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DISSERTATION

VIDEO IMAGE ANALYSIS AS A PREDICTOR OF BEEF CARCASS RED MEAT YIELD PERCENTAGE

Submitted by
Robert Charles Cannell
Department of Animal Sciences

In partial fulfillment of the requirements
for the Degree of Doctor of Philosophy
Colorado State University
Fort Collins, Colorado
Spring 2000

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WE HEREBY RECOMMEND THAT THE DISSERTATION PREPARED UNDER OUR SUPERVISION BY ROBERT CHARLES CANNELL ENTITLED VIDEO IMAGE ANALYSIS AS A PREDICTOR OF BEEF CARCASS RED MEAT YIELD PERCENTAGE BE ACCEPTED AS FULFILLING IN PART REQUIREMENTS FOR THE DEGREE OF DOCTOR OF PHILOSOPHY.

Committee on Graduate Work

Keith Belk

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ABSTRACT OF DISSERTATION

VIDEO IMAGE ANALYSIS AS A PREDICTOR OF BEEF CARCASS RED MEAT YIELD PERCENTAGE

An improved ability to predict differences in the fabrication yields of beef carcasses would facilitate the application of value-based marketing. The first part of this study was conducted to evaluate the ability of the Dual-Component Australian VIASCAN™: (1) to predict fabricated beef subprimal yields as a percentage of carcass weight at each of three fat-trim levels and (2) to augment USDA yield grading, thereby improving accuracy of grade placement. Steer and heifer carcasses (n = 240) were evaluated using VIASCAN™, as well as by USDA expert and online graders, before fabrication of carcasses to each of three fat-trim levels. Cutability prediction using: (a) Expert yield grade, (b) online yield grade, (c) VIASCAN™ estimate of yield, and (d) VIASCAN™ augmented yield grade (using expert grader estimates of adjusted fat thickness and percentage of kidney-pelvic-heart fat, actual hot carcass weight and VIASCAN™ estimate of ribeye area), respectively: (1) accounted for 51, 37, 46, and 55% of the variation in fabricated yields of commodity-trimmed (2.54 cm.-trim) subprimals, (2) accounted for 74, 54, 66, and 75%

of the variation in fabricated yields of closely trimmed (.64 cm.-trim) subprimals, and (3) accounted for 74, 54, 71 and 75% of the variation in fabricated yields of very closely trimmed (<.64 cm.-trim) subprimals. The VIASCAN$^{\text{TM}}$ estimate of yield predicted fabrication yields more accurately than online yield grade and, the VIASCAN$^{\text{TM}}$-augmented yield grade improved the accuracy of cutability prediction, at packing plant line speeds, to a level matching that of expert graders applying grades at a comfortable rate. The second part of this study was conducted to evaluate the ability of a commercial VIA system, the Canadian Computer Vision System (CVS$^{\text{TM}}$): (1) to predict yields of commercially fabricated beef subprimals as a percentage of carcass weight and (2) to augment USDA yield grading, to improve accuracy of grade placement. The CVS$^{\text{TM}}$ was evaluated as a completely installed production system operating on a full-time basis at chain-speeds. Steer and heifer carcasses ($n = 296$) were evaluated using CVS$^{\text{TM}}$, as well as by USDA expert and online graders, before fabrication of carcasses to closely trimmed subprimal cuts. Expert yield grade, online yield grade, CVS$^{\text{TM}}$ estimate of yield, and CVS$^{\text{TM}}$-augmented yield grade (using expert grader estimates of adjusted fat thickness and percentage of kidney-pelvic-heart fat, actual hot carcass weight and

VIASCAN™ estimate of ribeye area), respectively, accounted for 67, 39, 64, and 65% of the variation in fabricated yields of closely trimmed subprimals. The CVS™ estimate of yield predicted fabrication yields more accurately than online yield grade and, the CVS™ augmented yield grade improved the accuracy of cutability prediction, under packing plant conditions and speeds, to a level close to that of expert graders applying grades without time pressure.

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DEDICATION

I would like to dedicate this dissertation to my wife Laura. Thank you and I love you.

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CHAPTER I

OBJECTIVES OF DISSERTATION

The objectives of this dissertation were:

(1) To evaluate the ability of the Australian VIASCAN™ System to predict differences in fabricated yields of beef carcasses.

(2) To evaluate the ability of the Australian VIASCAN™ System to augment the application of USDA Yield Grades to beef carcasses.

(3) To evaluate the ability online of the commercially available Canadian CVS™ System to predict differences in fabricated yields of beef carcasses online and under plant conditions.

(4) To evaluate the ability online of the commercially available Canadian CVS™ System to augment the application of USDA Yield Grades to beef carcasses online and under plant conditions.

CHAPTER II

Literature Review

Introduction

In the current state of the beef industry, the majority of cattle are traded on the cash market which, by design, pays producers an average price regardless of the quality of their cattle. Cross and Savell (1994) stated that a functioning value-based marketing system is critical to the future economic health of the beef industry. According to Cross and Savell (1994), beef producers must be paid for producing what consumers want and clear economic signals must pass through all levels of the marketing chain from consumers to producers. Without these clear economic signals, there exist no real incentives for producers, feeders, or packers to breed, feed, or fabricate animals and products to meet consumer demands.

Some packers have begun offering formula pricing schemes that price cattle individually based on the estimated values of various combinations of Yield and Quality Grades. These early efforts to employ value-based marketing are, to some degree, hampered by the lack of accuracy and precision in the application of USDA Yield Grades.

In a national study of beef carcass grading accuracy, Cross et al. (1984) found that 11.6% of online grader applied yield grades (assigned as whole grades) were incorrect. The U.S. beef industry needs a value-based marketing system, and instrument grading might improve accuracy-value of assessments of value in such a system; average trading of animals is a major impediment to value-based marketing (Cross and Whittaker, 1992). If the current yield grading system -- replaced and/or augmented by VIA technology -- could be used to predict, accurately, carcass yields of primal/subprimal cuts (including yields at different fat-trim levels), implementation of value-based marketing would be greatly enhanced.

Yield Grades

Murphey et al. (1960) identified the regression equations that eventually were used to develop the current USDA Yield Grade equations. The most useful equation for estimating boneless retail cuts included fat thickness over the ribeye, carcass weight, percentage of kidney fat, and area of the ribeye (Murphey et al., 1960) and it was also concluded that further improvements in predictive accuracy could be achieved by using a subjective adjustment of fat thickness to account for variations in fat deposition across various parts of the carcass. USDA Yield Grading was implemented in 1965 using an equation derived from the work of Murphey et al. (1960).

Since the implementation of yield grading, numerous studies have evaluated/validated the accuracy of the original "Murphey" equations (including Cross et al., 1973, Crouse et al., 1975, Abraham et al., 1980, Crouse et al., 1986, Shackelford et al., 1995, Belk et al., 1996, and George et al., 1996). Cross et al. (1973) evaluated regression equations for the prediction of boneless retail cut yields of beef carcasses and reported that the best equation ($R^2 = .74$) for cutability prediction utilized the same independent variables that are included in the USDA Yield Grade equation. Crouse et al. (1975) found that a prediction equation containing the yield grade factors accounted for 77% of the variability in beef carcass cutability percentage. Abraham et al. (1980) found that the factors in the USDA Yield Grade equation (adjusted fat thickness, kidney-pelvic-heart fat percentage, ribeye area and hot carcass weight) predicted actual cutability with a coefficient of determination of .83.

In more recent studies, researchers continue to validate the USDA Yield Grade equation for beef carcasses and the factors included in the equation. Crouse et al. (1986) evaluated the accuracy of yield grades (with and without kidney-pelvic fat in the carcass) for predicting carcass cutability and reported that yield grade accounted for 68% and 66% of the variation in cutability in beef carcasses with kidney-pelvic fat in vs. out, respectively, of the carcasses. In a study designed to develop and evaluate the accuracy of beef cutability prediction equations, Shackelford et al. (1995), reported a simple correlation coefficient of -.80 between USDA Yield Grade and retail product yield. In a review of the state of instrument grading technologies, Belk et al. (1996) concluded that USDA Yield Grades, when applied correctly, are very effective in segregating carcasses into classes reflecting real value-differences in expected yields of trimmed cuts.

Johnson and Baker (1997) studied the abilities of various linear and area measures of the *longissimus* muscle for prediction of carcass muscle percentage. Fat thickness at the 10th rib had the highest coefficient of determination (R^2 = .62) and the smallest residual standard deviation (RSD = 3.40) for prediction of total muscle percentage, and the best overall equation for predicting percentage of total muscle in beef carcasses included 10th rib fat thickness, carcass weight and eye muscle area (R^2 = .73 and RSD = 2.90; Johnson and Baker, 1997).

Instrument Grading Introduction

Although the USDA Yield Grade equation is very accurate and useful in predicting carcass cutability (and related value), the conclusions of Cross et al. (1984) -- that the application of yield grades was often performed incorrectly in the industry -- has led researchers to look for more objective grading systems that are not limited by the inconsistencies of human evaluators. Cross and Savell (1994) identified development of an instrument for the assessment of carcass value, as a primary need of an effective value-based marketing system.

Ultrasound for Prediction of Beef Carcass Cutability

One of the technologies that has been extensively evaluated for cutability prediction is use of ultrasound. Ultrasonic scanning was developed by the medical industry, and its ability to view fatness and muscling indicators through the hide of a live (or dead) animal led a number of researchers to evaluate this technology for prediction of yields. Ultrasound technology utilizes ultra-high frequency sound waves to penetrate tissues and then reflect back to the instrument. The machine interprets the differences in sound reflectance (caused by different densities of tissues) and displays the results as a real-time picture on a display (B-mode ultrasound) or as a value representing fat thickness (A-mode ultrasound).

In a paper discussing the history and progress of instrument grading, Cross and Whitaker (1992) concluded that ultrasound-based technologies offered, then, the best chance of success for instrument grading; included in its capabilities was the ability to segment carcasses by cutability prior to chilling (24-48 h ahead of carcass grading). Hamlin et al. (1995) found that ultrasonic predictors explained about 10% less of the variation in retail product percentage than did carcass measures. In a study to compare the cutability prediction abilities of ultrasonically measured fatness and muscling with the same traits measured on carcasses, Herring et al. (1994) reported coefficients of determination of .527, .596, and .484 for the prediction of cutability (subprimals trimmed to .32 cm of fat) for yield grade, regression of yield grade factors, and live/ultrasound factors, respectively.

Williams et al. (1997) used ultrasound measures and beef carcass weight to predict percentage of retail products and achieved an R^2 value of .318.

Griffin et al. (1999) concluded that ultrasonic evaluation of fat thickness and ribeye area on the slaughter floor was of limited usefulness compared with the greater accuracy of chilled beef carcass assessments. They (Griffin et al., 1999) concluded that although ultrasound measures showed potential for the prediction of cutability, more development of automated ultrasound measuring equipment would be necessary before ultrasound could become a viable technology in high-speed beef packing plants. Griffin et al. (1999) found that, for the prediction of yield of major boneless subprimals trimmed to .64 cm of fat, USDA Yield Grade, yield grade factors, and ultrasound fat thickness combined with KPH percentage, achieved R^2 values of .34, .49 and .38 respectively. Griffin et al. (1999) found (as did Hamlin et al., 1995) that cutability prediction of beef carcasses using ultrasound measures results in R^2 values approximately 10% lower than those achieved by yield grades or a regression of yield grade factors.

Electromagnetic Scanning as a Measure of Carcass Muscling

Another technology that has been evaluated for the prediction of beef carcass cutability is electromagnetic scanning (EMS) which is sometimes called total body electrical conductivity (ToBEC). Electromagnetic scanning technology operates as a carcass or carcass part moves through a magnetic field. Changes in the magnetic field that occur as more or less electrically conductive tissues pass through are interpreted as spikes on a display or chart. Gwartney et al. (1994), scanned full hindquarters and streamlined forequarters and, using electromagnetic scan data in combination with the weight of the quarter and the fat thickness at the 12th rib, explained 61 to 75% of the observed variability in lean content of beef carcasses. Belk et al. (1996) found that substitution of ToBEC peak value for expert ribeye area (in the calculation of yield grade) achieved the same predictive accuracy as did expert grader applied yield grade (R^2 = .84), but concluded that ToBEC was not then capable of being incorporated into carcass grading systems that operate at industry standard chain-speeds. Although EMS has been shown to be an accurate predictor of cutability, its use as a evaluation system is limited in commercial applications. EMS systems are very large and are affected by stray (external) electrical fields and, because the carcass or carcass part must be transported through the system, EMS cannot currently keep pace with industry operating speeds.

Use of Round Weight/Percentage to Improve Yield Grade Accuracy

Attempts have been made to improve predictive accuracy of yield grades by adding trimmed boneless round weight to regression equations. Brungardt and Bray (1963) reported that the addition of trimmed round percentage to the factors of actual fat thickness, kidney-pelvic-heart fat percentage, ribeye area and carcass weight, increased the R^2 value by .15 to .82. Reiling et al. (1992), reported that in addition to current yield grade factors, boneless closely trimmed round percentage alone accounted for 57% of the variability in retail yield, and when combined with other yield grade factors (hot carcass weight, adjusted fat thickness, ribeye area and percentage KPH fat) improved the predictive accuracy by .188 units (over the use of yield grade factors) to .665. The largest limitation to the use of a trimmed primal weight (or percentage) to enhance the predictive abilities of yield grades is the fact that information wouldn't be available until the carcass is fabricated.

Subdividing Yield Grades to Improve Yield Grade Precision

Another approach to improving the precision of yield grades has been to suggest subdividing yield grades. Currently yield grades are applied as integers from 1 (highest predicted cutability) to 5 (lowest predicted cutability) but it would be reasonable to split two of the yield grades (2 and 3) to create a seven-grade system (1, 2A, 2B, 3A, 3B, 4, and 5). Kerth et al. (1999) evaluated the comparative accuracy of online application of yield grades using both the traditional five-grade system and the seven-grade system proposed above and found that the accuracy of application decreased significantly when online graders used the seven grade system. The limitations of grading time (because of chain-speed and additional grades from which to choose) appear to defeat the purpose of increased precision that a seven-grade system should provide.

Video Image Analysis for Predicting Beef Carcass Cutability

The grading technology that is the focus of the current research study is Video Image Analysis (VIA). VIA utilizes a video camera to collect an image of all or parts of the carcass (the whole carcass in a "hot" system, the 12th rib surface in a "cold" system and both images in a "dual component" system). The image is analyzed and segmented into areas of interest by computer. The resulting output is commonly in the form of a predicted cutability percentage, a machine yield grade, or raw data (such as fat thickness or ribeye area) for incorporation into other prediction equations. The most common systems are either cold systems or dual scan systems.

Cross et al. (1983) evaluated the ability of a video image analysis system (capable of image scanning and processing within normal packing plant chain-speed intervals) to predict lean yield of 9th-10th-11th rib sections of beef carcass, and compared predictive abilities to USDA Yield Grade factors. Those researchers (Cross et al., 1983) concluded that VIA ribeye area from the system was highly correlated with measured ribeye area (r = .84), and VIA fat thickness was highly correlated with measured and adjusted fat thickness (.90 and .89, respectively). Regression equations using VIA measures (Cross et al.,

1983) accounted for 81.6 to 89.0% of the variation in percentage lean from 9^{th}-10^{th}-11^{th} rib sections. Cross et al. (1983) concluded that further research to evaluate VIA systems under commercial conditions was warranted.

Wassenberg et al. (1986) evaluated the ability of VIA to predict primal lean cutout (maximum fat thickness = 1.27 cm), and compared VIA predictive accuracy with that of expert yield grades. Those researchers (Wassenberg et al., 1986) found that VIA prediction of cutability (CD = 46.35%) was slightly higher than that achieved by expert yield grade.

Jones et al. (1992) stated that over the previous decade there had been major advances in cost, speed, size and storage capacity of microcomputers that could result in VIA becoming a viable and practical commercial method for collection of carcass data and the prediction of carcass cutability. Those researchers (Jones et al., 1992) substituted VIA measures of loineye area and fat thickness into the Canadian yield equation and achieved an R^2 value of .82 (RSD = 1.61%) when using this equation to predict percentage lean as determined by the Canadian yield equation using manual measurements of loineye area and fat thickness. Jones et al. (1992) concluded that VIA measurements of fat thickness and ribeye area can be used to assess beef carcass lean percentage.

Augmentation of USDA Yield Grades

Murphey et al. (1983) studied the assignment of yield grade factors to beef carcass sides with different amounts of external fat removed from different locations on one side, and concluded that with adequate experience, graders would be as proficient in estimating fat thickness and adjusted fat thickness as they were in assessing the same traits for carcasses with intact fat coverings.

Belk et al. (1996) stated that expert yield grade was then the most accurate and precise estimator of carcass composition but concluded that USDA online Yield Grade accuracy and precision suffered because of the rate at which factors and grades had to be applied and calculated. Those researchers (Belk et al., 1996) observed a reduction of 20% in explained variability from online application of yield grades as compared with yield grades applied by expert graders (working at leisure). Belk et al. (1996) concluded that, with the state of the technology at that time, the predictive accuracy of applying yield grades suffered a reduction of 12% when VIA measured ribeye area was substituted for ribeye area measured by expert graders.

Belk et al. (1998) compared online USDA graders and USDA grading supervisors with an expert panel of carcass evaluators and reported that: (1) online grader ribeye area (REA) estimates (at chain-speeds) were only nominally related (r = .48) to mechanical REA measurements and (2) online graders' adjusted preliminary yield grade (PYG) estimates were very closely related to the adjusted PYG measurements of the experts (r = .91).

Because yield grades when properly applied, are capable of accurately predicting beef carcass cutability, research studies with the purpose of assisting or augmenting their application by online graders are needed. With augmentation, online grading might be improved to a level of accuracy comparable to that of expert graders (working without time constraint).

Belk et al. (1996) concluded that yield grading could be improved if actual carcass weight and grader-applied factors of adjusted fat thickness and percentage of kidney-pelvic-heart fat were augmented with instrument-measured ribeye area. In a simulated augmentation study, Belk et al. (1998) found that online grader applied factors of adjusted fat thickness and kidney-pelvic-heart fat percentage, combined with actual hot carcass weight and actual ribeye area achieved an R^2 value of .93 in predicting yield grades applied by an expert grading panel (working off-line with unlimited time and access). The augmentation system improved the predictive accuracy of yield grade application by 25% over online yield grades applied traditionally leading Belk et al. (1998) to conclude that instrument augmentation of the ribeye area would improve accuracy and precision of placement of USDA Yield Grades applied online.

Belk et al. (1998) concluded that application of USDA Yield Grades could best be augmented by: (1) providing an accurate assessment of ribeye area and (2) performing the calculations needed to determine the yield grade accurately at the chain-speeds normally encountered in a commercial packing plant.

Conclusion

Numerous studies have validated the ability of the USDA Yield Grade equation to predict differences in beef carcass cutability. When properly applied, USDA Yield Grades remain the gold standard for prediction of beef carcass cutability and the standard to which all other methods, systems and technologies are compared. Problems, though, arise when graders are expected to apply yield grades to carcasses in 10 to 12 seconds and accuracy of grade placement is such that the usefulness of yield grades for determining carcass value is greatly diminished. There are other technologies that can accurately evaluate carcasses for differences in cutability, but only VIA appears to possess the combination of accuracy, speed, and ease of application necessary for adoption by the industry. In fact, there is a commercially available VIA system that was specifically designed for evaluating beef carcass cutability under U.S. industry conditions).

CHAPTER III

Dual-Component Video Image Analysis System (VIASCAN^{TM}) as a Predictor of Beef Carcass Red Meat Yield Percentage and for Augmenting Application of USDA Yield Grades

Introduction

Accurate assessment of cutability differences is necessary to identify value differences among carcasses; and, with accurate value determination, value-based marketing systems can function properly. With accurate value assessments on a carcass-by-carcass basis, the industry practice of trading cattle on averages can be eliminated which, according to Cross and Whittaker (1992), is a major impediment to value-based marketing.

Belk et al. (1998) found that online grader yield grades were substantially less accurate than yield grades applied by experts working without time or access constraint. The yield grade factor of greatest concern was ribeye area, which when applied online was only nominally related ($r = .48$) to measured ribeye area (Belk et al.

1998). It was proposed by Belk et al. (1998) that providing a machine (VIA) measure of ribeye area and performing the yield grade calculations could improve online accuracy of yield grade assignment.

The objectives of this study were to evaluate the ability of the VIASCAN^{TM} system to: (1) predict differences in fabricated yields in beef carcasses, and (2) augment the application of USDA Yield Grades to beef carcasses.

Experimental Procedure

This study determined the accuracy of the Australian Dual-Component VIASCAN^{TM} System both singularly, and in combination with USDA Yield Grade factors, for predicting beef carcass cutting yields. Cutting yields were determined using three sets of fat-trim specifications: (1) commodity-trimmed (external fat thickness not to exceed 2.54 cm); (2) closely trimmed (external fat thickness not to exceed .64 cm); and (3) very closely trimmed (some cuts with external fat thickness not exceeding .64 cm and other cuts completely denuded, with no remaining subcutaneous fat).

Steer/heifer carcasses (N=240) were selected according to a stratification plan that called for six final USDA Yield Grade groupings (YG1, YG2A, YG2B, YG3A, YG3B, YG4-5), two sex classes (steer and heifer), and two carcass-weight groups (249 to 339 kg, 340 to 430 kg). The population of sides tested, arrayed by sex class, carcass weight class, and yield grade is outlined in Table 3.1.

In the Australian Dual-Component VIASCAN^{TM} System, one video camera (Hot Assessment System; <u>HAS</u>) obtains an image of the outside surface fatness and contour of beef sides as

Table 3.1. Numbers of carcass sides tested, arrayed by sex class, carcass weight class and yield grade (YG).

	Steers		Heifers		
YG[a]	Light[b]	Heavy[c]	Light[b]	Heavy[c]	Overall population
1	10	10	9	10	39
2A	11	10	9	10	40
2B	10	10	11	10	41
3A	10	10	10	10	40
3B	10	10	10	10	40
4-5	10	10	10	10	40
	61	60	59	60	240

[a] YG, 1=yield grade 1.00 to 1.99, 2A=yield grade 2.00 to 2.49, 2B=yield grade 2.50 to 2.99, 3A=yield grade 3.00 to 3.49, 3B=yield grade 3.50 to 3.99, 4-5=yield grade 4.00 to 5.99. Based on USDA Yield Grades, applied at leisure by expert graders.

[b] Light = hot carcass weight less than or equal to 339 kg.

[c] Heavy = hot carcass weight greater than or equal to 340 kg.

they pass by on the rail, and a second video camera (Chiller Assessment System; CAS) records an image of the exposed 12th/13th rib interface. Computer analyses of HAS readings resulted in calculations of total carcass dimension, "butt shape," and carcass fat distribution; computer analyses of the CAS readings resulted in calculations of fat thickness (3/4 measure) and ribeye area. From those calculations, predictions were made of Wholesale Yield (WY)--in U.S. vernacular, expected cutability.

Together, the two VIA units (HAS and CAS) comprised the "Dual Scan VIA" or VIASCAN™ (Dual-Component VIA System). The VIASCAN™ System assessed characteristics of carcasses that could be visualized, transformed the readings into pixels, and analyzed the information using computer algorithms and equations that were developed by the Australian Meat Research Corporation (MRC).

USDA Yield Grades (to the nearest full yield grade) were assigned, as they are normally in no more than 12 s, by one of four online graders. In addition, and as an ideal (unlimited evaluation time), yield grades (to the nearest one-tenth yield grade) were assigned by three experts with no time or access constraints imposed. Carcasses were subjected to VIASCAN™ evaluation twice (HAS on the slaughter/dressing floor and CAS in the grading cooler following chilling for 36 h). Carcasses were then fabricated, sequentially, to obtain percentage yields of primal/subprimal cuts at each of the three specified fat-trim levels (commodity-trimmed, closely trimmed, very closely trimmed) by an in-plant, trained, experienced and supervised (by CSU personnel) cutting team.

For each of the 6 wk that this experiment was conducted, a number of carcasses (enough to ensure that a sufficient number of carcasses meeting the remaining design stratification plan criteria were available for selection) were scanned using the HAS on the harvesting floor before passing through the final washing cabinet.

Limited selection pressure was applied to the carcasses in terms of suitability for testing. Carcasses were deemed ineligible for testing if: (1) slaughter damage was extensive enough to prevent assignment of a USDA Yield Grade, (2) slaughter damage was extensive enough to prevent accurate attainment of fabrication specifications on the major subprimals, or (3) the carcass was identified for a specific brand-name program (presence of a blue ink stamp on the outside round was identified as a potential problem in HAS scanning because of the color and location of the stamp). All scanned carcasses were tagged to identify them as test carcasses and then allowed to enter the normal carcass chilling system (36 h).

On Mondays of each testing week, carcasses that had been scanned on the harvesting floor (using HAS) during the preceding week entered the grading cooler for subsequent evaluation by USDA online graders and by use of the CAS. One of four online graders, full-time employees of the USDA Meat Grading Branch of the Agricultural Marketing Service, Program in Livestock and Seed, independently assigned a USDA Yield Grade (to the nearest full yield grade) to each carcass during the regular period of time (no more than 12 sec.) that a carcass moves by the grading station at regular chain-speeds.

Following evaluation, carcasses were railed onto a static holding rail and CAS data were collected at the standard (in the U.S.) 12th-13th rib interface. Each carcass also was evaluated by three of four yield-grading experts (three experts were supervisory or administrative personnel of AMS-USDA, one was a University scientist) who assigned USDA Yield Grades (to the nearest one-tenth yield grade) using grids, probes, rulers, etc., in whatever period of time was necessary to accomplish the task as accurately as possible.

Sides were then transferred to a testing area for sequential fabrication to the three cutability end-points (commodity-trimmed, closely trimmed, very closely trimmed). Carcasses were assigned to cells in the 2 X 2 X 6 factorial design (Table 3.1) based on hot carcass weight and the final yield grade assigned by the "expert grading panel". Sides were then fabricated to generate primal/subprimal cuts that were trimmed sequentially to each of the three levels of remaining external fatness.

First, kidney, pelvic, and heart fat was removed (as much as could be removed without affecting individual cut specifications). Each primal/subprimal cut was then manufactured to the commodity-trimmed fat specification, then to the closely trimmed fat specification and finally to the very closely trimmed fat specification; sequential weights (all parts remaining and removed) were retained and weighed at each stage of the fabrication process. The fabrication yields for each cut were calculated as a percentage of the intact side weight from which they were produced and as a percentage of that side weight with the kidney, pelvic, and heart fat removed.

All fabrication, cutting, manufacturing, and trimming steps were performed by a crew of in-plant, journeymen meat-cutters. Cut specifications were defined according to

NAMP numbered specifications and purchaser specification option (PSO) numbers (NAMP, 1997). All recording of weights and other data was performed by students and staff personnel of Colorado State University. Approximately 12 to 14 sides were fabricated and manufactured into cuts on Tuesday, Wednesday, and Thursday of each testing week (for a total of approximately 40 sides per week) for the six-week duration of in-plant testing.

Cuts included in the final commodity-trimmed end-point were: 2-piece boneless chuck (NAMP 115); 107 rib (NAMP 107); bone-in short rib (NAMP 123B); striploin (NAMP 180); top sirloin butt (NAMP 184); peeled tenderloin (NAMP 189A); inside round (NAMP 168); gooseneck round (NAMP 170); and, knuckle (NAMP 167). Cuts included in the final closely trimmed end-point were: chuck roll (NAMP 116A); clod (NAMP 114, .64 cm fat trim); chuck tender (NAMP 116B); 5.08 cm. lip-on ribeye (NAMP 112A); bone-in short rib (NAMP 123B); striploin (NAMP 180, PSO 3, .64 cm fat trim); top sirloin butt (NAMP 184, .64 cm fat trim); peeled tenderloin (NAMP 189A); inside round (NAMP 168, .64 cm fat trim); heel-out gooseneck (NAMP 170A, .64 cm fat trim); and, peeled knuckle (NAMP 167A). Cuts included in the very closely trimmed end-point were: neck-off chuck-eye roll (NAMP 116A, PSO 1); extra-trim (XT) clod (NAMP 114C, .64 cm fat trim, infraspinatus separated and trimmed but included); chuck tender (NAMP 116B); ribeye roll (NAMP 112); boneless short-rib (NAMP 123D); striploin (NAMP 180, PSO 2, backstrap removed, .64 cm fat trim); XT top sirloin butt (NAMP 184B); peeled tender (NAMP 189A); denuded inside round (NAMP 169A, denuded fat trim); bottom round flat (NAMP 171B, .64 cm fat trim); bottom round eye (NAMP 171C, .64 cm fat trim); and, peeled knuckle (NAMP 167A).

All statistical analyses including elementary statistics, probability calculations, correlation and regression analyses were performed using SAS (1988). Carcasses were selected for evaluation using a 6 by 2 by 2 factorial design in an attempt to assure that a full range of carcass cutability differences was evaluated. Although a factorial design was used for carcass selection, the factorial design was not used for statistical analysis.

Multiple regression was used to regress the dependent variables of cutability percentages at the three trim endpoints on the independent variables of VIA measures, yield grades and yield grade factors. Regression equations for the prediction of cutability percentages were derived using forward stepwise selection with the minimum Mallow's CP criteria. Additional modifications assured that the beta values for all independent variables were significant

$(P < .05)$. Estimated cutability classifications were compared to actual classifications in a 3 by 3 table, from which probabilities of misclassification were estimated. Within each fabrication endpoint, mean yield percentages were compared by predicted yield class using Tukey's HSD procedure (.05).

Results and Discussion

The original factorial design called for 10 sides within each of the multiple factor levels, but two substitutions were made. To the extent possible, sides were selected within each sex, weight and yield grade subclass to reflect different amounts of muscling (thick, intermediate, thin) in order to ensure that variation in fabricated yields was not due to differences in fatness alone, and in order to ensure that the VIASCAN^{TM} instruments would be challenged relative to their applicability across the range in carcass composition encountered in U.S. beef fabrication facilities.

Means and standard deviations for hot carcass weight, ribeye area, actual and adjusted fat thickness, percentage kidney-pelvic-heart (KPH) fat and final yield grade (as applied by expert graders) are presented in Table 3.2. Mean carcass characteristics conformed closely to those reported in the National Beef Quality Audit (Smith et al., 1995); as a result, findings of this study should be applicable across a wide range of U.S. steer/heifer packing and fabrication facilities.

The mean expert grader estimate (Table 3.2) for percentage of kidney, pelvic and heart fat (percent KPH

Table 3.2. Simple correlation coefficients; expert grader and actual yield grade factors, final yield grade and VIASCAN™ system measures vs. actual fabrication yields to three fat-trim end-points calculated as percentages of intact side weight.

			r-values at three cutout yield end-points[a]		
Carcass measurement or VIASCAN™ factor[b]	Mean	SD	Commodity -trimmed	Closely trimmed	Very closely trimmed
Hot carcass wt (kg)	336.1	32.9	NS	NS	NS
Ribeye area (cm^2)	85.2	11.6	.53	.59	.60
KPH fat (%)	2.39	.55	-.30	-.29	-.30
Actual fat thickness (cm)	1.12	.56	-.52	-.70	-.68
Adjusted fat thickness (cm)	1.42	.58	-.62	-.80	-.78
Yield grade	2.96	.99	-.72	-.86	-.86
CASFAT	12.24	7.56	-.45	-.59	-.57
CASMDFAT	15.78	6.30	-.54	-.70	-.69
CASREA	90.00	13.32	.56	.60	.61
CASWY	70.66	1.95	.68	.80	.82
HASWY	76.93	.89	.43	.57	.61

[a] Cutout yield end-point: Commodity-trimmed = subprimal cuts from the four major primals trimmed to 2.54 cm maximum fat depth; Closely trimmed = subprimal cuts from the four major primals trimmed to .64cm maximum fat depth; Very closely trimmed = subprimal cuts from the four major primals with trim ranging from .64 cm maximum fat depth to denuded.

[b] VIA factors: CASFAT = chiller assessment system ¾ measure fat depth; CASMDFAT = chiller assessment system median fat depth; CASREA = chiller assessment system ribeye area; CASWY = chiller assessment system estimated wholesale yield; HASWY = hot assessment system estimate wholesale yield.

NS = Correlation not different from zero ($P > .05$)

fat) was within .11 unit of 2.5%. That the average KPH fat estimate approximated a nominal value of 2.5% was not unexpected inasmuch as graders and grading officials accept that amount of KPH fat as being "normal" in the present population of fed steers/heifer carcasses.

Mean actual and adjusted fat thickness measurements of carcasses also are listed in Table 3.2. There were undoubtedly hide-pulls and dressing errors that caused the measured fat thickness to be a poor index of general carcass fatness, but of all of the expert grader factors and VIASCAN^{TM} measurements, adjusted fat thickness accounted for a higher proportion of the variance in fabricated yields at all three fat-trim levels tested (39, 64, and 62% for commodity-trimmed, closely trimmed, and very closely trimmed end-points, respectively, derived by squaring appropriate correlation coefficients in Table 3.2) than any other single variable (Table 3.2). Abraham et al. (1968) studied cutability data from 835 steer carcasses and found that fat thickness was the most important variable in multiple regression equations predicting percentages of boneless steak and roast meat; and average fat thickness measurements (taken at the ¼, ½ and ¾ measures of the longitudinal axis of the ribeye muscle and then averaged) resulted in higher coefficients of multiple determination (when used in multiple regression equations) for cutability end-points than did a single ¾ (of the longitudinal axis of the ribeye muscle) fat thickness measurement.

In this study, CAS-predicted wholesale yield (CAS-WY) and expert assigned yield grade achieved higher levels of predictive accuracy than did adjusted fat thickness; however, both CAS-WY and expert yield grade are compound variables themselves, resulting from computations based on multiple variables, including measures of fatness (Table 3.2). Additionally, adjusted fat thickness accounted for 12, 15, and 15% more of the variation in fabrication yields (commodity-trimmed, closely trimmed, and very closely trimmed end-points, respectively) than did actual fat thickness (Table 3.2). The improvement in ability (of adjusted fat thickness over actual fat thickness) to predict fabricated yields clearly showed the merit of using adjusted fat thickness when determining USDA Yield Grades (Table 3.2). Murphey et al. (1983) studied the application of yield grading factors to beef carcass sides that had been trimmed to remove different amounts of external fat from different locations on the side, compared with their mate sides that had not been trimmed. Murphey et al. (1983) found that three of eight human evaluators had essentially the same repeatability in evaluating adjusted fat thickness on trimmed and untrimmed sides and concluded that with additional experience, evaluators could become nearly equally proficient in evaluating the preliminary yield grade of carcasses with different amounts of fat missing from different locations vs. carcasses with intact external fat coverings.

Inasmuch as relative surface area of the ribeye (longissimus muscle) is used as an indicator of the amount of muscling in a carcass ("relative" means, when placed in "size register"; that is, when ribeye area is expressed per unit of carcass weight), mean values for ribeye area in this study were very close to "typical" (based on the standard used for making adjustments for ribeye area and carcass weight in the USDA Yield Grade equation--the standard ribeye size for a carcass of given weight = 24.52+.171*hot carcass wt)--although the standard deviations were substantially larger than what would be expected based on the range in carcass weight (Table 3.2). This comparatively large standard deviation was due to the intentional selection of individual carcasses with thick, intermediate or thin, visual muscling scores within each selection subclass. Ribeye area was significantly correlated with fabrication yields (Table 3.2) at all three fat-trim levels (coefficients of .53, .59, and .60 for commodity-trimmed, closely trimmed, and very closely trimmed, respectively). Abraham et al. (1968) also found that ribeye area was significantly related to yields of boneless steak and roast meat. CAS ribeye area was slightly more highly correlated (Table 3.2) than expert ribeye area (measured with a grid) with fabrication yields at all three fat-trim levels (coefficients of .56, .60, and .61 for commodity-trimmed, closely trimmed, and very closely trimmed, respectively).

Of VIASCAN™ measures, CAS estimates (Table 3.3) of: (1) median fat depth ($r = .82$) and wholesale yield ($r = -.84$) were most closely correlated with actual (by expert graders) fat thickness estimates; (2) median fat depth ($r = .84$) and wholesale yield ($r = -.85$) were most closely correlated with adjusted fat thickness estimates; (3) ribeye area was very highly correlated ($r = .94$) with actual ribeye area measurements; (4) other carcass traits were not correlated with KPH fat percentage estimates; and (5) wholesale yields ($r = -.89$) were highly correlated with final yield grades assigned by expert graders. HAS estimates accounted for 34% or less of the observed variability in factors assigned by expert graders, with the best of such estimates, wholesale yield, being correlated reasonably well ($r = -.58$) with final yield grades assigned

Table 3.3. Simple correlation coefficients; VIASCAN™ system measures vs. expert grader factors.

	Expert grader factors				
ViaScan™ factor[a]	Actual fat thickness	Adjusted fat thickness	Ribeye area	Percentage KPH fat	Final yield grade
CASFAT	.79	.71	-.43	.08	.67
CASMDFAT	.82	.84	-.48	.13	.79
CASREA	-.45	-.49	.94	NS	-.71
CASWY	-.84	-.85	.69	-.18	-.89
HASLN	NS	NS	.31	NS	NS
HASWID	.16	.19	.26	NS	.14
HASWY	-.41	-.51	.47	NS	-.58

[a] VIA factors: CASFAT = Chiller assessment system ¼ fat depth; CASMDFAT = Chiller assessment system median fat depth; CASREA = Chiller assessment system ribeye area; CASWY = Chiller assessment system estimated wholesale yield; HASLN = Hot assessment system carcass length; HASWID = Hot assessment system carcass width; HASWY = Hot assessment system estimate wholesale yield.

NS = Correlation not different from zero (P > .05)

by expert graders (Table 3.3). Results of correlation analyses of relationships between CAS and HAS estimates, and estimates made by expert graders, were high enough to greatly encourage further study and future refinements of Dual-Component VIASCAN^{TM} assessments for replacing and/or augmenting assignment of yield grades by human evaluators.

Online graders, making assignments to the nearest full yield grade, were able to explain 37, 54, and 54% of the observed variability in cutout yields from carcass sides fabricated to commodity-trimmed, closely trimmed and very closely trimmed product end-points, respectively (Table 3.4). George et al. (1996), using data from 265 steer/heifer carcasses, compared instrument estimates with estimates by online and expert graders for predicting percentages of boxed beef at .64 cm fat trim, and reported that expert graders more accurately predicted yield than did online graders ($r = -.89$ vs. $-.77$). These researchers concluded that the current USDA Yield Grade system is, in fact, an accurate and effective means of predicting carcass yields, and that the inaccuracies in assignment of USDA Yield Grades to individual carcasses arise from the demands placed on USDA online graders to assign yield grades at extremely high chain-speeds (George et al., 1996).

Table 3.4. Simple correlation coefficients; expert yield grade calculated to tenth, whole, and half grades and online grader yield grade vs. actual fabrication yields to three fat-trim end-points calculated as percentages of intact side weight.

	Cutout yield end-point[a]		
Yield grade (YG) measure	Commodity-trimmed	Closely trimmed	Very closely trimmed
Expert YG tenth[b]	-.72	-.86	-.86
Expert YG whole[c]	-.69	-.81	-.81
Expert YG half[d]	-.71	-.85	-.85
Online grader YG[e]	-.61	-.74	-.73

[a] Cutout yield end-point: Commodity-trimmed = Subprimal cuts from the four major primals trimmed primarily to 2.54 cm maximum fat depth; Closely trimmed = Subprimal cuts from the four major primals trimmed primarily to .64 cm maximum fat depth; Very closely trimmed = Subprimal cuts from the four major primals with trim ranging from .64 cm maximum fat depth to denuded.

[b] Expert YG tenth, yield grade calculated to the tenth of the grade.

[c] Expert YG whole, yield grade calculated to the tenth of the grade, then converted to whole grade (<2.0=1, 2.0 to 2.9=2, 3.0 to 3.9=3, 4.0 to 4.9=4, >4.9=5).

[d] Expert YG half, yield grade calculated to the tenth of the grade, then converted to half grade (<1.5=1.0, 1.5 to 1.9=1.5, 2.0 to 2.4=2.0, 2.5 to 2.9=2.5, etc.).

[e] Online grader YG, yield grade as applied by online USDA graders in whole grades.

NS = Correlation not different from zero (P > .05)

In the present study (Table 3.4), compared with yield grades assigned by online USDA graders, increases in ability to account for variation in commodity-trimmed, closely trimmed and very closely trimmed cutout yields, respectively, of: (1) 11, 12, and 12% were observed when expert graders assigned yield grades to the nearest whole grade, (2) 13, 17, and 18% were observed when expert graders assigned yield grades to the nearest half grade, and (3) 14, 20, and 19% were observed when expert graders assigned yield grades to the nearest tenth grade. There is no doubt that the finer the precision with which yield grade is assigned, the greater is the ability of the yield grade to explain the observed variability in cutout yields; the advantage, though, of assigning yield grades to the nearest tenth of a grade as compared to assignments to the nearest half of a grade was only 1 to 3% in predictive accuracy.

A number of regression models utilizing VIASCAN^{TM} measures, expert-grader yield grade factors, expert-grader yield grade, online grader yield grade, and combinations of machine-assessed and grader-applied factors were tested (Table 3.5) to determine the ability of the VIASCAN^{TM} System to replace and/or augment application of yield grades to predict fabrication yields from intact (KPH fat in) sides.

Table 3.5. Results from simple and multiple regression models predicting actual fabrication yields to three fat-trim end-points calculated as percentages of intact side weight.

	Cutout yield end-point[a]					
	Commodity-trimmed		Closely trimmed		Very closely trimmed	
Terms in model[b]	R^2	RSD	R^2	RSD	R^2	RSD
HASWY	.19	1.53	.32	1.83	.38	1.69
CASWY	.46	1.25	.64	1.34	.68	1.21
CASREA CASMEDFAT	.40	1.32	.57	1.44	.57	1.39
HCWT CASREA CASMEDFAT	.46	1.25	.64	1.32	.64	1.27
CASWY HASWY	.46	1.25	.66	1.31	.71	1.16
CASREA HASLN HASWID CASMEDFAT	.44	1.27	.60	1.41	.59	1.38
HCWT CASREA HASLN CASMEDFAT	.46	1.25	.64	1.33	.64	1.28
EXPYG	.51	1.19	.74	1.13	.74	1.09
HCWT REA EXPKPH ADJFAT	.53	1.18	.75	1.12	.75	1.08
HCWT REA ADJFAT	.49	1.22	.72	1.19	.71	1.15
LINEYG	.37	1.44	.54	1.64	.54	1.51
HCWT CASREA EXPKPH ADJFAT	.55	1.15	.75	1.11	.75	1.08

[a] Cutout yield end-point: Commodity-trimmed = Subprimal cuts from the four major primals trimmed primarily to 2.54 cm maximum fat depth; Closely trimmed = Subprimal cuts from the four major primals trimmed primarily to .64 cm maximum fat depth; Very closely trimmed = Subprimal cuts from the four major primals with trim ranging from .64 cm maximum fat depth to denuded.

[b] Terms in model: CASMDFAT = Chiller Assessment System median fat depth; CASREA = Chiller Assessment System ribeye area; CASWY = Chiller Assessment System estimated wholesale yield; HASLN = Hot Assessment System carcass length; HASWID = Hot Assessment System carcass width; HASWY = Hot Assessment System estimate wholesale yield; HCWT = Hot carcass weight; REA = Ribeye area; EXPKPH = Expert grader estimate of kidney, pelvic, heart fat percentage; ADJFAT = Expert grader adjusted fat depth; EXPYG = Expert grader final yield grade to tenth of the grade; LINEYG = Online grader yield grade to whole grade.

Abraham et al. (1968) analyzed data from 835 steer carcasses and reported that equations containing the same variables that are included in the USDA Yield Grade equation (carcass weight, ribeye area, kidney, pelvic, and heart fat, and fat thickness) resulted in the highest coefficients of multiple determination (R^2) for estimating percentage of boneless steak and roast meat.

In the present study, expert-grader assigned yield grade alone accounted for 51, 74, and 74% of the variation in fabrication yields for commodity-trimmed, closely trimmed and very closely trimmed end-points, respectively (Table 3.5). George et al. (1996) found that estimates by expert yield graders, assigning yield grades to the nearest .1 yield grade, accounted for 79% of the variability in .64 cm external fat-trim, boxed beef yields, from 265 steer and heifer carcasses. Unfortunately, in present practice, assignment of the "factors" of adjusted fat thickness, ribeye area, kidney, pelvic, and heart fat percentage, and therefore final yield grade, is imprecisely accomplished because of the time-pressures under which USDA graders do their job. In a study of yield grade application accuracy by Cross et al. (1984), a three-member grading panel evaluated 5,582 beef carcasses at 56 plants and found the national percentage error for assignment of yield grades (to the nearest whole yield grade) to be 11.6; in other words, 1 of every 8.6 carcasses that was yield graded had the wrong yield grade number assigned to it.

If beef carcasses are traveling past the grading stand at the rate of 350 carcasses per hour, the USDA grader has a little over 10 seconds in which to: (1) evaluate maturity and marbling to assign a quality grade, (2) evaluate subcutaneous fat thickness, general fatness over the entirety of the carcass surface, ribeye area, hot carcass weight, and kidney, pelvic, and heart fat percentage to assign a yield grade, (3) make the calculations, and (4) stamp both grades on the hindquarter. Augmentation (providing estimates of some of these factors to the grader) should allow the grader to make more studied estimations of those factors that cannot be measured by use of VIA technology (for example, the adjusted preliminary yield grade).

Ferguson et al. (1995) reported the findings of several beef carcass cutting-yield tests designed to determine the accuracy of the HAS and CAS to predict saleable beef yield, and found that R^2 values for the combination of assessments by the CAS and HAS, for prediction of saleable beef yield percentage, ranged from .72 to .76. Jones et al. (1995) reported findings from 436 beef carcasses and 57 dairy carcasses that were graded and assessed using Australian VIA; the CAS explained 55% of the variation in cutting yield (sum of cut weights expressed as a percentage of side weight).

In the present study, the best single-component machine prediction was achieved using CAS-WY which accounted for 46, 64, and 68% of the variation in fabrication yields for commodity-trimmed, closely trimmed and very closely trimmed end-points, respectively (Table 3.5). This is much higher than the levels of prediction (achieved by another VIA system) reported by George et al. (1996); in that study, the best VIA measure accounted for 37% of the variability among carcasses in .64 cm.-trim boxed beef yields.

The best dual-component machine prediction (Table 3.5) used both CAS-WY and HAS-WY and achieved yield predictions of 46, 66, and 71% for commodity-trimmed, closely trimmed and very closely trimmed end-points, respectively. This agrees closely with results of Jones et al. (1995) who found that estimates by the HAS combined with those from the CAS explained 68% of the variation in cutting yield. In the present study, online grader applied yield grade accounted for 37, 54, and 54% of the differences in yield for commodity-trimmed, closely trimmed and very closely trimmed end-points, respectively (Table 3.5). These percentages were slightly lower than those reported by George et al. (1996) who found that online grader estimates, assigning yield grades to the nearest .1 yield grade, accounted for 59% of the variability among carcasses in .64 cm.-trim boxed beef yields; but the difference in predictive accuracies occurred, in part, because yield grades were applied to the nearest full yield grade by online graders in the present study. By combining expert grader yield grade factors of adjusted fat thickness, and KPH fat percentage with CAS estimated ribeye area and hot carcass weight (which could be provided electronically in an augmentation system) in an augmentation model, 55, 75, and 75% of yield variation for commodity-trimmed, closely trimmed and very closely trimmed end-points, respectively, was explained (Table 3.5).

Regression models utilizing machine (Dual-Component VIA System) measures, expert-grader factors, and combinations of machine-assessed and grader-applied factors were tested (Table 3.6) to determine the ability of the VIASCAN™ System to replace and/or augment and to improve the application of yield grades to predict fabrication yields from carcass sides from which their kidney, pelvic, and heart fat deposits had been removed before weighing and

Table 3.6. Results from simple and multiple regression models predicting actual fabrication yields to three fat-trim end-points calculated as percentages of side weight with KPH fat removed.

	Cutout yield end-point[a]					
	Commodity-trimmed		Closely trimmed		Very closely trimmed	
Terms in model[b]	R^2	RSD	R^2	RSD	R^2	RSD
HASWY	.24	1.42	.36	1.78	.41	1.64
CASWY	.46	1.19	.63	1.34	.67	1.22
CASREA CASMEDFAT	.42	1.22	.58	1.41	.58	1.37
HCWT CASREA CASMEDFAT	.49	1.14	.66	1.28	.65	1.25
CASWY HASWY	.47	1.18	.66	1.29	.72	1.14
CASREA HASLN HASWID CASMEDFAT	.48	1.17	.62	1.37	.60	1.35
HCWT CASREA HASLN CASMEDFAT	.49	1.15	.65	1.30	.66	1.26
HCWT REA ADJFAT	.53	1.11	.74	1.12	.73	1.10
HCWT CASREA ADJFAT	.54	1.09	.74	1.12	.72	1.12

[a] Cutout yield end-point: Commodity-trimmed = Subprimal cuts from the four major primals trimmed primarily to 2.54 cm maximum fat depth; Closely trimmed = Subprimal cuts from the four major primals trimmed primarily to .64 cm maximum fat depth; Very closely trimmed = Subprimal cuts from the four major primals with trim ranging from .64 cm maximum fat depth to denuded.

[b] Terms in model: CASMDFAT = Chiller Assessment System median fat depth; CASREA = Chiller Assessment System ribeye area; CASWY = Chiller Assessment System estimated wholesale yield; HASLN = Hot Assessment System carcass length; HASWID = Hot Assessment System carcass width; HASWY = Hot Assessment System estimate wholesale yield; HCWT = Hot carcass weight; REA = Ribeye area; ADJFAT = Expert grader adjusted fat depth.

subsequent fabrication. Equations (Table 3.6) combining hot carcass weight, ribeye area, and adjusted fat thickness estimates by expert graders explained 53, 74 and 73% of the observed variation in cutout yields of commodity-trimmed, closely trimmed and very closely trimmed products, respectively; those equations explained 6, 8, and 1% more of the variation in yields of commodity-trimmed, closely trimmed and very closely trimmed products, respectively, than did the best combination of machine readings (CAS-WY plus HAS-WY). Combinations of expert grader adjusted fat thickness with CAS estimated ribeye area and hot carcass weight resulted in an augmentation model (Table 3.6) that accounted for 54, 74 and 72% of the variation in yields of commodity-trimmed, closely trimmed and very closely trimmed products, respectively. This level of prediction accuracy, achieved for carcasses with the KPH fat removed, compared favorably to the predictive accuracy of expert yield grades assigned to intact carcasses without any time or access constraints being imposed on the expert grading panel.

Assessments by use of HAS-WY alone, accounted for small percentages of the variation in yields at the commodity-trimmed, closely trimmed and very closely trimmed end-points (R^2 = .19, .32, and .38, respectively). These values were somewhat lower than those suggested by the findings of Jones et al. (1995), who found that the Whole Carcass VIA System explained 42% of the variation in carcass yields, and the findings of Ferguson et al. (1995) who reported that R^2 values for the Whole Carcass VIASCAN^{TM} for prediction of saleable beef yield percentage ranged from .39 to .69. Compared to use of hot carcass weight and the P8 fat depth, the HAS system was advantageous for predicting saleable beef yield percentage, with the only exception to this trend being the Japanese grain-fed carcasses, which by virtue of their long finishing period on a grain ration, were heavy and excessively fat compared to carcasses in other market categories (Ferguson et al., 1995).

It is possible that the reliance of the HAS on color to assess fat coverage makes that system less useful for predicting cutability of overfat carcasses (Ferguson et al., 1995). Ferguson et al. (1995) found that the cutability of carcasses from cattle fed grain for long periods of time was less accurately estimated than was the cutability of carcasses from grass-fed or short-fed cattle and this may explain why cutability for U.S. carcasses (which are typically from more heavily finished cattle) were less accurately estimated by the HAS in the present study than were carcasses from less heavily finished cattle, like those in Australia.

One advantage of using the HAS is that it produced an estimation of carcass yields from the hot carcass; so, data were available before the carcasses were placed in coolers for chilling, 24 to 48 hr before fabrication. Although HAS-WY estimates accounted for relatively little variation in cutout yields, a simple classification of carcasses using this system could accurately segregate carcasses into high, intermediate and low yielding groups. The results of using HAS-WY to classify carcasses into three predicted-cutability or yield groups are provided in Table 3.7. Using data from the very closely trimmed end-point, mean yields for subprimal cuts from the four major primals were 39, 37, and 36%, respectively, for high, intermediate and low HAS yield classes, and all three mean percentages differed ($P < .05$).

More important than mean values, with regard to a sorting system, are values for error probability, or the probability of classifying a carcass into one yield class when, in fact, it belongs in another. Table 3.7 includes error probabilities calculated two ways. First was the probability of misclassifying a carcass by greater than one half of one yield class. For example, this would be

Table 3.7. Carcass classification scheme based on wholesale yield predicted by the Hot Assessment System (HAS).

				Probability of misclassification	
HAS yield class	Fabrication end-point	Mean yield, %	SD of yield, %	greater than ½ class	greater than 1 class
High	Commodity	57.1^a	1.4	.14	<.001
Intermediate	Commodity	55.5^b	1.6	.49	
Low	Commodity	54.8^c	1.5	.30	.005
High	Closely trimmed	45.4^a	1.9	.10	<.001
Intermediate	Closely trimmed	42.8^b	2.0	.42	
Low	Closely trimmed	41.9^c	1.9	.28	.005
High	Very closely trimmed	39.3^a	1.8	.08	<.001
Intermediate	Very closely trimmed	36.6^b	1.8	.38	
Low	Very closely trimmed	35.7^c	1.7	.26	.004

[a,b,c] Means in same column and section with different superscripts are different ($P < .05$)

equivalent to classifying a carcass as "high yield" when, in fact, it would yield less than the average of the "intermediate" yield class. The probabilities for misclassification errors at the very closely trimmed end-point were 8% for the "high yield" class, 26% for the "low yield" class and 38% for the "intermediate" class (Table 3.7). The error rate for the "intermediate" class was higher because it was a 2-sided probability as opposed to being one-sided (as in the "high yield" and "low yield" classes). The second error probability computed was for misclassifying a carcass by more than one full yield class, such as classifying a carcass "high yield" when in fact it should have been classified as "low yield". These probabilities for the very closely trimmed end-point were <.1% for the "high yield" class and .4% for the "low yield" class (Table 3.7). No value was available for the "intermediate" class, as it was impossible in a 3-class system to miss from the middle class by more than one yield class. In this classification system, the probability of classifying a carcass as either "high yield" or "low yield" when, in fact, it was the opposite was very low.

Error probabilities were similar for the commodity-trimmed and closely trimmed end-points (Tables 7 and 8), but some classification accuracy was lost in fabrication end-points, where more fat remained intact on the subprimal cuts (this loss of accuracy was evident in all predictions of yield, including those using CAS predictions and human grade data). A classification of beef carcasses using the CAS, included in Table 3.8, was more accurate than was the classification using HAS because of the additional data available for carcass yield prediction (fat thickness and ribeye area) when CAS was used for this purpose. However, at the point in time where CAS-WY was calculated, the other variables needed for the best prediction of cutability (online grader yield grade, CAS-WY, and HAS-WY) were already available, so little would be gained by using CAS for sorting carcasses.

Table 3.8. Carcass classification scheme based on wholesale yield predicted by the Chiller Assessment System (CAS).

				Probability of misclassification	
CAS yield class	Fabrication end-point	Mean yield, %	SD of yield, %	greater than ½ class	greater than 1 class
High	Commodity	57.5^{a}	1.5	.10	.001
Intermediate	Commodity	55.6^{b}	1.3	.17	
Low	Commodity	53.9^{c}	1.5	.13	.002
High	Closely trimmed	46.0^{a}	1.8	.05	<.001
Intermediate	Closely trimmed	43.0^{b}	1.6	.09	
Low	Closely trimmed	40.5^{c}	1.5	.05	<.001
High	Very closely trimmed	40.0^{a}	1.7	.03	<.001
Intermediate	Very closely trimmed	36.7^{b}	1.5	.09	
Low	Very closely trimmed	34.5^{c}	1.2	.03	<.001

^{a,b,c}Means in same column and section with different superscripts are different ($P < .05$)

Implications

Prediction models utilizing VIASCAN™ estimates (either alone or combined with some human grader estimates) more accurately predicted carcass cutout yields than did yield grades assigned by online graders. Based on these data: (1) Regression equations to predict fabrication yields using VIASCAN™ assessments produced R^2 values higher than those of yield grades assigned by online graders and approaching those of yield grades assigned by expert graders. (2) An augmentation system combining yield grade factors assigned by expert graders with CAS ribeye area produced R^2 values matching those of yield estimates made by expert graders. (3) VIASCAN™ assessments and/or yield grade factors assigned by online graders could be applied at chain-speeds, allowing for higher yield prediction R^2 values than those achieved by online yield grade alone. 4) Sorting of carcasses, prior to chilling, into yield classes using HAS, could provide useful information, regarding product inventories, to plant personnel.

CHAPTER IV

Online Evaluation of a Commercial Video Image Analysis System (Canadian Computer Vision System™) as a Predictor of Beef Carcass Red Meat Yield Percentage and for Augmenting Application of USDA Yield Grades

Introduction

As the U.S. beef industry moves towards a value-based marketing system, the need for instrument grading systems that can assist in the accurate determination of beef carcass value differences, has become acute.

Cannell (Chapter III of this dissertation) found that a dual-component video image analysis system could assess carcass cutability differences and could successfully augment the application of USDA Yield Grades at packing plant chain-speeds. The objectives of this part of the dissertation were to evaluate the ability of the CVS™ (Canadian Computer Vision System) to: (1) predict differences in fabricated yields of beef carcasses, and (2) augment the application of USDA Yield Grades to beef carcasses, not only at chain-speeds, but also as a fully installed commercial system evaluated online in a commercial beef packing plant.

Experimental Procedure

This study determined the accuracy of the CVS™ both singularly, and in combination with USDA Yield Grade factors, for predicting beef carcass cutting yields. Cutting yields were determined using closely trimmed wholesale subprimal specifications with external fat thickness not to exceed .64 cm.

Steer/heifer carcasses (N=296) were selected according to a stratification plan that called for six final USDA Yield Grade groupings (YG1, YG2A, YG2B, YG3A, YG3B, YG4-5), two sex classes (steer and heifer), and two carcass-weight groups (249 to 339 kg, 340 to 430 kg). The population of sides tested, arrayed by sex class, carcass weight class, and yield grade is outlined in Table 4.1.

In the Dual-Component CVS™ System, one video camera (Hot Camera) obtains an image of the outside surface fatness and contour of unribbed beef sides as they pass by on the rail, and a second video camera (Cold Camera) records an image of the exposed 12th/13th rib interface. Computer analyses of Hot Camera readings provide for calculations of total carcass dimension, carcass shape, and carcass fat distribution; computer analyses of the Cold Camera readings make possible calculations of fat thickness

Table 4.1. Numbers of carcass sides tested, arrayed by sex class, carcass weight class and yield grade (YG).

	Steers		Heifers		
YG[a]	Light[b]	Heavy[c]	Light[b]	Heavy[c]	Overall population
1	17	4	5	14	40
2A	16	11	7	13	47
2B	19	12	8	21	60
3A	15	7	9	14	45
3B	10	13	12	9	44
4-5	26	8	10	16	60
	103	55	51	87	296

[a] YG, 1=yield grade 1.00 to 1.99, 2A=yield grade 2.00 to 2.49, 2B=yield grade 2.50 to 2.99, 3A=yield grade 3.00 to 3.49, 3B=yield grade 3.50 to 3.99, 4-5=yield grade 4.00 to 5.99. Based on USDA Yield Grades, applied at leisure by expert graders.

[b] Light = hot carcass weight less than or equal to 339 kg.

[c] Heavy = hot carcass weight greater than or equal to 340 kg.

(at the 1/4, 1/2, 3/4, 4/4 measures of the longitudinal axis of the ribeye muscle) and ribeye area. From those calculations, predictions were made of Wholesale Yield (WY) which in U.S. vernacular is expected cutability.

Together, the two VIA units (Hot Camera and Cold Camera) comprised the CVS™ (a dual-component VIA system). The CVS™ System assessed characteristics of carcasses that could be visualized, transformed the readings into pixels, and analyzed the information using computer algorithms and equations that were developed by Research Management Systems Inc.

USDA Yield Grades (to the nearest full yield grade) were assigned, as they are normally in no more than 12 s, by an online grader. In addition, and as an ideal (unlimited evaluation time), yield grades (to the nearest one-tenth yield grade) were assigned by three experts with no time or access constraints imposed. Carcasses were subjected to CVS™ evaluation twice (Hot Camera prior to the carcass being ribbed and Cold Camera on the grading chain following chilling for 36 h and ribbing). Carcasses were then fabricated, sequentially, to obtain percentage yields of primal/subprimal cuts as well as yields of waste fat and bone by an in-plant, trained, experienced and supervised (by CSU personnel) cutting team, working at fabrication chain-speeds. Fabrication testing was performed using the normal plant fabrication facilities and personnel, but instead of carcasses being run sequentially (approximately every 10 to 12 seconds, as is normal for full-speed plant production), the carcasses (one side of each carcass) were run sequentially approximately every 5 minutes (during a special shift) to allow for complete capture of data and weighing of all fabrication products from each test carcass side before the next carcass side entered production.

For each of the 3 wk that this experiment was conducted, carcasses were selected on the grading chain according to the stratification plan.

Limited selection pressure was applied to the carcasses in terms of suitability for testing. Carcasses were deemed ineligible for testing if: (1) slaughter damage was extensive enough to prevent assignment of a USDA Yield Grade, (2) slaughter damage was extensive enough to prevent accurate attainment of fabrication specifications on the major subprimals. Attempts were made to include carcasses with levels of dressing defects ranging from none or nearly none to substantial (not, however, so excessive as to interfere with regular grading processes and/or fabrication specifications) in order to best evaluate the performance of yield grades and CVS™ under normal plant conditions. After scanning, test carcasses were tagged, transferred to a holding cooler and fabricated on the following day.

Carcasses were evaluated with the Hot Camera on Fridays as the entered the grading cooler, and then evaluated by USDA online graders and by the Cold Camera at full line speed. One of three online USDA graders independently assigned a USDA Yield Grade (to the nearest full yield grade) to each carcass at normal grading speed (no more than 12 sec.).

Following evaluation by online graders and by the CVS™, carcasses were railed onto a static holding rail and each carcass was evaluated by three of four yield-grading experts (three experts were supervisory or administrative personnel of AMS-USDA and one was a University scientist) who assigned USDA Yield Grades (to the nearest one-tenth yield grade) using grids, probes, rulers, etc., in whatever period of time was necessary to accomplish the task. Carcasses were assigned to cells in the 2 X 2 X 6 design (Table 4.1) based on hot carcass weight and the final yield grade assigned by the expert grading panel.

On the day following evaluation, carcass sides were fabricated into wholesale subprimal cuts. The fabrication yield for each cut was calculated as a percentage of the intact side weight from which it was produced. All parts from each fabricated side were retained and weighed, including wholesale cuts, fat, bone, and trimmings to assure that the sum of all parts equaled 99% of the beginning side weight.

All fabrication, cutting, manufacturing, and trimming steps were performed by a crew of in-plant, journeymen meat-cutters. Cut specifications were defined according to NAMP numbered specifications and purchaser specification option (PSO) numbers (NAMP, 1997). All recording of weights and other data was performed by students and staff personnel of Oklahoma State University and Colorado State University. Approximately 80 to 120 sides were fabricated and manufactured into cuts on Saturday of each testing week for the three-week duration of in-plant testing.

Cuts included in the final closely trimmed end-point were: chuck roll (NAMP 116A); clod (NAMP 114, .64 cm fat trim); chuck tender (NAMP 116B); 5.08 cm. lip-on ribeye (NAMP 112A); bone-in short rib (NAMP 123B); striploin (NAMP 180, PSO 3, .64 cm fat trim); top sirloin butt (NAMP 184, .64 cm fat trim); peeled tenderloin (NAMP 189A); inside round (NAMP 168, .64 cm fat trim); heel-out gooseneck (NAMP 170A, .64 cm fat trim); and, peeled knuckle (NAMP 167A).

All statistical analyses including elementary statistics, correlation and regression analyses were performed using SAS (1988). Carcasses were selected for evaluation using a 6 by 2 by 2 factorial design in an attempt to assure that a full range of carcass cutability differences was evaluated. Although a factorial design was used for carcass selection, the factorial design was not used for statistical analysis.

Multiple regression was used to regress the dependent variables of cutability percentage on the independent variables of VIA measures, yield grades and yield grade factors. Regression equations for the prediction of cutability percentages were derived using forward stepwise selection with the minimum Mallow's CP criteria. Additional modifications assured that the beta values for all independent variables were significant ($P < .05$).

Results and Discussion

The original factorial design called for 12 sides within each of the multiple factor levels, but because of the availability and lack thereof of certain carcass types and the three week time-constraint, a number of substitutions were made. Although the original design called for a total of 288 carcass sides, additional sides were tested in order to evaluate as many as possible carcasses in the less populated cells. To the extent possible, sides were selected within each sex, weight and yield grade subclass to reflect different amounts of muscling (thick, intermediate, thin) in order to ensure that variation in fabricated yields was not due to differences in fatness alone, and in order to ensure that the CVS™ instruments would be challenged relative to their applicability across the range in carcass composition encountered in U.S. beef fabrication facilities.

Means and standard deviations for hot carcass weight, ribeye area, actual and adjusted fat thickness, percentage kidney-pelvic-heart fat (KPH) and final yield grade (as assigned by expert graders) are presented in Table 4.2. As with the sample carcasses in the study presented in the previous chapter, mean carcass characteristics conformed

Table 4.2. Simple correlation coefficients; expert grader and actual yield grade factors, final yield grade and CVS™ system measures vs. actual fabrication yields of wholesale cuts, fat trim and bone, calculated as percentages of intact side weight.

Carcass measurement or CVS™ factor[b]	Mean	SD	r-values to fabrication yields[a]		
			Wholesale cuts	Fat trim	Bone
Hot carcass wt (kg)	342.3	33.9	NS	NS	NS
Ribeye area (cm^2)	84.9	12.1	.63	-.52	NS
KPH fat (%)	2.52	.68	-.18	.22	-.38
Actual fat thickness (cm)	1.25	.59	-.65	.74	-.36
Adjusted fat thickness (cm)	1.45	.55	-.74	.87	-.46
Yield grade	3.09	.98	-.82	.82	-.27
CVS grade fat	13.49	6.11	-.65	.70	-.32
CVS mid fat	11.69	5.33	-.65	.71	-.33
CVS ribeye area	90.26	14.05	.65	-.58	NS
CVS cold system yield	71.66	2.15	.63	-.63	.19
CVS hot system yield	72.63	1.64	.12	-.23	.17

[a] Fabrication yields: Wholesale cuts = subprimal cuts from the four major primals trimmed to .64cm maximum fat depth; Fat trim = waste fat from the production of wholesale cuts; Bone = waste bone from the production of wholesale cuts.

[b] VIA factors: CVS grade fat = ¼ measure fat depth; CVS mid fat = ½ measure fat depth; CVS ribeye area = machine measured ribeye area; CVS cold system yield = machine estimated wholesale yield chilled and ribbed carcass; CVS hot system yield = machine estimated wholesale yield hot and intact carcass.

NS = Correlation not different from zero ($P > .05$)

closely to those reported in the National Beef Quality Audit (Smith et al., 1995); therefore, findings of this study should be applicable across a wide range of U.S. steer/heifer packing and fabrication facilities.

The mean expert grader estimate (Table 4.2) for percentage of kidney, pelvic and heart fat (percent KPH fat) was within .02 unit of 2.5%. As reported in the previous chapter, graders and grading officials accept 2.5% KPH fat as being normal in the U.S. population of fed steer/heifer carcasses.

Mean actual and adjusted fat thickness measurements of carcasses also are listed in Table 4.2. Of all of the expert grader factors and CVS™ measurements, adjusted fat thickness accounted for a higher proportion of the variance in fabricated yields (55%, derived by squaring appropriate correlation coefficients in Table 4.2) than any other single variable (Table 4.2). Although, by design, there were fat pulls and other dressing defects that could hinder its ability to predict fabrication yields, actual fat thickness accounted for as much or more of the variance in fabricated yields (42%) as any other single variable except adjusted fat thickness (Table 4.2). In a study to evaluate relationships among the independent variables in the USDA Yield Grade equation, Crouse et al. (1975) found fat thickness at the 12t^{h} rib to be the single most useful predictor of cutability (r = -.76). Murphey et al. (1960) reported that predictive accuracy of the regression equation utilizing fat thickness, percentage KPH fat, ribeye area, and hot carcass weight was improved by utilizing a subjective adjustment of fat thickness to account for differences in fat deposition across the entire carcass.

In this study, expert yield grade achieved higher levels of predictive accuracy than did adjusted fat thickness; however, expert yield grade is a compound variable, resulting from computations using several traits including measures of fatness (Table 4.2). Adjusted fat thickness accounted for 13% more of the variation in fabrication yields than did actual fat thickness (Table 4.2) verifying its use in determining USDA Yield Grades. Although the reason for subjective adjustment of the actual (measured) fat thickness is to account for irregularities in fat deposition on the carcass and for inconsistency of overall fatness with fatness over the ribeye, Murphey et al. (1983) found that experienced graders can accurately and repeatably adjust carcass fat thickness.

Inasmuch as relative surface area of the ribeye (longissimus muscle) is used as an indicator of the amount of muscling in a carcass (relative means, when placed in size register; that is, when ribeye area is expressed per unit of carcass weight), mean values for ribeye area in this study were very close to typical (based on the standard used for making adjustments for ribeye area and carcass weight in the USDA Yield Grade equation the standard ribeye size for a carcass of given weight = 24.52+.171*hot carcass wt) although the standard deviations were substantially larger than what would be expected based on the range in carcass weight (Table 4.2). This comparatively large standard deviation for ribeye area was due to the intentional selection of individual carcasses with thick, intermediate or thin visual muscling scores within each selection subclass. Ribeye area was significantly correlated (r = .63) with fabrication yields (Table 4.2). Abraham et al. (1968) also found that ribeye area was significantly related to yields of boneless steak and roast meat. Cold Camera ribeye area was slightly more highly correlated (Table 4.2) than expert ribeye area (measured with a grid) with fabrication yield (r = .65). Adjusted fat thickness was the most highly correlated of all single variables to percentage fat trim and to percentage bone (Table 4.2).

Of CVS^{TM} measures, Cold Camera estimates (Table 4.3) of: (1) midpoint fat depth (half measure; r = .93) and bottom fat depth (r = .93) were most closely correlated with actual (by expert graders) fat thickness measurements; (2) midpoint fat depth (r = .85), bottom fat depth (r = .85) and grade fat depth (three quarter measure; r = .85) were most closely correlated with adjusted fat thickness estimates; (3) ribeye area was very highly correlated (r = .93) with actual ribeye area measurements; (4) no CVS^{TM} carcass traits were correlated with KPH fat percentage estimates; and (5) wholesale yields (r = -.71) were highly correlated with final yield grades assigned by expert graders.

Hot Camera wholesale yield estimates accounted for 3.2% or less of the observed variability in factors assigned by expert graders (Table 4.3). Results of correlation analyses of relationships between Cold Camera estimates, and to a lesser degree, Hot Camera estimates, and estimates made by expert graders, were high enough to greatly encourage further study and future refinements of Dual-Component CVS^{TM} assessments for replacing and/or augmenting assignment of yield grades by human evaluators.

Online graders, assigning full yield grades explained 40% of the observed variability in cutout yields from

Table 4.3. Simple correlation coefficients; CVS^{TM} system measures vs. expert grader factors.

	Expert grader factors				
CVS^{TM} factor[a]	Actual fat thickness	Adjusted fat thickness	Ribeye area	Percentage KPH fat	Final yield grade
CVS grade fat	.86	.85	-.49	NS	.79
CVS mid fat	.93	.85	-.45	NS	.78
CVS top fat	.89	.81	-.46	NS	.77
CVS bottom fat	.93	.85	-.48	NS	.80
CVS ribeye area	-.49	-.57	.93	NS	-.78
CVS cold yield	-.71	-.69	-.52	NS	-.71
CVS hot yield	-.15	-.18	.12	NS	-.18

[a] VIA factors: CVS grade fat = ¼ measure fat depth; CVS mid fat = ½ measure fat depth; CVS top fat = fat depth measure at top of ribeye; CVS bottom fat = fat depth measure at bottom of ribeye; CVS ribeye area = machine measured ribeye area; CVS cold yield = machine estimated wholesale yield from chilled and ribbed carcass; CVS hot system yield = machine estimated wholesale yield from hot and intact carcass.

NS = Correlation not different from zero ($P > .05$)

fabricated carcass sides (Table 4.4). George et al. (1996) concluded that the USDA Yield Grade system is accurate and effective for the prediction of carcass yields but that the high chain-speeds in packing plants caused inaccuracies in the application of yield grades by online graders when compared with expert graders working without time constraint (r = -.77 vs. -.89, respectively).

Compared with yield grades assigned by online USDA graders (Table 4.4), increases in ability to account for variation in cutout yields, of: (1) 18% were observed when expert graders assigned yield grades to the nearest whole grade, (2) 24% were observed when expert graders assigned yield grades to the nearest half grade, and (3) 27% were observed when expert graders assigned yield grades to the nearest tenth grade. There is no doubt that the finer the precision with which yield grade is assigned, the greater is its ability to explain the observed variability in cutout yields; the advantage, though, of assigning yield grades to the nearest tenth of a grade as compared to assignments to the nearest half of a grade was only 3% in predictive accuracy. Expert yield grades to the half or tenth of a grade were highly correlated to percentage fat trim (r = .82). No yield grade measure was highly correlated to percentage bone, and although online yield

Table 4.4. Simple correlation coefficients; expert yield grade calculated to tenth, whole, and half grades and online grader yield grade vs. actual fabrication yields of wholesale cuts, fat trim and bone, calculated as percentages of intact side weight.

Yield grade (YG) measure	Fabrication yields[a]		
	Wholesale cuts	Fat trim	Bone
Expert YG tenth[b]	-.82	.82	-.27
Expert YG whole[c]	-.76	.79	-.27
Expert YG half[d]	-.80	.82	-.28
Online grader YG[e]	-.63	.70	-.32

[a] Fabrication yields: Wholesale cuts = subprimal cuts from the four major primals trimmed to .64cm maximum fat depth; Fat trim = waste fat from the production of wholesale cuts; Bone = waste bone from the production of wholesale cuts.

[b] Expert YG tenth, yield grade calculated to the tenth of the grade.

[c] Expert YG whole, yield grade calculated to the tenth of the grade, then converted to whole grade (<2.0=1, 2.0 to 2.9=2, 3.0 to 3.9=3, 4.0 to 4.9=4, >4.9=5).

[d] Expert YG half, yield grade calculated to the tenth of the grade, then converted to half grade (<1.5=1.0, 1.5 to 1.9=1.5, 2.0 to 2.4=2.0, 2.5 to 2.9=2.5, etc.).

[e] Online grader YG, yield grade as applied by online USDA graders in whole grades.

NS = Correlation not different from zero (P > .05)

grade was lowly correlated with percentages of subprimals and fat trim, it was correlated with percentage bone ($r = -.32$).

A number of regression models utilizing CVS™ measures, expert-grader yield grade factors, expert-grader yield grade, online grader yield grade, and combinations of machine-assessed and grader-applied factors were tested (Table 4.5) to determine the ability of the CVS™ System to replace and/or augment application of yield grades for predicting fabrication yields from carcass sides. Cross et al. (1973) reported that equations containing the same variables that are included in the USDA Yield Grade equation (carcass weight, ribeye area, kidney, pelvic, and heart fat, and fat thickness) accounted for the highest percentage of variability when estimating percentage of boneless closely trimmed beef retail cuts.

In the present study, expert-grader assigned yield grade alone accounted for 67% of the variation in fabrication yields (Table 4.5). Unfortunately, under industry conditions, assignment of adjusted fat thickness, ribeye area, percentage kidney-pelvic-heart fat, and consideration of hot carcass weight to arrive at the final yield grade, is imprecisely accomplished because of the time-pressures under which USDA graders do their job.

Table 4.5. Results from simple and multiple regression models predicting actual fabrication yields of wholesale cuts, fat trim and bone, calculated as percentages of intact side weight.

	Fabrication yields[a]					
	Wholesale cuts		Fat trim		Bone	
Terms in model[b]	R^2	RSD	R^2	RSD	R^2	RSD
CVSWYhot	.02	2.31	.05	2.84	.03	1.20
H5 H8 H18 H43 H47 H83	.26	2.02	.21	2.61	.08	1.18
CVSWYcold	.39	1.81	.39	2.27	.03	1.20
CVSWYcold CVSWYhot	.46	1.71	.41	2.24	.04	1.19
HCWT CVSMIDFAT CVSREA H38 H60 118	.64	1.41	.60	1.87	.24	1.07
CVSREA CVSGDFAT	.56	1.55	.56	1.94	.14	1.13
HCWT CVSREA CVSGDFAT	.59	1.49	.57	1.92	.14	1.13
HCWT CVSREA CVSMIDFAT CVSBTFAT	.61	1.46	.60	1.85	.16	1.12
EXPYG	.67	1.33	.69	1.63	.08	1.17
HCWT REA EXPKPH ADJFAT	.67	1.35	.77	1.40	.46	.90
HCWT REA ADJFAT	.66	1.36	.76	1.43	.39	.95
LINEYG	.39	1.81	.49	2.09	.10	1.15
HCWT CVSREA EXPKPH ADJFAT	.65	1.38	.77	1.39	.42	.94
HCWT CVSREA ADJFAT	.65	1.39	.77	1.42	.34	.99

[a] Fabrication yields: Wholesale cuts = subprimal cuts from the four major primals trimmed to .64cm maximum fat depth; Fat trim = waste fat from the production of wholesale cuts; Bone = waste bone from the production of wholesale cuts.

[b] Terms in model: CVSWYhot = Hot Camera estimated wholesale yield percent; H5, H8, H18, H38, H43, H47, H60, H83, H118 = Hot Camera linear carcass dimensions; CVSWYcold = Cold Camera estimated wholesale yield percent; CVSMIDFAT = Cold Camera fat thickness measure at midpoint of ribeye; CVSGDFAT = Cold Camera fat thickness measure at three quarter point of ribeye; CVSBTFAT = Cold Camera fat thickness measure at bottom point of ribeye; CVSREA = Cold Camera ribeye area measure; HCWT = Hot carcass weight; REA = Ribeye area; EXPKPH = Expert grader estimate of kidney, pelvic, heart fat percentage; ADJFAT = Expert grader adjusted fat depth; EXPYG = Expert grader final yield grade to tenth of the grade; LINEYG = Online grader yield grade to whole grade.

Cross et al. (1984) found, when comparing USDA Yield Grades applied by online graders vs. those assigned by a panel of expert graders, that 11.6% of carcasses had been assigned an incorrect yield grade.

If beef carcasses are traveling past the grading stand at the rate of 350 carcasses per hour, the USDA grader has a little over 10 seconds in which to: (1) evaluate maturity and marbling to assign a quality grade, (2) evaluate subcutaneous fat thickness, general fatness over the entirety of the carcass surface, ribeye area, and kidney-pelvic-heart fat percentage and use hot carcass weight to assign a yield grade, (3) make the calculations, and 4) stamp both grades on the hindquarter. Augmentation (providing estimates of some of these factors to the grader) should free-up the grader and allow more studied estimation of those factors that cannot be estimated or measured by use of VIA technology (for example, the adjusted preliminary yield grade).

Comparing VIA vs. manual measures of fat thickness and ribeye area in the Canadian yield equation, Jones et al. (1992) reported an R^2 value of .82.

In the present study, the best machine prediction of beef carcass cutability was achieved with three Hot Camera variables (H38, H60, H118), two Cold Camera variables (midpoint fat and ribeye area) and hot carcass weight and accounted for 64% of the variation in cutability (Table 4.5). The best machine prediction of beef carcass cutability without Hot Camera variables used three Cold Camera variables (midpoint fat, bottom fat and ribeye area) and hot carcass weight and accounted for 61% of the variation in fabrication yields (Table 4.5). It is interesting to note that with the exception of estimated percentage kidney-pelvic-heart fat, the best CVS^{TM} prediction is very similar to the yield grade prediction equation which also utilizes carcass weight, fat thickness and ribeye area. The level of prediction by the CVS^{TM} is much higher than the levels of prediction (achieved by another VIA system) reported by George et al. (1996); in that study, the best VIA measure accounted for 37% of the variability among carcasses in .64 cm.-trim boxed beef yields. The predictive accuracy of the cold camera system wholesale yield prediction was surprisingly low, accounting for only 39% of the variability in fabrication yields. Perhaps this low predictive accuracy resulted from calibration of the Cold Camera for predicting yields as based on Canadian fabrication styles.

In the present study, online grader applied yield grade accounted for 39% of the differences in fabrication yield (Table 4.5). These percentages were lower than those reported by Cannell (Chapter III of this dissertation) who found that online grader estimates accounted for 54% of the variability among carcasses in .64 cm.-trim boxed beef yields; but, the difference in predictive accuracy occurred, in part, because fabrication yields were determined under less stringent conditions in the study of the CVS™ system. By combining expert grader yield grade factors of adjusted fat thickness, and KPH fat percentage with Cold Camera estimated ribeye area plus hot carcass weight (which could be provided electronically in an augmentation system) in an augmentation model, 65% of yield variation was accounted for (Table 4.5).

The best equation for the prediction of fat trim (R^2 = .77) was the equation containing the expert grader estimates of adjusted fat thickness and KPH percentage along with hot carcass weight and CVS™ ribeye area (Table 4.5). The equation containing the four standard yield grade factors (hot carcass weight, adjusted fat thickness, percentage KPH and ribeye area) had the largest coefficient of multiple determination for bone percentage, accounting for 46% of the variation (Table 4.5). Predictive accuracy for augmented yield grades was only 2% less than Expert yield grade, and was 26% greater than the predictive accuracy of yield grades applied online.

Implications

Prediction models utilizing CVS™ estimates (either alone or combined with grader estimates) more accurately predicted carcass cutout yields than did yield grades assigned by online graders. Based on these data: (1) Regression equations to predict fabrication yields using CVS™ assessments produced R^2 values higher than those of yield grades assigned by online graders and approaching those of yield grades assigned by expert graders. (2) An augmentation system combining yield grade factors assigned by expert graders with Cold Camera ribeye area produced R^2 values nearly matching those of yield estimates made by expert graders.

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