Computer Aided Bucking on a Mechanized Harvester

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ABSTRACT

During June 1989, researchers from the Forest Engineering Department at Oregon State University evaluated the feasibility of using the computer program BUCK® to aid the Hahn Harvester operator in determining the best bucking cuts.

The computer was able to increase the total value by 7.5%. This is about US $6.40 per tree for the 38-cm [15-in] diameter trees we processed. This increase was from improved log quality and increased scaling volume when Scribner rules were used. The computer solution cuts roughly 16% more logs. The computer solution increased the volume in the best export sort by 8%.

The computer solution could increase the total value by 19.6% if more accurate tree quality information were sent to the computer before the bucking cuts were made.

Key words: *Optimal bucking, computerized decision making, merchandizing logs, mechanized processing, sortyard.*

ACKNOWLEDGMENT

This is Paper 2645 of the Forest Research Laboratory, Oregon State University.

INTRODUCTION

Recent studies [1] suggest that computer-aided bucking at the stump can increase the net value of harvested timber by cutting log lengths that maximize quality (log grades) and volume (scale). The bucking decisions take harvesting and hauling costs into account. Computer-aided bucking is especially effective if there are several potential buyers because prices and specifications of each buyer can be compared to allow the best allocation of cuts. This careful merchandizing is important in view of recent export markets, where the same quality logs are often sold for as much as twice the value per one-thousand board feet (mbf) as in the domestic market.

This study describes computer-aided bucking under current Pacific Northwest conditions, where some second-growth trees can be transferred whole to a central processing area. Trees are then delimbed and bucked by mechanized equipment. From input on stem size, quality, and market conditions the BUCK® program specifies where cuts should be made in order to obtain the greatest value from the logs. Similar work on optimizing bucking during delimbing is reported from Scandinavia by Sondell [2] and from New Zealand by Twaddle [3]. In its 1988 Work Program the Forest Engineering Research Institute of Canada states that it is developing a delimbing bucker optimizer.

A study of the feasibility of using BUCK® as an "on line" process for delimbing and bucking was made possible by the cooperation of an industrial operator using a Hahn Harvester in a field study in spring 1989. Before any cuts are made BUCK requires inputs on tree diameter at 6-m [20-ft] intervals, surface quality, and mill specifications. Two methods of obtaining diameter estimates were tested. The first method involved moving the entire stem past the diameter encoder. The second method involved measuring the diameter 4.6 m [15 ft] from the butt and estimating the remaining diameters from a taper equation. This initial reading corresponds to the present location of the diameter encoder when the stem butt breaks the light barrier. If BUCK® could recommend bucking cuts with only this information, no additional repositioning of the log would be required. Surface quality grades would be based on visual estimates by the operator.

Our study focused on five main issues:

1. How much extra time is required when the computer-aided program (BUCK®) is used?
2. Can diameter at various locations along the length of the tree be estimated from taper equations?
3. How does the harvester's accuracy in measuring diameter and length affect bucking decisions made by the computer?

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4. Can the operator assess the quality of the tree from the cab?
5. What increase in value is possible with the aid of BUCK®?

STUDY DESCRIPTION

One hundred thirty-five trees were sidetracked from the main production stream to an adjacent area and identified with numbered tags. Researchers then measured and recorded the diameters of each tree at 1.5-m [5-ft] intervals starting at the butt and ending at a top diameter of 10 cm [4 in]. The entire length of the tree was assigned to one of four surface-quality categories. If the tree needed to be bucked to eliminate butt swell or rot, or to minimize the effect of sweep, then the "must buck" location was recorded. This information served as the control for any subsequent measurements.

Trees were then processed by the Hahn Harvester operator as follows. After a tree had been placed on the horizontal bed of the harvester, a set of delimbing knives passed along the bole to shear or break off the limbs. The operator, aided by a digital display of diameter and log length to be cut, chose where to activate the bucking saw.

Time Study

To determine the additional time required to make diameter measurements for BUCK®, the harvester operator was asked to pass the complete length of the tree past the diameter-measuring device (located near the bucking saw position). The tree was then retrieved and bucking was performed in the normal manner. If diameters are obtained in this way, time is an additional cost that needs to be deducted from the potential savings gained from optimal bucking.

Taper Equation Estimates

Diameters at 1.5-m [5-ft] intervals were measured with calipers on 33 trees. Data from eight of these trees were used to calculate the parameters for a standard taper equation. The diameters on the remaining 25 trees were estimated from the equation and then compared with actual diameters.

The taper equation selected is a modified version of an equation in Walters and Hahn [4], where Y is the ratio of diameter differences used to predict d_i in the equation,

$$Y=(d_i-d_m)/(DIB-d_m) =(H-h_i)H+A_1(H^2-h_i^2)h_i/(H^2*(DIB-d_m)) \quad (1)$$

where H=height from 4.6 m [15 ft] to merchantable top

h_i =distance above 4.6 m where diameters were measured

d_m=diameter at merchantable top

d_i =diameter at distance h_i

DIB=diameter at 4.6 m

A_1=regression coefficient

H was estimated using the quadratic form:

$$H=B_0+B_1(DIB-d_m)+B_2(DIB-d_m)^2 \quad (2)$$

where B_0, B_1, B_2 are regression coefficients.

The equations (1) and(2) were selected because they could be regressed by a linear least squared program.

B_0, B_1, and B_2 should be estimated each time a significant change occurs in the size and form class of trees arriving at a processor, on the basis of measurements on a small sample of trees (ca 10). These coefficients provide an estimate of H, which is then used to calculate A_1.

Diameter, Length, and Surface Quality

Diameters and lengths of 89 butt logs were recorded from the digital display on the console in the machine cab of the Harvester while logs were being processed. Measurements were later checked with a logger's tape in a roll-out area. Inside bark diameter of the face of the small end was averaged for two directions.

Four categories of surface quality were relevant for the grade sorts of the timber being processed. A researcher experienced in assessing surface quality worked alongside the full-time log quality personnel in the sort yard until he was proficient. He then assigned surface quality to the 135 trees spread out in the roll-out area. When trees were processed through the Hahn harvester, the same researcher, sitting in the cab, assigned surface quality to each tree as it passed before him. These qualities combined with lengths and diameters determine the sort categories. An example of the export sorts in order of descending value (the actual prices are confidential) are shown in Table 1:

Table 1. Quality and dimensions of export categories.

Sort	Quality	Diameter (cm [in]) Min	Max	Length (m [ft]) Min	Max
S	1	30[12]	76[30]	11[36]	12[40]
	1	30[12]	76[30]	8.5[28]	10.5[34]
	1	30[12]	76[30]	8[26]	8[26]
I	2	30[12]	76[30]	11[36]	12[40]
Sx (3SM)	2	20[8]	28[11]	11[36]	12[40]
	2	20[8]	28[11]	8[26]	10.5[34]
Tri	3	20[8]	76[30]	11[36]	12[40]
	3	20[8]	76[30]	10.5[34]	10.5[34]
Peewee	3	15[6]	18[7]	11[36]	12[40]
Mini	3	10[4]	13[5]	11[36]	12[40]

Comparison of Value

A sample of 25 trees was used to compare the value received from three different methods of bucking: 1) "As bucked"—how the operator actually bucked the trees; 2)"Taper equation"—how the BUCK® program would have bucked them based on diameters from the taper equation and quality judgements from the cab; and 3)"Roll-out"—how the BUCK® program would have bucked them based on actual diameters and surface quality assessed at the roll-out area. When using BUCK®, if the operator cut out cull sections or 2.7-m [9-ft] butt logs, these were forced into the solution with the "must buck" option on the computer. The program then optimized the rest of the tree, subject to these predetermined bucking cuts. The third method represents the ideal situation where accurate information is available. In reality, the input information is never completely accurate.

RESULTS

Time Study

If the taper equation approach for estimating diameters is unsatisfactory, then direct measurement will be used. A time study was conducted to estimate the additional cost of this direct measurement method.

Average characteristics of the 52 trees used in the time study were:

butt diameter	38 cm [15 inches]; range 23-56 cm
merchantable length	24 m [78 feet]; range 17-31 m
top diameter	15 cm [6 inches]
number of bucking cuts	2.7

Thirty-four trees were processed by the current method and 18 were subjected to procedures required by the BUCK® optimizer program. Average time in minutes per tree for the two methods was:

	CURRENT METHOD	BUCK
loading	0.22	0.22
measuring	-	0.40
repositioning	-	0.29
processing	1.08	0.76
Total	1.30	1.67

Processing time for BUCK® trees was less because much of the delimbing had occurred during measuring and repositioning. BUCK® total time required an additional 0.37 min per tree (29% increase), which was significant at the p =.005 level. Hahn currently processes 460 cycles per 10-hour shift. This would be reduced to 360 cycles if the additional measurements were made with the existing instrumentation. About 8% of the cycles processed more than one tree (from two to five) so that an average of 1.2 trees were processed per cycle.

Based on a total system hourly cost of US $66 per hour, using BUCK® cost US $1.53 compared with current costs of US $1.19 per tree. If an additional measuring device were mounted on the frame at the point where the delimbing grapple first grabs the tree, then measurement travel (average of 30 m [99 ft]) and the reposition travel (average of 19 m [63 ft]) could be eliminated. Installation would probably cost about US $15,000. This investment would be recovered in 6 months by the elimination of the additional measurement cost of US $.34 per tree.

Taper Equation Estimates

For each of the 25 trees, the diameter DIB (inside bark diameter at 4.6 m [15 ft]) was recorded. DIB was used to estimate H. DIB and H are then used to estimate the remaining diameters at approximately 6-m (20-ft) intervals along the tree stem. When these estimates were compared with the previous caliper measurements, the taper equations did an excellent job of predicting the diameters. In 90% of the cases the error was 1.3 cm [0.5 in] or less. This is within the range of accuracy needed by BUCK®, where the input diameters are to the nearest inch. The use of taper equations to predict diameters eliminates costs associated with measuring and repositioning.

Accuracy of the Hahn Harvestor Length and Diameter Measurements

Because of rot, butt swell, or sweep, the operator cut cull sections of from 0.3 to 1.2 m [1 to 4 ft] from 38% of the trees. An additional 18% of the merchantable logs were 2.4-m [8-ft] merchantable "long butts" cut for similar reasons. The operator cut 73% of the merchantable butt logs in the 11- to 12-m [36- to 40-ft] preferred-length range. The rest of the merchantable butt logs (9%) were in 3- to 10.5-m [10- to 34-ft] lengths.

The measuring device started measuring at 4.6 m [15 ft], so the "long butts" length was estimated by a mark on the machine rather than by the digital readout. The target trim length on the long butts was 0.27 m [0.9 ft]. The actual cut length averaged 0.07 m longer [0.23 ft] (SD, 0.13 m [0.43 ft]).

The target trim on longer logs was 0.2 m [0.7 ft], with the actual cut 0.03 m longer [0.11 ft] (SD, 0.06 m [0.21 ft]). On longer logs, a diameter comparison was possible. The actual face diameter averaged 0.5 cm [0.19 in] less than the digital readout (SD, 1.5 m [0.61 in]). Differences in measurement were caused by bark irregularity, knot stubs, or non-symmetrical cross-sections, and were too small to affect the optimizing procedure.

Assigning Surface Quality

Figure 1 compares quality assignments for 25 trees. When in the cab, the researcher tended to upgrade too much of the tree's length to categories 1 and 3. The distinction between quality 1 and 2 depends on ring count. This cannot be assessed from the cab, which leads to misclassification of quality 2 logs. Some quality 3 should have been quality 4. The higher knot frequency of a quality 4 was visually "masked" or minimized due to the high travel speed of the stem, which created an illusion of a quality 3 surface.

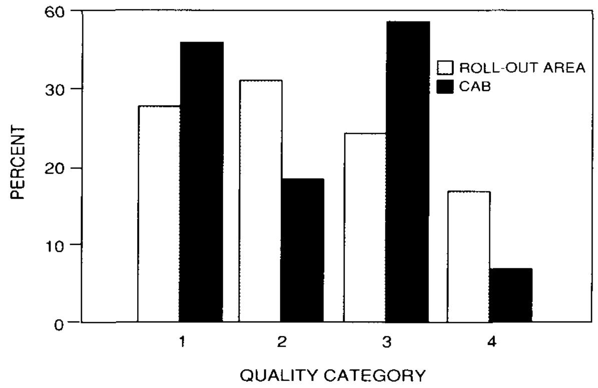

Figure 1. Quality estimates for 25 trees at the roll-out area and from the cab.

Comparison of Value

Grades are assigned according to surface quality, ring count, diameter, and lengths. Export and domestic grades are listed separately below, roughly in order of their value in US $/m^3[$/mbf]. The value ranged from US $254/m^3[US $600 per net mbf] for the best export down to US $74/m^3[US $175 per net mbf] for chips.

The relationship of the value of the grades is:
- Export grades: S > I > Sx(3SM) > Tri > Pewee
- Export grades > Domestic grades
- Domestic grades: 2 Saw > 3 Saw > chip

As shown in Table 2, the taper case had a 5.8% increase in total volume over the as-bucked case. The roll-out case had an 11.1% increase. As-bucked, taper and roll-out cut 64, 74 (16% increase), and 78 (22% increase) logs, respectively. The increase in volume is partly due to cutting more (shorter) logs, to take advantage of scaling rules.

The computer aided solutions were able to shift volume upward from the "Tri" grade into the "I" and "S" grades. The price differential between these grades is from US $34/m^3 to US $85/m^3 [US $80/mbf to US $200/mbf], so this volume shift produces a significant improvement in total value.

The taper case had a 7.5% increase in total value (Table 2) compared with the logs as they were actually bucked. This came from an increase in the total volume (mainly in domestic grades) and from the upgrade of export logs. The roll-out case had a 19.6% increase in the total value compared to the as-bucked logs. This increase came mainly from changes in the

Table 2. Log mix comparisons showing percentage sort obtained from 25 sample trees.

SORTS	AS-BUCKED	TAPER	ROLL-OUT
Export			
S[36'-40']11m to 12m	-	3.3	3.2
S[28'-34']8.5m to 10.5m	2.4	7.2	4.6
S[26']8m	-	-	4.6
I[36'-40']11m to 12m	8.5	8.8	14.3
Sx[36'-40'](3SM) 11m to 12m	21.7	19.5	19.6
Sx[26'-34'](3SM) 8m to 10.5m	-	2.9	4.2
Tri[35'-40']11m to 12m	32.2	22.7	15.4
Tri[34']10.5m			
PEEWEE[36'-40']11m	3.2	0.9	0.9
to 12m	1.0	0.9	0.9
MINI[36'-40']11m to 12m			
TOTAL EXPORT			
(percent)	69.1	66.2	67.7
(volume)	[4290 BF] 10.12m^3	[4350 BF] 10.27m^3	[4670 BF] 11.02m^3
Domestic			
2S[36'-40']11m to 12m	-	-	-
2S[26'-34']8m to 10.5m	-	-	-
2S[12'-24']		0.9	0.9
3S[36'-40']11m to 12m	8.7	11.7	8.3
3S[26'-34']8m to 10.5m	6.3	0.6	10.0
3S[12'-24']3.5m to 7.5m	4.3	8.2	5.4
[8']2.5m	6.9	6.8	5.2
CHIP	4.7	5.5	2.6
TOTAL DOMESTIC			
(percent)	30.9	33.8	32.3
(volume)	[1920 BF] 4.53 m^3	[2220 BF] 5.24 m^3	[2230 BF] 5.26 m^3
All mills			
(percent)	100.0	100.0	100.0
(volume)	[6210 BF] 14.65m^3	[6570 BF] 15.51m^3	[6900 BF] 16.28m^3

export logs. More export volume was bucked and better grades were obtained.

Individual Tree Values

The roll-out solution had a value improvement on all but one of the 25 sample trees, and the taper equation solution had improvements on over one-half of the trees (56%) (Table 3). The remaining trees either showed no improvement or lost value when compared with the actual logs that were bucked.

Table 3. Comparison of Individual Tree Values in US $.

TREE NUMBER	AS-BUCKED	TAPER SOLUTION	ROLL-OUT SOLUTION
1	$81	$88	$104
2	$73	$62*	$81
3	$163	$187	$187
4	$21	$21*	$32
5	$60	$65	$79
6	$89	$81*	$92
7	$25	$33	$33
8	$122	$151	$160
9	$117	$118	$118
10	$81	$80*	$84
11	$47	$57	$59
12	$84	$101	$115
13	$22	$39	$39
14	$60	$75	$79
15	$99	$146	$163
16	$63	$68	$74
17	$132	$143	$139
18	$179	$194	$196
19	$68	$60*	$68*
20	$73	$67*	$81
21	$125	$122*	$151
22	$61	$61*	$69
23	$77	$77*	$101
24	$117	$110*	$151
25	$93	$86*	$95
TOTAL	$2132	$2292	$2550
% INCR.	--	7.5%	19.6%

*indicates no improvement over As-Bucked solution

Overall this solution showed a 7.5% (US $6.40/tree) increase in net value over the operator's bucking solution.

EXAMPLES OF THE "BUCK®" COMPUTER SOLUTION IMPROVEMENTS

The actual logs cut from three representative trees are shown, with the computer solution for the same trees to illustrate how increases in volume, grade, and total value are accomplished (Table 4). It is not likely that an operator could make these improvements unaided, since they involve a complex set of log combinations that are unique for any given tree. Processing costs have been subtracted from the value.

In Tree #1, BUCK® took advantage of scaling rules by getting more volume from an increased small-

Table 4. Comparison between BUCK® and actual cut for three trees.

Tree		length m[ft]	diameter cm[in]	volume m^3[b.f.]	grade	value US $
1	BUCK®	11[36]	38[15]	.75[320]	I	
		11[36]	25[10]	.33[140]	3 saw	
		3.5[12]	18[7]	.05[20]	3 saw	
		4.0[14]	10[4]	.05[20]	chip	
	Total	29.5[98]		1.18[500]		187
	Actual	12[40]	36[14]	.68[290]	I	
		9[30]	25[10]	.26[110]	3 saw	
		5.5[18]	15[6]	.05[20]	3 saw	
		3.0[10]	10[4]	.03[10]	chip	
	Total	29.5[98]		1.02[430]		163
2	BUCK®	11.5[38]	23[9]	.26[110]	Sx(3SM)	
		9[30]	15[6]	.09[40]	3 saw	
		4.0[14]	10[4]	.05[20]	chip	
	Total	24.5[82]		.40[170]		59
	Actual	12[40]	20[8]	.21[90]	Sx(3SM)	
		11.5[38]	10[4]	.14[60]	chip	
	Total	23.5[78]		.35[150]		47
3	BUCK®	8.5[28]	30[12]	.33[140]	S	
		8.5[28]	23[9]	.17[70]	Sx(3SM)	
		6.5[22]	18[7]	.09[40]	chip	
	Total	23.5[78]		.59[250]		115
	Actual	12[40]	25[10]	.35[150]	Sx(3SM)	
		11.5[38]	18[7]	.17[70]	chip	
	Total	23.5[78]		.52[220]		84

end diameter for the first log, and again for the next two logs. In Tree #2, BUCK® again used scaling rules to get more volume from the first log. The second log was cut short to obtain a better grade. A third log was made from the remaining chip material. For Tree #3, a major grade increase was made possible by cutting a shorter first log. The second log was also cut shorter to obtain a better grade. The combination of diameter also gave a total volume increase by utilizing Scribner board-foot scale rules. The "chip" grade may be weight-scaled sawlogs or chip material.

On all three trees an extra log was cut, which meant additional handling. The average log length was shorter for the computer solutions. The increased volume due to scaling rules only increases the real value of the logs if they are sold. The grade increases are a result of bucking logs near spots where the quality of the tree changes. In this way the log buyer is charged for the high quality portion because it is not combined in the same log with a small fraction of lower quality log, which would have been purchased entirely at the lower quality log price.

DISCUSSION

Our results are specific to second-growth coastal Douglas-fir. Different limb characteristics would significantly affect repositioning and processing time. The delimbing grapple traveled at a variable speed of from 0 to 183 m [0 to 600 ft] per min. The grapple had to grasp the tree several times because it had a maximum travel limit of 11 m [36 ft]. Sometimes it made more than one pass over the same spot to achieve delimbing, but this did not slow it down. Many of the limbs were already broken off by the time the stem was placed on the bed of the harvester, and those that were removed by the grapple snapped off with little resistance.

Two of the 20 stems processed broke during repositioning. This breakage presumably can be avoided as the operator gains skill. No penalty cost was assigned to compensate for the value loss incurred from this breakage, and times were averaged on the remaining 18 trees.

The analysis in this study was done on office computers, but to make the system functional an onboard computer would have to be designed. Length and diameter measurements from digital readouts or from taper-equation estimates would be fed directly to the computer. The operator would key in quality codes to correspond with changes along the stem. The computer program would then find the best bucking solution and display it. The operator would be able to override this solution if he wished. Bucking cuts could then be made either by the operator or by an automated process. The level of technology required to implement this process is within the capability of many companies.

The computer solution suggested cutting 11-m [36-ft] logs to take advantage of grade changes along the stem, whereas the operator tended to cut 12-m [40-ft] lengths. Judging surface quality is one area where improvement is needed. If the operator could be trained to recognize surface quality changes more exactly, he could cut 11- or 11.5-m [36- or 38-ft] logs where appropriate.

Butt logs bucked by the operator were almost exclusively 12 m [40 ft] long and were usually of exportable quality, resulting in 96.5% of the export volume being in 11- to 12-m [36- to 40-ft] preferred lengths. The two computer aided solutions on the other hand tended to cut 11-m [36-ft] butt logs. This increased the small-end diameter, which often upgraded the log because of a larger diameter and also better surface quality. The taper equation had 82.1% of the export volume in the 11- to 12-m [36- to 40-ft] preferred-length range. The roll-out measurements method had 77.5% of the export volume in the preferred lengths.

The difference between the total value of the roll-out measurements and the taper equation was mainly due to inaccurate quality input. The computer was dictating cuts on the basis of faulty input, which resulted in logs dropping a grade in many cases. The diameter and length accuracy, on the other hand, was good enough that the computer only rarely made a poor bucking choice because of a wrong diameter or length.

Diameters displayed by the harvester were compared with roll-out area scaling diameters of the sample butt logs. In 77% of the cases they shared the same scaling diameter class. In 14% of the cases display readout overestimated scaling diameter by an average of 2.5 cm [1 in], which could be due to outside bark readings. Underestimation, probably due to stems not being round, occurred on 6.5% of the logs.

SUMMARY

1. Repositioning stems to have data for the BUCK® optimizer program took an additional 0.37 min. per tree, which is a 29% increase. This could be greatly reduced or eliminated if an additional measuring device were installed, or if the computer were programmed to predict diameters from taper equations.

2. A taper equation, generated by regression analysis from the dimensions of the first 8 trees, was used to predict diameters at 6-m [20-ft] intervals for the next 25 trees. When predicted diameters were compared to actual measurements, 90% were within 1.3 cm [0.5 in]. This is accurate enough for BUCK® input.

3. Lengths measured with a logger's tape in a roll-out area averaged 0.03 m [0.11 ft] longer than those from digital readings. Scaling diameter averaged 0.5 cm [0.19 in] less than the Hahn digital readings. This is within the range of accuracy required by BUCK®.

   Displayed and scaled lengths of the sample butt logs were also compared. With a 25-cm [10-inch] trim allowance, 58% of the logs had adequate trim. The trim deficiencies were caused by uneven butt cuts and adjustment of the desired trim on the length display. Both can be easily corrected through end cutting, monitoring, and adjusting of the displayed trim.

4. The surface quality judgements were made and recorded on the trees prior to processing. The two sets of quality ratings for each tree were then compared (Figure 1). The qualities assigned from the cab operator's view overestimated the percentage of the stems in the top quality by 8%. It underestimated the percentage by 10% for the lowest quality category. This seriously affected BUCK®'s ability to make correct bucking choices.

5. The taper equation case represents the current state-of-the-art. To improve the roll-out case results, a better method of assessing surface quality needs to be devised.

   The taper solution would have cut 82.1% of the export volume into preferred lengths, mainly 11-m [36-ft] logs (Table 1). The actual operation cut 96.5% of the export volume into preferred lengths, mainly 12-m [40-foot] logs.
   The value received from each of the 25 trees for the three cases is shown in Table 2. On 44% of the trees (11 of 25) the taper case did not give an improved solution. In fact, in 32% of the trees (8 of 25), the taper case resulted in a decrease in value. We were not able to identify, a priori, which trees these would be. The roll-out solution gave improved solutions on all but one tree.

   Since "perfect" information of diameters and quality was available from the preprocessing measurements done in a roll-out area, this information was also entered into BUCK®. This would represent the "bench mark target" solution that would be possible if no input errors existed. This hypothetical solution had an 11.1% increase in scale volume.

6. The 7.5% increase in value is possible by implementing current technology. This would give a competitive rate of return on the investment and training dollars. Further developments would be needed in order to achieve the 19.6% increase in total value.

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