Economic Feasibility Analysis for an Automated On-Line Poultry Inspection Technology

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ABSTRACT On-line carcass inspection of chickens in the United States is currently done using visual (organoleptic) methods. Inspectors from the USDA Food Safety and Inspection Service (FSIS) inspect the viscera and carcass and, for older birds, the heads using a sequence of observations and palpations at a postmortem inspection station. The streamlined inspection system (SIS) and the new line speed inspection system (NELS) are the most prevalent visual inspection methods. The former has a line speed of 70 birds/min with two inspectors per line, and the latter has a line speed of 91 birds/min requiring three inspectors per line. Both inspection methods are labor intensive and prone to human error. In addition, the speed of the slaughter line is dictated by the number of birds per minute that can be inspected by FSIS inspectors. Ninety-one birds/min is currently the maximum visual inspection line speed allowed under current Federal regulations. This study evaluates the economic benefits of using automated inspection in place of visual inspection from the perspective of both the slaughter plant and FSIS. The results indicate that FSIS and slaughter plants would gain economic benefits by using automated inspection in place of visual inspection. The economic benefits to FSIS would accrue from labor savings, whereas the economic benefits to slaughter plants would accrue primarily from increased throughput from faster inspection line speeds.

(*Key words*: automated inspection system, broiler, profitability, slaughter plant, visual inspection)

2000 Poultry Science 79:265–274

INTRODUCTION

Since the establishment of the postmortem poultry inspection program in 1959, individual on-line carcass inspection at US poultry slaughter plants has been conducted using visual organoleptic methods. Inspectors employed by the USDA Food Safety and Inspection Service (FSIS) visually examine the exterior, the inner surfaces of the body cavity, and the organs of each poultry carcass for visual discrepancies resulting from diseases. The FSIS inspectors also inspect for fecal or other contamination and condemn cadaver and bruised carcasses that are due to slaughter problems.

The demand for chicken products and chicken production have substantially increased since 1959. Per capita consumption of broilers grew from 10.7 kg in 1960 to 36.9 kg in 1996 (USDA, ERS, 1997a,b), and the number of young chickens slaughtered under federal inspection expanded from 1.5 billion birds in 1960 to 7.5 billion birds in 1996 (USDA, ERS, 1997b; USDA, NASS, 1997). Inspection line speeds have grown to accommodate the increased production and demand. In 1959, the average inspection line speed was 30 birds/min. Since then, inspection line speeds have increased to 70 birds/min under the FSIS streamlined inspection system (SIS), utilizing two poultry inspectors per line. The new line speed inspection system (NELS), introduced in the 1980s, is currently being used in plants equipped with on-line quality control. The NELS method employs three inspectors per line and has an inspection line speed of 91 birds/min.

Visual bird-by-bird inspection is very labor intensive. Sixty-two percent of the in-plant slaughter inspector work force (42% of the entire FSIS inspection work force) is engaged in the task of visual on-line carcass inspection. (Federal Register, 1997). In addition, the speed of visual inspection has a direct effect on the amount of throughput passing through a plant in a year. Production lines in many slaughter plants can operate at speeds above 91 birds/min. With current inspection methods, throughput capacity at slaughter plants can be increased only by adding additional slaughter lines or by increasing inspec-

Received for publication August 31, 1998.
Accepted for publication September 30, 1999.

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Abbreviation Key: A = automated inspection, followed by number to indicate inspection line speed at 70, 91, or 140 birds/min; FSIS = Food Safety and Inspection Service; HACCP = Hazard Analysis and Critical Control Points; ISL = Instrumentation and Sensing Laboratory; NELS = new line speed inspection system; SIS = steamlined inspection system; V = visual inspection, followed by number to indicate inspection line speed at 70 or 91 birds/min.

tion line speeds up to or above 91 birds/min. Both situations require the hiring of additional FSIS inspectors. However, FSIS is currently under a hiring freeze due to budgetary constraints and is unlikely to hire any additional inspectors without monetary support from the food industry. Legislation will be proposed for the 1999 Federal Budget that will require the food industry to pay the majority of the cost of federal inspection through user fees (Billy, 1998; Woteki, 1998).

The FSIS also desires to redeploy inspectors away from on-line carcass inspection to other inspection tasks in the plant (Federal Register, 1997). The workload of federal inspectors has expanded with the advent of the Hazard Analysis and Critical Control Points (HACCP) program. Slaughter plants are now required to develop and adopt an HACCP plan for each of their processes (USDA, FSIS, 1996c). Under HACCP, plants identify critical control points where potential hazards for biological, chemical, or physical contamination can occur. As part of the inspection process, FSIS evaluates the appropriateness and successful operation of each HACCP plan and tests for the prevalence of *Salmonella* and *Escherichia coli* contamination (USDA, FSIS, 1996c). In addition to HACCP tasks and on-line carcass inspection, federal inspectors monitor sanitation procedures throughout the plant to verify whether or not plant management is carrying out its sanitation responsibilities.

Automated on-line inspection systems offer great potential to increase the overall efficiency of both poultry carcass inspection and slaughter line operation. Automated inspection systems would reduce the amount of labor required for individual carcass inspection. The labor saved from using automated inspection could be shifted to HACCP and other federal inspection tasks in the plant. Additionally, automated inspection systems could theoretically allow inspection line speeds to be increased beyond the current maximum of 91 birds/min. Finally, automated inspection systems have the potential to eliminate inspector errors, because electronic machines are not restricted by normal human limitations.

The Instrumentation and Sensing Laboratory (ISL) of the USDA, ARS in Beltsville, Maryland, has developed an automated on-line inspection system and has shown that subcomponents of the system perform favorably in the classification of wholesome and unwholesome carcasses (Chen, 1993; Chen and Massie, 1993; Park and Chen, 1994; Park *et al.*, 1995; Chen *et al.*, 1998a,b; Park *et al.*, 1998). The objective of this paper is to determine the economic feasibility of using automated inspection in place of visual inspection in a poultry slaughter plant.

The Automated Inspection System

The ISL Machine Vision Inspection System consists of two subsystems. One subsystem uses four spectral cameras to capture computer images of the front and back of the chicken carcass. The imaging subsystem inspects for abnormalities like skin tears, tumors, missing parts, abnormal color, and other visible defects. This subsystem mimics visual inspection and identifies and rejects all carcasses appearing unwholesome. The second subsystem uses a near-infrared and visible light probe to scan the surface skin and underlying breast area of a carcass. Spectral reflectance from the carcass is analyzed using a spectrophotometer, which compares the light spectrum of the scanned carcass to that of a standard wholesome carcass. Presently, the inspection system does not detect fecal contamination, but plans are currently under way to incorporate fecal detection into the system.

Recent testing conducted by the ISL indicates overall prediction accuracy of the Machine Vision Inspection System can range from 95 to 100% when the system conclusions are compared with those of an FSIS veterinarian. The system correctly classifies unwholesome carcasses with little to no error but errs on the safe side by misclassifying some wholesome carcasses as unwholesome. The percentage of misclassified wholesome carcasses is typically around 4 to 5%. Therefore, carcasses that pass through the system may be sent to an inspection-passed line, an inspection-rejected line, or a reinspection-required line. This new technology substantially reduces the burden of visual inspection for FSIS inspectors, because only carcasses that are classified unwholesome and tagged rejected would need to be visually inspected, rather than all carcasses on the slaughter line.

Figure 1 shows how a typical slaughter line may be equipped with the ISL Machine Vision Inspection System. This figure shows the relative placement, in an actual plant setting, of the imaging subsystem and the near-infrared and visible subsystem. In this machine vision configuration, one inspector replaces three inspectors.

MATERIALS AND METHODS

This economic study uses a present value of net benefits approach to evaluate the net benefits and costs of automated inspection systems over visual inspection. Net benefits are defined as gross benefits (b_t) less costs (k_t) for a given period of time t. We could summarize a stream of net benefits derived over time from automated inspection as $B_0, B_1, \ldots, B_t, \ldots, B_T$, where $B_t = (b_t - k_t)$, and T = total number of periods (years) in the net benefit stream. The net benefit for each period may be positive or negative depending on whether or not gross benefits outweigh costs. The present value of the stream of discounted net benefits is calculated as

$$PV = \sum_{t=0}^{T} \frac{B_t}{(1+r)^t} \qquad [1]$$

where PV = present value for a stream of discounted net benefits for $t = 0, 1, 2, \ldots, t, \ldots, T$ periods; $B_0, B_1, \ldots, B_t, \ldots, B_T$ = stream of net benefits; and r = discount rate.

The benefits of automated inspection over visual inspection are 1) increased throughput value resulting from increased inspection speed, 2) labor savings resulting from using one poultry inspector and one system operator

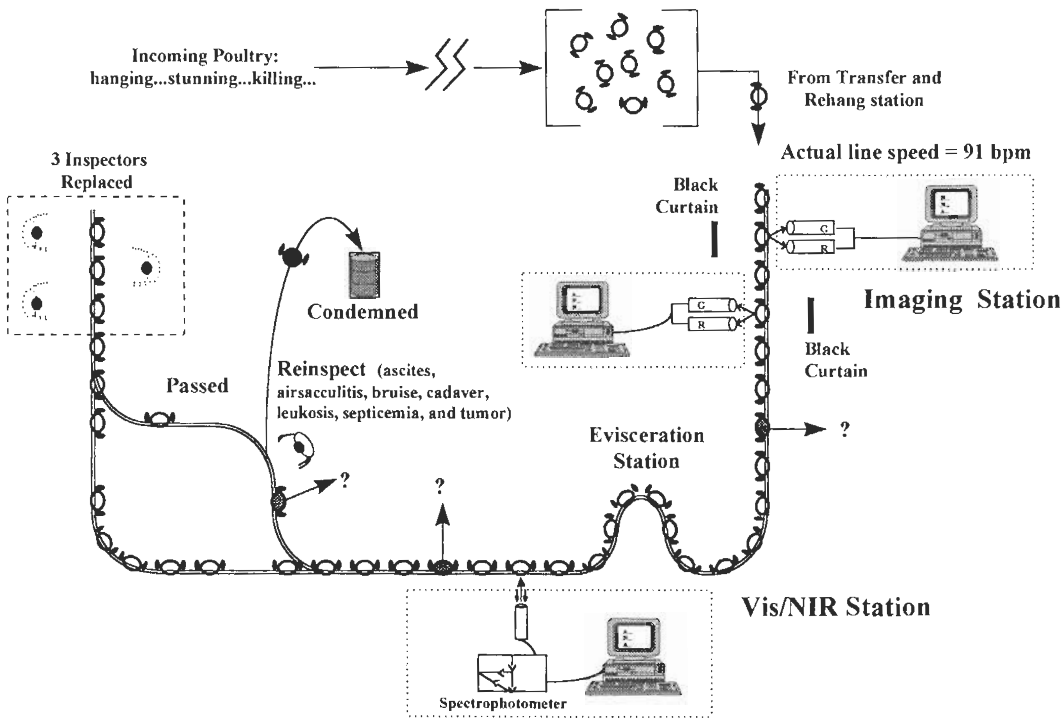

FIGURE 1. Automated on-line poultry inspection with the machine vision inspection system.

per shift in place of using two to three poultry inspectors per line, and 3) more consistent classification of unwholesome carcasses. The costs of automated inspection represent the equipment and utility cost for the automated inspection system, the cost of employing one automated inspection system operator per shift, and the cost of using one visual inspector per shift to reinspect retained carcasses and make a final disposition for wholesomeness. The next few sections will describe the procedures used to calculate the benefits and costs of using an automated on-line inspection system in place of visual inspection.

Baseline Plant

A baseline plant was hypothetically constructed based on information from an actual slaughter plant visited by the authors. The assumptions used for construction of the baseline plant are presented in Table 1. The baseline plant has three slaughter lines and operates two slaughter shifts and one sanitation shift each day. The plant operates 5 d/wk, 52 wk/yr and sometimes operates on Saturday, depending on market demand throughout the year. We assume the plant operates 17 Saturdays out of the year. Thus, the plant operates 277 d/yr. The plant operates 24 h/d with 8 h allocated to each work shift. Two hours per day are spent conducting between-shift cleanups, mid-shift cleanups, and morning sanitation inspections. Therefore, the plant operates two slaughter shifts (14.67 h/d, or 7.33 h/shift) and one sanitation shift (7.33 h/d).

Number of Birds Inspected by Inspection Method

The number of birds inspected per year under visual and automated inspection for the baseline plant was calculated using the following formula:

$$BI = BPM \times 60 \times SHRS \times days \times lines \qquad [2]$$

where BI = number of birds inspected per year for the plant by inspection method; BPM = birds per minute line speed by inspection method; $SHRS$ = number of net slaughter hours per day; $days$ = number of days plant operates in a year; and $lines$ = number of lines in the slaughter plant.

Two inspection speeds (BPM) were evaluated for visual inspection: 1) 70 birds/min and 2) 91 birds/min. The 70 birds/min inspection speed represented the SIS method and required two poultry inspectors per line, and the 91 birds/min inspection speed represented the NELS method and required three poultry inspectors per line. Automated inspection was evaluated at inspection speeds of 70, 91, and 140 birds/min. The latter line speed is the desired goal of most slaughter plants because of advances in evisceration equipment. One automated inspection system was installed per line, and one system operator was employed per shift to operate and maintain each system.

Birds Classified as Wholesome or Unwholesome by Inspection Method

There is always some true number of wholesome carcasses and some true number of unwholesome carcasses for any given number of birds inspected. It is up to the inspection method to correctly sort the wholesome from the unwholesome carcasses. The inspection method used may not always be 100% accurate. We assumed the true number of unwholesome birds passing through the plant in a year was equal to the number of birds inspected per year multiplied by the US young chicken (broiler) condemnation rate for 1996, which was approximately 0.96% of the amount of young chickens inspected for that year (USDA, FSIS, 1996b).

Error percentages were used to convert the number of true wholesome birds and the number of true unwholesome birds inspected per year for each inspection method into correctly classified wholesome birds, incorrectly classified wholesome birds, correctly classified unwholesome birds, and incorrectly classified unwholesome birds. We assumed automated inspection would correctly classify all true unwholesome carcasses with 100% accuracy but would misclassify 4% of the true wholesome carcasses as unwholesome. We also assumed there would be no classification error for visual inspection. However, it is unlikely that visual inspection is truly 100% accurate, because some unwholesome carcasses may pass through the inspection process undetected because of human error resulting from fatigue, lighting problems, eyesight problems, distractions, and other factors.

With the *BI* calculated for each inspection method in Equation [2] and the 0.96% postmortem condemnation rate, the number of birds correctly and incorrectly classified as wholesome and unwholesome for visual and automated inspection were calculated by using the following set of formulas:

$$\begin{aligned} WW &= (BI \times [1 - PU]) \times PWW \\ UU &= (BI \times PU) \times PUU \\ WU &= (BI \times [1 - PU]) \times PWU \\ UW &= (BI \times PU) \times PUW \end{aligned} \qquad [3]$$

where WW = number of true wholesome birds per year classified as wholesome; PU = true percentage of inspected birds that are unwholesome; PWW = percentage true wholesome birds classified as wholesome; UU = number of true unwholesome birds per year classified as unwholesome; PUU = percentage true unwholesome birds classified as unwholesome; WU = number of true wholesome birds per year misclassified as unwholesome; PWU = percentage true wholesome birds misclassified as unwholesome; UW = number of true unwholesome birds per year misclassified as wholesome; and PUW = percentage of true unwholesome birds misclassified as wholesome.

Wholesome birds misclassified as unwholesome (*WU*) represented birds that must be visually reinspected and reclassified as wholesome before they can be further processed. One FSIS inspector is required per shift to reinspect retained carcasses to make a final disposition for wholesomeness. Unwholesome birds misclassified as wholesome (*UW*) represented unwholesome birds that pass through the inspection process undetected. In this analysis, *UW* is zero for both visual and automated inspection. Correctly classified unwholesome birds (*UU*) represented birds that were condemned and discarded from the slaughter line, whereas correctly classified wholesome birds (*WW*) represented wholesome birds that may be further processed. With the information generated from the formulas in [3], the total number of birds classified as wholesome and unwholesome per line for each inspection method were calculated as

$$\begin{aligned} WBI &= WW + UW \\ UBI &= UU + WU \end{aligned} \qquad [4]$$

TABLE 1. Baseline inputs for a three-line broiler plant with two slaughter shifts

Plant operation time	
Total slaughter hours	16
Total sanitation hours	8
Hours spent for between-shift cleanups, within-shift cleanups, and morning sanitary inspection.	2
Net slaughter hours per day	14.67
Days per week plant operates	5
Number of Saturdays plant operates in a year	17
Days per year plant operates	277
Number of poultry inspectors/automated inspection system operators	
Total FSIS poultry inspectors for plant, visual inspection, 70 birds/min[1]	12
Total FSIS poultry inspectors for plant, visual inspection, 91 birds/min	18
Total automated inspection system operators for plant, automated inspection	2
Total visual inspectors per plant, automated inspection	2
Labor cost by inspection method	
Salaries less benefits per year, FSIS poultry inspector ($)[2]	29,350
Salaries and benefits per year, FSIS poultry inspector ($)[3]	38,155
Salaries and benefits per year, automated inspection system operator	38,155
Automated inspection system equipment costs	
System equipment cost per line ($)	102,309
Yearly cost of replacement components per line ($)	2,008

[1]Seventy birds/min = SIS (streamlined inspection system); 91 birds/min = NELS (new line speed inspection system).

[2]FSIS = Food Safety and Inspection Service. Richard Gamble and Robert Charlton, 1997, USDA, FSIS, Resource Management Staff, Washington, DC 20250, personal communication.

[3]Annual FSIS inspector salary ($29,350) plus 30% of salary for benefits ($8,805).

TABLE 2. Ready-to-cook cost and value data

Live weight per bird inspected (kg/bird)[1]	2.17
Wholesale ready-to-cook weight as a percentage of live weight passing inspection (%)[2]	74.35
Wholesale ready-to-cook price ($/kg)[3]	1.35
Wholesale ready-to-cook production cost ($/kg)[4]	1.23
Hazard Analysis and Critical Control Point cost ($/bird)[5]	0.0096
Real discount rate for equipment cost annualization and present value calculations (%)[6]	4.81

[1]Average 1996 live weight per young chicken reported in USDA, NASS (1997).

[2]1996 Ready-to-Cook weight of young chickens (11,946 billion kg) as a percentage of young chicken slaughter live weight (16,345 billion kg) less young chicken postmortem condemned weight in a live weight basis (278 million kg). The USDA reports young chicken postmortem condemned weight in New York dressed weight (250 million kg). Young chicken postmortem condemned weight was converted to a live weight basis by dividing by 0.9. 1997 (USDA, NASS, 1997).

[3]12-City composite broiler ready-to-cook wholesale price for 1996. (USDA, ERS, 1996a).

[4]1996 Young chicken wholesale production cost, ready-to-cook basis. (USDA, ERS, 1996a).

[5]$0.0044 Per kg multipled by the 1996 average live weight per young chicken (USDA, FSIS, 1996a).

[6]Average long-term bond rate (7.66%) less inflation (2.84%) for 1992 through 1996.

where *WBI* = total number of birds classified as wholesome; and *UBI* = total number of birds classified as unwholesome.

Throughput Value and Cost of Visual and Automated Inspection Methods

Wholesale ready-to-cook values were used to *measure* the value of throughput under visual and automated inspection. The number of birds classified as wholesome (*WBI*) and the number of wholesome birds misclassified as unwholesome (*WU*) for each inspection method were converted to wholesale ready-to-cook weights with the following formulas:

$$RTCWHT = WBI \times LWHT \times PRTCW$$
$$RIWHT = WU \times LWHT \times PRTCW \quad [5]$$

where *RTCWHT* = wholesale RTC weight of wholesome classified birds (kilograms); *LWHT* = live weight per bird (kilograms per bird); *PRTCW* = ready-to-cook (RTC) weight as a percentage of wholesome classified live weight; and *RIWHT* = reinspected wholesome RTC weight (kilograms).

The values used for *LWHT* and *PRTCW* are given in Table 2. With the wholesale RTC weights from Equations [5], the net wholesale RTC value of plant throughput for visual inspection in a year is calculated as

$$PLANT^V = [(RTCP - RTCC) \times RTCWHT] - (HACCP \times BI) - VIL \quad [6]$$

and the net wholesale RTC value of plant throughput from automated inspection in a year is calculated as

$$PLANT^A = [(RTCP - RTCC) \times (RTCWHT + RIWHT)] - (HACCP \times BI) - SOL - RL - AIC - AIRC \quad [7]$$

where $PLANT^V$ and $PLANT^A$ = net wholesale read-to-cook (RTC) value of plant throughput for visual inspection (V) and automated inspection (A), respectively; *RTCP* = wholesale RTC price (dollars per kilogram); *RTCC* = gross wholesale RTC production cost (dollars per kilogram); *HACCP* = HACCP cost per bird; *VIL* = visual inspector labor cost; *SOL* = system operator labor cost per year for automated inspection; *RL* = visual reinspection labor cost per year for automated inspection; *AIC* = annualized capital cost of the automated inspection system; and *AIRC* = yearly replacement component cost of the automated inspection system.

The values used for *RTCP*, *RTCC*, and *HACCP* are listed in Table 1. The *AIC* represents the annualized capital cost of the automated inspection system evaluated using a 5-yr replacement period and 4.81% real discount rate reported in Table 2. The real discount rate was calculated as the average long-term bond rate of 7.66% for the period 1992 through 1996 less average inflation of 2.84% for the same period. Average inflation was calculated based on the Consumer Price Index. The *AIRC* represents the annual cost of replacement components per year for the automated inspection system. The last term in [6] and the last four terms in [7] represent costs of visual and automated inspection, respectively, to the plant if the plant pays for on-line carcass inspection.[2] If FSIS pays for on-line carcass inspection, then *VIL* in [6] and *SOL*, *RL*, *AIC*, and *AIRC* in [7] will equal zero for the plant. The cost of visual inspection for FSIS is calculated as:

$$FSIS^V = VIL \quad [8]$$

and the cost of automated inspection to FSIS is calculated as

$$FSIS^A = SOL + RL + AIC + AIR \quad [9]$$

where $FSIS^V$ and $FSIS^A$ = total cost of visual and automated inspection, respectively, to FSIS, if FSIS pays for on-line carcass inspection.

[2]We do not charge a cost for utilities with automated inspection, as we assume these costs to be negligible.

Present Value of Automated Inspection over Visual Inspection

The two primary benefits of using automated inspection systems in place of visual inspection are increased throughput value and labor savings.[3] The benefit of increased throughput accrues to the slaughter plant, whereas labor savings may accrue to either the plant or FSIS, depending on which agency pays for on-line carcass inspection. The present value of discounted net benefits of automated inspection to the plant was calculated as

$$PV_{plant} = \sum_{t=1}^{5} \alpha^t (PLANT_t^A - PLANT_t^V) \qquad [10]$$

where PV_{PLANT} = present value to the plant of a 5-yr stream of discounted net benefits from automated inspection; $PLANT_t^A - PLANT_t^V$ = increased (reduced) value of throughput to the plant using automated inspection in place of visual inspection for year t; and α^t = discount factor = $1/(1 + r)^t$, where r = the discount rate. The net benefit stream period is assumed to be 5 years, which equals the replacement period for the automated inspection system.

For FSIS, the present value of net benefits may be evaluated in two ways. If FSIS continues to pay for on-line carcass inspection, the present value of net benefits of automated inspection over visual inspection would be calculated as

$$\begin{aligned} PV_{FSIS} &= \sum_{t=1}^{5} \alpha^t (FSIS_t^V - FSIS_t^A) \\ &= \sum_{t=1}^{5} \alpha^t (VIL_t - SO_t - RL_t - AIC_t - AIR_t). \qquad [11] \end{aligned}$$

The information in the parentheses of Equation [11] represents the difference in cost between visual inspector labor (VIL_t) and automated inspection ($SOL_t + RL_t + AIC_t + AIR_t$) for year t. If the latter is smaller than the former, FSIS will receive net benefit from adopting automated inspection. If plants pay for on-line carcass inspection, the present value of net benefits to FSIS would be

$$PV_{FSIS} = \sum_{t=1}^{5} \alpha^t FSIS_t^V = \sum_{t=1}^{5} \alpha^t VIL_t \qquad [12]$$

where VIL_t in Equation [12] represents the cost per year for visual inspection recouped by FSIS.

RESULTS

The number of birds inspected per year and the number of birds classified as wholesome and unwholesome under visual and automated inspection are reported by line speed for the baseline plant in Table 3. Visual (V) inspection at a line speed of 70 birds/min (V70; Table 3) resulted in the least birds inspected per year (51.2 million), and automated inspection (A) at a line speed of 140 birds/min (A140; Table 3) resulted in the most birds inspected per year (102.4 million). Many wholesome carcasses are misclassified as unwholesome under automated inspection (2.0 million for A70, 2.6 million for A91, and 4.0 million for A140; Table 3). This result occurs because automated inspection errs on the safe side and misclassifies 4% of all true wholesome birds as unwholesome. These wholesome carcasses can be salvaged using visual reinspection of all carcasses classified unwholesome and retained.

Inspection costs per year and per bird inspected are presented by inspection method and plant size in Table 4. The V91 has the largest inspection cost across inspection methods ($687 thousand per year or 1.03 cents per bird inspected for the three-line plant) because it employed three inspectors per line. The V70 had a lower inspection cost ($458 thousand per year or 0.89 cents per bird inspected), because it employed one less inspector per line than V91. The cost of automated inspection was invariant across inspection line speeds, because equipment and labor costs remained constant, regardless of line speeds. However, the cost of automated inspection increased as the size of the plant increases, because each additional line required one additional automated inspection system. The total cost per year of automated inspection ranged from $204 thousand/yr for the two-line plant to $255 thousand/yr for the four-line plant.

Inspection cost per bird inspected varied for automated inspection by both line speed and plant size. For example, inspection costs range from 0.60 cents per bird inspected for the two-line plant using A70 to 0.37 cents per bird inspected for the four-line plant using A70. Similarly, inspection costs ranged from 0.45 cents per bird inspected for the three-line plant using A70 to 0.22 cents per bird inspected for the three-line plant using A140. Therefore, economies of size existed for the automated inspection methods (e.g., as throughput increased, the inspection cost per unit of throughput decreased). Economies of size did not exist, however, for the visual inspection methods.

Inspector cost per bird inspected was invariant across plant size for the visual inspection methods. This result occurred because adding an additional line to a plant would result in a proportional increase in the number of inspectors per plant. For example, addition of an additional line to a two-line plant using the V70 inspection method would increase the number of visual inspectors from 8 per plant to 12 per plant. Therefore, the yearly

[3]Other potential benefits of using automated inspection arise from more consistent inspection of unwholesome carcasses. Benefits from greater unwholesome carcass inspection consistency can accrue both to the slaughter plant and to society. In the case of the plant, increased consistency of unwholesome carcass inspection could result in a reduction in the number of unwholesome carcasses passing through the inspection process and a reduced risk of accruing product recall costs, loss of business, and other associated costs. For the public in general, increased consistency of unwholesome carcass inspection could result in fewer people becoming ill from consuming unwholesome carcasses. In this instance, the cost of hospitalization to society would be reduced. These benefits are difficult to quantify in monetary values.

TABLE 3. Throughput per year by inspection variable and inspection method for a three-line broiler plant with two slaughter shifts

Inspection variable	V70[1]	V91	A70	A91	A140
			(1,000 Birds)		
Total birds inspected (BI)	51,190	66,546	51,190	66,546	102,379
True wholesome birds (WB)	50,698	65,908	50,698	65,908	101,396
True unwholesome birds (UB)	491	639	491	639	983
Birds classified wholesome (WBI)	50,698	65,908	48,670	63,271	97,341
Birds classified unwholesome (UBI)	491	639	2,519	3,275	5,039
Wholesome birds misclassified unwholesome (WU)	0	0	2,028	2,636	4,056
Unwholesome birds misclassified wholesome (UW)	0	0	0	0	0

[1]V = visual inspection, V70 is the streamlined inspection system method, V91 is the new line speed inspection system method; A = automated inspection; and 70, 91, and 140 = inspection line speeds in birds per minute.

inspection cost per plant would increase but the inspection cost per bird inspected would remain constant as plant size increased. In addition, there were diseconomies of size from increasing line speed using visual inspection methods (e.g., as throughput increased, the inspection cost per unit of throughput increased). Increased line speed from 70 birds/min to 91 birds/min resulted in an increase in inspection costs in dollars per year (increase of $229 thousand per year for the three-line plant) and cents per bird inspected (increase of 0.14 cents per bird for plants of all sizes). Again, this result occurred because moving from 70 to 91 birds/min required one additional visual inspector per line.

Throughput values per year and per bird inspected are presented by inspection method for alternative plant sizes in Table 5. When FSIS paid for on-line carcass inspection, throughput value represented gross wholesale RTC value less RTC production cost and HACCP cost. Gross value, production cost, and HACCP cost were all per unit items. Therefore, throughput value per bird inspected was constant across inspection methods and plant sizes (18.10 cents per bird inspected in Table 5). Because the throughput value per bird inspected was constant, throughput value for the plant will increase as line speeds increase. Thus, plants would prefer automated inspection to visual inspection only if switching to automated inspection resulted in a greater inspection line speed. Plants would earn more value when FSIS used A140 ($18.5 million per year for the three-line plant) than when FSIS used V70 or V91.

Throughput values per year and per bird inspected were slightly reduced when plants paid for on-line carcass inspection. However, throughput values per year and per bird inspected were larger for automated inspection under this scenario. For example, A70 earned $9.0 million/yr and 17.66 cents per bird inspected, and V70

TABLE 4. Inspection labor and automated inspection capital cost per year and per bird inspected for broiler plants operating two slaughter shifts, visual and automated inspection

	Two lines		Three lines		Four lines	
Inspection method	($1,000)	(¢/Bird)	($1,000)	(¢/Bird)	($1,000)	(¢/Bird)
Visual inspection						
V70[1]	305	0.89	458	0.89	610	0.89
V91	458	1.03	687	1.03	916	1.03
Automated inspection						
Automated system operator						
A70	76	0.22	76	0.15	76	0.11
A91	76	0.17	76	0.11	76	0.09
A140	76	0.11	76	0.07	76	0.06
Reinspection labor						
A70	76	0.22	76	0.15	76	0.11
A91	76	0.17	76	0.11	76	0.09
A140	76	0.11	76	0.07	76	0.06
Annualized capital cost[2]						
A70	51	0.15	77	0.15	102	0.15
A91	51	0.12	77	0.12	102	0.12
A140	51	0.07	77	0.07	102	0.07
Total, automated inspection						
A70	204	0.60	229	0.45	255	0.37
A91	204	0.46	229	0.34	255	0.29
A140	204	0.30	229	0.22	255	0.19

[1]V = Visual inspection, V70 is the streamlined inspection system method; V91 is the new line speed inspection system method; A = automated inspection; and 70, 91, and 140 = line speeds in birds per minute.

[2]$23,508 Per year per system ($102,309 per system in Table 1 annualized using a real discount rate of 4.81 and a 5-yr replacement period) plus the $2,008/yr charge for replacement components in Table 1, multiplied by the number of slaughter lines per plant.

TABLE 5. Net ready-to-cook value less inspection cost per year and per bird inspected for broiler plants operating two slaughter shifts, visual and automated inspection

Inspection method	Two lines ($1,000)	Two lines (¢/Bird)	Three lines ($1,000)	Three lines (¢/Bird)	Four lines ($1,000)	Four lines (¢/Bird)
FSIS Pays on-line carcass inspection[1]						
V70	6,178	18.10	9,267	18.10	12,356	18.10
V91	8,031	18.10	12,047	18.10	16,063	18.10
A70	6,178	18.10	9,267	18.10	12,356	18.10
A91	8,031	18.10	12,047	18.10	16,063	18.10
A140	12,356	18.10	18,534	18.10	24,712	18.10
Plants pay on-line carcass inspection						
V70	5,873	17.21	8,809	17.21	11,745	17.21
V91	7,574	17.07	11,360	17.07	15,147	17.07
A70	5,974	17.51	9,038	17.66	12,101	17.73
A91	7,828	17.64	11,818	17.76	15,808	17.82
A140	12,152	17.80	18,305	17.88	24,457	17.92

[1]FSIS = Food Safety and Inspection Service; V = visual inspection, V70 is the streamlined inspection system method; V91 is the new line speed inspection system method; A = automated inspection; and 70, 91, and 140 = line speeds in birds per minute.

earned $8.8 million/yr and 17.21 cents per bird inspected for the three-line plant. Similarly, A91 earned $11.8 million/yr and 17.76 cents per bird inspected, and V91 earned $11.4 million and 17.07 cents per bird inspected for the three-line plant. In both instances, the plant received labor savings from using automated inspection in place of visual inspection.

Yearly net benefits, 5-yr present values of yearly net benefits, and automated inspection payback periods for broiler slaughter plants are presented in Table 6. When FSIS paid for on-line carcass inspection, slaughter plants gained net benefit from automated inspection only when line speeds were increased. For example, the net benefit per year for the three-line plant was $0 when FSIS used A70 in place of V70 but was $2.8 million per year when FSIS used A91 in place of V70. Similarly, the present value of net benefits to the three-line plant was $0 when FSIS used A70 in place of V70 and was $12.1 million when FSIS used A91 in place of V70. Slaughter plants gained the largest present value of net benefits when FSIS used A140 in place of V70 ($40.3 million for the three-line plant).

The net benefits of shifting from visual to automated inspection were always positive when plants paid for on-line carcass inspection. When line speeds were equal for both visual and automated inspection, the increased net benefits per year were solely the result of labor savings. For example, the net benefit of shifting from V70 to A70 for the three-line plant ($229 thousand) was equal to the labor savings of using two inspectors and two system

TABLE 6. Net benefits per year and 5-yr present value of net benefits to broiler plants from shifting to a faster line speed or to automated inspection

Inspection method conversion	Two lines: Net benefit per year ($1,000)	Two lines: 5-yr Present value[1]	Two lines: Automated inspection payback period (mo)	Three lines: Net benefit per year ($1,000)	Three lines: 5-yr Present value	Three lines: Automated inspection payback period (mo)	Four lines: Net benefit per year ($1,000)	Four lines: 5-yr Present value	Four lines: Automated inspection payback period (mo)
FSIS Pays on-line carcass inspection cost									
From V70 to V91[2]	1,853	8,066	—	2,780	12,099	—	3,707	16,132	—
From V70 to A70	0	0	—	0	0	—	0	0	—
From V70 to A91	1,853	8,066	—	2,780	12,099	—	3,707	16,132	—
From V70 to A140	6,178	26,887	—	9,267	40,330	—	12,356	53,773	—
From V91 to A91	0	0	—	0	0	—	0	0	—
From V91 to A140	4,325	18,821	—	6,487	28,231	—	8,649	37,641	—
Plants pays on-line carcass inspection cost									
From V70 to V91	1,701	7,402	—	2,551	11,103	—	3,402	14,804	—
From V70 to A70	102	442	17.6	229	995	12.9	356	1,548	11.4
From V70 to A91	1,955	8,508	1.3	3,009	13,094	1.3	4,063	17,680	1.2
From V70 to A140	6,280	27,329	0.4	9,496	41,325	0.4	12,712	55,322	0.4
From V91 to A91	254	1,106	8.5	458	1,992	7.3	661	2,877	6.8
From V91 to A140	4,579	19,927	0.6	6,944	30,223	0.6	9,310	40,518	0.5

[1]Discounted at a rate of 4.81%.

[2]V = visual inspection, V70 is the streamlined inspection system method; V91 is the newline speed inspection system method; A = automated inspection; and 70, 91, and 140 = inspection line speeds in birds per min.

TABLE 7. Net benefits (loss) per year and 5-yr present value of net benefits to the Food Safety and Inspection Service (FSIS) from shifting to faster line speed or to automated inspection

Inspection method conversion	Two lines			Three lines			Four lines		
	Net benefit (loss) per year	5-yr Present value[1]	Automated inspection payback period	Net benefit (loss) per year	5-yr Present value	Automated inspection payback period	Net benefit (loss) per year	5-yr Present value	Automated inspection payback period
	($1,000)		(mo)	($1,000)		(mo)	($1,000)		(mo)
FSIS pays individual carcass inspection cost									
From V70 to V91[2]	–153	–664	—	–229	–996	—	–305	–1,328	—
From V70 to A70, A91, or A140	178	774	17.6	305	1,327	12.9	432	1,881	11.4
From V91 to A70, A91, or A140	331	1,438	8.5	534	2,324	7.3	737	3,209	6.8
Plants pay individual carcass inspection cost									
From V70	305	1,328	—	458	1,993	—	610	2,657	—
From V91	458	1,993	—	687	2,989	—	916	3,985	—

[1]Discounted at a rate of 4.81 percent.

[2]V = visual inspection, where V70 is the SIS inspection method (70 birds per min) and V91 is the NELS inspection method (91 birds per min). A = automated inspection. 70, 91, and 140 = inspection line speeds in birds per min.

operators for the plant in place of 12 inspectors for the plant under visual inspection. In this instance, the 5-yr present value of net benefits was $995 thousand for using automated inspection of the three-line plant. When line speeds were increased, net benefits from automated inspection accrued from both labor savings and increased plant throughput. Plants gained the most present value of net benefits when shifting from V70 to A140 ($41.3 million for the three-line plant).

Automated inspection payback periods were longest when shifting from visual inspection to automated inspection without increasing line speed. When shifting from V70 to A70, the payback period ranged from 17.6 mo for the two-line plant to 11.4 mo for the four-line plant, and when shifting from V91 to A91, the payback period ranged from 8.5 mo for the two-line plant to 6.8 mo for the four-line plant. The payback period was substantially shorter for faster inspection line speeds. For the three-line plant, the payback period ranged from 12.9 mo when shifting from V70 to A70 to 0.4 mo when shifting from V70 to A140.

Net benefits (losses) per year, 5-yr present values of net benefits (losses), and automated inspection payback periods for FSIS are presented in Table 7. Net benefits and present values would have been larger for FSIS if slaughter plants paid on-line carcass inspection. In this instance, net benefits represented labor savings to FSIS resulting from recouping the cost of visual on-line carcass inspection. Yearly net benefits and present values would be greatest at plants where V91 is currently used, because V91 is more labor-intensive than V70. The FSIS would earn $687 thousand per year in net benefits and $2.99 million in present value over 5 yr from the three-line plant if the plant paid for on-line carcass inspection.

If FSIS continues to pay for on-line carcass inspection, it will gain positive net benefits by switching from visual to automated inspection. Net benefits and the present value of net benefits will be larger when shifting from V91 to automated inspection at all line speeds (yearly net benefit equals $534 thousand, and present value equals $2.3 million for the three-line plant) than when shifting from V70 to automated inspection (yearly net benefit equals $305 thousand, and present value equals $1.3 million for the three-line plant). In addition, the automated inspection payback period was longer when shifting from V70 to automated inspection (12.9 mo for the three-line plant) than when shifting from V91 to automated inspection (7.3 mo for the three-line plant). The V91 was more labor intensive than V70. Thus, shifting from V91 to automated inspection resulted in greater labor savings for FSIS than shifting from V70 to automated inspection. Conversely, FSIS would realize negative net benefits and negative present values by shifting from V70 to V91 (yearly net benefit equals -$229 thousand, and present value equals -$996 thousand for the three-line plant), because such a shift would require one additional inspector per line and would thus increase the cost of inspector labor to FSIS.

DISCUSSION

The benefits of automated inspection are labor savings and increased throughput value. Economic benefits of automated inspection to FSIS are entirely due to labor savings when compared with either the SIS or the NELS methods currently used at most broiler slaughter plants in the US. The labor savings for automated inspection would be greatest when converting from slaughter plants using the NELS method, because the NELS method requires three inspectors per line, whereas the SIS method requires two inspectors per line.

Slaughter plants could potentially gain from automated inspection regardless of who pays the inspection cost. The primary benefit of automated inspection to slaughter plants is increased throughput value resulting from faster inspection line speeds. The cost of on-line carcass inspection is small relative to the value of throughput passing through the slaughter plant. The calculated throughput value per bird inspected is 18.10 cents per bird, whereas the cost of visual inspection ranges from 0.89 cents per bird inspected with the SIS method to 1.03 cents per bird inspected with the NELS method. Similarly, inspection costs for automated inspection ranges from 0.60 cents to 0.19 cents per bird inspected, depending on plant size and inspection line speed.

We assumed FSIS or the slaughter plant pays the cost of on-line carcass inspection. However, FSIS currently pays for on-line carcass inspectors. It is doubtful that FSIS would make slaughter plants responsible for on-line carcass inspection. It is also unlikely that FSIS would use automated inspection to replace human beings with machines, because FSIS has labor union issues to consider. It is much more probable that FSIS would best use automated inspection technology to shift inspector labor away from on-line carcass inspection to other, more essential HACCP tasks within the slaughter plant. Under this scenario, FSIS would pay the installation cost of automated inspection technology. It might be in the best interest of slaughter plants to pay the installation cost of automated inspection, because they could potentially receive increased throughput value resulting from faster inspection line speeds.

Finally, this study assumes automated inspection systems are durable enough to withstand the harsh environment of a slaughter plant. Factors such as water condensation, the abrasive chemicals used in the sanitation process, and the high-pressure hoses used to cleanse the components of the slaughter line can be very harmful to electrical equipment. Automated inspection technologies would have to be modified to withstand these harmful forces. A solution to this problem may be very near. Chen *et al.* (1998a) indicate that a visible or near-infrared spectrophotometer operating at line speeds of 60 to 90 birds/min can achieve training, validation, and testing accuracies of 100% when sensing in a dark environment. The implication of these findings is that the automated inspection technology can be housed in a separate room and be protected from the harsh environment of the slaughter plant.

ACKNOWLEDGMENTS

The authors gratefully acknowledge the helpful guidance of Frank Gwozdz, who diligently supplied much of the technical information for the manuscript. The views and opinions expressed in the manuscript are solely those of the authors and do not necessarily represent the official views of the US Department of Agriculture.

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