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Evaluation of delivery strategies for forest fuels applying a model for Weather-driven Analysis of Forest Fuel Systems (WAFFS)

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HIGHLIGHTS

- Studied systems delivering forest fuel to a heating plant.
- Developed a weather-driven analysis model using discrete-event simulation.
- Evaluated the use of information-driven supply strategies.
- Improvements were possible when delivering the right biomass at the right time.

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ABSTRACT

Earlier studies have highlighted the importance of quality and quantity in forest fuel supply chains, since these parameters affect product value and handling properties, but both are constantly changing over time. Great monetary losses can be incurred if forest fuel material has to be delivered to end-users in non-optimal condition, e.g. to meet seasonal fuel demand with its large short-term variations. Thus earlier studies have also highlighted the importance of more information on the forest fuel supply chain. This paper describes development of a model for Weather-driven Analysis of Forest Fuel Systems (WAFFS) that can be used when analysing forest fuel supply chains and that accounts for both active machine activities and passive activities such as quality changes during storage. The aim was to develop a methodology that can be used to evaluate forest fuel supply chain scenarios and analyse various delivery strategies under different conditions. Application of WAFFS to evaluate delivery strategies for forest fuels showed that system improvements were possible when the right biomass was delivered at the right time. The WAFFS model gives an overview of biomass actually stored at different geographical locations and places (heaps or windrows) in terms of both quality and quantity. Delivery strategies actively prioritising biomass storage proved capable of delivering more energy when most needed, thereby improving yearly machine utilisation for contractors in the supply chain.

1. Introduction

Space heating is a vital energy service in many countries in Europe. District heating currently only covers 13% of this heating market, but many European cities have been identified as technically suitable for district heating systems. However, the market share varies significantly, e.g. in Scandinavia and the Baltic states it is as high as 40–60%. Recent studies have cited district heating technologies as a cost-efficient pathway for decarbonisation of the EU energy system [1,2] and 45 countries world-wide had renewable heating and cooling targets in place by the end of 2015 [3]. In Sweden, where the heating market is one of the dominant energy markets and district heating represents approximately 50% of heat delivered, decarbonisation has already occurred [4]. During recent decades fossil oil has gone from being the main fuel in the sector, with around 90% share, to an almost negligible contribution today. Wood fuels, but also municipal solid waste, have enabled this transition, with 40.6% of district heating energy coming from biofuels, most of which are by-products from the forest industry and primary forest fuels supplied directly from the forest [5,6]. Large-scale systems for collection of logging residues for production of forest chips intended for heat plants (HP) and combined heat and power (CHP) plants are in place. The utilisation of primary forest

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fuels, mainly logging residues, has increased steadily to date and there is potential for a sustainable increase in the use of logging residues [7]. However, in recent years increased competition from recycled wood fuels and household waste, both domestic and imported, has been seen [8].

To increase the supply of logging residues, different aspects must be considered, e.g. it is necessary to cut unnecessary costs and to increase product value in order to make the product more competitive. Earlier studies have highlighted moisture content (M) as a factor strongly affecting fuel costs due to its links to fuel value and to transport properties [9]. Moreover, delivering a material that matches the fuel amounts and quality demanded is desirable, since it strengthens product competitiveness. However, the logistics of the supply chain for forest fuels are more challenging and complex than those of supply chains for many other products, e.g. fossil fuels [8,10].

A difficulty lies with the seasonality of fuel demand at district heating plants, which varies widely in both the short term and long term during the year as a consequence of fluctuating outdoor temperatures [11,12]. Logging residues, on the other hand, are produced more steadily all year around, as a by-product from conventional forest operations. District heating plants are often located close to cities, meaning that they rarely have large storage areas available on-site [8]. Thus they rely on demand-based inflow of material, preferably in the form of chips directly from the forest or from storage terminals. Logging residues are a bulky material, which causes inefficient and costly transport [13,14], so to avoid this the material is chipped before transportation from the forest. However, wood chips are more easily degraded than uncomminuted residues and therefore cannot be stored for long periods [15]. For these reasons, chipping and transport contractors and their employees can expect much work in peak load times and little work in the summer time. If a truck transports drier material or material from nearby locations, it can deliver more energy per day. Improved work methods and scheduling routines involving planning and resource allocation to increase machine utilisation and system output can bring large increases in system efficiency [16,17].

Another problem is that logging residues can have fluctuating quality, meaning that the monetary value of the stored material is constantly changing. Besides storage for seasonal demand reasons, residues are also stored for quality reasons, mainly to reduce the moisture content. However, there is a trade-off situation between potential natural drying caused by the ambient weather and a reduction in dry matter due to biodegradation. Moreover, storage is no guarantee of achieving drier material, since rewetting can occur in rainy periods. There is thus a risk of large monetary losses for the supplier if the material is delivered at untimely periods, as payment in the trading system is often based on the lower heating value, which is mainly a function of moisture content. Moreover, storing the material adds costs for handling and ties up working capital, so unnecessary storage is undesirable [18,19].

Finding ways to cut costs through smarter logistics in the biomass supply chain for energy has been a priority in recent research, and simulation [20–23], optimisation [24–27] and GIS approaches [28–30] have been used. In simulation, the discrete-event approach has frequently been used [31], at least from the early 1970s [32–34], when analysing the supply chain of forest fuel and forest products. This is due to its ability to represent real-world processes, which often include changes over time, randomness and interactions that potentially cause queues and bottlenecks in the system. Analytical solutions for such problems can be difficult to devise [35,36]. Many previous biomass supply chain studies have focused on active processes such as machine activities and material handling, while excluding passive activities such as storage, e.g. [21,37–39]. One reason is that until recently, there has been limited information available on quality changes in logging residues during storage. Focusing on increasing value can be as important as cutting costs in the forest fuel supply chain [9] and profit has been shown to be strongly connected to quality on delivery [40]. In recent years, there has been more awareness of value creation processes [41] and some studies have attempted to combine drying equations with logistic models [16,42,43]. Weather-dependent models for estimating moisture content changes in logging residues during storage have been developed [44–46]. The results provide a constant overview of what is actually stored at different locations in terms of quality, enabling product value to be monitored. This opens up great possibilities for development of analysis tools for forest fuel logistics. In the agriculture sector, dynamic weather-driven logistic models have been successfully developed and implemented since the late 1990s [47–49].

This paper describes the development of a new dynamic model for Weather-driven Analysis of Forest Fuel Systems (WAFFS) and its implementation in the case of a logging residue supply chain. The general aim of the work was to develop a methodology and a tool that can be used to evaluate forest fuel supply chain scenarios and analyse various delivery strategies under different conditions. The specific objective was to evaluate strategies for prioritising which object to deliver, based on information regarding storage time, fuel quality and transport distance. Possible benefits for the supply company and the end-user were of interest and the effects on delivery system, machine utilisation and quality on delivery were assessed.

2. Method

2.1. Model description

2.1.1. Model overview

In order to create the WAFFS model, a discrete-event simulation approach utilising the ExtendSim® platform was used, enabling dynamic and stochastic simulations to be carried out. A discrete-event model is built up of a linked structure of queues and activities according to pre-defined model logic. Items (entities) having different attributes flow through the structure. An event list handles propagation of time in discrete steps driven by changes in the system state.

The WAFFS model is based on a family of previously developed models [9,38,50]. It comprises a composite model with six modules and is programmed and designed as a hybrid push and pull model driven by imported historical weather data. In the model, logging residues are created at various locations at different times, handled and delivered to one single customer, a CHP plant (Fig. 1). All wood chips needed for the plant are assumed to be delivered by the simulated machine system.

2.1.2. Module for creating objects

The first module of the WAFFS model, creation/harvest of objects, is designed to mimic the process when logging residues are produced during conventional harvesting. During fuel-adapted logging operation, the residues intended for fuel are placed in small heaps throughout the regeneration area, waiting to be forwarded to a landing at a later stage. In the model, one item represents each object (biomass at a regeneration area) and it carries information in attributes regarding geographical location, quantity and quality. A model structure where objects are pushed into the model as a result of logging is used. Monthly variations are based on recent logging statistics for soft wood provided by the Natural Resources Institute Finland (LUKE) (Table 1). Objects are created in the model at a rate based on the size of the object, the logging statistics and a scale parameter. A lag period equal to the