An Automated Cleaning, Pod Sizing, Shelling, and Kernel Sizing System for Grading Farmers Stock Peanuts[1]

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ABSTRACT

In response to peanut industry requests to improve the farmers stock grading system, an automated grading system was developed that reduced the variability in measuring most grade factors up to 50%. The automated system reduced sampling error by grading a larger sample while maintaining approximately the same sample processing speed. The system reduced inspector error by simplifying the grading process and eliminating opportunities for mistakes to occur. The system reduced equipment error by replacing outdated equipment with more efficient and effective equipment. Implementing the system could result in a return of about $10,350 annually per buying point and save the entire U.S. peanut industry up to $6 million each year. In addition, reducing errors in measuring grade factors should improve the quality of peanuts reaching consumers.

Key Words: Peanuts, grading, automation, variability.

The current farmers stock grading system requires a labor force of about 2000 inspectors to grade the 600,000 lots marketed annually at over 500 locations throughout the peanut-producing states. The current system has remained relatively unchanged since the 1960s while consumer demands for improved quality continually increase. Thus, the U.S. peanut industry requested the current grading system be improved to help meet consumer demands for quality (National Peanut Council, 1988; Amer. Peanut Shellers Assoc., 1994). Sampling, equipment, and human errors cause inaccuracies in the current system. Equipment capacity limits sample size, thus limiting the inspection service's ability to reduce sampling error. Failure to upgrade equipment since the 1960s contributes to equipment error. Subjectivity inherent in the current grading process contributes to human error. Thus, to effectively address sampling, equipment, and human errors, an improved grading system must be developed.

A complete description of the current grading system is given elsewhere (Davidson *et al.*, 1982; USDA, 1990). Briefly, the process begins with collecting a 1800-g sample from a lot of farmers stock peanuts. Foreign material (FM) and loose shelled kernels (LSK) are then removed by a cleaner and by hand. Inspectors then reduce the sample to 500 or 1000 g, depending on lot size. Pods are then sized, shelled, kernel moisture content (MC) measured, and the kernels sized using a slotted screen. Kernels riding the screen are inspected for damaged kernels (DK). The remaining kernels are classified as sound mature kernels riding the screen (SMKRS), sound split kernels (SS), or oil stock. SMKRS are split and examined for internal damage. SMKRS and SS weights are combined and reported as total sound mature kernels (TSMK). All kernels are inspected for *Aspergillus flavus* Link. All weights are hand-recorded on grade notesheets and calculations made by hand.

Errors in the current system may occur if a representative sample is not collected. Also, during the cleaning process, equipment and human error may induce errors due to improper classification of FM, LSK, or pods. Other errors occur when inspectors subdivide the pods from the cleaned bulk sample to obtain a 500- or 1000-g pod sample. This is done by spreading the entire cleaned sample on a table top and scraping the desired sample weight into a pan. This induces some error since a representative sample or a sample weighing exactly 500 or 1000 g may not be obtained. The amount of the sample that can be lost or gained during the grading process is ±1%. Failure to meet this tolerance when adding all fractions of the sample requires regrading the sample. Due to time constraints, inspectors may use a sample slightly larger than the 500 or 1000-g standard to ensure the tolerance is met if some of the sample is lost, but make calculations based on 500 or 1000 g. However, this error results in an overestimation of grade factors. Additional errors may occur during kernel sizing if screens are not punched accurately, if slots contain dirt buildup, or if the screen shaker is not properly adjusted. Sample identification errors can occur since about 10 samples can be at different stages of the grading process at once, resulting in inadvertent switching of sample identifications. Errors may occur also during hand recording data, calculating percentages, and keypunching results.

All the errors listed here can result in over- or underpayment to the seller, improper segregation of the peanut lot, or inaccurate grade information supplied to the buyer. Dickens *et al.* (1984), Davidson *et al.* (1990), Whitaker *et al.* (1991), and Dowell (1992) reported grade factor coefficient of variations (CV) of up to 30%. Dowell (1992) reported that equipment and human errors account for approximately 24% of the total error.

The current system requires significant amounts of labor during the cleaning and shelling processes and during data-recording and calculating. Inspectors must assist the cleaning equipment in removing FM and LSK. The sheller requires considerable hand labor on some samples since unshelled pods must be hand-shelled. Many pods are not symmetrical, which means kernels in a two-seeded pod are usually not the same size. During pod sizing, the pod is sized according to the largest kernel. However, during shelling, the hull is removed

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from the large kernel, but small kernels may fall through the perforated grid unshelled, thus requiring hand-shelling. During data recording, inspectors throughout the peanut-producing area hand record about 9 million pieces of grade information and hand calculate about 7 million percentages. Thus, opportunities for reducing labor, and subsequent human errors, exist.

This paper reports development of an automated sample cleaning, pod sizing, shelling, and kernel sizing system designed to reduce errors in the current grading system. Specific objectives were to (a) determine if an automated grading system reduces errors in measuring peanut quality and (b) sources of economic return.

Materials and Methods

Dowell *et al.* (1994) used systems engineering to determine minimum acceptance requirements for any new grading system as dictated by the peanut industry. Briefly, the peanut industry specified that any improved grading system should be at least as accurate as the existing system, should not be slower, must not decrease inspector safety, should reduce labor and cost, should not require more maintenance or skill, should reduce inspector errors, and should not reduce the supply of edible peanuts.

Description of the Automated System. Automation research began in 1988 with attempts to reduce labor-intensive hand shelling of pods. The system evolved into one machine consisting of a cleaning module, shelling module, and kernel sizing module (Fig. 1) (Dowell *et al.*, 1995). The cleaning module removed FM and LSK and sized pods for shelling through various aspiration and sizing mechanisms. Removal of large FM occurred by passing the sample over a gap large enough to drop all pods and LSK, but forced large FM into a separate container. Air columns then separated light and heavy foreign material from pods

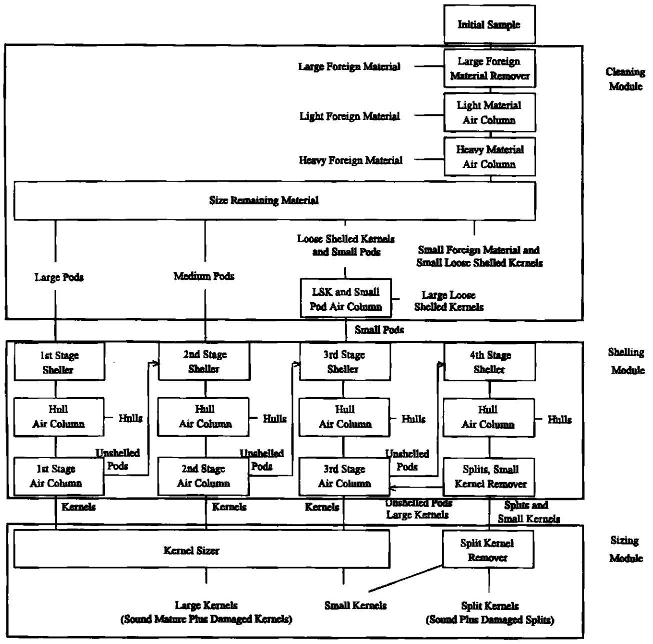

Fig. 1. Flow chart of an automated grading system for farmers stock peanuts.

and LSK by aspiration. A set of diverging belts removed small FM, LSK, and sized pods. Small FM and split LSK fell through narrow gaps in the belt whereas progressively larger pods fell through the belts into different sheller compartments as the gap widened. Pods the same diameter as LSK fell into an air column that separated the less dense pods from the LSK before conveying the sized pods into the sheller.

The shelling module consisted of four sheller compartments with a shelling action similar to the three-compartment sheller used in the manual system. After shelling, the kernels, hulls, and any unshelled pods fell through the sheller grids and were conveyed to an air column where hulls are removed. Kernels and unshelled pods from the 1st and 2nd stage shellers fell into the 1st and 2nd stage air columns, respectively. Material from the 3rd and 4th sheller stages fell into the 3rd stage air column. Kernels fell out of the air columns while the less dense unshelled pods are conveyed back into a sheller compartment with smaller grid openings. For example, unshelled pods passing through the 2nd stage sheller are separated from kernels in the 2nd stage air column and conveyed to the 3rd stage sheller. Unshelled pods are continually recirculated until most are shelled. Small unshelled pods ended up in the 4th compartment where the grid size and sheller bar design removed hulls from virtually any material entering this compartment.

Split kernels have the same flotation velocity as pods and cannot be separated by the air columns. Thus, split kernels circulated through the system with the pods until they reached the 4th compartment. All material falling through the 4th compartment sheller grid and the hull air column passed over parallel round belts that allowed split kernels and small kernels to fall through. Any material passing over the belts was conveyed into the 3rd stage air column that separated any remaining kernels from pods. The pods were conveyed back to the 4th stage sheller.

The sizing module separated small kernels, large kernels, and split kernels. All kernels falling from the 1st, 2nd, and 3rd stage air columns fell into a kernel sizer developed by the USDA-ARS Market Quality and Handling Research Lab in Raleigh, NC (Whitaker *et al.*, 1993). The kernel sizer consisted of a perforated screen that resembles a cylinder. End caps cover the two ends of the cylinder whereas the circumference of the cylinder was slotted with openings similar to the flat screens used to size kernels in the manual grading system. These openings allowed small kernels to fall out of the cylinder as it rotated about its axis. Once all kernels entered the cylinder, it rotated at 29 RPM for 60 sec. Kernels falling through the screen were classified as oil stock. Split kernels and small kernels falling through the parallel belts of the 4th sheller stage fell onto an inclined flat belt. The incline, speed, and design of the belt caused whole kernels to roll and fall off into a container, whereas split kernels rode up the belt into a separate container. Split kernels have a flat side that prevented them from rolling. The kernels falling off the belt were combined with the oil stock kernels falling through the barrel screen since the gap in the parallel belts in the shelling module allowed only oil stock to fall through. MC was determined by taking a sample of all kernels mixed together after weighing all components. This completed the entire sample cleaning, shelling, and sizing process by the automated equipment. All grade components were then processed with the automated the data collection equipment that consisted of a digital balance and moisture meter interfaced to a computer and described by Dowell (1995).

Sample Collection, Equipment Testing, and Data Analysis Procedure. FSIS inspectors tested two laboratory prototype automated grading systems in the laboratory in 1993 on 242 samples of runner peanuts (Table 1). In these tests, 8-kg bulk samples were obtained from various locations in Georgia, Alabama, Florida, and Texas by collecting the unused portion of the grade sample after the official sample was removed during the pneumatic sampling process. These 8-kg samples were divided into four 2-kg test samples using an official farmers stock divider. Two of the samples were graded using the two automated systems and the remaining two samples graded using two separate commercial grading rooms. Grading of the four grade samples from one bulk sample occurred on the same day to reduce moisture loss effects on grades.

Inspectors field-tested three commercially built automated grading systems in 1994. These systems were built from plans of the laboratory prototypes and one automated system was placed in each of the three marketing areas. Testing occurred on 797 samples of runner-type peanuts in Smithville, GA, 737 virginia-type peanuts in Suffolk, VA, and 431 runner and spanish-type peanuts in Comyn, TX. In these tests, bulk samples obtained for official inspection were divided into two grade samples. One sample was graded using the official grading system and the other was graded using the automated system. Samples from the same lot were graded on the same day as sampling at most locations to reduce moisture loss effects on grades. Data collected in the tests included grade factors, grading speed, and inspector comments.

Table 1. Locations and number of samples used to compare the current manual farmers stock grading system to a proposed automated system.

Year	Location	Type of system tested	Peanut type	No. of samples
1993[a]	Nat. Peanut Research Lab Dawson, GA (subsample A1)	Automated	Runner	242
	Birdsong Peanut Company Dawson, GA (subsample A2)	Manual	Runner	242
	Nat. Peanut Research Lab Dawson, GA (subsample B1)	Automated	Runner	242
	Stevens Industries Dawson, GA (subsample B2)	Manual	Runner	242
1994[b]	Smithville Peanut Co. Smithville, GA	Automated & manual	Runner	797
	Birdsong Peanut Co. Suffolk, VA	Automated & manual	Virginia	737
	Golden Peanut Co. Comyn, TX	Automated & manual	Runner Spanish	367 64

[a]A bulk sample was collected from 242 different lots and divided into four grade samples. Each grade sample was then graded at each of the four locations.

[b]A bulk sample was collected from individual lots and divided into two grade samples. One grade sample was graded on the current manual system and one on the automated system. Number of samples indicates numbers graded for each system.

In this experimental design, all variances and CVs reflect total error (σ^2_t) which is the sum of lot-to-lot variation (σ^2_l), sampling error (σ^2_s), equipment error (σ^2_e), and human error (σ^2_h).

$$\sigma^2_t = \sigma^2_l + \sigma^2_s + \sigma^2_e + \sigma^2_h \qquad \text{[Eq. 1]}$$

All variances in Table 2, except variances in the column labeled "Average" for 1993, were calculated from one sample pulled from individual lots. Thus, the variance estimates include lot-to-lot variation. Tsai *et al.* (1993) estimated σ^2_l and σ^2_s was about 97% of σ^2_t. Thus, reductions in equipment and human errors are difficult to observe when σ^2_t includes σ^2_l and σ^2_s.

Sample size directly affects σ^2_s, thus doubling sample size should reduce σ^2_s by 50%. The automated system shelled a sample three to four times larger than the manual system. Thus, any reductions in total error observed in TSMK, SS, oil stock kernels (OK), DK, extra large kernels (ELK), hulls, and value include the benefit from an increase in sample size. The sample size for FM, LSK, and MC was the same for both systems.

In the column labeled "Average" in 1993, variances for either the automated or manual system were calculated using two of the four samples pulled from one lot. An average, variance, and CV was calculated for each system from the data for that one lot. This process was repeated for 242 lots, yielding 242 averages, 242 variances, and 242 CVs for the manual and automated system. The 1993 "Average" column reports the averages of these three statistics. Thus, the variance and CV estimates in the 1993 "Average" column eliminate lot-to-lot variations. Dowell (1992) estimates s^2_s makes up only about 78% of s^2_t when lot-to-lot variation is removed. The 1993 "Average" column in Table 2 gives a better picture of reductions in errors achievable by the automated system. Means and variances in all tests were compared using the equality of means and equality of variances tests described by Steele and Torrie (1980).

Results and Discussion

Automated System Performance. Table 2 shows FM averages were not significantly different ($P<0.05$) for either method at most locations. This was expected since the FM sample size for both methods was about the same. However, the variance and CV estimates were higher for the automated system indicating it may induce some equipment or human error in measuring FM. Inspectors noted that the automated system required less labor to clean samples, thus human error when measuring FM should be less with the automated system. However, inspectors also noted that the air in the room with the automated system was dustier than in current grading rooms. This suggests that air columns used to separate FM from the sample may blow light FM from the sample into the air, thus contributing to equipment error even though means were not significantly different.

Table 2. Average (Avg), variance (Var.[a]), and coefficient of variation (CV[a]) of grade factors and value determined using the current manual (Man.) farmers stock grading system and a proposed automated system (Auto.) to grade runner, virginia, and spanish-type peanuts.

Grade factor			1993 Georgia-A (runner)	1993 Georgia-B (runner)	1993 Average[b] (runner)	1994 Georgia (runner)	1994 Virginia (virginia)	1994 Texas (spanish)	1994 Texas (runner)
Foreign material	Avg (%)	Man.	3.77	3.74	3.75	4.17	4.54[s]	5.06	4.14
		Auto.	3.46	4.00	3.73	4.10	4.10[s]	5.27	4.18
	Var.	Man.	5.10[s]	5.39[s]	0.96[s]	4.98[s]	4.25[s]	6.72[s]	4.51[s]
		Auto.	5.57[s]	7.20[s]	1.18[s]	5.45[s]	4.17[s]	6.05[s]	4.70[s]
	CV (%)	Man.	59.92	62.07	16.22	53.49	45.44	51.19	51.26
		Auto.	68.21	67.13	19.42	56.97	49.89	46.66	51.83
Loose shelled kernels	Avg (%)	Man.	4.13[s]	4.20[s]	4.17[s]	5.43[s]	4.17	3.67	4.26[s]
		Auto.	3.09[s]	3.27[s]	3.18[s]	4.32[s]	4.14	3.61	3.76[s]
	Var.	Man.	8.26[s]	8.79[s]	0.49[s]	13.96[s]	3.10[s]	5.75[s]	4.00[s]
		Auto.	5.48[s]	5.78[s]	0.40[s]	10.05[s]	3.13[s]	5.96[s]	3.33[s]
	CV (%)	Man.	69.63	70.56	13.46	68.82	42.27	65.34	46.94
		Auto.	75.82	73.60	15.16	73.44	42.75	67.74	48.49
Moisture content	Avg (%)	Man.	7.48	7.36	7.42	8.69	8.58	8.45[s]	9.31[s]
		Auto.	7.38	7.34	7.36	8.62	8.60	7.64[s]	8.45[s]
	Var.	Man.	1.21[s]	0.94[s]	0.24[s]	1.16[s]	0.60[s]	1.55[s]	0.54[s]
		Auto.	1.05[s]	0.95[s]	0.38[s]	1.13[s]	0.52[s]	1.29[s]	0.62[s]
	CV (%)	Man.	14.73	13.15	3.63	12.41	9.06	14.74	7.88
		Auto.	13.89	13.28	4.38	12.36	8.36	14.87	9.29
Total sound mature kernels	Avg (%)	Man.	69.33	70.06	69.69[s]	75.39	69.80[s]	68.75	72.25
		Auto.	69.77	70.26	70.01[s]	75.12	68.64[s]	68.73	72.08
	Var.	Man.	24.05[s]	21.61[s]	2.67[s]	7.65[s]	4.30	15.84[s]	21.20[s]
		Auto.	22.07[s]	19.11[s]	1.72[s]	7.15[s]	4.29	16.18[s]	19.92[s]
	CV (%)	Man.	7.07	6.64	1.84	3.67	2.97	5.79	6.37
		Auto.	6.73	6.22	1.41	3.56	3.02	5.85	6.19
Sound splits	Avg (%)	Man.	6.20[s]	3.85[s]	5.02[s]	2.06[s]	2.28[s]	4.72[s]	3.09[s]
		Auto.	12.17[s]	10.61[s]	11.39[s]	4.30[s]	2.99[s]	7.37[s]	5.29[s]
	Var.	Man.	14.12[s]	6.33[s]	5.10[s]	3.42[s]	2.13[s]	12.26[s]	5.51[s]
		Auto.	26.83[s]	19.06[s]	6.57[s]	8.74[s]	2.79[s]	19.12[s]	8.69[s]
	CV (%)	Man.	60.62	65.35	36.01	89.94	63.80	74.21	75.96
		Auto.	42.58	41.16	17.26	68.76	55.93	59.36	55.74
Oil stock kernels	Avg (%)	Man.	6.36	5.92	6.14	4.11	2.14[s]	3.58	4.31
		Auto.	6.19	6.09	6.14	4.13	2.44[s]	3.77	4.60
	Var.	Man.	8.71[s]	7.39[s]	1.34[s]	2.76[s]	0.62[s]	2.54[s]	5.09[s]
		Auto.	7.61[s]	6.69[s]	0.66[s]	2.50[s]	0.54[s]	2.23[s]	5.59[s]
	CV (%)	Man.	46.39	45.93	13.91	40.39	36.80	44.46	52.31
		Auto.	44.57	42.47	10.92	38.27	30.21	39.39	51.41
Damaged kernels	Avg (%)	Man.	0.98[s]	0.77	0.88[s]	0.30[s]	0.41	0.53	0.51[s]
		Auto.	0.53[s]	0.81	0.67[s]	0.35[s]	0.38	0.41	0.32[s]
	Var.	Man.	1.16[s]	0.67[s]	0.43[s]	0.26[s]	0.28[s]	0.50[s]	0.36[s]
		Auto.	0.38[s]	0.52[s]	0.21[s]	0.09[s]	0.09[s]	0.20[s]	0.11[s]
	CV (%)	Man.	109.84	106.27	54.01	170.19	128.45	134.09	118.23
		Auto.	115.55	88.35	53.00	84.11	81.08	107.25	104.48
Hulls	Avg (%)	Man.	23.23[s]	22.95[s]	23.09[s]	19.99[s]	27.66	26.81	22.83[s]
		Auto.	22.89[s]	22.11[s]	22.50[s]	19.58[s]	27.63	26.27	22.11[s]
	Var.	Man.	5.07[s]	5.22[s]	0.48[s]	1.97[s]	2.54[s]	6.59[s]	8.07[s]
		Auto.	4.88[s]	4.22[s]	0.55[s]	2.04[s]	1.92[s]	8.70[s]	6.53[s]
	CV (%)	Man.	9.70	9.95	2.03	7.02	5.77	9.58	12.44
		Auto.	9.65	9.29	2.66	7.29	5.01	11.23	11.56
Value	Avg ($)[c]	Man.	618.21[s]	624.98	621.59[s]	654.92[s]	633.84[s]	599.36	631.33
		Auto.	632.10[s]	631.31	631.70[s]	660.25[s]	626.61[s]	602.94	638.63
	Var.	Man.	2907.91[s]	2543.00[s]	272.60[s]	1071.46[s]	913.34	2608.75[s]	1985.02[s]
		Auto.	2438.19[s]	2309.65[s]	127.33[s]	955.01[s]	917.38	2583.57[s]	2013.54[s]
	CV (%)	Man.	8.72	8.07	2.05	5.00	4.77	8.52	7.06
		Auto.	7.81	7.61	1.38	4.68	4.83	8.43	7.03

Table 2 (Continued)

Grade factor			1993 Georgia-A (runner)	1993 Georgia-B (runner)	1993 Average[b] (runner)	1994 Georgia (runner)	1994 Virginia (virginia)	1994 Texas (spanish)	1994 Texas (runner)
Extra large kernels	Avg (%)	Man.					37.15[s]		
(VA type only)		Auto.					34.47[s]		
	Var.	Man.					51.61[s]		
		Auto.					45.50[s]		
	CV (%)	Man.					19.34		
		Auto.					19.57		

[a]Except for the Average column, one variance and CV was calculated for each grade factor using samples from all lots.

[b]In 1993 tests, 242 samples were divided into four grade samples. A grade sample was graded on each of the two automated systems and a grade sample on each of the two manual systems. A mean, variance, and C.V. was calculated for each sample using the two grade samples graded on each system, resulting in 242 estimates of these statistics for each method. The values in this column report the average of the 242 means, variances, and CVs.

[c]Values reported are per 908 kg. A typical lot weighs about 4540 kg.

[s]Manual and automated system averages or variances in the same column for a given grade factor are significantly different at P=0.05.

LSK averages were less for the automated equipment than the manual system at most locations. This indicates either the manual system creates some LSK during cleaning, or that the automated equipment loses some LSK. The only way for the automated equipment to lose LSK is for the kernels not to be removed before shelling and thus pass through the sheller as TSMK or oil stock. This can occur if the spacings in the pod sizer belt do not allow removal of all LSK. A decrease in LSK should then be reflected by an equivalent increase in TSMK and oil stock. The data did not show that this occurred. The data did indicate that locations with the largest differences in LSK were using feeding devices on the sample cleaner in the manual system that can damage pods, resulting in an overestimation of LSK. Some locations use an improved feeding device that eliminates the potential for creating LSK in the manual system (Dowell, 1994). Thus, locations using the old feeding device may be creating LSK. Significantly lower automated system variances at most locations likely reflect the significantly lower automated system means. However, the higher automated system CVs indicated the error for measuring LSK is higher. Thus, the data suggest the automated system LSK means may more closely reflect actual LSK means, but the error associated with that mean is higher.

The MC means, variances, and CVs for both systems showed no significant trends for most locations. This was expected since grading of samples on both systems occurred on the same day at most locations, thus minimizing moisture loss. Also, the moisture meter uses the same sample size of about 250 g regardless of the initial sample size so variances and CVs should not be affected. The Texas location showed significantly lower MC means for the automated system because that location would not release the sample for grading on the automated system until about 24 hr after the manual system graded the corresponding sample.

Table 2 shows no significant difference in TSMK means for most locations. This was expected since total kernels in the sample are not affected by the method of grading. However, most locations showed significantly lower variances and CVs for the automated system indicating that system more accurately measures TSMK due to a decrease in sampling error, human error, or equipment error. For those locations where a reduction in variance occurred, the average reduction in total variance was about 6.5% and the average reduction in total CV was about 4%. However, the column labeled "Average" in Table 2, which has the lot-to-lot variation removed, showed a reduction in the variance and CV estimates of 36 and 23%, respectively. The TSMK difference in virginia-type peanuts is discussed below.

All automated system SS averages significantly exceeded the manual system. This is not a concern as long as a correlation between the two systems exists. The higher SS means was expected since the flotation velocity of some whole kernels is the same as unshelled pods. Thus, when unshelled pods are recirculated to the sheller by the air columns, some whole kernels are recirculated also. Some of these whole kernels are split by the sheller. Although the split estimates are higher with the automated system, the CV estimates showed an average reduction of about 25%. Thus, the automated system determines SS more consistently than the manual system. The average SS values for Georgia A and Georgia B illustrate the inconsistency in measuring SS in the manual system. Since samples graded at the two locations in 1993 originated from the same lots, the average SS value for the two manual systems should be similar. However, the manual SS values of 6.20 and 3.85% for Georgia A and Georgia B differed by about 40% whereas the automated system values differed by only 19%.

A regression of the 1994 SS data for each peanut type gave a prediction equation of:

Runner $SS_{auto} = 1.9 + 1.2\ SS_{manual}$ R=0.81 [Eq. 2]
Spanish $SS_{auto} = 2.2 + 1.1\ SS_{manual}$ R=0.88 [Eq. 3]
Virginia $SS_{auto} = 0.8 + 1.0\ SS_{manual}$ R=0.83 [Eq. 4]

The current marketing system penalizes sellers $0.80

per 908 kg for every percent of SS over 4%. Thus, the penalty needs to be adjusted by the amounts in Eqs. 2-4 to correctly assess SS penalties when using the automated system to determine value. The 1993 data were not used to determine the SS adjustment because samples graded in 1993 were collected and allowed to sit from 1 d to several weeks before processing. Thus, MC was lower than would be encountered in actual grading conditions. Lower kernel moisture content occurring during 1993 testing caused a higher percentage of splits, thus biasing correlations.

Most oil stock kernel averages in Table 2 were not significantly different. This was expected since the cylindrical sizing device used the same slot size for sizing kernels as the flat screen used in the manual system. However, most variance estimates were significantly lower for the automated system. The variance estimates averaged 11% lower for the automated system with lot-to-lot variation included, whereas the variance estimated for the automated system with lot-to-lot variation excluded was greater than 50% lower than the manual system. All CV estimates were lower for the automated system, averaging about 8% less than the manual system. Whitaker *et al.* (1993) reported cylindrical screen CVs were about 50% less than flat screen CVs when repeatedly sizing the same sample on both screen types. Thus, the automated system reduced error associated with measuring oil stock by reducing sampling, equipment, and/or human error while the cylinder used for sizing kernels produced the same average oil stock as the manual system for most peanut types.

The data showed no clear trends in damaged kernel averages. Three locations showed no significant difference in damaged kernel means and the largest discrepancy between the systems was 0.45%. Thus, there is probably no practical difference between the automated and manual system for damaged kernels. However, all automated system variances and most CVs were less than the manual system, with the average decrease in CV being about 27%. Thus, the automated system reduced the error associated with measuring damaged kernels. The reduction in CVs is likely due to reductions in sampling error from the larger sample size since the method of determining damage is the same for both systems.

Table 2 shows significantly lower hull averages for the automated system. This is likely due to hulls lost as dust. The hull collection system consisted of a negative pressure fan that pulled hulls from kernels. The hulls then passed through the fan vanes and were blown into a porous bag. The fan vanes pulverized the hulls, resulting in some fine hull pieces passing through the hull bag pores. These lost hulls likely contributed to the lack of significant trends in variance and CV estimates. Hulls do not add to or reduce lot value and are not a quality factor, thus losing hulls does not affect value or quality estimates and should not be a concern except when accounting for the original sample components. The manual system requires inspectors to account for 99 to 101% of the original sample after weighing all components. If the weight of the components falls outside this range, then the sample must be regraded. Thus, failure to change this tolerance will result in regrading more automated system samples since less hulls are measured with the automated system. The data show the automated system measured about 0.5% fewer hulls, thus the inspector should be allowed to account for 98.5% of the original sample, instead of the current 99%, when using the automated grading system.

Virginia-type peanuts are the only type with extra large kernels (ELK). Results showed the automated system measured about 2.7% fewer ELK than the manual system. Although the means were significantly different, the reduction in ELK reduces lot value by less than $1 per 908 kg. An increase in split kernels or a slight difference in screen size may contribute to the ELK difference. The slots widths in the cylindrical screen used with the automated system measured within the 0.05-mm tolerance allowed when fabricating screens. The slot length in the ELK screen is less critical than the width and averaged about 0.1 mm shorter in the cylindrical screen than the tolerance recommended in the specifications. This should cause fewer ELK to fall through with the automated system. The inspection service reported the manual screens met their specifications when put into use several years ago. However, there is no reason for the screen size to change unless residue builds up in the slots over time. The decrease in ELK measured with the automated system is likely due to an increase in splits since large kernels are more likely to split than small kernels. The TSMK measured for virginia-type peanuts by the automated system were also significantly lower than the manual system while oil stock kernels were significantly higher. As with the ELK screen, the slot width for the cylindrical screen used with the automated system measured within allowable tolerances while the length was slightly less than allowable tolerances. Thus, either the TSMK screen was slightly undersized in the manual system or some factor such as rotation time or speed for the cylindrical screen needs further study to improve the TSMK correlations for virginia-type peanuts.

Lot dollar value is a function of all grade factors except for hulls. Results showed no significant difference in lot value for three locations. The Virginia location showed the only decrease in value by the automated system. This is likely due to the TSMK, ELK, and oil stock kernel size distribution discussed above. The largest difference in value occurred in 1993 where the automated system lot value exceeded the manual system by an average of $13.89 per 908 kg at one location. TSMK and oil stock account for most of the lot value, but most TSMK and oil stock averages were not significantly different. Thus, most difference in lot value is likely due to differences in LSK. When calculating lot value, the weight of FM and LSK is subtracted from the total marketed gross weight. Most of the lot value comes from the resulting net weight. Thus, measuring fewer LSK results in a larger net weight and increases lot value.

A larger or smaller dollar value as determined by the automated system is not a concern because the current quota support system averages out any increase or decrease in value over a 5-yr period. If the Agricultural Marketing Service chooses, it can make changes immediately. Thus the value of each component would be adjusted as necessary for each peanut type so that the average lot value measured by the automated system is not significantly different from the manual system. This prevents any undo penalties to the buyer or seller for using a different grading system. Although the current marketing structure averages out differences in dollar value over time, reductions in variances achieved by the automated system would still exist. Table 2 shows significantly smaller dollar value variances for the automated system in most cases. The average variance reduction was over 11%. In the 1993 test with the lot-to-lot variation removed, the automated system reduced value variance by more than 50%. All automated system CVs were less than the manual system, with an average reduction of about 8%. In the test with the lot-to-lot variance removed, the automated system CV reduction was about 22%.

Reductions in sampling, equipment, and human errors account for the reductions in variance and CV achieved by the automated system. The larger sample graded by the automated system caused the reduction in sampling error. Any reductions in equipment error are difficult to quantify and are likely due simply to using equipment built to stricter specifications and due to processes, such as air separations, which may perform more consistently than those currently used. The possible creation of LSK in the manual system by the sample cleaner mentioned previously is one source of equipment error eliminated by the automated system.

Human error is reduced through several methods. When analyzing data from the manual system, about 25% of all grade certificates had errors in recording and calculating grade factors (Dowell, 1995). Errors included such mistakes as failure to record data, incorrect addition, and incorrect percentage calculations. These errors affected price in up to 17% of all lots in some tests. Errors were not random and were biased toward the buyer or seller at different locations. For example, recording and calculating errors at one location cost the buyer \$10.78/t on 17% of all lots tested. This type of error would cost an average buying point handling 4500 t/yr about \$8250. The automated data collection system eliminated all calculating and recording errors identified in the manual system.

Other human errors may occur in the pod selection for the 500-g cleaned sample in the manual system. Some inspectors may select only large pods for the 500-g sample since large pods are less likely to pass through the sheller without being shelled, thus reducing hand shelling and speeding the grading process. However, this biases TSMK and oil stock values since large pods typically have large kernels. Other human errors occurred when weighing the 500-g pod sample mentioned previously. The automated system eliminates these errors since the entire sample is shelled. Some human errors may occur in the manual system due to the staging of samples in the cleaner, pod sizer, sheller, and kernel sizer. Since a separate sample can be in each of these four machines simultaneously, it is possible to switch sample identifications. The automated system eliminates this error because one sample is cleaned, pod-sized, shelled, and kernel-sized before another sample is processed.

After testing in 1994, inspectors completed evaluation sheets on manual and automated grading systems. Most inspectors completing the evaluation had experience on both systems. Using a rating of 1 to 5, with a 5 being better, the inspectors rated the automated system as slightly easier to learn to use (4.2 vs. 4.5) but slightly more difficult to use from day to day (4.4 vs. 4.2). They rated the ruggedness of the two systems identical (4.2), which indicates that neither system was more susceptible to break-downs. The inspectors rated the manual system as slightly easier to clean and maintain (4.4 vs. 4.2). In an overall rating of inspector satisfaction, the automated system scored slightly higher (4.2 vs. 4.3). When asked for additional feedback, all inspectors liked the automated data collection portion of the prototype system better than handwriting and manual calculations of the current system. They also liked not having to move samples from the cleaner, to the pod sizer, to the sheller, and then to the kernel sizer as with the manual system.

Dislikes expressed by the inspectors included noise levels. Noise created by the automated system exceeds OSHA levels for 8-hr exposures. Thus, inspectors must wear hearing protection. Another dislike was that the automated system prevented bypassing of some grading procedures. When under intense pressure from buying points to process samples quickly during the busy part of the harvest season, some inspectors may bypass or short-cut grading procedures to speed the inspection process. This may sacrifice the accuracy of information but increases sample processing speed, thereby returning trailers to farmers quicker so the harvest process is not slowed. The automated system should improve the accuracy of grade data but may do so at the expense of grading speed.

Economic Return. Despite the increased grading accuracy achieved by the automated system, it must show some economic return. Mandatory equipment for current grading rooms costs about \$9200. Addition of commercial automated data collection equipment to the manual equipment costs an additional \$10,000 (available from Sage Systems Technology, Melbourne, FL). The manual grading system requires a cleaning station and shelled kernel station which mandates two scales and two networked computers and adds to the cost of the commercial automated data collection equipment.

The automated cleaning, shelling, and sizing commercial prototypes tested in 1994 cost about \$11,000 each. The automated data collection equipment is much simpler for the automated grading system since the two stations of the current manual system are no longer needed. All grade components are weighed at once on one set of scales. The automated data collection equipment for the automated grading system costs only about \$1500 since it is much simpler and the buying point can install and maintain the software. Thus, a complete automated grading system that includes automated cleaning, shelling, and sizing equipment and automated data collection equipment costs about $12,500 whereas the current manual grading equipment costs from $9200 to $19,200, depending on whether the commercial automated data collection equipment is included. For new grading rooms, the automated system compares favorably to purchasing a current grading system. However, if the automated system replaces the current grading system, the purchaser must realize a benefit of at least $12,500.

Tests showed similar sample processing speeds for both systems when using the same number of inspectors (Table 3). Thus, the number of inspectors cannot be reduced and no cost savings can be realized through reduced labor required to grade samples. However, automatically collecting data saves some labor through eliminating key punching data into the program used to calculate lot value and through eliminating the need to check keypunched data against hand-written grade certificates. Reducing hand shelling saves additional labor. In a test on 19 samples, the automated system left significantly (P=0.01) fewer unshelled pods per sample than the manual system, although the initial pod sample size for the automated system is about three times larger. These reductions in labor should save about $1000 annually in labor costs for a 4500 t/yr buying point. In addition, the official grade certificate can be eliminated since the form used to calculate lot value contains all grade information, saving another $100 annually.

Table 3. Approximate time to grade one sample using the current system and the proposed automated cleaning, pod sizing, shelling, and kernel sizing system with various numbers of inspectors. Times are averages of periods where sample availability, equipment breakdowns, lunch breaks, etc. did not affect sample grading times.

	Time to complete grade			
	Runner/spanish type		Virginia type	
No. inspectors	Current system	Automated system	Current system	Automated system
	----- min. -----		----- min. -----	
2	14.7	15.8	18.2	
3	9.6	9.4	12.4	12.0
4	9.0	7.6		11.0
5	8.0	7.0		

Additional economic savings may result but are difficult to quantify. For example, implementing the automated system reduces errors in recording peanut quality factors, resulting in better management decisions about subsequent handling of the crop. The impact of more accurate grading on management decisions at the buying point includes better drying practices since MC is more accurately recorded, and fewer problems during storage since lots with excess FM are more accurately determined

Truckloads of peanuts often are regraded (nonofficial) when the bulk storage warehouse is unloaded. This grade is known as the "bale-out" grade and is used as a guideline for setting shelling plant parameters. If the automated grading system is used to obtain the bale-out grade, then the more accurate grade information should provide more precise measurement of quality factors to assist in setting sheller parameters and better segregation of inedible peanuts since damaged kernel calculations are more accurate. All these benefits should help the peanut industry reduce operating costs and improve peanut quality reaching consumers.

Aflatoxin in edible peanuts is affected by segregation, drying, storage, and sorting after shelling. Current marketing regulations require testing all edible raw shelled peanuts for aflatoxin. Lots failing the test must be blanched, remilled, or rendered inedible. If an improved farmers stock grading system reduces the number of lots failing aflatoxin tests by 1/10, then an average buying point will save approximately $1000 per year.

The total savings to an average 4500 t/yr buying point through eliminating grading mistakes, eliminating data keypunching, eliminating checking forms, eliminating duplicate forms, and reducing aflatoxin in edible peanuts could exceed $10,350. Thus, if the automated system replaces existing manual system, an average buying point could realize a return on their investment during the second year of use. When projected across the entire peanut industry, implementing the automated grading system could save the U.S. peanut industry from $1 to 6 million annually depending on the types of errors occurring at each buying point. Hopefully this estimate is conservative since the improved grading system should increase quality to consumers, thus increasing demand for U.S. peanuts.

Summary and Conclusions

An automated system developed for peanut grading rooms reduced the variability in measuring most grade factors and in calculating lot value. The automated system reduced inspector labor by reducing or eliminating recording, calculating, and checking grade data, hand shelling, and hand cleaning samples. The automated system reduced inspector error by simplifying the grading process and eliminating opportunities for mistakes to occur. Implementing the system could result in a return of about $10,350 annually per buying point and save the entire U.S. peanut industry up to $6 million annually. In addition, the quality of peanuts reaching consumers should increase since quality is more accurately measured, which results in better decisions about segregating, storing, and shelling.

If the automated system is implemented, any adjustments to the loan schedule will likely require additional data from future testing. Additional research to reduce sampling error and measure additional quality factors, such as toxin levels or single kernel moisture variability, is needed. The peanut industry is currently considering implementing the automated system and research that addresses industry questions about implementation should continue.

Acknowledgments

The author thanks Hank Sheppard, Engineering Technician, Larry

Dettore, Engineering Technician, and Sandra Bowen, Computer Technician for their help in developing and testing the automated grading system. The author also thanks the National Peanut Foundation, the American Peanut Shellers Association, and the Georgia Peanut Commission for funding, and the USDA ARS Market Quality and Handling Research Lab, the USDA AMS Statistics Branch, and the USDA AMS Fruit and Vegetable Division for their assistance in testing and developing specifications.

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Accepted 5 March 1996