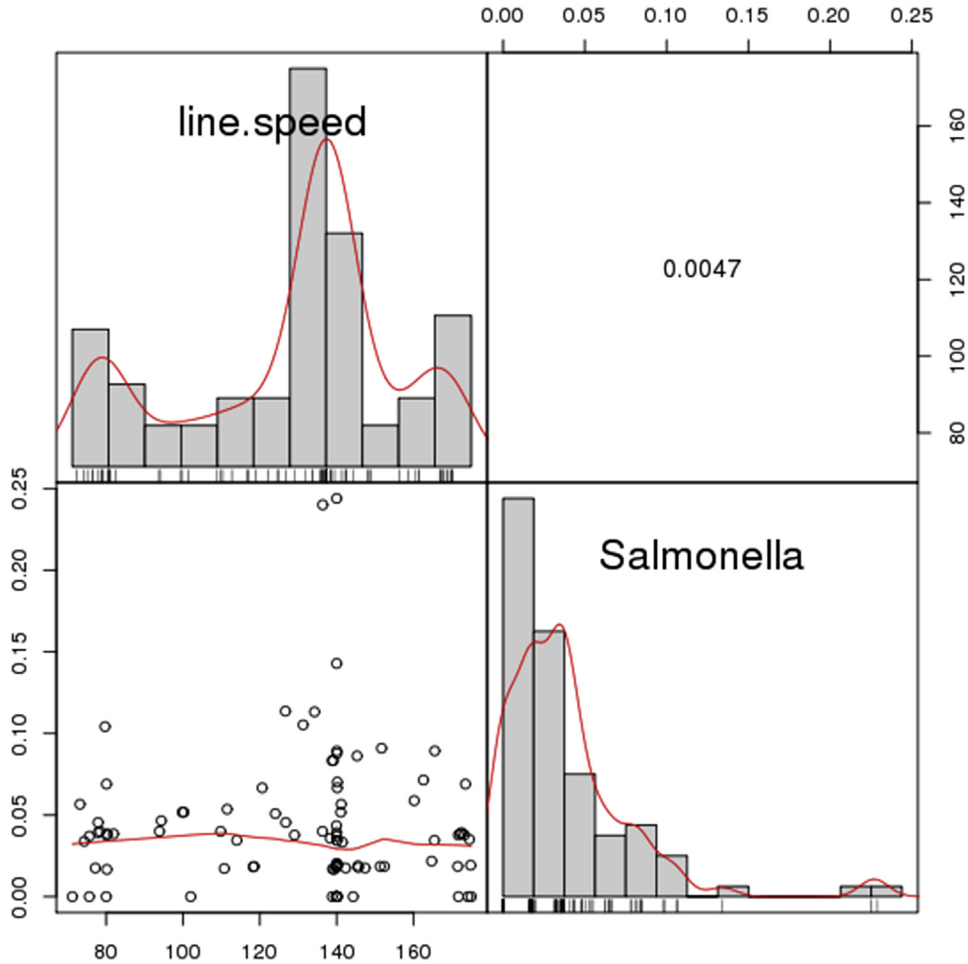

Figure 2. Histograms (with kernel density overlays), scatterplot, and correlation for line speed and *Salmonella* (mean positive *Salmonella* count) for 97 establishments. The histograms show relative proportions of the establishments. Units for the axes (at the top right and bottom left) are bpm for line speed and relative frequency for *Salmonella*. Horizontal axes: Line speeds in birds-per-minute (bpm) for the 2 left panels (upper panel shows a histogram of relative number of establishments with different line speeds; lower left panel shows *Salmonella* contamination rates (y axis) vs. line speed in bpm. The lower right panel shows a histogram for relative number of establishments (vertical axis) with different contamination levels (horizontal axis, scale at top right). Upper right panel has no figure but shows the linear correlation (0.0047, not significantly different from 0) between line speed and *Salmonella* contamination rates in carcasses from different establishments.

these parametric regression models. The same is found in multivariate linear regression modeling and also in nonparametric classification and regression tree analyses (not shown); none of the other variables in Table 1 is identified as a significant predictor of *Salmonella* (or *Campylobacter*).

DISCUSSION

More than 3 decades ago, the National Research Council wrote that "Before it can be stated with assurance that line speed is irrelevant from a public health perspective, more studies on this subject need to be conducted. Current evidence seems to indicate, however, that the mix of changing conditions in production and slaughter—including accelerated line speeds—results in a product that is not contaminated more often than it was before line speeds were increased" (National Research Council, 1987). The analyses presented here indicate that today's establishments running at higher line speeds do not cause increased *Salmonella* risk under the conditions present during this study. Although there has been useful clarification and much discussion of various potential sources of risk at higher line speed in regulatory, industry, and food safety circles in the decades since the National Research Council report, including discussions of occupational safety (Ronholm, 2018), to our knowledge this is the first study to provide recent survey data on today's establishments addressing the issue of line speed and *Salmonella* contamination rates on chicken carcasses.

Owing to the type and availability of data, this study has several limitations. No data were available to identify potential causal drivers of *Salmonella* such as changes in temperatures, flock health, inspection practices, or other unmeasured variables. Therefore, this analysis focused on whether differences in line speed predicted significant differences in *Salmonella* and other microbial outcomes under the conditions of

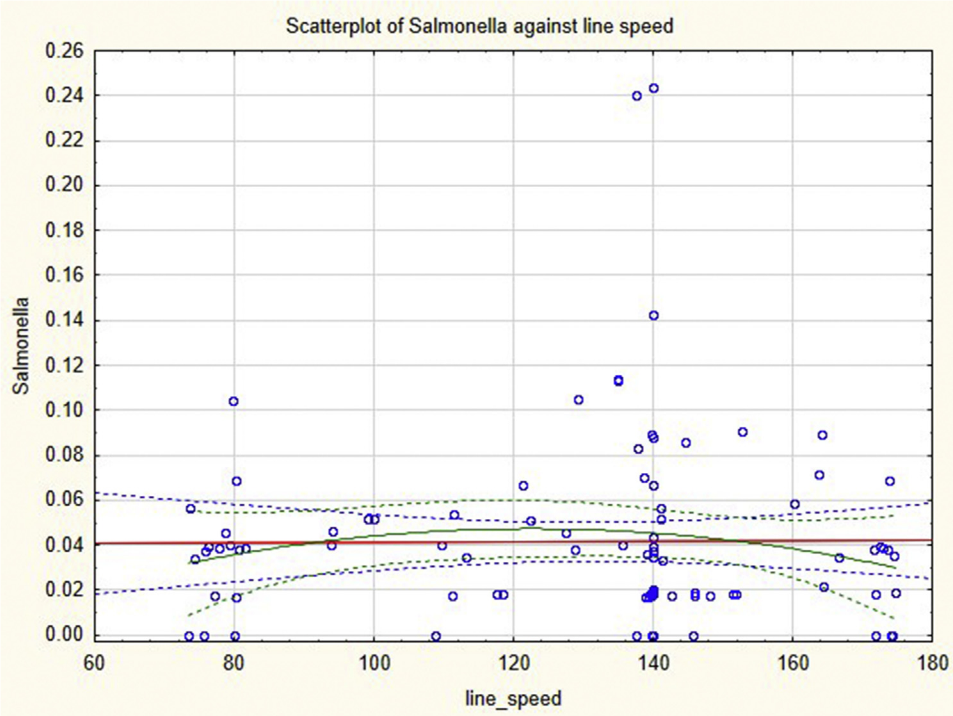

Figure 3. Scatter plot of mean values of *Salmonella* against line speed, with quadratic regression curve and 95% confidence bands. Data points represent establishments. The data do not reject the null hypothesis that *Salmonella* risk has the same value (e.g., 0.04) for all line speeds. Units are bpm for line speed and relative frequency for *Salmonella*. (This plot was generated using the *Statistica* statistics software package.)

the study. There were insufficient data on *Campylobacter* to conduct a useful analysis or to perform detailed intervention (interrupted time series) analyses. The very large differences in average *Salmonella*-positive rates across establishments (Figure 3) invite further analysis into causes and effective controls, but such analysis is outside the intended scope of this study.

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DISCLOSURES

The author declares no conflicts of interest.

SUPPLEMENTARY DATA

Supplementary data associated with this article can be found in the online version at https://doi.org/10.1016/j.psj.2020.09.084.

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