Forwarding work study with automatic data recording

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Summary: Most often forwarder work follow-up data are still collected manually. We collected automatically a large dataset with the TimberLink program. As TimberLink was found to be capable to recognise different work tasks on a detailed level, traditional manually collected forwarder work follow-up datasets could be replaced by the automatically collected datasets in many applications. For instance, traditional follow-up field studies on the harvester work are already about to be replaced by the automatically collected datasets.
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Introduction

Traditionally forest work data are collected manually through field studies. As collecting data manually is a labour intensive work the datasets tend to be small due to the financial limitations (e.g. McNeel & Rutherford 1994; Gullberg 1995; Tiernan et al. 2004; Mederski 2006; Nurminen et al. 2006). Therefore the tendency during the last decades has been to collect data automatically by the computers mounted on the forest machines. This enables gathering of larger datasets while keeping costs on a reasonable level. However, so far the studies based on the large-scale follow-up datasets have addressed the harvester work (e.g. Purfürst 2010; Purfürst & Erler 2011; Gerasimov et al. 2012); while similar studies for forwarder work are lacking.

Materials and methods

We used the TimberLink program (John Deere Forestry Oy, Finland) for the data collecting. TimberLink applies a probabilistic classification algorithm (Viterbi) for the operator's multivariate control signals to recognise different work elements. As the standard control area network (CAN) data do not include complete information on forwarder work elements the use of a probabilistic methodology was required to choose the most likely alternative (i.e. work element) to occur at any given moment.

Our dataset consisted of work data from two similar large-sized (21.8 tonnes) John Deere 1910E (John Deere PowerTech Plus 6090) forwarders with 19 tonnes' payload capacity. Moreover, the forwarders were driven by nine different operators. The dataset was collected at final felling stands which were located in the province of Dalarna, mid-Sweden.

The work elements loading and loading drive could overlap, and also the work elements unloading and unloading drive could overlap respectively. Data were not cleaned, i.e. there was no filtering and no elimination of out-layers. The used productive machine (PM) time included only effective work time (IUFRO 1995).

Results and discussions

On average loading phase (including both crane work and driving) PM time made up 45.9% of total time per load followed by unloading phase (including both crane work and driving) PM time (19.2%), other time pooled (14.2%), driving empty PM time (9.4%) and driving loaded PM time (8.3%) (Table 1). Our finding is in line with published literature in which loading and unloading (including both crane work and driving) together make up 80-85% of the total forwarding time consumption (cf. Manner et al. 2013). In our study, other time made up 14.2% of the total forwarding time consumption which is slightly higher than in Kuitto et al. (1994) and Väkevä et al. (2001). But this was expected as in our study other times were basically extracted from the CAN-bus data, and compared studies are based on manually collected data with a precision that do not reach the high resolution level of CAN-bus based data.

Expectedly, we found that the driving empty speed on average was the fastest among the driving speeds. The average driving empty speed was 17% higher than the corresponding driving loaded speed, and 62% higher than the average loading drive speed. (One-way ANOVA, $p<0.001$, adjusted $R^2=30.0\%$, $n=26077$).

Loading and unloading crane cycle times were nearly identical. However, on average the loading phase included twice as many crane cycles as unloading phase, or respectively unloading grapple size was on average twice as large as loading grapple size (paired t-test, $p<0.001$, $n=8868$).

On average, pooled driving empty and driving loaded distances made up 56.2% of the total driven distance, while the pooled loading drive and unloading drive distances made up 39.5%, whereas 4.3% of the total driven distance could not be specified. Driving empty and driving loaded distances in current literature vary considerably but on average the different distance observations in our study are in line with published studies (c.f. Kellogg and Bettinger 1994; McNeel and Rutherford 1994; Nurminen et al. 2006). However, average loading drive distance in our study was considerably longer than in many other studies (c.f. Kellogg and Bettinger 1994; Nurminen et al. 2006). Short loading drive distance in Kellogg and Bettinger (1994) is explained, at least partly, by the considerable high forwarded log concentration. And on the other hand, long loading drive distance in our study is explained by the load capacity which was considerably larger in the forwarder model used in our study compared with the forwarder models used in Kellogg and Bettinger (1994) and Nurminen et al. (2006).

Spearman's rank correlation coefficient between loading drive distance and total time per load was 0.454, whereas it was 0.352 for the relationship between extraction distance and total time per load. Extraction distance was defined as the mean of driving empty and driving loaded distances. Thus, given the higher correlation between loading drive distance and time consumption per load was found to be a better estimator for the total forwarding time consumption than the extraction distance. Moreover, the positive correlation coefficients indicated that time consumption increased expectedly with increasing distances (both loading drive and extraction).

On average driving only made up 53% of the forwarders total fuel consumption followed by crane use only (39%), simultaneous driving and crane use (4%) and other (3%). Fuel consumption figures per load, time unit and driven distance were slightly higher in our study compared with the figures given in Nordfjell et al. (2003). However, this was also expected as the forwarders in Nordfjell et al. (2003) were notable smaller than the ones used in our study.

We found TimberLink as an useful tool to automatically collect a large amount of forwarder follow-up data. Herein paper we only presented the most traditional forwarder elements but TimberLink is capable to recognize work elements even on the more detailed level which is crucial for the machine monitoring systems and the advanced forwarding work analyses.

Table 1. Medians and means for the forwarding work. Observation unit is one load and the number of observations for each work element was 8868. Median absolute deviations (MAD) and standard deviations (SD) are given in parentheses.

	Time consumption (minutes/load)	
Work element	Median (MAD)	Mean (SD)
Driving empty, productive machine (PM) time	3.5 (2.1)	4.3 (3.6)
Loading phase, PM time	18.8 (6.1)	21.0 (11.8)
Driving loaded, PM time	2.8 (1.9)	3.8 (3.6)
Unloading phase, PM time	7.5 (2.2)	8.8 (5.8)
Other time pooled	3.4 (2.2)	6.5 (11.9)
Total time	42.1 (11.8)	45.8 (24.1)

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