Examining the optimal bucking method of clear cutting operations in Nasu Forest Owners’ Co-operative, Tochigi prefecture, Japan

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43 woody biomass power generation plants in Japan

23 Woody biomass only
20 Coal co-firing
These resources are mainly supplied by sawmill residues and construction waste woods.

Large amount of woody biomass, in particular forest residues, still remains unused due to high harvesting costs.
Feed-in tariffs (FIT) in Japan

- Feed-in tariffs (FIT) were introduced in Japan from July 1, 2012.
- In FIT, power generation with unused materials such as thinned woods and logging residues was given incentives.
- Buying prices: 32 cents/kWh for unused woods
  - 24 cents/kWh for general woods: sawmill residues
  - 13 cents/kWh for recycled woods: construction waste
- Power generation costs: about 8 cents/kWh for coal
- Over 50 plants with unused materials were planned or under construction, and will be operated this year.
Introduction

The extraction of small diameter logs and logging residues could increase total revenues, but would also increase costs compared with saw logs, subsequently might decrease profitability.
Introduction


- In this study, clear cutting operations were investigated and the relationships between log sizes and operational costs were analyzed.

- Then, the equations to estimate operational costs according to log sizes and the optimal bucking methods to maximize profits were developed.

- Finally, the optimal bucking methods were applied to two operational sites in numerical experiment.
Contents

- Study sites
- Development of the equations to estimate operational costs according to log sizes
- Development of the optimal bucking method to maximize profits
- Examination of the optimum extraction rate of extracting thinned woods
Nasu in Tochigi Prefecture, Japan
Study sites

- Site A: 0.77 ha
  - Age: 58 years old
  - DBH: 30 cm
  - Height: 23 m
  - Volume: 0.89 m$^3$/stem
  - Slope: 28 degrees

- Site B: 1.45 ha
  - Age: 50 years old
  - DBH: 28 cm
  - Height: 22 m
  - Volume: 0.71 m$^3$/stem
  - Slope: 6 degrees
Forestry operation system

- Chainsaw felling
- Grapple-loader bunching
- Processor processing
- Forwarder forwarding
- Truck transportation

- Strip road for operation
- Road width: 3.5 m
- Road density: 300 m/ha
- Road cost: USD5.00/m
Contents

- Study sites
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The existing equations to estimate operational costs

- **Chainsaw felling** $O_E F$
  - Site A: $0.45/V_n + 0.51$ (USD/m³)
  - Site B: 0.58 (USD/m³)

  $V_n$: Stem volume (m³/stem)

- **Grapple-loader bunching** $O_E S$
  - Site A: 6.40 (USD/m³)
  - Site B: 4.23 (USD/m³)

Productivities of chainsaw felling and grapple-loader bunching were not affected by log sizes because these operations were conducted with whole trees. The existing equations to estimate operational costs were used.
The existing equations to estimate operational costs

- **Processing** $OEP$
  - Site A: $\frac{2.32}{V_I} + 2.50$ (USD/m$^3$)
  - Site B: $\frac{1.12}{V_I} + 2.05$ (USD/m$^3$)

$V_I$: Extracted volume per stem (m$^3$/stem)

- **Forwarding** $OEE$
  - Site A: $0.00448L + 4.79$ (USD/m$^3$)
  - Site B: $0.00482L + 5.07$ (USD/m$^3$)

$L$: Forwarding distance (m)

The existing equations consisted of extracted volumes for processing and forwarding distances for forwarding.
The existing equations to estimate operational costs

- **Processing** $OE_P$
  - **Site A:** $2.32/V_l + 2.50$ (USD/m³)
  - **Site B:** $1.12/V_l + 2.05$ (USD/m³)

  $V_l$: Extracted volume per stem (m³/stem)

- **Forwarding** $OE_E$
  - **Site A:** $0.00448L + 4.79$ (USD/m³)
  - **Site B:** $0.00482L + 5.07$ (USD/m³)

$L$: Forwarding distance (m)

- The existing equations did not consider log sizes. Measured values were different even with same extracted volumes and forwarding distances.
Development of the equations to estimate operational costs according to log sizes

**Processing** $O_{EP}$

- **Site A:** \[
    \frac{(2.13V_{la} + 0.28)n + 1.05}{V_{la} \times n}
\]
  
  (USD/m$^3$)

- **Site B:** \[
    \frac{(0.65V_{la} + 0.19)n + 0.60}{V_{la} \times n}
\]
  
  (USD/m$^3$)

**Forwarding** $O_{FE}$

- **Site A:** \[
    \frac{0.0118L + 0.0541n + 6.50}{6.93V_{la} + 2.01}
\]
  
  (USD/m$^3$)

- **Site B:** \[
    \frac{0.0127L + 0.0541n + 6.50}{6.93V_{la} + 2.01}
\]
  
  (USD/m$^3$)

$V_{la}$: Log volume (m$^3$/log), $n$: No. of log (log/stem)

This study developed the equations consider log sizes. Costs were reduced according to the increased average log volume.
Development of the optimal bucking method to maximize profits

- Determination of the taper-curve formula
- Estimation of extracted volumes
- Estimation of revenues
- Estimation of expenses
- Estimation of economic balances
- Determination of the optimal bucking method and extraction rate to maximize profits.
Determination of the taper-curve formula

Stem diameter $d$ (cm) at the height above ground $h$ (m) was estimated in the following taper-curve formula:

$$d = \frac{\{a(1 - 1.2 / H) - 0.9a + 1.8\}(1 - h / H)}{\{a(1 - h / H) - 0.9a + 1.8\}(1 - 1.2 / H)}$$

$$a = \frac{(18 - 21.6 / H) - 12.6\sqrt{7} / 10f}{(2 - 2.4 / H) + (0.7 - 8.4 / H)\sqrt{7} / 10f}$$

$$f = 4Vn / (HD^2\pi / 10,000)$$

- Average RMSE was 1.1 cm. Log diameters were usually rounded by 2 cm. Therefore, RMSE was within allowable ranges.
Estimation of extracted volumes and revenues

- Extracted volumes and revenues were estimated with possible combinations of log length bucked from a wood using log prices

- Saw logs between USD75.00/m³ and USD130.00/m³
  - 3.00-m long exceeding 10-cm diameter
  - 3.65-m long exceeding 26-cm diameter
  - 4.00 m long exceeding 10-cm diameter

- Lamina logs with USD50.00/m³
  - 2.00-m long exceeding 16-cm diameter.

- Chip logs with USD30.00/m³
  - 2.00-m long exceeding 6-cm diameter
Estimation of expenses

- Direct operation expenses: chainsaw, grapple-loader, processor, forwarder
- Strip road expenses: USD5.00/m
- Truck transportation expenses: USD13.00/m³ for saw logs, USD0/m³ for lamina and chip logs because of landing sale
- Machine transportation expenses: USD50.00/machine
- Insurance costs: 20% of direct expenses
- Handling fees of forest owners’ cooperative: 5% of revenues
- Handling fees of the log market: 5% of revenues in the log market
- Piling fees in the log market: USD7.00/m³
Estimation of economic balances

- Economic balances were estimated with revenues and costs of possible combinations of log length bucked from a wood.
- The optimal bucking method and the optimal extraction rate were determined as the bucking method and the extraction rate with maximum profits.
Revenues were increased according to the increased saw log volumes with relatively higher log prices.

Direct expenses were decreased according to the increased average log volumes using the equation developed in this study.
The optimum bucking successfully optimized extracted volumes to increase saw logs with relatively higher log prices.
Future study

- Stem diameter at the height above the ground was estimated with the taper curve formula.
- Detailed description of stem shape such as sweep and lean were not considered.
- Terrestrial LiDAR has been used to measure detailed description of stem shape.
- The future study will apply terrestrial LiDAR to optimal bucking algorithm to consider detailed description of stem shape such as sweep and lean.
Terrestrial LiDAR


Treemetrics, Ireland
Future study


- Uusitalo, J. (2010): Introduction to forest operations and technology