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Analysis of factors affecting productivity and costs for a high-performance chip supply system

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HIGHLIGHTS

- A discrete-event simulation model of a chip supply system was constructed.
- A larger buffer size reduces chipper and chip truck interdependencies.
- Increased buffer size and improved shift scheduling improves system performance.
- Chipping and chip transport should be regarded as one operation, not two separate.

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ABSTRACT

Declining market prices make it necessary to reduce supply costs of forest chips to ensure profitability in the supply chain and a continued supply of forest chips to the energy industry. Comminution and transport are two of the major contributors to the total costs in the forest fuel supply system. In order to fully utilise truck payloads and reduce transport costs, logging residues are usually chipped at the landing. For the chipping contractor, it is important to maximise the proportion of effective work time in relation to scheduled work time. Currently it is not uncommon that effective work time is less than 50 per cent of scheduled work time, due to chip transports using the chipper, waiting for chip trucks, and other delays. Increased chipper utilisation requires greater coordination between the chipper and the chip trucks transporting the produced chips to the customer. Supply systems have been simulated to examine how transport distance, number of trucks, shift scheduling and chip buffers affect the system costs for a high-performance chipper system. System costs and machine utilisation vary greatly, depending on system configuration. It is always beneficial to have six containers in the buffer on the landing rather than three, and trucks should begin their shifts at one-hour intervals. To maximise chipper use and minimise system costs, four container trucks are needed if the transport distance exceeds 50 km. However, the large seasonal fluctuations in demand for biomass chips makes it hard to fully utilise the potential of the system over the whole year. The study concludes that it is important to regard chipping and chip transport as one operation, not two separate ones, as they are so dependent on each other.

1. Introduction

The European Union has targeted that 20 percent of energy should be produced from renewable sources by 2020. Each member state has its own target and Sweden aims to produce 49 per cent and Finland 38 per cent of its energy from renewable sources by this date [1]. In both countries, biomass from the forest plays an important role in the energy system. Although the bulk of this biomass is by-products from the forest industry a significant part is supplied directly from the forests as primary forest fuels; i.e. defective roundwood, logging residues (tops and branches), and tree sections from early thinning.

Between 2013 and 2014 the use of primary forest fuels in Sweden declined from 20.2 to 18.0 TW h [2,3], as an effect of a warmer winter and increased competition from other fuels. This was accompanied by declining prices for the delivered forest chips [4]. Given the lower prices the supply chain must be made more cost effective in order to ensure profitability within the supply chain and an acceptable remuneration to landowners for the delivered biomass. If cost-effectiveness is not improved, there is a risk

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that the potential to supply the CHP industry with forest chips will decrease.

Forest fuel supply chains are challenging, since the material is scattered over large areas and has difficult properties e.g. small piece size, varied shape, and bulkiness [1,5]. Large research efforts have been made to develop efficient supply systems, e.g. [5–9]. Chipping and transport are two of the major contributors to the total supply costs for forest fuels [10,11]. Transport costs for logging residues and tree sections are high as the biomass is collected from wide areas and the bulkiness of the material makes it hard to reach full payloads [12]. The effects of transport costs on forest fuel supply is well known and is a factor affecting strategic decisions such as investments in and location of heating plants and terminals. Transport costs also affects tactical and operational decisions e.g. from which areas should the biomass be sourced, how much should be chipped on the landing and how much at the terminal and what equipment should be used. Optimisation [13–19], simulation [20–22] and GIS-techniques [23–25] have been used to find feasible solutions at these planning levels.

To increase payloads and thereby reduce transport costs, many forest fuel assortments are chipped on the landing prior to transport. This is a result of the work on optimisations in the 1980s by Eriksson & Björheden [13], who showed that chipping on the landing reduces the total cost for chipping and transport. Chipping the material on the landing is less cost-effective than at a terminal because smaller machines are used, but transport costs are reduced, as truck payloads are increased. The increased payloads are an effect of the higher bulk density of chips compared to loose residues. The optimal supply systems used vary according to transport distance [15,26]. Although terminals usually add costs they may be necessary to ensure an adequate supply of fuel during periods when landings are inaccessible [18,27] or a when buffer is needed to meet sudden changes in demand [1,28]. Chipping at the user plant can be an attractive solution for landings close to the plant, but payloads are small for trucks delivering uncomminuted biomass [14].

In order to further reduce supply costs chipping and transport systems need to be improved and new systems must be developed and tested. This can involve either field studies or analytical approaches. Field studies of chip supply systems tend to involve short-term time studies of the performance of a specific system setup. For practical and economic reasons, it is not easy or even feasible to manipulate landing conditions, system design and the capacity of the transport fleet in these studies. Furthermore, results are easily influenced by external factors, such as differences in road conditions, delivery quotas, and the material to be chipped.

Discrete event simulation of system performance is a way to avoid these disruptions and enables viable studies of different system configurations. This approach has been used for studying chipping systems delivering pulpwood chips [29,30] and forest fuel chips [20,22,31–33]. These studies show that hot chipping systems are sensitive to chipper/truck interactions and that these interactions can cause substantial waiting times for the machines in the system. Using a static model for the analysis and disregarding the stochastic behaviour of the system would significantly overestimate system performance and underestimate waiting costs [34].

Chipping is a major cost item in the supply systems for forest fuels, so it is important to increase the cost-effectiveness of chipper use by improving chip supply systems. One reason is that the chipping equipment has some of the highest hourly costs of any machinery used in Swedish forestry. Although many of the chippers used on landings have high productivity per effective chipping hour, they are often not used efficiently. The chipping season is short, often not more than 8 to 9 months per year, since the demand for chips is seasonal, and chipping operations often involve considerable delays [35].

In many of the chipping studies carried out in recent years, the proportion of efficient chipping work in relation to scheduled work time has been as low as 40–60 per cent. The rest of the time is spent on other activities, such as shunting chips on the landing [33], waiting for trucks, waiting because the landing is occupied by trucks fetching chip containers or chips, and maintenance [36–39]. Many of these delays are caused by interactions between the chipper and the trucks delivering the chips to the customer. These interactions occur, although in Sweden it is uncommon for the chippers to chip directly into the trucks transporting the chips. There is usually some intermediate storage between the chipping phase and transport, with the chips stored either in containers or simply piled on the landing.

In order to increase chipper utilisation, contractors are testing new ways to organise their work. For instance, chips on the landing can be shunted with a separate machine, thereby enabling the chipper to concentrate on chipping [37], or relocation and shunting can be reduced by using a chipper truck that can handle containers [40]. Container-handling chipper trucks spend more time chipping than standard chipper trucks, while cheaper and lighter container trucks are used for transport. Common for these solutions is that utilisation of the chipper becomes increasingly dependent on the capacity of the transport fleet, and the possibilities to work in a rational way on the landing [41].

The layout of the landing is significant for the efficiency of both chipping and transport. A landing suitable for a conventional forwarder-mounted chipper might not be suitable for a chipper truck, and vice versa [42]. In the systems that use containers for chip transport, there must be room for a buffer of containers close to the material that is to be chipped. Opinions vary among chipping contractors about whether the buffer should consist of three or six containers. Using three containers requires less space on the landing and less foresight and planning of the work compared with six containers, but a larger buffer reduces dependence on the truck transport.

More container trucks in the system increases chipper utilisation, but also increases the risk of queues on the landing, thereby reducing truck utilisation [31]. This risk can be reduced by careful scheduling of the trucks. In an area with many chipping operations, this can be achieved by planning the transports in a way that prevents two trucks arriving at the landing at the same time. In smaller operations it can be achieved by the truck drivers starting their shifts at different times, usually an hour apart. The benefits of the latter approach are thought to be considerable, but this has not yet been studied.

The overall aim of this study was to identify ways to reduce the supply cost for forest chips through more efficient use of existing chipper systems. The study also attempted to describe how the supply costs for a chipping system, consisting of a chipper, a forwarder for shunting containers, and container trucks, are affected by shunting distance, buffer size, truck scheduling, and number of trucks available.

2. Material and methods

The study was carried out using a discrete event simulation model of the system. The model was constructed based on experiences from a field study of a similar system [37]. Simulations were run with three shunting distances (100, 200 and 300 m), two buffer sizes (three and six containers), two shift types (simultaneous and staggered), and two, three or four trucks. A simulation lasted one working week and ten simulations were run for each treatment combination.

The model simulates the supply chain of forest chips, from a stack of logging residues on the landing until the chips are deliv-