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Analysis on operational efficiencies and costs for extracting thinned woods in small-scale forestry, Nasunogahara area, Tochigi prefecture, Japan †

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Abstract: In this study, two operation methodologies to extract thinned woods were investigated on Nasunogahara area, Tochigi prefecture, Japan. Methodology 1 included manual extraction and light truck transportation. Methodology 2 included mini-forwarder forwarding and 4-ton truck transportation. Furthermore, a newly introduced chipper was investigated. As a result, costs of manual extractions within 10 m and 20 m were JPY942/m^3 and JPY1,040/m^3, respectively. On the other hand, forwarding cost of mini-forwarder was JPY499/m^3 which was significantly lower than those of manual extractions. Transportation costs with light truck and 4-ton truck were JPY7,224/m^3 and JPY1,298/m^3 with 28-km transportation distances. Chipping operation costs were JPY1,036/m^3 and JPY1,160/m^3 with 3 and 2 persons, respectively. Lastly, total costs of methodologies 1 and 2 from extraction within 20 m to chipping were estimated as JPY9,300/m^3 and JPY2,833/m^3 with 28-km transportation distances and 3-men chipping operations (EUR1 = JPY126 as on August 12, 2020).

Keywords: manual extraction; light truck; mini-forwarder; 4-ton truck: chipper

1. Introduction

In July 2011, the Feed-in Tariff (FIT) Scheme for Renewable Energy Use was introduced in Japan, in accordance with new legislation entitled the Act on the Purchase of Renewable Energy-Sourced Electricity by Electric Utilities. Under the FIT program, electricity generated from woody biomass must be procured at a fixed price (without tax) for over 20 years for (a) unused materials such as thinned wood and logging residue (at JPY32/kWh), (b) general materials such as sawmill residue (at JPY24/kWh), and (c) recycled materials such as construction waste wood (at JPY13/kWh) [1]. Incentives have promoted the use of power generated from unused materials.

The price of JPY32/kWh for unused materials was determined based on a model plant featuring 5 MW of direct combustion with initial cost JPY410,000/kW, annual operating cost JPY27,000/kW, and Internal Rate of Return 8%. Annual consumption of fuel wood chips was 60,000 ton/year collected within 50 km with a price of JPY12,000/ton consisting of 34% (JPY4,080/ton) was extraction, 25% (JPY3,000/ton) was transportation, 16% (JPY1,920/ton) was chipping, and 25% (JPY3,000/ton) was chip transportation. However, forest ownership in Japan is characterized by a large number of small, fragmented, and scattered forest owners [2]. Therefore, it is difficult to supply the amount of 60,000 ton/year stably from such small, fragmented, and scattered forests.

To promote the use of thinned wood and logging residue from these forests, the price of JPY40/kWh for unused materials with less than 2 MW of direct combustion was set, starting from April 2015. The price of JPY40/kWh was determined based on a model plant featuring 1.5 MW of direct combustion with initial cost JPY620,000/kW, annual operating cost 64,000/kW, and Internal

Rate of Return 8%. Annual consumption of fuel wood chips was 20,000 ton/year collected within 30 km with a price of JPY9,000/ton excluding chip transportation because a small-scale power generation plant could chip small amount volumes necessary for its own plant on its own place.

An agrarian organization in the Nasunogahara area in Tochigi Prefecture is willing to conduct thinning operations and extract thinned woods for a small-scale woody biomass power generation in cooperation with the Forest owners' cooperative. This nurtures river resources as well as maintains forests for soil and water conservation. Forest ownership for the region studied is also characterized by a large number of small, fragmented, and scattered forest owners. Therefore, it is difficult to aggregate forestry operation sites in this region even though private forests are located on relatively gentle slope areas and forest road networks are well established. Thus, the optimal method to extract logging residues from such small, fragmented and scattered forests should be examined separately from the mechanized operational systems used on aggregated forestry operation sites.

In many regions of the world, small-scale harvesting machines have been used in forestry where terrain condition and size of forest operations are not limiting [3]. In some European counties, farm tractors are commonly used for various forest harvesting tasks including felling, processing, extraction and transportation in small-scale logging systems. Especially, a standard winch and a sulky can be fitted to any tractor at relatively low cost, and can be used for part-time forest operations [4]. This simple technology has a strong potential for effective deployment in farm forestry in developing countries. On the other hand, various animal species (oxen, horses, buffalos and mules) have been used for skidding operations. Oxen are commonly used for skidding in Turkey [5]. Furthermore, over 80% of extraction operations in Turkish forest are conducted with manpower as skidding or sliding, but these methods have technical, ergonomic and environmental problems. To overcome these problems, manual extractions with plastic chutes has been examined [6]. In Japan, mini-forwarders were commonly used for forwarding operations by small-scale private forest owners and logging companies [7]. Furthermore, light trucks with 350 kg loading capacity are also commonly used for commuting to the forests and transporting small sized logs.

Niyodo, a local community in the Kochi area of southwestern Japan, has started a government-subsidized woody biomass utilization project. The project collects logging residues for a processing plant using three methodologies: (1) a large-scale methodology operated by a logging contractor, (2) a medium-scale methodology operated by a Forest owners' cooperative, and (3) a small-scale methodology operated by an individual forest owner. Although the expected largest source of logging residues was the large-scale methodology, the small-scale methodology procurement was, in fact, the largest [8]. Therefore, a small-scale methodology used by individual forest owners with mini-forwarders and light trucks would be important for extracting logging residues from such small, fragmented and scattered forests all over Japan as well as in some other regions of the world with manual logging.

In this study, two operation methodologies to extract thinned woods were investigated on Nasunogahara area, Tochigi prefecture, Japan. Methodology 1 included manual extraction and light truck transportation. Methodology 2 included mini-forwarder forwarding and 4-ton truck transportation. Furthermore, a newly introduced chipper was investigated.

2. Materials and Methods

The study was conducted by the following steps: (1) small-scale methodologies operated by an individual forest owner and a private logging contractor were investigated (Figure 1), (2) cycle times were analyzed, (3) equations to estimate productivities and costs were established, and (4) costs of the small-scale methodologies – manual extraction and a light truck operated by an individual forest owner, and an mini-forwarder and an 4-ton truck operated by a private logging contractor – were estimated and compared. This study assumed that a private logging contractor were professional whereas an individual forest owner was amateur and had recently commenced forestry operations from logging residues extraction.

Figure 1. Loading to a light truck by individual forest owners (Left) and unloading from mini-forwarder with truck crane by a private logging contractor (Right).

Study site was a 29-year-old Japanese cedar (*Cryptomeria japonica*) and 23-year-old Japanese cypress (*Chamaecyparis obtusa*) plantation. In Japanese cedar plantation, its area was 0.23 ha, with average slope angle: 7 degrees, stand density: 1,700 stem/ha, average diameter at breast height (DBH): 19.5 cm, average tree height: 16.0 m and average stem volume: 0.24 m^3/stem. In Japanese cypress plantation, its area was 0.62 ha, with average slope angle: 8 degrees, stand density: 1,600 stem/ha, average diameter at breast height (DBH): 17.3 cm, average tree height: 13.6 m and average stem volume: 0.17 m^3/stem. Precommercial thinning operations were conducted by a Forest owners' cooperative. Thinned woods were left in the forest.

Thinned woods were manually extracted and transported with a light truck (loading capacity 0.35 ton) by individual forest owners, and extracted with a mini-forwarder (Chikusui Canycom Yamabiko BFY1001, 7.4 kW engine horsepower) and transported with a truck (loading capacity 4 ton) by a private logging contractor. Time study was conducted to analyse cycle times and productivities. Manual extractions were conducted by 3 persons within 10 and 20 m, respectively. Mini-forwarder extractions were conducted within 20 m. Chipping was conducted using Dynamic VP3000, 83 kW engine horsepower with 3 and 2 persons (Figure 2).

Figure 2. Chipping.

The productivities, P (m^3/h) were estimated with average cycle time, T (s/cycle) and average volume, V (m^3/cycle):

$$P = \frac{3{,}600 \times V}{T}, \quad (1)$$

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The direct operational expenses, *OE* (JPY/m³) were estimated using productivities and hourly operational expenses consisting of labour expenses, *OL* (JPY/h) and machinery expenses, *OM* (JPY/h).

$$OE = \frac{OL+OM}{P}, \quad (2)$$

Labour expenses, *OL* (JPY/h), were set at JPY1,300/h. Machinery expenses, *OM* (JPY/h), consisted of maintenance, management, depreciation, and fuel and oil expenses, JPY570/h for a light truck, JPY572/h for a mini-forwarder, JPY1,320/h for a 4-ton truck and JPY3,155/h for a chipper [9,10].

3. Results

Productivities of manual extractions were 3.53 m^3/h with the average log volume of 0.018 m^3/log within 10 m and 2.01 m^3/h with the average log volume of 0.017 m^3/log within 20 m in Japanese cedar, and 5.15 m^3/h with the average log volume of 0.019 m^3/log within 10 m and 5.80 m^3/h with the average log volume of 0.022 m^3/log within 20 m in Japanese cypress. Productivities in Japanese cypress were higher than those in Japanese cedar. In Japanese cypress, productivities within 20 m were also higher than those within 10 m. One of the reasons for these was the higher average log volume.

The average cycle time and volume with a mini-forwarder were 792 s/cycle and 0.84 m^3/cycle. Therefore, productivity was estimated at 3.75 m^3/h. As the average productivity of manual extractions within 20 m was estimated at 1.25 m^3/person/h whereas that within 10 m was estimated at 1.38 m^3/person/h, the productivity of a mini-forwarder was higher. The direct operational expenses of manual extractions were estimated at JPY942/m^3 and JPY1,040/m^3 within 10 m and 20 m, respectively. On the other hand, the direct operational expense of a mini-forwarder was JPY499/m^3 within 20 m. Using a mini-forwarder reduced the direct operational expenses of extractions.

The average cycle time and volume of loadging/unloading with 2 persons and a light truck were 795 s/cycle and 0.644 m^3/cycle with the average log volume of 0.028 m^3/log in Japanese cedar. Therefore, productivity was estimated at 2.92 m^3/h. The average cycle time and volume of loadging/unloading with a light truck were 816 s/cycle and 0.552 m^3/cycle with the average log volume of 0.023 m^3/log in Japanese cypress. Therefore, productivity was estimated at 2.42 m^3/h. The productivity in Japanese cedar was higher than that in Japanese cypress because of the higher average log volume.

The average cycle time and volume of loading/unloading with a 4-ton truck were 2,160 s/cycle and 4.950 m^3/cycle. Therefore, productivity was estimated at 8.25 m^3/h. As the average productivity of loading/unloading with a light truck was estimated at 1.34 m^3/person/h, the productivity of loading/unloading with a 4-ton truck was higher.

The cycle time, T (s/cycle), of transportation was related to transportation distance, L (km/cycle), travel velocities, V (km/h), and the loading and unloading time, tf (s/cycle).

$$T = tf + 7{,}200L/V, \quad (3)$$

Travel velocities were assumed to be 30 km/h. As the loading and unloading time was 1,612 s/cycle for a light truck with one person and 2,160 s/cycle for a 4-ton truck, the cycle times were:

$$\text{Light truck: } T = 1{,}612 + 240L, \quad (4)$$

$$\text{4-ton truck: } T = 2{,}160 + 240L, \quad (5)$$

As the average volumes were 0.598 m^3/cycle for a light truck and 4.950 m^3/cycle for a 4-ton truck, productivities were:

$$\text{Light truck: } P = 2{,}153/(1{,}612 + 240L), \quad (6)$$

$$\text{4-ton truck: } P = 17{,}820/(2{,}160 + 240L), \quad (7)$$

The direct operational expenses were:

$$\text{Light truck: } OE = 1{,}400 + 208L, \quad (8)$$

$$\text{4-ton truck: } OE = 318 + 35L, \quad (9)$$

Transportation costs with a light truck and a 4-ton truck were estimated at JPY7,224/m^3 and JPY1,298/m^3 with 28-km transportation distances from the test site to a planned woody biomass power generation plant.

Chipping operations were conducted with 82 logs for 3 persons and 124 logs for 2 persons. Average small end diameters were 11 cm and 11 cm, average log lengths were 2.1 m and 1.7 m, and average log volumes were 0.022 m^3/log and 0.021 m^3/log for 3 and 2 persons, respectively. Therefore, chipping volumes were 1.763 m^3 and 2.639 m^3 for 3 and 2 persons. As chipping times were 932 seconds and 1,221 seconds for 3 and 2 persons, productivities were 6.81 m^3/h (2.27 m^3/person/h) and 4.96 m^3/h (2.48 m^3/person/h), respectively. Therefore, chipping operation costs were JPY1,036/m^3 and JPY1,160/m^3 with 3 and 2 persons, respectively.

Total cost with manual extraction within 20 m, 28-km transportation with a light truck and chipping for 3 persons was estimated at JPY9,300/m^3 (Figure 3) whereas that with mini-forwarder, 4-ton truck and 3-men chipping was JPY2,833/m^3 (Figure 4). As the price of fuel wood chips, JPY9,000/ton for a small-scale power generation plant was converted to JPY6,120/m^3 with bulk density of 0.68 ton/m^3 [11], thinned woods could be utilized within 13-km transportation distances even with manual extractions and a light truck.

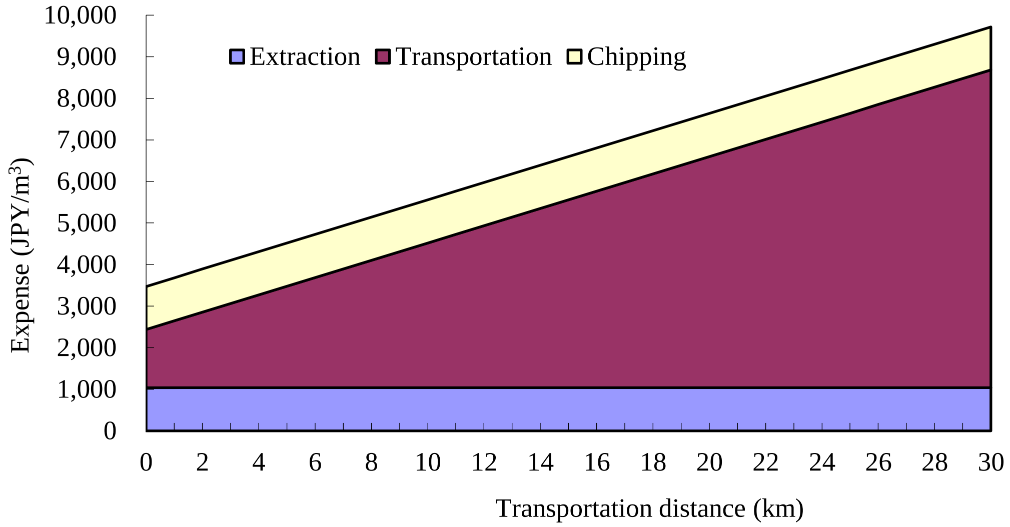

Figure 3. Total cost with manual extraction within 20 m, light truck transportation and chipping for 3 persons.

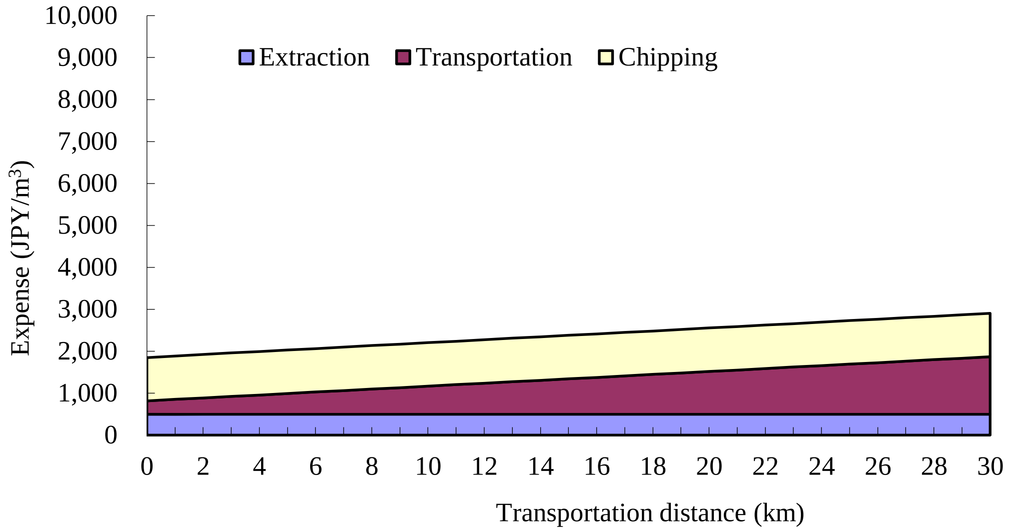

Figure 4. Total cost with a mini-forwarder, a 4-ton truck and chipping for 3 persons.

4. Discussions

Logging by chainsaw felling and chainsaw or processor processing followed by forwarding, is widely used at small and large sites in the mountainous forests of Japan. However, a grapple equipped with a forwarder is usually small and the forwarder's operational efficiency for loading and unloading is low. An arm roll forwarder was developed to overcome this problem [12-15]. An arm roll forwarder can only load a steel container that has been fully loaded with logs by processor beforehand, and it can only unload such a container afterward. Therefore, such a forwarder can shorten the loading time and improve loading operational efficiency significantly.

In addition to the investigation of an arm roll forwarder with 3-m logs [15], an arm roll forwarder with 2-m logs and biomass containers, and an arm roll truck were investigated (Figure 5). As a result, total costs of an arm roll forwarder between 610-780 m forwarding distances, an arm roll truck with 28-km transportation distances and 3-men chipping were estimated at JPY5,206/ton and JPY8,040/ton for 2-m logs and biomass containers, respectively (Figures 6 and 7). Therefore, thinned woods and logging residues could be used as fuel wood chips for a small-scale woody biomass power generation plant. However, forwarding distances were longer in this site. If grapple loader could just load thinned woods without forwarding, total costs reduced to JPY4,603/ton. As the total cost with a mini-forwarder, a 4-ton truck and 3-men chipping was estimated at JPY4,166/ton with bulk density of 0.68 ton/m^3, the small-scale systems could be effective for harvesting small areas.

Figure 5. An arm roll forwarder with 3-m logs (Top left), 2-m logs (Top right), and biomass containers (Bottom left), and an arm roll truck (Bottom right).

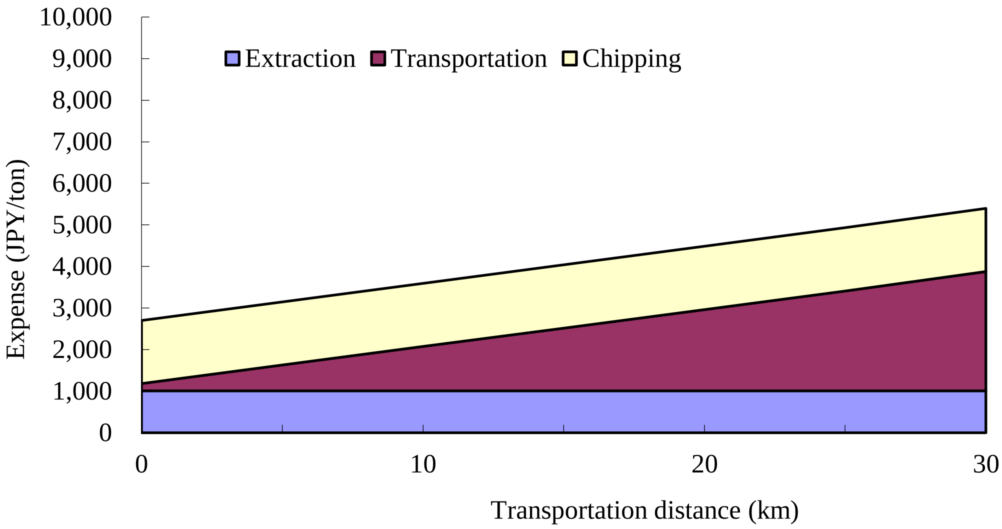

Figure 6. Total cost of an arm roll forwarder with 2-m logs, an arm roll truck and chipping for 3 persons.

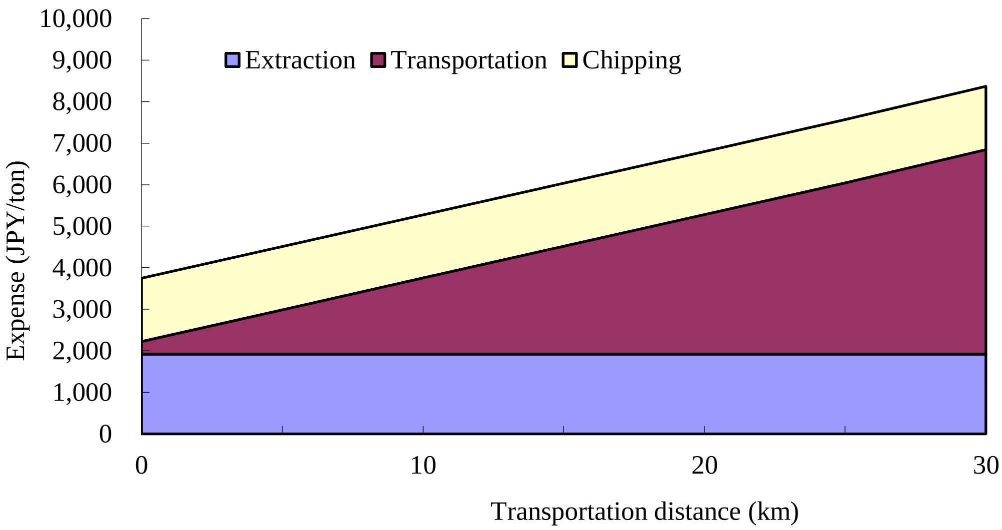

Figure 7. Total cost of an arm roll forwarder with biomass containers, an arm roll truck and chipping for 3 persons.

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