# MARKET COMPLEXITY AND ITS EFFECT ON VARIABLES THAT GAUGE THE ECONOMICS OF HARVESTING PRODUCTION

GLEN E. MURPHY, HAMISH MARSHALL,

Department of Forest Engineering, Oregon State University
Peavy 215, Corvallis, Oregon 97331, United States

and IAN CONRADIE

Warnell School of Forest Resources, University of Georgia
Athens, Georgia 30601, United States

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## ABSTRACT

The effect of market complexity in North America and New Zealand was evaluated for five species/market combinations. The number of log-sorts was used as the surrogate for market complexity as the trend in the industry is to increase the number of log-sorts to obtain maximum value by producing products that meet the very explicit specifications set by log buyers. The results of our study suggest that theoretical value-recovery increases sharply as a few log-sorts are added but then flattens out as the total number of log-sorts increases above five. The effect of the number of log-sorts on piece size and number of pieces handled, variables known to affect production and costs, was inconsistent between species/market combinations.

**Keywords**: value recovery; waste; log sorting; costs.

## INTRODUCTION

In many parts of the world log markets are becoming increasingly competitive and complex. Buyers are demanding, and suppliers are offering, logs that have been cut for very specific end-uses; niche markets, not mass markets, are becoming the norm.

At the same time the numbers of characteristics used to specify log-sorts are increasing. Where at one time species, dimensions, and external quality characteristics (such as branch size, sweep, scarring, and decay) may have been sufficient to specify a log-sort, consideration is now being given to specifying such wood properties as stiffness, strength, density, spiral grain, extractives content, and consumption of energy for processing (Andrews 2002; Meder *et al.* 1999; So *et al.* 2002; Walker 2000; Young 2002). For example, Corson (2001) noted that one integrated market-kraft pulp/newsprint operation required its pulp logs to be separated into eight different log grades based on wood density and the process (mechanical pulping or kraft) for which they were destined.

To satisfy the requirements of the different users and to ensure that maximum value and quality are obtained from the raw material, trees must be cut and sorted into a variety of products. If the separation into multiple log-sorts is done in-forest to meet market needs it can have an impact on a range of harvesting production variables such as equipment requirements, value recovery (income derived from the sale of the log products), waste generation, productivity, cost, and landing size. These in turn can affect the economics of the operation.

For complex markets it would be impractical to expect that all stands or all logging crews could provide all log-sorts. Procedures for allocating stands and cutting patterns to multiple logging crews to meet combined market and operational requirements and to obtain maximum economic returns have been described elsewhere (Weintraub *et al.* 1991; Ogweno 1994; Murphy 1998) and are not the focus of this paper.

A conceptual model of the economic effects of number of log-sorts for a single logging crew is illustrated in Fig. 1:

(1) As the number of sorts increases the theoretical or potential gross value-recovery increases rapidly and then plateaus;
(2) Actual gross value-recovery increases then decreases as log-makers have difficulty measuring stems accurately and making decisions on the best products to cut;
(3) Production costs increase for a variety of reasons;
(4) Net value-recovery at first increases and then decreases.

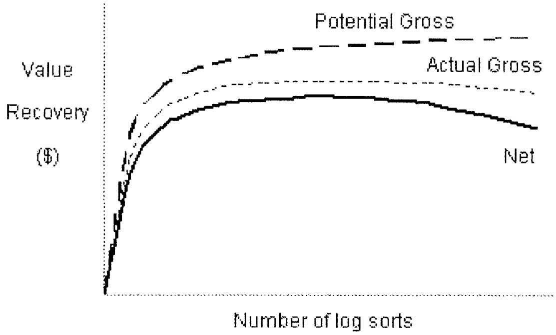


FIG. 1–Conceptual model of the effect of number of log-sorts on potential, actual, and net value-recovery.

This would lead to the expected conclusion that there is an optimal number of log-sorts for each logging crew for a given set of conditions.

Greber & Smith (1986) commented that in order to fully evaluate logging opportunities, it is necessary to look at a wide variety of product specifications, market conditions, and merchandising strategies. In this paper we report the effects of market complexity on selected economic production variables for a range of forest/market types in North America and New Zealand from the perspective of a single logging crew, and see whether there is evidence to support the model shown in Fig. 1. Number of log-sorts is the surrogate we have used for market complexity.

## Literature Review

There are wide differences reported between the numbers of log-sorts handled by individual logging crews. For example, Gingras (1996) described an eastern Canadian crew separating only two log-sorts, but Donovan (1988) described 11 Pacific Northwest United States logging crews whose log-sorts ranged from three to 18. Parker *et al.* (1995) commented that it is not unusual for New Zealand log makers to attempt to produce more than 20 log-sorts at one time.

Blinn & Sinclair (1986) looked into the profitability of various timber-harvesting systems as affected by product sorting and stand parameters. They modelled the impact of three levels of sorting intensity (two, five, and six log-sorts) on productivity, costs, and profitability in 13 aspen/hardwood stands in the north-eastern United States. Profitability was calculated by subtracting costs from potential gross value-recovery, not from actual gross value-recovery. Their model demonstrated that profitability generally increased with sorting intensity, indicating that the increased delivered product value of the expanded product mix exceeded the increase in production costs and the decrease in productivity. They found, however, that the level of profitability was stand-dependent; some stands with small amounts of sawlog material incurred cost increases which exceeded the additional value from sorting this product. They also noted that the impacts of sorting on profitability were affected by the harvesting system used.

Studies on harvesters, delimbers, and processors in eastern Canada over the past decade have provided mixed results. Gingras (1996) reported that there was no noticeable loss in productivity for up to four log-sorts when a single grip harvester was used and that these results were similar to those found in several studies in the Nordic countries. Favreau (1994) noted a similar result in a study of a single grip processor which produced up to six different log-sorts. In a more recent study where piece size and removal intensity were tightly controlled, Gingras & Favreau (2002) found that harvesting productivity decreased around 4% per additional log-sort for cut-to-length systems. This is higher than the 1% per additional log-sort found in studies of cut-to-length systems in Sweden (Brunberg & Arlinger 2001).

Studies of stroke delimbers have shown that productivity of an operation with two log-sorts would be expected to be about 5–10% lower, and costs to be higher, than a single log-sort operation (Gingras 1996).

Gingras (1996) and Gingras & Favreau (2002) noted that forwarder productivity and costs were greatly affected if it had to sort multiple products. They found that forwarding productivity decreased around 6–7% per additional log-sort for cut-to-length operations where extraction distances were about 150 m. They commented that the actual decrease is likely to depend on extraction distance as well as number of log-sorts. Brunberg & Arlinger (2001) reported that studies in Sweden showed decreases of 3–4% in forwarder productivity.

Once stems have been converted into logs they need to be stockpiled at the roadside, on landings, or in a central sortyard. Costs of handling logs are a function of average piece size and variability (McNeel & Nelson 1991); the smaller the piece, the higher the cost per tonne. Raymond (1988) also indicated that productivity and costs are dependent on the number of log-sorts, their layout, and how efficient the truck scheduling is. He stated that "the solution to the multiple log-sort problem is in improving truck scheduling, thus enabling an efficient layout to be maintained".

Construction of landings for stem processing and/or temporary storage of logs is also a cost to the forest owner, either in direct terms at the time of harvesting or indirectly in terms of land taken out of future production if the landings are permanent. The bigger the landing, the higher the cost. Hampton (1981) noted that the area required for temporary storage of log products in a dry-land log sortyard is affected both by the number of different log-sorts to be piled and the variability in their lengths (random log ends waste space). The same is true of log landings in New Zealand plantation forests. Raymond (1987) reported that there was a linear relationship between landing sizes in New Zealand and number of log-sorts. He found, for example, that a landing where 10 log-sorts were processed and stored required about three times the area of a landing with one log-sort. Donovan (1988) provided data on Pacific Northwest landings that also showed a trend for increasing landing size with greater numbers of log-sorts. Compared with Raymond's results, the landing size/log-sort relationship for the Pacific Northwest landings was weaker, the rate of increase was smaller and the landing sizes themselves were smaller. This was due primarily to the fact that the Pacific Northwest logs were cut to length at the stump prior to extraction whereas the New Zealand logs were cut to length on the landing.

Costs are only part of the profit equation. Delivered product value is another important component. The number of value-recovery studies reported has been steadily increasing over the past two decades (Murphy 2003). We have an improved understanding of the effects of such factors as tree size, species, markets, harvesting systems, processing location, and human variables on value recovery. However, there have been very few studies that have attempted to determine the effect of number of log-sorts on value recovery. One of the few was conducted by Parker *et al.* (1995) who studied eight log-makers to determine the effect of number of log-sorts on log-making errors. The number of log-sorts ranged from six to 19. They found that there was an increase in the number of log-making errors if more than 10 log-sorts were used. Harris & Chaney (1969) have noted that the detection of defects in inspection tasks declines as the task becomes more complex. Although not specifically stated in the report by Parker *et al.* (1995), it could be deduced that log-making errors would have had a negative impact to the extent that actual value-recovery beyond 10 log-sorts would have remained static or possibly even decreased.

Gingras & Godin (1997) found that sorting errors were greater for a three-way log-sort than a two-way log-sort in an eastern Canadian pulpwood operation. They noted, however, that the differences were due to a species mix in the three-way log-sort that was slightly different from that in the two-way log-sort operation.

In a value-recovery study carried out in second-growth forests in coastal British Columbia, Young (1998) found value losses of 3.4% and 7.2% for mechanised processing operations with five and seven log-sorts respectively. He also found a value loss of 2.2% for a manual processing operation with 12 log-sorts. Murphy (2003) has reported that average value loss from 39 audits of mechanised operations was about twice that of 48 audits of manual processing operations — approximately 20% *vs* 10%.

Waste wood produced from log-making at landings is made up of branches cut from the stem and of pieces of solid wood sections such as slovens, small-diameter head sections, and low-quality mid-stem sections. Hall (1994) reported that waste accounted for 2.5% and 4.7% respectively of extracted volume for ground-based and cable-logging operations studied in New Zealand. He also commented that waste on landings can be costly to dispose of and, if left on site, can provide a breeding ground for insect and pathogen pests, can be a fire and debris-slide risk, and is perceived as unsightly and wasteful by the public. Hall (1999) later summarised results from another 56 studies and noted that waste on landings was affected by the log-making system used; mechanised log-making produced more waste than did manual or computer-optimised log making. He did not comment on the effect of number of log-sorts on waste generation.

# METHODS

## Tree Stem Data Sets

Stem data from four tree species were used in the analyses. The data were collected from a *Pinus ponderosa* P.Lawson et Lawson stand in eastern Oregon, two *P. taeda* L. stands in Alabama and Georgia, a *P. radiata* D. Don forest in New Zealand, and a *Pseudotsuga menziesii* (Mirb.) Franco stand in southern Washington. The stands are listed here in order of increasing tree size removed.

One hundred *Pinus ponderosa* trees were selected from a thinnings stand which had an average 27 cm dbh, an average stocking of 415 stems/ha prior to thinning and 102 stems/ha post-thinning. Average volume for the selected trees was 0.35 $m^3$.

Sixty *P. taeda* trees were selected from a thinnings stand in Alabama. The selected trees averaged 25 cm dbh. No information is available on average stocking. Average volume for the trees selected for the study was 0.58 $m^3$.

Sixty-one *P. taeda* trees were selected from a clearfell stand in Georgia. The selected trees averaged 31 cm dbh. No information is available on average stocking. Average volume for the trees selected for the study was 1.02 $m^3$.

One hundred and five *P. radiata* trees were selected from pruned clearfell stands in the central North Island of New Zealand. The trees were selected to represent a stand with an average 47 cm dbh and an average stocking of 320 stems/ha. Average volume for the selected trees was 2.28 $m^3$.

One hundred *Pseudotsuga menziesii* trees were selected from a clearfell stand in Washington which averaged 46 cm dbh and had an average stocking of 273 stems/ha. Average volume for the trees selected for the study was 2.35 $m^3$.

After felling, each tree was measured in detail for taper and changes in quality along the tree stem, using procedures that have been used for value recovery audits in New Zealand for the past two decades (Forest Research Institute 1995). A tape was used to measure lengths and a caliper was used to measure diameters along the stem.

## Markets

Each stand had a different initial market scenario, with varying numbers of log-grades which could have multiple lengths. We define a log-sort as a log-grade of given length/s. Number of log-sorts ranged from five to 17. For ease of reference the stand/market combinations will be referred to as the "market", e.g., the *Ps. menziesii* market.

The *P. ponderosa* market included three log-grades, and lengths ranged from 2.4 to 6.7 m. The highest-value log-grade was a saw log with a value of US$62/$m^3$. The lowest-value log-grade was a chip log with a value of \$4/m$^3$. We split the *P. ponderosa* market into seven log-sorts based on grade and length.

The *P. taeda* market for the Alabama stand included four log-grades, and lengths ranged from 3.0 to 6.1 m. The highest-value log-grade was a ply log with a value of US\$35/m$^3$. The lowest-value log-grade was a pulp log with a value of \$2.50/m$^3$. We split this *P. taeda* market into five log-sorts based on grade and length.

The *P. taeda* market for the Georgia stand included three log-grades, and lengths ranged from 3.6 to 6.2 m. The highest-value log-grade was a saw log with a value of US\$31/m$^3$. The lowest-value log-grade was a pulp log with a value of \$2/m$^3$. We split this *P. taeda* market into six log-sorts based on grade and length.

The *P. radiata* market included 12 log-grades, and lengths ranged from 3.7 to 12.2 m. The highest-value log-grade was a pruned export log with a value of US\$76/m$^3$. The lowest-value log-grade was a pulp log with a value of \$4/m$^3$. We split this *P. radiata* market into 17 log-sorts based on grade and length.

The *Ps. menziesii* market included nine log-grades, and lengths ranged from 3.6 to 12.2 m. The highest-value log-grade was an export saw log with an average stumpage value of US\$157/m$^3$. The lowest-value log-grade was a pulp log with a value of \$22/m$^3$. We split the *Ps. menziesii* market up into nine log-sorts based on grade and length.

The market scenarios used were relevant to the areas where the stands were located at the times the data were collected. For all five stands, however, we assumed that markets were not constrained by demand — i.e., all log-sorts could be supplied in unlimited quantities.

## Optimal Value Recovery Assessment

Two computer programs were used to determine the optimal value for the selected trees based on detailed stem measurements and the markets described above. PCAVIS was used for the value-recovery assessments in New Zealand and Georgia (Forest Research Institute 1995), and a new value-recovery optimisation system being developed at Oregon State University was used for the assessment in Oregon and Washington.

The following procedure was used for each stand. The full complement of log-sorts was included in the initial analysis. We then dropped one log-sort at a time and re-ran the analysis repeatedly until a single pulp or chip log-sort was left. Selection of the log-sort to be dropped was based on the least contribution to total value at the end of each run. The only exception to this rule was that the highest value pulp log-sort was always included in the list of log-sorts. The aim of this exception was to minimise waste generation. It is possible, however, that selecting a different log-sort to be dropped, other than the one with the least contribution to total value, may have resulted in a higher value recovery than we found. The implication of this happening is that fewer log-sorts than we have shown may have been required to obtain a given level of value recovery. Our value-recovery figures may be conservative.

It should be emphasised that the value recovery used in the analysis was a theoretical optimal recovery. Value-recovery audits of actual logging operations show that log makers may recover optimal value on some stems but rarely recover optimal value on all stems.

## Economic Production Variables

Five variables were recorded after each computer run: dollar value recovery, waste volume, number of merchantable logs, average piece size, and coefficient of variation for log lengths. Dollar value recovery and number of merchantable logs were normalised for individual stands, based on the full complement of log-sorts.

Value recovery provides a direct measure of the economics of production. The other four variables provide indirect measures. Waste is a measure of raw material utilisation and of cost if the waste has to be re-handled for slope stability or re-establishment reasons. Number of pieces to be handled and average piece size both affect sorting and loading costs. Length variation affects the area required for landings and the cost of log handling.

# RESULTS

## Value Recovery

Because of tree size and log price differences, there were very large variations in the theoretical value for the five markets. As an indicator of these differences the value per tree, for a full complement of log-sorts, was about US$12 for the Alabama *P. taeda* market, about US$13 for the *P. ponderosa* market, about US$26 for the Georgia *P. taeda* market, about US$89 for the *P. radiata* market, and about US$283 for the *Ps. menziesii* market.

At least 95% of the normalised, theoretical, value recovery for these five markets was obtained with five or fewer log-sorts (Fig. 2). Increasing the number of log-sorts to as many as 17 resulted in a small increase in value recovery. The major increases came from adding domestic or export grade saw log-sorts or plywood log-sorts.

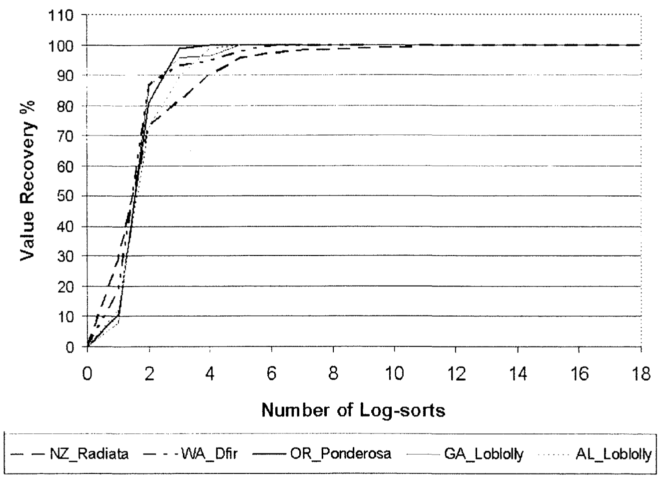


FIG. 2–Effect of number of log-sorts on theoretical value recovery

## Waste

For four of the five markets there was a general trend for waste to increase as the number of log-sorts increased. Waste ranged from zero percent of total wood volume up to about

4.25% (Fig. 3). The trend was not always non-declining, however; sometimes adding a log-sort would result in a decrease in waste. The anomaly for the general trend was the Alabama *P. taeda* market where inclusion of a variable length pulp log-sort in combination with sawlogs yielded zero waste for all combinations of log-sorts.

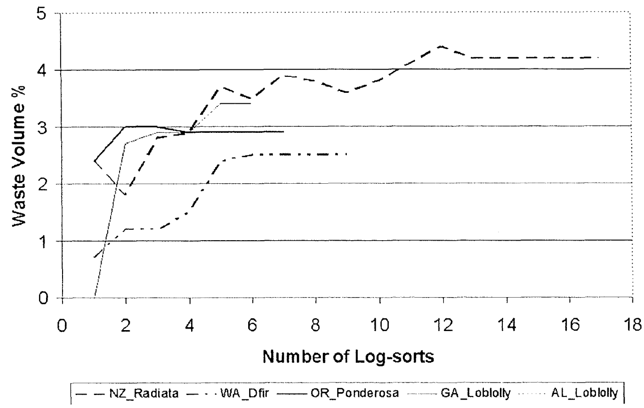


FIG. 3–Effect of number of log-sorts on waste.

## Number of Merchantable Logs

There was no clear trend for the effect of number of log-sorts on the number of merchantable logs cut from each stand (Fig. 4). Three of the five markets (Alabama *P. taeda* , *Ps. menziesii*, and *P. ponderosa*) showed an increase in the number of merchantable logs produced while two of the markets (Georgia *P. taeda* and *P. radiata*) showed a decrease.

For all five markets, the increase, or decrease, in the number of merchantable logs produced was within 25% of the number of merchantable logs for a single log-sort of pulp.

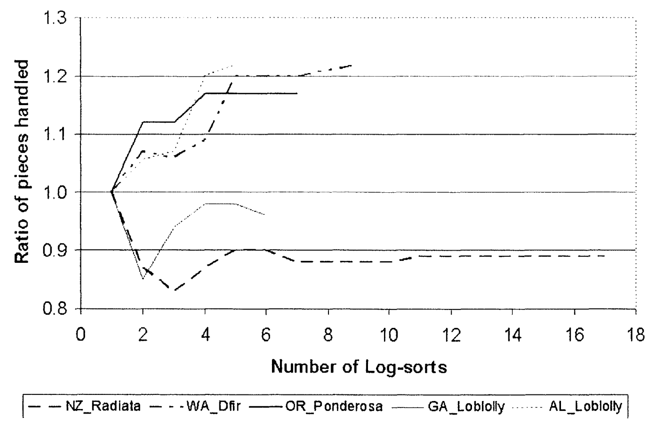


FIG. 4–Effect of number of log-sorts on the number of merchantable logs produced relative to a single log-sort of pulp.

## Average Piece Size and Coefficient of Variation in Log Length

There was no clear trend for the effect of number of log-sorts on the average piece size cut from each stand. In Fig. 5 average piece size for each market is expressed as a ratio of the piece size for a single log-sort of pulp. Two of the five markets (Georgia *P. taeda* and *P. radiata* ) showed an increase in average piece size while three of the markets (Alabama *P. taeda* , *Ps. menziesii*, and *P. ponderosa*) showed a decrease. The increase, or decrease, in average piece size was within 20% of the average piece size for a single log-sort of pulp.

Coefficient of variation (COV) is a standard statistical measure of dispersion about the mean, expressed as a ratio of the mean, and COV for the maximum log lengths tended to increase as the number of log-sorts increased (Fig. 6). The trend was neither consistent nor strong.

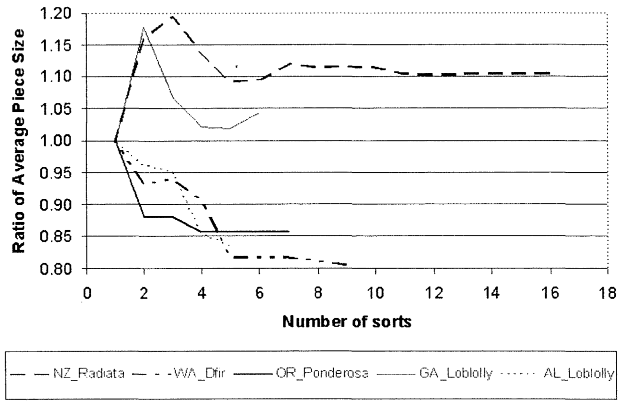


FIG. 5–Effect of number of log-sorts on average piece size relative to the average piece size for a single log-sort of pulp.

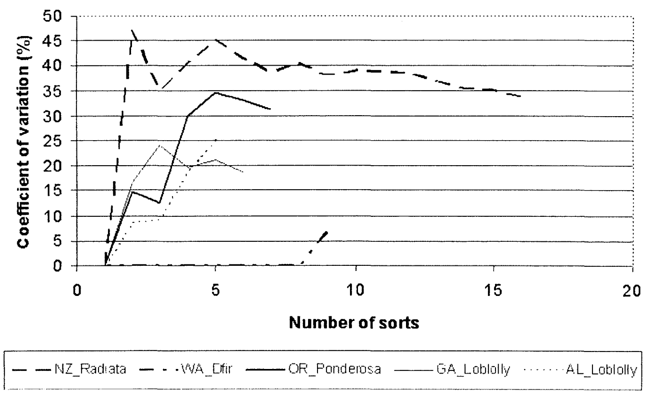


FIG. 6–Effect of number of log-sorts on coefficient of variation of log length.

## DISCUSSION AND CONCLUSIONS

The conceptual model (Fig. 1) suggests that net value-recovery for a single logging crew reaches a maximum at a certain number of log-sorts. After this point any theoretical value-recovery gains made by increasing the number of log-sorts are offset by increases in log-making errors and in processing, extraction, and landing costs.

It was found from five different market scenarios that the theoretical value that could be recovered under increasing market complexity quickly climbs and then plateaus; 95% of the theoretical value was obtained with five or fewer log-sorts. This study was not set up to measure the impacts of market complexity on actual value-recovery — if there is no effect and the percentage of theoretical value-recovery remains constant, then actual value-recovery will also rise quickly and plateau. There is some indication in the literature, however, that increasing the complexity of the decision-making by adding more log-sorts may eventually result in a drop in actual value-recovery (Harris & Chaney 1969; Parker *et al.* 1995). This is an area which deserves more research.

Number of pieces handled, average piece size, variation in log lengths, and the additional time required to segregate extra log-sorts all affect production costs either directly or indirectly. There were no consistent trends related to number of log-sorts and production variables and costs for the five markets assessed in this study. For some markets, increasing the number of sorts resulted in larger average piece sizes, and fewer pieces to be handled. For other markets the opposite was true; piece size decreased and the number of pieces to be handled increased. These inconsistencies may explain why some researchers have reported small cost increases with increasing numbers of log-sorts and others have found no change in costs. Perhaps where the number of log-sorts is low, adding one or two extra log-sorts has little impact. One would expect, however, that handling a large number of log-sorts would result in productivity decreases and cost increases. The effect of number of log-sorts on costs is another area which requires more research to identify under what conditions cost increases do and do not occur.

The percentages of waste generated in these analyses were similar to those reported by Hall (1994, 1999), i.e., up to 4.5%. Waste generally increased as the number of log-sorts increased. More complex markets could generate two to three times the amount of waste that single log-sort markets do. As noted earlier, waste generation can result in additional indirect costs due to fire, pest, and debris-flow risks, and the poor public perception of waste.

The results presented support the general shape of the theoretical value-recovery curve of the conceptual model in Fig. 1 but do not provide enough evidence to support either the actual or net value-recovery curves. Further research needs to be undertaken to determine how market complexity affects actual value-recovery and production costs. By properly understanding the relationship between market complexity and these economic performance measures, forest owners and logging contractors could better determine log-cutting strategies needed to obtain the optimal net value-recovery.

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