Comparing a High-speed Forwarder with a Tractor-and-Trailer Unit Using Commercial GPS/GSM Technology

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Abstract:
Recent studies demonstrate that harvesters and processors have become increasingly popular with the Italian logging companies working in the Alps. In contrast, the introduction of specialized forwarders have been much less successful. The main reason is the peculiar use of forwarding units made by the Alpine logging firms. These generally use the same machine for extraction and intermediate off-road transportation on mountain trails, inaccessible to truck and trailer units. Conventional Nordic forwarders are not designed for fast (>20 kmh) transportation on trail and therefore they cannot replace conventional tractor and trailer units. However, new high-speed forwarders could prove effective in both task, qualifying for substitution. With this background, CNR set up a long-term follow-up study to determine the use pattern of a conventional tractor and trailer unit and a new high-speed forwarder. To this purpose, CNR installed commercial black-box GPS/GSM units for continuous real-time collection of the main work data, including: position, status, speed and fuel consumption. The study showed that the high-speed forwarder could actually travel at a speed higher than 30 km h^{-1}, and it performed both extraction and intermediate transportation. Like the tractor, it was capable of independent relocation, which made it most suitable for small-scale forestry. Use pattern was very intense for both machines, but it was substantially higher for the forwarder, possibly due to its better flexibility and to the need for depreciating a larger investment.

Keywords: logistics, forwarding, mountain, black-box, precision forestry

1 Introduction

Mechanized CTL harvesting has revolutionized forest operations, with strong impacts on value recovery, labour productivity and work safety (Chiorescu and Grönlund 2001). Normally, the whole system is based on two machines only: the harvester for felling and processing, and the forwarder for extraction. Such machines are now common in all industrialized countries (Gellerstedt and Dahlin 1999), far beyond the borders of the Nordic regions where they were first developed and thoroughly studied (Nurminen et al. 2006). Harvesters and forwarders are remarkably flexible, and can be adapted to cope with a variety of terrain and work conditions, including steep slopes (Frutig et al. 2007). Alpine countries like Austria, Bavaria, Italy and Switzerland host a sizable harvester and processor fleet, often teamed with cable yarding equipment (Spinelli et al. 2010). In contrast, forwarders seem to be less popular, despite the strong interest shown by operators (Ferrari et al. 2012). In the Italian Alps, logging contractors operate 48 forwarders and 1366 tractor-and-trailer units, with a ratio of 1 to 28 (Spinelli et al. 2012). The overwhelming success of the less productive tractor-and-trailer units depends on many factors, not least the peculiar use of forwarding equipment made by the Alpine logging firms. These generally use the same machine for extraction and intermediate transportation on low-standard roads, inaccessible to trucks. Unfortunately, conventional Nordic forwarders are specifically designed for off-road transportation over very short distances, in the order of 400 m (Tiernan et al. 2004). Intermediate transportation on low-standard roads requires specialty equipment (Stokes and Schilling 1997), often obtained from the adaptation of quarry dumpers (Hall 1995). However, these machines can cause heavy damage to the forest soil and suffer the opposite limitation of Nordic forwarders: they are appropriate for intermediate transportation, but unsuitable for off-road extraction (Spinelli et al. 2004). Hence the interest for a new generation of high-speed forwarders that could prove effective in both tasks, due to their compact size and enhanced transmission box. These machines may replace the ubiquitous farm-tractor units, doing the same job with better efficiency. The goal of this study was to gauge the potential of these new machines, by comparing their usage pattern with that of traditional farm-tractor units. In particular, the study determined for both machine types: monthly usage, incidence of travelling time over total time, distance covered and travel speed. The null hypothesis was that use pattern, average travel distance and speed distribution did not differ between traditional tractor and trailer units and high-speed forwarders.

2 Materials and methods

Two representative machines were selected for the study: a 6-wheeled Welte 130T forwarder (110 kW) and a Same Silver 130 farm tractor (95 kW), equipped with a 12-tonne Galvagni forwarding trailer. Both machines were road-legal and could travel to a theoretical maximum speed of 40 km h^{-1}. The machines were owned by two separate small-scale logging contractors, representative of the region. Both worked in the same valley in Northeastern Italy, and were operated by the same owner-operator. For the purpose of the study, CNR researchers installed on both machines a commercial black-box GPS/GSM unit for continuous real-time collection of the main work data, including: position, status (engine off, engine on, travelling) and speed (Figure 1).

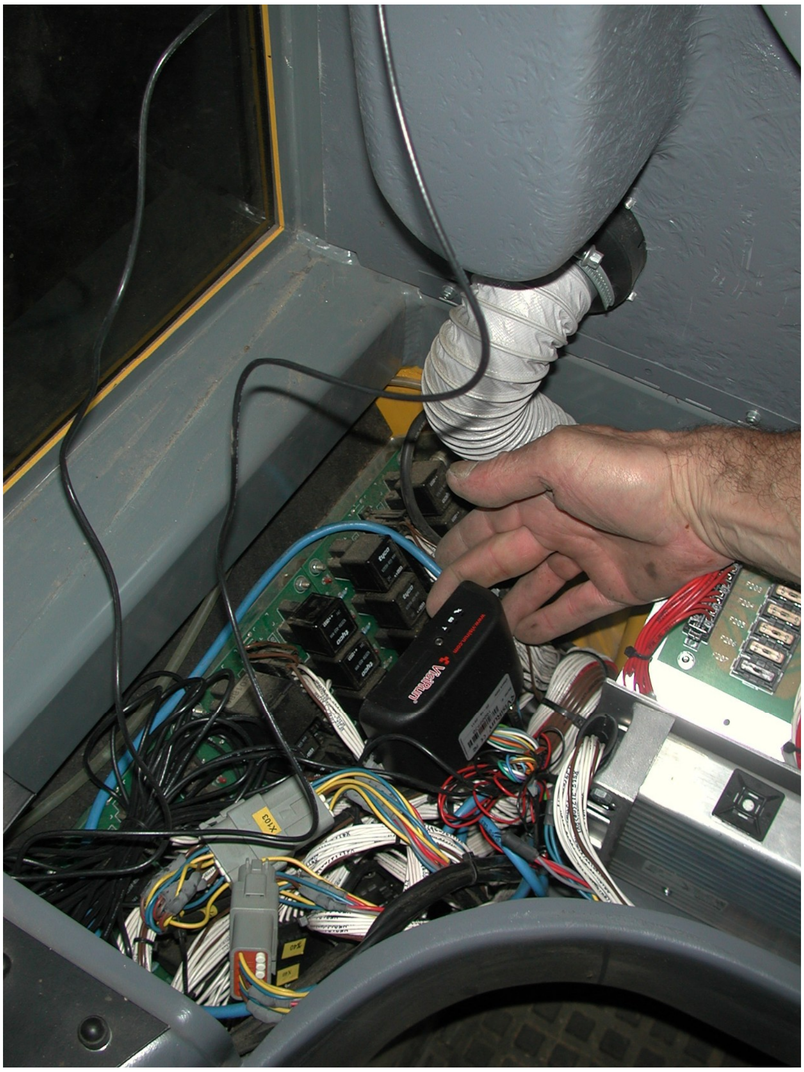

Figure 1: Installing the GPS/GSM black-box unit

The GPS/GSM black box collected position data at 30 second intervals and had a buffer memory in order to store data when GSM coverage was unavailable. Stored data were sent to the server as soon as the unit could hook again into the GSM network. The units used for the study were a commercial product used for truck fleet management, available at a very attractive monthly fee (www.visirun.com). Similar units have recently been used in forest engineering studies dealing with wood transportation (Holzleitner et al. 2011a). Previous research shows that GPS tracking offers acceptable results with forwarding units (Veal et al. 2001) and is used for such delicate tasks as measuring mobility parameters (Suvinen and Saarilahti 2006) or autonomous path tracking (Ringdahl et al. 2011).

The black-box system used for the study downloaded all data at the end of each day in a single spreadsheet per machine. Data processing was rationalized by developing a new automated procedure to merge all daily spreadsheets in a single master data base per machine, in order to convert it into a Data Base Managing System (DBMS). Data were then processed with the software Oracle® Database Express Edition 10g Release 2 (10.2), which is easily available, efficient and ready to interface with other software. Data were cleaned from errors using a query view obtained in Standard Query Language (SQL). That allowed selecting and editing all the events with less or more than two records per minute, which was the standard data collection rate at a 30-second pulse interval. Query views were finally converted into a spreadsheet (MS Excell) or a DBMS (MS access) in order to produce suitable pivot tables.

The data considered in this preliminary study cover 6 months during the same period, from December 2011 to May 2012, included. The following data were used in the analysis: duration of the working day in hours (roughly the same as worksite time); time when the engine is running, in hours; time the machine is moving, in hours; total distance travelled in km. Before analysis, daily figures were consolidated into five-workdays sums, in order to reduce the confounding effect of daily variability. The distribution of consolidated travel distance data was normalized through LOG-transformation. Current speed data were recorded every 30 seconds, and each record was allocated to one of the following speed classes: 0 to 2, >2 to 5, >5 to 12, >12 to 20, >20 to 30, >30 to 40 and >40 km h^{-1}. Again, the incidence of each speed class over total travel time was cumulated as a five-workdays sum to dampen the effect of extreme daily values. Before statistical analysis, the distribution of percent incidence data was normalized through arcsine transformation.

3 Results

Over the six-month study period, the forwarder worked 122 days and the tractor 99 days. The average workday lasted 8.9 and 7.9 worksite hours, respectively for the forwarder and the tractor. The longest workday lasted 13.1 and 17.4 worksite hours, respectively. The total worksite time accumulated during the study period by the forwarder and the tractor was 1109 and 827 hours, respectively. Engine time was 829 hours for the forwarder and 495 hours for the tractor. Utilization was then 75% for the forwarder and 60% for the tractor. Doubling engine time offers a good reference figure for annual use, as recorded on a standard hour meter. Therefore, annual use was 1658 and 989 hours for the forwarder and the tractor, respectively. Hence, the forwarder was used 68% more intensely than the tractor. Table 1 shows the average figures for the cumulated five-workday data. The forwarder worked more hours per work week and had a higher utilization than the farm tractor. In contrast, it covered a shorter distance. Over the year, the forwarder would cover 4100 km, and the tractor 4700 km. The analysis of variance showed that all these differences were statistically significant, except for travel distance (Table 2). Although a significant factor, machine type seldom accounted for more than 20% of the variability in data pool, which was consistent with the prevalent effect of site variability in natural forests. The cumulative distance covered in five consecutive workdays did not differ significantly between the two treatments, but the hours worked during the same time did, and therefore the tractor covered a significantly longer distance per unit time. The six-month average was 2.6 and 6.2 km per engine hour, respectively for the forwarder and the tractor. This difference was tested with the non parametric Mann-Whitney U-test and resulted statistically significant at the 5% level.

Table 1: Worksite time, engine time, utilization and travel distance

Cumulated values for five workdays		Forwarder Mean	Forwarder SD	Tractor and trailer Mean	Tractor and trailer SD	Difference %
Worksite time	h	35.8	9.6	26.7	14.4	34.1
Engine on	h	26.7	9.1	15.9	12.5	67.9
Moving	h	26.9	9.2	16.0	12.4	68.1
Utilization	%	74.5	16.6	58.7	23.8	26.9
Distance	km	66.2	37.6	75.5	61.9	-12.3

Table 2: ANOVA Table for worksite time, engine time, utilization and travel distance

Worksite time						
Factor	DF	SS	%	F-Value	P-Value	Power
Machine type	1	1281.887	12.4	8.515	0.005	0.833
Residual	60	9032.212				
Engine time						
Factor	DF	SS	%	F-Value	P-Value	Power
Machine type	1	1802.704	20.2	15.178	0.0002	0.982
Residual	60	7126.174				
Move time						
Factor	DF	SS	%	F-Value	P-Value	Power
Machine type	1	1849.921	20.4	15.38	0.0002	0.983
Residual	60	7217.084				
Distance (LOG km)						
Factor	DF	SS	%	F-Value	P-Value	Power
Machine type	1	0.027	0.3	0.208	0.65	0.073
Residual	60	7.706				
Utilization (%)						
Factor	DF	SS	%	F-Value	P-Value	Power
Machine type	1	0.384	13.2	9.085	0.0038	0.859
Residual	60	2.535				

These results were compatible with the distribution of move time within predefined speed classes, shown in Figure 2. Almost 70% of forwarder move time fell within the slowest speed class, compared to 54% for the tractor. In contrast, the percent of move time falling within the high speed classes (>12 km h^{-1}) was twice as high for the tractor as for the forwarder. The proportion of move time the tractor travelled at a speed higher than 20 km h^{-1} was 6.7%, which dropped to 1.1% with the forwarder. These differences were statistically significant, except for the second slowest class that represented between 15 and 17 % of move time regardless of machine type (Table 3). Technically, both the tractor and the forwarder were capable of travelling at a speed higher than 30 km h^{-1}. The database even contained rare speed records higher than 40 km h^{-1}, but these could be the result of a position errors.

Table 4 shows the number of hours spent moving at a given speed for the whole six-month study period. This was obtained by multiplying total move time by the percent incidence of each speed class, since the incidence alone did not fully reflect usage pattern. During the whole study period, the forwarder spent very little time moving at speeds higher than 20 km h^{-1}. In contrast, the tractor moved at speeds higher than 20 km h^{-1} for three to six times as many hours. That may indicate that the forwarder reached the highest speed only when travelling unloaded during relocations, whereas the tractor was also used for road transportation.

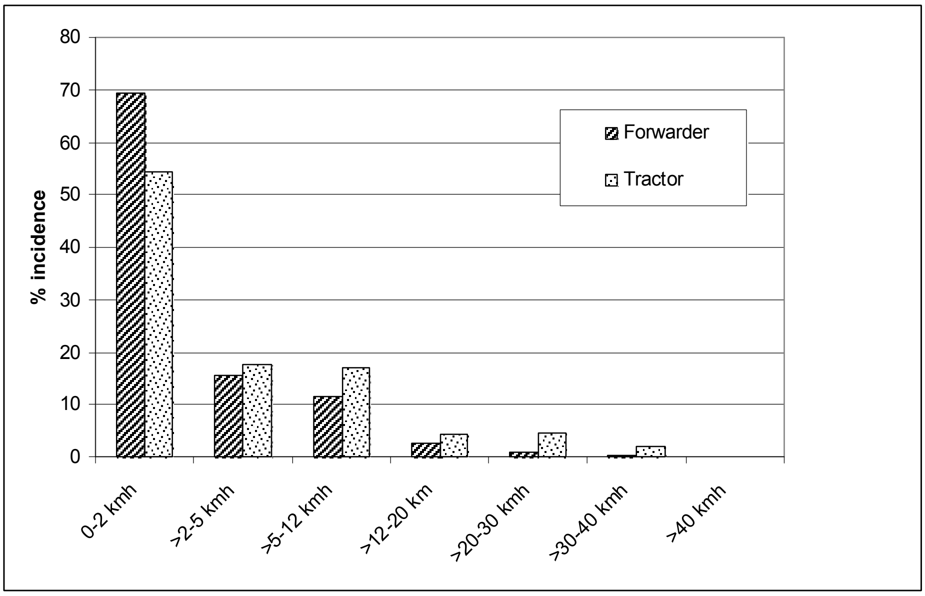

Figure 2: Breakdown of moving time within speed classes

Table 3: ANOVA Table for the percent breakdown of move time within speed classes

Factor	DF	SS	%	F-Value	P-Value	Power
% incidence of the 0-2 km h^{-1} speed class						
Factor	DF	SS	%	F-Value	P-Value	Power
Machine type	1	0.279	20.4	12.029	0.0011	0.942
Residual	47	1.09				
% incidence of the >2-5 km h^{-1} speed class						
Factor	DF	SS	%	F-Value	P-Value	Power
Machine type	1	0.008	2.0	0.894	0.3439	0.145
Residual	47	0.396				
% incidence of the >5-12 km h^{-1} speed class						
Factor	DF	SS	%	F-Value	P-Value	Power
Machine type	1	0.069	9.7	5.02	0.0298	0.586
Residual	47	0.646				
% incidence of the >12-20 km h^{-1} speed class						
Factor	DF	SS	%	F-Value	P-Value	Power
Machine type	1	0.029	7.4	3.779	0.0579	0.464
Residual	47	0.362				
% incidence of the >20-30 km h^{-1} speed class						
Factor	DF	SS	%	F-Value	P-Value	Power
Machine type	1	0.168	34.3	24.531	<0.0001	1
Residual	47	0.322				
% incidence of the >30-40 km h^{-1} speed class						
Factor	DF	SS	%	F-Value	P-Value	Power
Machine type	1	0.121	27.1	17.483	0.0001	0.992
Residual	47	0.325				
% incidence of the >40 km h^{-1} speed class						
Factor	DF	SS	%	F-Value	P-Value	Power
Machine type	1	0.002	16.7	7.189	0.0101	0.755
Residual	47	0.01				

Table 4: Hours travelled within each speed class during the six-month study period

Speed class	Forwarder	Tractor
0-2 km h^{-1}	578	270
>2-5 km h^{-1}	129	87
>5-12 km h^{-1}	96	84
>12-20 km h^{-1}	21	22
>20-30 km h^{-1}	8	23
>30-40 km h^{-1}	2	11
>40 km h^{-1}	0	0
Total	835	496

4 Discussion

The study showed that the two machines were used differently, disproving the null hypothesis that usage pattern did not change with machine type. The main difference in usage pattern was that the tractor was occasionally used for road transport, while the forwarder was not. On the other hand, both seemed equally capable of intermediate transport on low-standard roads, since the hours worked at speeds between 12 and 20 km h^{-1} were about the same for both machines. Indeed, intermediate transport is generally performed within that speed range, as already indicated by Holzleitner et al. (2011). On low-standard roads, higher speeds may prove very difficult to maintain, due to the excessive vibration stress suffered by both machine and operator (Rehn et al. 2005). While it remains primarily an off-road extraction vehicle, the new high-speed forwarder seems also suitable for intermediate transportation.

Annual usage was substantially higher for the forwarder than it was for the tractor, probably due to the combination of its better work capability and the need for depreciating the larger capital investment (Spinelli and Magagnotti 2010). The annual use figure estimated for the forwarder finds an almost exact match in the 1617 hours per year reported in a worldwide survey of cut-to-length equipment (Spinelli et al. 2011). Nevertheless, the tractor was also used intensely and it cannot be considered a machine for the part-time logger, at least in this specific case. That may reinforce the point that many Alpine loggers resort to tractor-and-trailer units for their specific technical capacity in the absence of suitable alternatives, and not for a supposed inability to accumulate a large enough workload. Readers must also notice that both machines could achieve a relatively intense use even during the winter season, since the study period went from December to May. That may disprove the assumption that mountain operations come to a halt during the winter, due to bad weather conditions. For this reason, we are extending the study over the summer season, in order to gauge the effect of bad weather on machine use, and check if the doubling of the six-month winter figures did not lead us to underestimate annual use.

This study also highlights the substantial difference between worksite time and engine time, or hour meter time. Difference between worksite time records and hour meter records has already been noticed in a previous study by Spinelli and Magagnotti (2011). This is obviously related to the effect of machine utilization, which this study approximates with the ratio of engine time to worksite time (Björheden et al. 1995). The machine utilization figures obtained in this study are slightly larger than those reported by Brinker et al. (2002), and more recently by Holzleitner et al. (2011b). That may depend on the inclusion of non-work time within engine time, which is bound to increase utilization. For that reason, we are planning further studies to compare GPS and manual records. These studies will also aim at determining productivity, which could not be estimated from the GPS records.

Independent relocation is a key advantage of tractor-and-trailer units, which is also enjoyed by the new high-speed forwarders. Expensive relocation by low-bed trucks is a main constraint to the use of conventional forest machines in small-scale forestry (Väätäinen et al. 2006), and wherever tract size is limited (Rickenbach and Steele 2006). So far, the main technical solution explored by manufacturers was to develop combination machines, in order to reduce the number of machine moves (Andersson and Eliasson 2004). The new forwarder solves the relocation problem in a more radical way, and it may also configure as a combination machine, if one considers extraction and intermediate transportation as two separate tasks.

5 Conclusions

The high speed forwarder could actually travel at a speed higher than 30 km h^{-1}, and it performed both extraction and intermediate transportation. In both tasks it could effectively replace conventional tractor-and-trailer units, although it could be used for road transportation. Like the tractor, it was capable of independent relocation, which made it most suitable for small-scale forestry. Use pattern was very intense for both machines, which configured as specialized contractor equipment. However, annual use and utilization were substantially higher for the forwarder, possibly due to its better flexibility and to the need for depreciating a larger investment.

Acknowledgments

This study is a part of the project "Organization and rationalization of logging operations" funded by Regione Autonoma Friuli-Venezia Giulia, Servizio Gestione Forestale e Produzione Legnosa. This study was also made possible thanks to funding received from the STSM programme of Action COST FP902. Special thanks are due to the two forest entrepreneurs hosting the study and to Franz Holzleitner, Christian Kanzian and Norbert Holler for their invaluable help with SQL building.

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