BIOSYSTEMS ENGINEERING 135 (2015) 10–20

Available online at www.sciencedirect.com

ScienceDirect

journal homepage: www.elsevier.com/locate/issn/15375110

Research Paper

Machine function integration and its effect on the performance of a timber yarding and processing operation

Bruce Talbot [a,*], *Karl Stampfer* [b], *Rien Visser* [c]

[a] *Department of Forest Technology, Norwegian Forest and Landscape Institute, P.O. Box 115, 1430 Ås, Norway*
[b] *University of Life Sciences, Vienna, Institute of Forest Engineering, Peter Jordan Strasse 82, A-1190 Vienna, Austria*
[c] *School of Forestry, University of Canterbury, Christchurch, New Zealand*

ARTICLE INFO

Article history:
Received 13 December 2014
Received in revised form
11 March 2015
Accepted 23 March 2015
Published online 15 May 2015

Keywords:
Steep terrain logging
Cable yarding
Systems analysis
Harvesting

An assessment of the benefits of a fully integrated yarder-processor was made against the alternative of splitting the yarding and processing functions onto two base machines. The effect of productivity rates, specific costs, and crew sizes on the relative performance of each working configuration was investigated. The systems analysis showed that for the integrated yarder machine, a two-man crew was considerably cheaper than a three-man crew at all yarding distances, although the difference became less pronounced with increasing mean tree volumes. The single integrated machine with a 2-man crew was cheaper than the modelled 2-machine system at medium and longer extraction distances, as the processor base machine in the 2-machine systems incurred a considerable cost penalty in waiting idly for the yarder. At shorter distances (75 m) the 2-machine system was cheapest, but became less competitive with increasing mean tree volume. For mid-sized trees (0.38 m^3) on a medium corridor length of 150 m, overall system productivity rates ranged from 5.2 m^3 per productive system hour (PSH) for the single machine system to 9.4 PSH^{-1} for the 2-machine system, although the specific net costs were almost identical at 31.5 € m^{-3}. A sensitivity analysis showed that reduced labour costs would promote use of the 2-machine system, suggesting that the optimum system configuration would be country specific. Despite being marginally more costly in small trees at short corridor lengths (75 m), the single fully-integrated machine was considered the working configuration of choice under Norwegian conditions.

* *Corresponding author*. Norwegian Institute for Forest and Landscape, Section for Forest Technology and Economics, P.O. Box 115, 1431 Ås, Norway. Tel.: +47 94 88 67 91.
E-mail addresses: bta@skogoglandskap.no (B. Talbot), karl.stampfer@boku.ac.at (K. Stampfer), rien.visser@canterbury.ac.nz (R. Visser).
http://dx.doi.org/10.1016/j.biosystemseng.2015.03.013

Nomenclature

SMH	Scheduled Machine Hour: equates to the sum of all planned shift hours for the year
PMH	Productive Machine Hour: effective working hours, excluding time lost to machine relocation, rigging, and mechanical or other delays exceeding in excess of 15 min
PSH	Productive System Hour: similar to PMH, but the system hour includes two or more machines or sequential operations necessary in completing the task
PMmin	Productive Machine Minutes: equivalent to PMH, but rescaled to minutes for improved readability
m^3	Solid cubic meter of timber
ha	hectare
WC	Work Configuration
Sc	Scenario

1. Introduction

1.1. *Cable yarding*

Cable yarding is a common method of extracting timber from steep or poorly accessible sites. It typically involves a tower and a winch set with multiple drums. The different drums are used to control a carriage or grapple along a skyline into the stand and extract the timber to roadside in a fully or partially suspended fashion (Heinimann, Stampfer, Loschek, & Caminada, 2001). Transition from ground-based harvesting systems (wheeled or tracked machines) to cable-based timber extraction is typically necessary for gradients from 20 to 40%, depending on factors like surface unevenness and slope length (Davis & Reisinger, 1990). There has been some focus on increasing the operating range of ground-based equipment and examples include wheeled machines such as the Menzi-Muck (Dale & Nitteberg, 1999), or tracked machines like the Valmet Snake harvester (Stampfer, 1999) or processor (Strandgard, Alam, & Mitchell, 2014). Specialised working methods have also been developed such as the use of an excavator to create temporary access roads (Lileng, 2007) or the use of tethered machines which provide capability to access slopes of around 60% (Sutherland, 2012). However, yarding remains a prevalent production method in the European Alps, especially in countries such as Austria, Italy and Switzerland where tower yarders are manufactured.

For tower yarders, the size, strength and stability of the end-tree (or tailspar), or the intermediate support trees, are important factors as the system is operated using high tensile forces in the skyline. Rigging fixed (i.e. static) skylines used in suspending and extracting trees requires pulling out, and then pre-tensioning, 2–400 m of 18–22 mm steel cable, and guying both the tower and the tailspar to withstand dynamic forces that are greater than the specified safe working load of the skyline which will typically range from 10 to 20 t (Visser, 1998). This is a time consuming and resource demanding process; requiring about 6 h of work for 3 people (Stampfer, Visser, & Kanzian, 2006). It reduces machine availability and increases costs, especially if combined with short corridors or low harvesting volumes.

However, in the inland boreal forests of Norway, trees in final harvest are generally much smaller than those in the Alps (0.2–0.5 m^3 per stem), as well as being more shallow rooting and therefore less stable. Harvest volumes are low (250–350 m^3 ha^{-1}) and stands are small (1–3 ha). This has made, in the past, running skyline configurations the system of choice. Since two lines support the load they can be of smaller diameter (~11 mm) and the tension in the system is lower. The main and haul-back drums are hydraulically interlocked in a way which maintains relatively constant tensions at any position of the lines. Running configurations can vary the deflection at any point of the span, adjusting itself to the weight of the load, the deflection increases with heavier loads to provide lift to the suspended load without adding to the line tension (Mann, 1969).

Excavator-based yarders, which are an alternative to the more conventional European truck or trailer mounted tower yarders, are often rigged for a live or running skyline. Yoshimura and Noba (2013) note that the highlead configuration is prevalent in Japan. Other countries with a documented use of excavator-based yarders are Ireland (Devlin & Klvač, 2014), Scotland (Tuer, Saunders, & MacIntosh, 2013), Canada (Gingras, 2013) and South Africa (McEwan, Brink, & van Zyl, 2013). Some of the advantages of excavator based yarders over conventional truck based units are (i) that guying is usually not necessary as the mass of the base machine itself provides enough ballast to counteract the forces in the cable, (ii) that the non-guyed machine is mobile on the landing and can move aside to allow passage of timber trucks in narrow confines, or move when space becomes confined due to a shortage of timber trucks (iii) that excavators are relatively cheap and commonly available base machines with seasonal demand in agriculture or road construction and maintenance, and (iv) it is relatively easy to switch between yarding and excavator functions (Talbot, Tarp, & Nitteberg, 2014). In addition, many Norwegian farmers own excavators and may be able to diversify into timber harvesting as a means of supplementing their incomes.

While substantial research has been done on the productivity of tower yarders (Cavalli, 2012) only a very limited number of studies have been reported on non-guyed yarding equipment. Largo, Han, and Johnson (2004) studied one Timbco feller-buncher based and one Caterpillar excavator based yarder in thinning operations in Idaho, USA. Both were fitted with double-drum winches and used in a live skyline with a gravity return carriage system (shotgun), and operated with 2-man crews. Torgersen and Lisland (2002) developed and tested an integrated excavator based machine that was fitted with a double-drum winch and a stroke delimber for processing. Devlin and Klvač (2014) studied operations with both 2 and 3 man crews on non-guyed yarders in Ireland. Talbot, Tarp, et al. (2014) evaluated the preferences of various groups for a range of functionality on such a yarder, while Talbot, Aalmo, and Stampfer (2014) reported on the productivity of a unique new yarder-processor. This machine integrates a modern 3-drum winch and a harvesting head on a wheeled excavator base machine and is unique in that, as it