Comparison of beef traceability in serial and parallel fabrication systems using RFID and two-dimensional barcodes[1]

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ABSTRACT: Traceability of beef attributes from small- and mid-sized farms through supply chains is a market barrier. The objective of this trial was to determine the influence of fabrication method on beef traceability system requirements. Individual identities of 54 animals were maintained through harvest, processing, packaging, and distribution. At harvest, each animal's unique radio frequency identification (**RFID**) animal identification number was transferred to a harvest label on each carcass quarter. Following transportation to a processor, nine carcasses were processed on alternating days by one of the two methods. Carcasses were fabricated, using a serial fabrication method (**SFM**), into wholesale cuts one at a time or fabricated using a parallel fabrication method (**PFM**), by processing multiple hindquarters or forequarters simultaneously into wholesale cuts. In-process labels were generated by scanning the two-dimensional (**2D**) barcode on the harvest label with a handheld mobile computer and printed from a wireless mobile printer. Tracking of SFM and PFM carcass quarters was accomplished by creating in-process labels for lugs and individual wholesale cuts, respectively. The process was recorded and the data was captured from video analysis. The mean number of in-process labels generated per carcass for SFM was 3.7 and for PFM was 30.9 ($P < 0.01$). The amount of time required for generating in-process labels for SFM (2 min 16 s) was less than PFM (8 min 45 s) ($P = 0.01$). The amount of time required to label each carcass was less ($P < 0.01$) for SFM (18 s) than for PFM (3 min 10 s) with in-process labels. Total cost of traceability, including fixed and consumable cost per carcass, was nearly twice as much for PFM ($17.98) than SFM ($9.02). Traceability, within both processing methods, was found to have 100% fidelity, as verified using DNA marker genotyping. Overall, the number of labels generated for traceability was less for SFM than that for PFM. The overall time spent on generating, applying, and removing labels was less for SFM than that for PFM. The total cost of traceability was approximately half for SFM compared with that for PFM; however both methods were able to track product accurately. Tracking of beef from individual animals, using RFID ear tags and 2D barcodes, appears to be feasible for the fabrication methods used in this study.

Key words: beef processing, beef fabrication, radio frequency identification, traceability, two-dimensional barcode

[1]Mention of trade names or commercial products in this article is solely for the purpose of providing specific information and does not imply recommendation or endorsement by Michigan State University, nor does it imply approval to the exclusion of other products. This project was supported in part by Michigan State University Extension. State funds for this project were matched with Federal funds under the Federal-State Marketing Improvement Program of the Agricultural Marketing Service, U.S. Department of Agriculture. The authors gratefully acknowledge the crews of the Michigan State University Beef Cow/Calf Teaching and Research Center, Upper Peninsula Research and Extension Center, and the Beef Cattle Teaching and Research Center for animal care. We gratefully acknowledge the cooperation of Ebels Meat Processing, Byron Center Meats, and MSU Residential and Hospitality Services for allowing us to work in their facilities. We are also appreciative of Advanced Traceability Solutions and ScoringSystem Inc. for their guidance in assembling the traceback system model. Lastly, the authors appreciate the help from Shelby Tackett for data collection and video analysis.

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Received 27 October, 2017.
Accepted 21 December, 2017.

Transl. Anim. Sci. 2018.2:101–110
doi: 10.1093/tas/txx007

INTRODUCTION

Many U.S. consumers have been shown to desire farm of origin information (Mennecke et al., 2007) and place significant value on that information (Varnold et al., 2011). The beef industry uniquely identifies a portion of beef cattle, but the identification of the cattle is often lost through the harvest process. With the combined use of radio frequency identification (**RFID**) ear tags, and two-dimensional (**2D**) barcode labels, a fully traceable supply chain can be obtained through a small-sized harvesting and processing facility, ultimately supplying consumers with animal origin information (Buskirk et al., 2013; Buskirk and Foster, 2017). A RFID ear tag can be scanned at harvest, and the unique 15-digit number can be recorded in a database. A 2D barcode can then be generated containing the unique identification, as well as other desired information to be placed on carcasses or meat cuts during fabrication. The objective of this study was to identify labeling techniques for a serial fabrication method (**SFM**) and parallel fabrication method (**PFM**) while tracking wholesale meat cuts back to the original animal in small processing facilities. The hypotheses for this study were 1) time spent generating and applying labels to wholesale beef cuts for PFM would be greater than SFM; 2) total cost of traceability would be less for SFM than that for PFM; and 3) accuracy of traceability for SFM would be greater than PFM.

MATERIALS AND METHODS

The procedures used in this study were approved by the Michigan State University (**MSU**) Institutional Animal Care and Use Committee (10/11-202-99). Seventy-two Angus × Simmental crossbred steers were used to compare two beef fabrication methods in a traceable supply chain. Sixty-one steers were born and raised at the MSU Upper Peninsula Research and Extension Center, Chatham, MI, and eleven steers were born and raised at the MSU Beef Cow-Calf Teaching and Research Center, East Lansing, MI. All steer calves received a RFID ear tag (Allflex USA, DFW Airport, TX) in the middle 1/3 of their left ear while at their farm of origin. Each RFID ear tag was previously coded with a 15-digit animal identification number (**AIN**) (Schelhaus and Harless, 2008). All steer calves were transported from their farm of origin to the MSU Beef Cattle Teaching and Research Center, East Lansing, MI, to be finished for market. Upon arrival at the feedlot, the steers were approximately 6 mo of age and weighed an average of 240 ± 33 kg. During the finishing stage at the feedlot, data points for each steer were recorded in an online database (ScoringSystem, Bradenton, FL) and included animal breed, birth date, sex, farm of origin, and AIN. The ScoringSystem database allowed viewing of public information on an entity by searching an AIN or database-assigned identification number (ScoringSystem Identification-Entity Identification, **SSI-EID**).

Harvest

Steers were sorted into four harvest groups, with 18 steers per group, based on weight and 12th rib fat thickness. The 12th rib fat thickness was obtained using ultrasound (Aloka SSD-500; Hitachi Aloka Medical, Ltd., Wallingford, CT). Each group was transported to a processing plant (Ebels Meat Processing, Falmouth, MI) during 4 successive weeks. The plant is a small (<499 employees) USDA Food Safety and Inspection Service establishment that harvests approximately 15 beef animals per hour. The first harvest group of 18 steers was used as a pilot study, so the processing personnel could be acclimated to the traceability methods, and data were not included in the analyses. Data were collected during 2 fabrication days, over each of the next 3 wk, for a total of 6 fabrication days. During exsanguination, the RFID ear tag was removed from each animal and scanned using a handheld RFID reader (*Lightning* ROD Reader; I.D.ology, Eau Claire, WI). The RFID data were transmitted into label design and barcode printing software (BarTender; Automation; Seagull Scientific, Bellevue, WA) using Bluetooth data exchange to initiate the harvest label (10.16 cm × 5.08 cm × 3 mm; Spinnaker Coating, Troy, OH) generation. As the RFID was scanned, the barcode software searched a prepopulated Microsoft Excel 2010 (Microsoft Corp., Redmond, WA) file, which cross-referenced the AIN and SSI-EID. Once exsanguinated, the carcasses were hung on an overhead rail. The rail was continuous and nonbranching, therefore carcass order was maintained throughout the harvest process. The HCW of each animal was recorded and entered into the barcode software. Eight identical harvest labels were printed using a laptop computer and an industrial thermal transfer printer (model GP MAXX; Godex Americas, Camarillo, CA). The harvest label included an AIN, SSI-EID, address of feedlot, premise identification number (PIN) of feedlot, print date, print time, federal establishment number of processor, HCW of left and right carcass halves, total HCW, and a 2D, four-segmented, GS1 DataMatrix barcode (Figure 1A). The 2D barcode contained the AIN, SSI-EID, federal establishment number of processor, feedlot name and location, and date and time of printing. The printed labels were placed onto heavy weight manila shipping tags (12.07 × 6.03 cm) (OfficeMax, Okemos, MI). One labeled tag was placed on the fore and rear quarter of each carcass half using deadlock tag fasteners. One labeled tag was placed in a plastic bag that contained the hanging tender for each carcass. The head, heart, and liver received the remaining three harvest labeled tags for each carcass, but were not tracked further during this study. The carcasses were chilled 24 h, cut between the 12th and 13th rib, and then yield and quality graded by USDA personnel. Following grading, carcasses were quartered and transported by refrigerated truck to the fabricator (Byron Center Meats Inc., Byron Center, MI). The plant is a small (<499 employees) USDA Food Safety and Inspection Service establishment that fabricates approximately four to five beef carcasses per hour.

Carcass Fabrication

Carcasses were placed in groups of nine and allotted to SFM or PFM treatment based on their order of arrival at the fabricator. Each treatment was fabricated on a single day, and treatment order was alternated each week. Only wholesale beef cuts were traced during harvest and fabrication of carcasses. Lean trim used for ground beef was comingled in separate lugs and was not tracked.

Serial fabrication method. The SFM was defined as one individual carcass (both hindquarters and forequarters) being processed before starting on the next carcass. As carcasses were processed to their final wholesale cuts, a set of food-grade polypropylene in-process labels (5.08 cm × 2.54 cm × 3 mm; Spinnaker Coating) were generated for each carcass using a mobile unit consisting of a handheld computer (model GPS SC; Intermec Technologies Corporation, Everett, WA) equipped with customized software (Advanced Traceability Solutions, Portland, ME) and a mobile printer (model P4T; Zebra Technologies, Lincolnshire, IL). A carcass-specific in-process label was placed in each

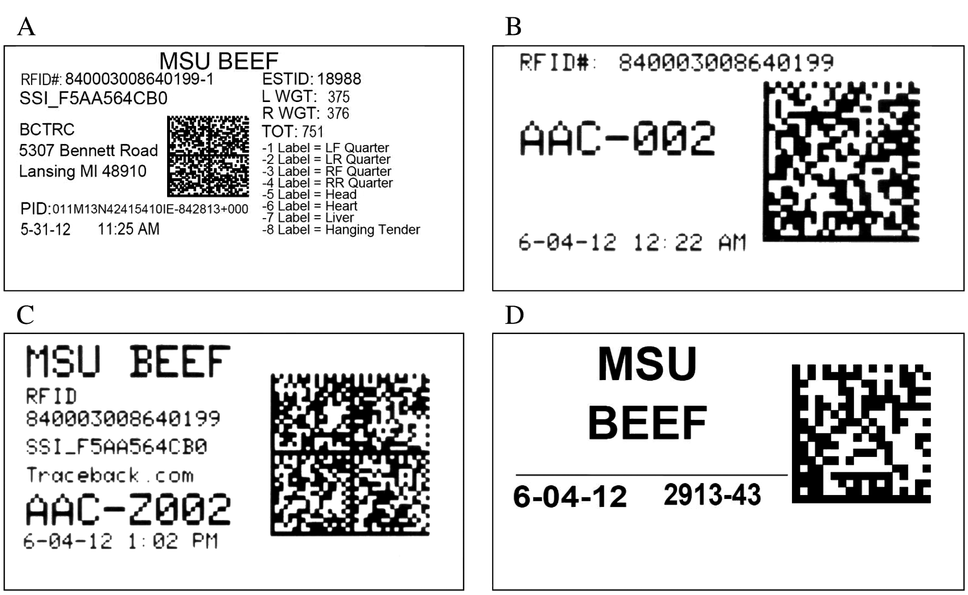

Figure 1. Example barcode label formats: (A) harvest label was placed on carcass quarters, (B) in-process label was used to track wholesale beef cuts during carcass fabrication, (C) final package label was placed on vacuum-sealed packages, and (D) box label was placed on shipping boxes.

lug that contained cuts from that carcass. Each lug contained wholesale cuts from only one carcass to preserve the integrity of traceability.

Parallel fabrication method. The PFM was defined as multiple carcasses being processed simultaneously. To achieve this, 10 hindquarters were processed, followed by the corresponding 10 forequarters, then 8 forequarters followed by the corresponding 8 hindquarters. During PFM, each wholesale cut was labeled individually with an in-process label that was created using the same method as described for SFM. Identified wholesale cuts were then placed into lugs before being moved.

In-process labeling. The 2D barcodes on carcass harvest labels were scanned immediately before carcass breakdown using the handheld computer. The handheld computer's barcode scanner recorded the information from the barcode of the harvest label. The SSI-EID, AIN, and date and time were included in the 2D GS1 DataMatrix barcode (1.59 × 1.59 cm) on the in-process label (Figure 1B). The mobile software also assigned a unique identity for each carcass using a three-character alpha sequence (i.e., first carcass = "AAA," second carcass = "AAB," and so on) followed by a serialized number indicating the number of labels printed for each carcass (i.e., first label for the carcass = "001," second label for the carcass = "002," and so on), which was also displayed as text on the printed in-process label (Figure 1B). This visual serialization method was found to be unnecessary and was discontinued after the pilot run. During the study, each carcass was assigned a sequential number, which was written on the back of the in-process label for quick visual identification by the beef cutters. The handheld mobile unit was used to print 6 (5.08 × 2.54 cm) labels for each carcass during SFM and 34 labels for each carcass for PFM. The in-process labels for PFM were placed on waterproof cure tags (6.99 × 3.49 cm) and then attached to the wholesale beef cuts using plastic carcass brads (Ketchum, Brockville, ON).

Beef package labeling. After each lug or wholesale beef cut was identified with an in-process label, the cuts were moved to a vacuum packaging station. The in-process label was removed from the top-most wholesale cut of each lug for SFM and each individual wholesale beef cut for PFM. Each beef cut was placed in a vacuum package (Cryovac, Sealed Air, Duncan, SC) bag, vacuum sealed, and dipped into a hot water bath. Each package was dried with a towel, the in-process label for the wholesale cut was scanned with a handheld mobile computer, and a final, food-grade, polypropylene beef package label (5.08 cm × 2.54 cm × 3 mm; Spinnaker Coating) was printed (Figure 1C). The label was then applied to the outside of the dried package. When the in-process label was scanned, the mobile computer stored the unique three-digit alpha character, SSI-EID, and AIN. The final package label also included the phrase "traceback.com," a serialized number, date, time, and a four-segmented 2D GS1 DataMatrix barcode (1.59 × 1.59 cm) that contained the Uniform Resource Locator (**URL**) for animal origin information. For example, beef from an animal with an SSI-EID of 09AE16F37C would have a unique URL of www.scoringag.com/scoringag/3/Ag.cfm?sfa=main.PSA&entity_id=SSI_09AE16F37C. This URL references the web page with previously entered data for that individual animal. The wholesale cuts then were moved to a boxing station.

Box labeling. At the boxing station, packages were placed into boxes with similar cuts according to North American Meat Processors Association (**NAMP**) specifications. Food-grade polypropylene box labels (10.16 cm × 5.08 cm × 3 mm; Spinnaker Coating) were created using the same laptop computer and industrial thermal transfer printer as the harvest labels. The box label included the phrase "MSU BEEF," date, serialized number, and a 2D GS1 DataMatrix barcode (Figure 1D). The 2D barcode referenced a mobile website, beeftrace.wirenode.mobi (Wirenode, Dallas, TX), that was created to contain information about the farm of origin for the beef steers utilized. Boxed beef was frozen and transported by refrigerated truck to MSU Food Service, East Lansing, MI, where the beef was kept frozen until transport to MSU food venues.

Video Analysis

Beef fabrication was recorded using four video cameras (model MX-9746VF; Skyway Security, Mauldin, SC) placed throughout the processing room with full coverage of processing and labeling areas. Two digital video recorders (model AV-04; Skyway Security) were used to capture the video data. The data collected from the video capture included times for processing each carcass, processing each day, creating in-process labels, labeling lugs, labeling wholesale cuts, removing in-process labels, and labeling of final beef packages. Times were determined by viewing the captured video on a personal computer using a video player application (2010 HD Player Version 1.1.6.0). Daily fabrication time was defined as the total cutting and labeling man-hours per day. Start time was recorded when the first carcass quarter was pulled from the rail and ended when the last wholesale cut was labeled. Time spent fabricating each carcass was determined by dividing the total fabrication time per day by the number of carcasses processed per day. In-process label creation time per day started when the mobile computer scanned the first harvest label tag and ended when the last label was adhered to the waterproof cure tag. The in-process label generation took place over several intervals throughout each day. Start and stop times were recorded in the same manner as described above and then summed for a total time of in-process label generation per day. Total time for labeling lugs for SFM and total time for labeling each beef cut for PFM were recorded. Start time for SFM was defined as when the beef cutter grasped the label and finished when the carcass brad was pushed in the top-most beef cut in the lug. This was done for all lugs labeled for each carcass. Start time for PFM was initiated when the beef cutter grasped the label and stopped when the carcass brad was placed in the wholesale cut. Time removing in-process labels was defined as the total time required for removing and discarding the label. Final package labeling time was defined as the total time spent drying and placing the label on the final beef package.

Traceability Cost

The overall cost of traceability was calculated by summing the costs of traceability hardware, consumables, including labeling and printer supplies, and labor. Depreciation of traceability hardware was calculated assuming 250 work d/yr and 20 carcasses processed/d. Labor cost was charged at $20.00/h which included employee fringe and benefits.

DNA Sampling

DNA marker technology was used to verify the fidelity of traceability between treatments. Use of DNA genotyping of single nucleotide polymorphisms (SNP) has been reported to be a sensitive method to definitively identify beef from individual cattle (Heaton et al., 2002). In this study, tissue samples of each steer were obtained during feedlot finishing by applying a tissue sampling ear tag (Typifix Yellow Panel Ear Tag, Prionics USA, Omaha, NE). Each ear tag contained a unique one-dimensional (**1D**) barcode that was electronically cross-referenced with the steer's AIN. The sample collector portion of the ear tag retained a tissue sample that was used for genotyping.

Wholesale cut sampling was conducted during beef thawing and preparation. Ninety-four beef samples were obtained at 10 different MSU food venues over the course of 9 mo. Samples were collected using meat sampling devices (IdentiGEN North America, Inc., Lawrence, KS) as described by Loftus and Meghan (2011). The sampling device contained a unique 1D barcode that was cross-referenced with the AIN indicated on the package tracking label by use of a handheld computer. Genomic DNA was extracted from the ear tissue and beef samples. SNP were genotyped using an end-point homogeneous fluorescence assay system (IdentiGEN North America). Individual sample genotypes were compared for identity across all SNP tested using computer algorithms. A match was identified when the probability of two samples having the same genotype was 1 in $>10^6$. A nonmatch was recorded when two or more allelic differences were observed.

Statistical Analysis

The GLM procedures of SAS v. 8.4 (SAS Inst. Inc., Cary, NC) were used to analyze the number of labels used, amount of time to label and track beef cuts, and cost of tracking. Carcass served as the experimental unit when analyzing the cost of in-process labels, number of in-process labels used, and total number of labels used. Day served as the experimental unit when analyzing time to generate in-process labels, apply in-process labels, remove in-process labels, apply final labels, and total amount of time spent on labeling. When number of labels and time were dependent variables in the model, treatment and replicate were independent variables. When cost was the dependent variable, treatment was the independent variable. The level of probability at which main effects were considered significant was $P \leq 0.05$.

RESULTS

The time required to label, and the number of labels used, varied between treatments (Table 1). Eight times more in-process labels were used on each carcass for PFM compared with SFM ($P < 0.01$). The PFM required each individual wholesale cut to be labeled, whereas SFM required only the lug

Table 1. Traceability labels and labeling time for serial and parallel beef fabrication methods

	Fabrication method			
Item	Serial[a]	Parallel[b]	SEM	*P* value
In-process labels used, number per carcass	3.7	30.9	0.2	<0.01
In-process label generation, seconds per carcass	136.0	525.0	52.2	0.10
In-process labeling, seconds per carcass	18.0	181.0	3.6	<0.01
In-process label removal, seconds per carcass	2.1	18.1	1.26	0.04
Final package labeling, seconds per carcass[c,d]	114.1	105.8	16.9	0.92
Time spent on traceability, total seconds per carcass	270.0	831.1	52.9	0.05
Labels used, total number per carcass	30.7	57.9	0.2	<0.01

[a]Defined as an individual carcass (both hindquarters and forequarters) being processed before starting on the next carcass.

[b]Defined as multiple carcasses processed simultaneously.

[c]Time to generate final package labels took 108 s for SFM and PFM.

[d]Twenty-seven labels were printed for each carcass for SFM and PFM.

to be labeled, thus reducing the amount of labels required to track product. More time tended to be spent on generating in-process labels for PFM than that for SFM ($P = 0.10$). Nine times more time was spent placing in-process labels on wholesale meat cuts for PFM than that for SFM ($P < 0.01$). Removal of in-process labels at the vacuum packaging station took 9 times more time per carcass for PFM compared with SFM ($P = 0.01$). Each treatment resulted in the same number of wholesale meat cuts; therefore, no variance between treatments for number of labels used and time spent on printing labels was observed during the final package labeling process. Total time spent on traceability tended to be greater for PFM than that for SFM ($P = 0.05$). Total number of labels used per carcass for SFM was less than PFM ($P < 0.01$).

Traceability costs were estimated to be higher for PFM than that for SFM (Table 2). Because twice as many labels were printed for PFM than SFM, the useful life of the PFM in-process mobile printer was estimated to be half that of the SFM mobile printer. Use of the mobile printer accounted for the only difference in fixed cost between the treatments. Consumable costs also varied between PFM and SFM. Shipping tags, deadlocks, stationary printer ribbon, carcass labels, and number of final package labels used were constant between PFM and SFM. The consumable cost for carcass brads, mobile printer ribbon, in-process labels, and waterproof tags were all greater for PFM. Total consumable cost for SFM was $5.54/carcass lower than PFM.

Labeling labor cost per carcass was 3.5 times lower for SFM than that for PFM (Table 2). The total traceability cost per carcass was more than doubled for PFM compared with SFM. This resulted in a total traceability cost of $0.07/kg and $0.15/kg of wholesale product cut for SFM and PFM, respectively.

A total of 94 meat samples were collected for DNA analysis; 47 from each SFM and PFM. Samples from 22 different beef animals for SFM and 26 different beef animals for PFM were collected. All beef samples that could be cross-referenced to their animal of origin were accurately labeled and tracked through the harvest and processing facility (Table 3). Three of 72 live animal tissue samples and 5 of 94 wholesale beef cut samples failed because of insufficient DNA collection. As a result, nine wholesale beef cut samples collected were unable to be traced back to an animal.

DISCUSSION

We have demonstrated that an AIN encoded in a RFID ear tag can be transferred to 2D barcode labels, effectively tracking carcasses and wholesale beef cuts through small processing plants. Data captured in the 2D barcode label, not only provided supply chain participants with information, but ultimately delivered farm of origin information to the beef preparer.

Transfer of information from farm of origin to end user can potentially add value to the product. Differentiation of “local” food is based on attributes other than simply local origin, such as producer values and production methods employed. Caswell and Mojduszka (1996) categorized food product traits as search, experience, or credence attributes. According to their definitions, search attributes can be identified before purchase through inspection or research (e.g., marbling, lean color, and external fat); experience attributes can be determined after consuming the product (e.g., juiciness, tenderness, and flavor); and credence attributes cannot be assessed, even after the product is purchased and consumed (e.g., locally produced, grass-fed, and humanely raised). With growing consumer interest

Table 2. Estimated traceability cost for serial and parallel beef fabrication methods, $/carcass

	Fabrication method	
	Serial[a]	Parallel[b]
Item	$/carcass	
Fixed cost		
Radio frequency identification (RFID) ear tag[c]	2.10	2.10
RFID handheld reader[d,e]	0.05	0.05
Notebook PC and printer[e,f]	0.36	0.36
Handheld mobile scanner 1 (in-process)[e]	0.39	0.39
Handheld mobile scanner 2 (final package)[e]	0.39	0.39
Mobile printer 1 (in-process)[g]	0.31	0.61
Mobile printer 2 (final package)[h]	0.61	0.61
Total fixed cost	4.21	4.51
Consumable cost		
Shipping tags	0.23	0.23
Deadlocks[i]	0.08	0.08
Carcass brads[j]	0.44	3.67
Stationary printer ribbon	0.32	0.32
Labels (10.16 × 5.08 cm)	0.24	0.24
Mobile printer 1 ribbon	0.15	1.24
In-process labels (5.08 × 2.54 cm)	0.07	0.56
Waterproof tags (6.99 × 3.49 cm)	0.10	0.83
Mobile printer 2 ribbon	1.16	1.16
Final package labels (5.08 × 2.54 cm)	0.52	0.52
Total consumable cost	3.31	8.85
Overall traceability cost		
Traceability equipment cost	4.21	4.51
Traceability consumable cost	3.31	8.85
Labeling labor cost[k]	1.50	4.62
Total traceability cost	9.02	17.98

[a]Defined as an individual carcass (both hindquarters and forequarters) being processed before starting on the next carcass.

[b]Defined as multiple carcasses processed simultaneously.

[c]Low-frequency, half-duplex, radio frequency identification ear tag.

[d]Handheld wand reader.

[e]Useful value of 2 yr borrowed money at 5% interest with quarterly payments.

[f]Assumed 250 work d/yr and 20 carcasses processed/d.

[g]Useful value of 2 yr for SFM and 1 yr for PFM with borrowed money at 5% interest with quarterly payments.

[h]Useful value of 1 yr with borrowed money at 5% interest with quarterly payments.

[i]Metal deadlock tag fastener used to hold carcass labels to carcass.

[j]Plastic carcass brad used to hold in-process label to wholesale meat cut.

[k]Labor cost charged at $20.00/h that included employee fringe and benefits.

in food origin and processes, comes a growing number of imaginable credence attributes. Labeling or linking beef with verified credence attributes would enable real choice to be exercised among foods produced in different ways.

There is a growing body of research examining the premium values of different beef credence attributes, such as grass or forage fed (Martin and Rogers, 2004; McCluskey et al., 2005; Umberger et al., 2009a; Crandall et al., 2013; Dentoni et al., 2014), no exogenous hormones (Lusk et al., 2003; Ward et al., 2008; Umberger et al., 2009b), no antibiotics used (Ward et al., 2008; Umberger et al., 2009b), all natural (Ward et al., 2008; Markus et al., 2014), source verified (Ward et al., 2008; Allen et al., 2011), and locally produced (Maynard et al., 2003; Alfnes and Sharma, 2010; Goddard et al., 2013; Ridley et al., 2014). To maintain credence attribute claims, a traceability system needs to be implemented to track products through the supply chain. However, traceability has developed largely as two separate systems in the beef industry: live animal traceability and product traceability (Bulut and Lawrence, 2007).

Internal traceability refers to traceability within a production unit or specific stage of production (Bulut and Lawrence, 2007). For a live animal provider to maintain traceability, it is suggested by the mpXML Inc. (2010) that the provider has a unique provider identity and accurate herd/house/pen information depending on species. Currently, live animal traceability is primarily being used for disease eradication programs and herd health record keeping that requires individual tagging and tracking of livestock. One example, as described by Murphy et al. (2008), is the use of individual identification in the effort to eradicate bovine brucellosis from the U.S. cowherd. Once an animal is vaccinated against the disease, it is tagged with a uniquely coded metal ear tag. As another example, the state of Michigan has implemented mandatory RFID tagging of all bovine species, before leaving the farm of origin, in an effort to control and eradicate *Mycobacterium bovis* (Kirk and Buskirk, 2006). Traceability in these two cases ends at time of animal harvest.

For functional traceability, the live animal must be uniquely identified. The traditional method of identification had been hot-iron branding which was typically used to distinguish one herd from another. Over the last several decades freeze branding and various other external tagging techniques have been practiced in the beef industry (USDA, 1997, 2007). The use of RFID tags in livestock has been explored in various applications requiring unique animal identification. As Singh et al. (2014) outlined, RFID transponders have been tested as ear tags, rumen boluses, collars, and microchips that are imbedded in the skin.

Table 3. Genotyping of SNP from live steers and beef products from live steers and beef

Wholesale beef cut	Fabrication method: Serial[a] cuts sampled	Fabrication method: Parallel[b] cuts sampled	Total cuts sampled	Confirmed DNA match	Confirmed DNA mismatch	Unconfirmed DNA match
Beef back rib	6	6	12	12	0	0
Beef eye of round	6	6	12	11	0	1[c]
Beef ribeye roast	3	6	9	7	0	2[c]
Chuckeye roll	3	3	6	4	0	2[c,d]
Chuck flat iron	3	0	3	3	0	0
Beef flank	3	3	6	6	0	0
New york strip	1	0	1	0	0	1[d]
Skirt steak	6	6	12	12	0	0
Striploin	10	10	20	19	0	1[c]
Top butt sirlion	3	3	6	4	0	2[d]
Top round	3	4	7	7	0	0
Total	47	47	94	85	0	9

[a]Defined as an individual carcass (both hindquarters and forequarters) being processed before starting on the next carcass.

[b]Defined as multiple carcasses processed simultaneously.

[c]Wholesale beef cut sample did not meet quality standards for DNA genotyping.

[d]Live animal tissue sample did not meet quality standards for DNA genotyping.

Chain traceability refers to traceability throughout the entire food chain (Bulut and Lawrence, 2007). Smith et al. (2008) conducted a review of 13 countries or communities that had cattle/beef traceability programs. Of the 13, 11 were mandatory (4 encompassed birth to retail; 7 covered birth to harvest) while 2 were voluntary programs (birth to harvest). Postharvest individual animal identification traceability can be accomplished using single-carcass fabrication units, tagging and separation/segregation, and/or DNA fingerprinting technology. In most countries, there has been no compelling reason for the beef industry to adopt such protocols or technology because these processes were time consuming and costly (Smith et al., 2008).

In this study, chain traceability was attempted by tracking live animal and beef product through the cow–calf, feedlot, harvest, fabrication, distribution, and wholesale segments of a beef supply chain. There were differences in traceability cost between SFM and PFM due to system components, such as those outlined by Mejia et al. (2010), like capital equipment and software; operating labor; consumable materials; and effects on line speed or operation efficiency. We found that full chain traceability in this study cost less than $20/carcass.

The fabricator believed the PFM may be more time efficient compared with the SFM. This was speculated due to greater repetition of fabricating the same wholesale beef cuts. We found however that fabrication time during PFM was greater than SFM (data not shown). In this particular processing plant, SFM would be more time efficient for carcass fabrication and also reduce traceability cost.

The two carcass traceability models compared in this study proved to have efficacy for tracking beef product. Both methods of tracking may be applicable to various types of beef processors and fabricators based on volume of animals processed and available labor to track product. The two tracking methods used in this study may not be feasible tracking methods in large processing systems (i.e., more than 100 carcasses fabricated daily). Large processing facilities typically comingle large numbers of carcasses on moving fabrication lines, thus making it difficult to track individual animals in a similar manner to what we used. Because large processing facilities may find it difficult to track product to specific carcasses, this may allow small processors the opportunity to add value to traced beef products and gain a competitive advantage. However, large processing systems may be able to track product to a batch or farm origin level. This can be done by creating a unique identification number for a batch rather than specific animals and establishing a unique identification number on a barcode or RFID tag on carcass trolley or bins for wholesale beef cuts.

Although tracking of individual wholesale cuts was successful in this study, some of the technology used for label creation could be improved. For example, the handheld scanners used Bluetooth technology, which took nearly 30 s to communicate with the mobile printer before printing in-process and final package labels. This time delay added overall cost to the label generating process. Future studies may also include such topics as optimal label size and placement on wholesale or retail beef packages.

In this study, the 2D barcode label was created at the harvest level, and then a new 2D barcode label was created during carcass fabrication. On a small scale, a simple, unique, alpha, or numeric character could be assigned to each carcass upon harvest that corresponds with the RFID ear tag number that is then carried through carcass fabrication. This number could be referenced when the beef cut is placed in the final package, and a final package label could be created and applied. This alternative could save on printer consumable costs during carcass fabrication.

Genotyping used to check quality of tracking beef products has been shown to be of high accuracy. On the basis of SNP allele frequencies at 20 loci in beef and dairy cattle, the mean probability that two randomly selected individuals would possess identical genotypes was 1 in 23 million (Heaton et al., 2005). During the genotyping process for checking the fidelity of tracking in this study, three ear tissue samples and four beef samples were unable to be cross-referenced due to insufficient amount of DNA sampled. Failure rates of tissue and beef samples found in this study are similar to that typically observed in DNA genotyping (S. Eliades, IdentiGEN, Lawrence, KS). To date, there are no published standards set by the industry on acceptable rates of success when tracking beef products.

This study used wholesale beef cuts for food service distribution channels and did not expose retail consumers to the traceability information. Further studies are needed to determine what specific attributes consumers desire most regarding beef products, the most important data that should be collected and traced throughout the beef supply chain, and aesthetics of 2D barcode design on retail packaging.

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