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Measuring the mobility parameters of tree-length forwarding systems using GPS technology in the Southern Italy forestry

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Abstract. The introduction of modern forwarders to Apennines forest operations must account for the traditional forwarding units used by local logging contractors. They generally use the same machine for extraction and intermediate off-road transportation on mountain trails, inaccessible to heavy road vehicles. Conventional forwarders are not designed for fast transportation on trail and cannot replace conventional. This research set up a long-term follow-up study to determine the use pattern of three conventional tractor-trailer units (Forwarder, forestry trailer and articulated truck). The goal of this study was to gauge the potential of these machines. 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. For this purpose, Global Positioning System/Global System for Mobile Communications data loggers were installed for continuous real-time collection of the main work data, including position, status, speed and fuel consumption. The study showed that new forwarders could actually travel at a speed higher than 24 km h^{-1}, and they performed both extraction and intermediate transportation. They were capable of independent relocation, which made them suitable for small-scale forestry. Both machine types were used intensively, but the annual usage of forwarders was almost twice as large as that of tractor-trailer units. Furthermore, forwarders had a 27% higher hourly productivity and a 50% higher fuel consumption per hour, compared with tractor-trailer units.

Key words: GPS – Track logger, data logger, extraction, precision forestry.

INTRODUCTION

Forests in southern Italy are an important area in terms of forest production, having the largest forest cover of all regions of the country even though the highest concentration of woodlands occurs in the northern regions of Italy. Forests cover 1,517,836 ha (NFI 2005) in southern Italy and consist mainly of mature beech, chestnut, Corsican pine, and silver fir forests (more than 300,000 ha combined). These forests account for a wooded area percentage of 31.8%. Therefore, use of these forests could certainly provide a more significant resource for the economy of the entire Mediterranean basin, an objective that could be attained with better and more efficient mechanization of forest operations, which should play a growing role (Istat, 2013). Unfortunately, the current level of mechanization is fairly low (Zimbalatti & Proto, 2009). The current increasing dynamism of the wood market has led to the development and improvement of technologies able to extract logs more efficiently by reducing consistently the time and labour required for production (Cavalli et al., 2014; Moneti et al., 2015). Indeed, the most common work method in southern Italy, referred to as traditional, can be considered as an early stage of mechanization. It is based mainly on agricultural tractors, sometimes equipped with specific forest-related machines (winches, hydraulic cranes, log grapples, etc.); use of animals for gathering and yarding is also widespread. This level of mechanization of forest resource extraction is due to the features of the forest sites, the characteristics of the forest properties, and the small dimensions of many forest enterprises (Proto et al., 2014).

Time motion study by GPS is a key factor for the road network planning (Cavalli & Grigolato, 2010). Similar methods have recently been used in forest engineering studies dealing with wood transportation (Holzleitner et al., 2011a), forwarding units (Veal et al. 2001), mobility parameters (Suvinen & Saarilahti, 2006) and autonomous path tracking (Ringdahl et al. 2011; Spinelli et al., 2015; Russo et al., 2016). Respect to the previous studies, however, the forest features, harvesting and skidding methods are completely different in South Italy, the sites of the present research. In Calabria, where the test were conducted, the expanse of forest is 40.6% respect on average data national of 34.7%. Every year, the average increase in wood volume in this region (equal to 6–8 m^3 ha^{-1}) exceeds and sometimes doubles the estimated increase in other forests in Italy (Proto & Zimbalatti 2015,), roughness, slope, and silvicultural system affect the mobility parameters of tree-length forwarding systems. In this respect, the present research aims to develop technical and economical knowledge regarding the different use of three machinery used in Calabria (South Italy) by using GPS/GSM technology.

MATERIALS AND METHODS

Three representative machines were selected for the study: an articulated Man Truck, model TGX 6×6 (471 kW), a forwarder, model John Deere 110 D (125 kW), and a forestry tractor-trailer (70 kW) (Table 1). All machines were road-legal and could travel at a theoretical maximum speed of 40 km h^{-1}. The machines were owned by separate small-scale logging contractors, which is typical of the region.

Table 1. Description of machines

Machine	Articulated Truck	Forwarder	Forestry Tractor-railer
Type	MAN	John Deere	Lamborghini
Model	TGX 6x6	110 D	1,060
Trasmission	Hydrostat	Hydrostat	Mechanic
Axles total	3	4	4
Power (kW)	353	125	77
Weight (kg)	33,000	14,600	8,050
Width (mm)	2,490	2,650	2,350
Length (mm)	5,200	5,000	2,350
Gps Study - Months	7	7	7

All these machines worked in the same valley in southern Italy and were operated by the same owner-operator. For the purpose of the study, the university researchers installed on all 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, traveling), and speed (Fig. 1).

The tests were carried out at three forest sites, indicated below by the letters A, B, and C and all located in the Serre massif (VV). Table 2 gives the features and vegetation characteristics of the three test sites from surveys carried out beforehand.

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

Table 2. Characteristics of the two test sites

Features	Measurement Units	Site A (Articulated truck)	Site B (Forwarder)	Site C (Forestry tractor-trailer)
Altitude	a.s.l.	950	800	850
Prevalent species	-	Chestnut	Corsican pine	Mediterranean pine
Government	-	Coppice	High forest	High forest
Treatment	-	Clearcuts with reservations	Thinning	Thinning
Stand density	n. p. ha^{-1}	2,400	900	1,200
Average volume per tree	m^3	0.20	0.65	0.40
Total volume	m^3 ha^{-1}	480	585	480
Average slope	%	31	22.5	27
Max gradient		50	38	43
Min slope		12	7	11
Roughness	-	Very rough	Moderately rough	Moderately rough

The GPS/GSM black box collected position data at 30-second intervals and had a buffer memory to store data when GSM coverage was unavailable. Stored data were sent to the server as soon as the unit could connect again to the GSM network. The units used for the study were a commercial tracker used for truck fleet management and available at a very attractive monthly fee (www.visirun.com).

The black-box system used for the study downloaded all data at the end of each day into one spreadsheet per machine. All position data carried a time stamp, which was used to estimate speed. Data loggers were connected to the engine contact, and hence they recorded the time that the engine was on. As a consequence, each produced a daily estimate of work hours, which was downloaded together with the position points and speed graphs (Fig. 2). Data processing was rationalized by developing a new automated procedure to merge all daily spreadsheets into a single master data base per machine to convert it into a data base management system. This made it possible to select and edit all the events. Data were recorded at two records per minute more or less, which was the standard data collection rate at a 30-second pulse interval. Query views were finally converted into a spreadsheet (MS Excel) to produce suitable pivot tables. The data were then processed using the SPSS software.

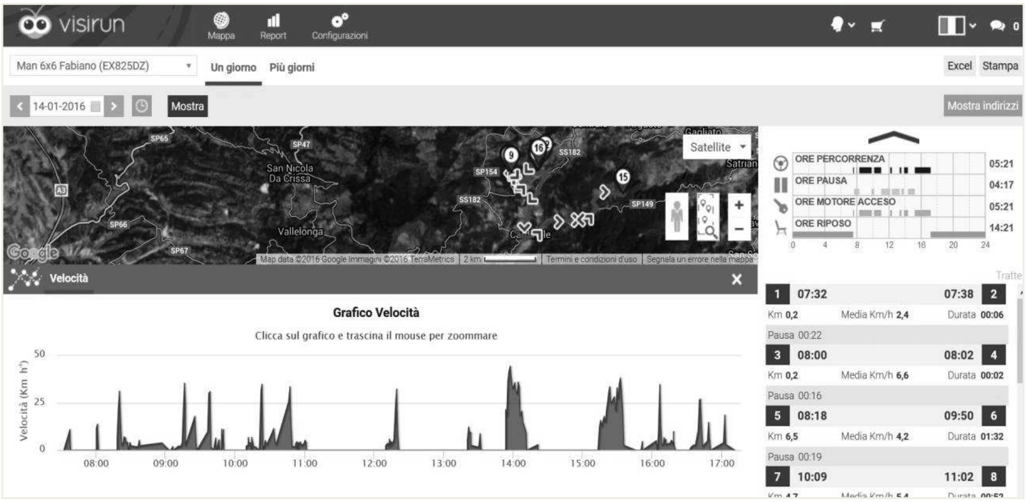

Figure 2. Example of machine track and speed graph for one work day.

The data considered in this preliminary study covered 7 months during the same period, from May 2015 to December 2015 inclusive. 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 was running, in hours; time that the machine was moving, in hours; and total distance traveled, in km. Before analysis, the daily figures were consolidated into sums representing five working days to reduce the confounding effect of daily variability. A similar consolidation was carried out to describe the volume of wood extracted in each trip to determine the mean hourly productivity of the different machines. The total number of logs was counted and their transportation recorded to calculate the volume of each load and hence to obtain a good estimate of the total volume carried. Overall data for the periods of work and the skidding-cycle volumes on the test days were also collected.

The logs obtained during the study at the three test sites were calculated by measuring the total length and the diameter at half height (Proto & Zimbalatti, 2015; Proto et al., 2016a). At the first site (A), the full-tree harvesting method was used; the trees were delimbed, topped, and bucked on site. At the second and third sites (B and C), the tree-length method was used. Trees were felled, then delimbed and topped at the stump. The volume of logs was calculated using the Huber formula (1):

$$V = D^2 \cdot \pi/4 \cdot L, \quad (1)$$

where: V = total tree volume (m^3); D = mid-height diameter (m); L = length (m).

The distribution of consolidated travel distance data was normalized through a logarithmic 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 10, > 10 to 20, and > 20 km h^{-1}. The incidence of each speed class over the total travel time was cumulated as a sum over five working days to dampen the effect of extreme daily values.

RESULTS AND DISCUSSION

Over the seven-month period, the forwarder worked 158 days, the articulated truck 85, and the forestry tractor-trailer 75 days. The average workday lasted 8.20 hours in the forwarder, 9.40 in the articulated truck, and 8.00 with the forestry tractor-trailer. The longest workday lasted 13.4 hours with the articulated truck, 10.2 with the forwarder, and 9.25 with the forestry tractor-trailer. The total worksite time accumulated during the study period by the forwarder was 3,807 hours, 2,263 by the articulated truck, and 1865 by the forestry tractor-trailer. Engine time was 1,383 hours for the forwarder, 561 for the articulated truck, and 600 for the forestry tractor-trailer. Utilization time was about 40% for the articulated truck, subdivided into 21% for loading and unloading and 19% for time spent traveling empty and facing delays. The forwarder was used 56% of the time, with 20% of this time spent in loading and unloading. The forestry tractor-trailer was used 52% of the time, with 40% of this time used for loading and unloading. In this last machine, the greatest amount of time was spent to load and unload the wood. This high time consumption is caused by the type of mechanical grapple used, which is less powerful than the other grapples on the forwarder and the articulated truck.

Table 3 shows the average monthly data over the cumulated 7-month study period. The forwarder worked more hours per week and had a higher utilization rate than the articulated truck or the forestry tractor-trailer. However, it covered a shorter distance. The articulated truck covered a total distance of 5,063 km at an average speed of 25.5 km h^{-1}, the forwarder 532 km at an average speed of 2.6 km h^{-1}, and the forestry tractor-trailer 412 km at an average speed of 1.4 km h^{-1}.

Table 3. Worksite time, engine time, utilization rate, and travel distance (average month)

		Articulated truck		Forwarder		Forestry tractor - trailer	
		Mean	SD	Mean	SD	Mean	SD
Worksite time	h	80.1	72.1	197.6	38.3	85.7	29.1
Engine on	h	81.6	68.1	218.6	43.1	128.6	37.6
Moving	h	26.7	25.3	176.4	34.1	51	20.9
Utilization	%	40	23.9	75	14.3	55	12.1
Distance	km	723	710.2	76	8.9	58.9	3.9

Analysis of variance showed that all these differences were statistically significant except for travel distance (Table 4). Although a significant factor, machine type seldom accounted for more than 20% of the variability in the data pool, which was consistent with the predominant effect of site variability in natural forests. The cumulative distance covered in 7months did not differ significantly among the three sites, but the hours worked during the same time did, and therefore the articulated truck covered a significantly longer distance per unit time (Table. 4).

Table 4. ANOVA for worksite time, engine time, utilization rate, and travel distance

	Sum of squares	df	Mean square	F	Sig.
Between groups	61,442.571	2	30,721.286	12.263	0.000
Within groups	45,092.000	18	2,505.111		
Total	106,534.571	20			
Engine time					
	Sum of squares	df	Mean square	F	Sig.
Between groups	67,848.667	2	33,924.333	12.769	0.0004
Within groups	47,823.143	18	2,656.841		
Total	115,671.810	20			
Move time					
	Sum of squares	df	Mean square	F	Sig.
Between groups	90,385.143	2	45,192.571	60.575	0.0000
Within groups	13,429.143	18	746.063		
Total	103,814.286	20			
Distance					
	Sum of squares	df	Mean square	F	Sig.
Between groups	2,008,388.667	2	1,004,194.333	5.972	0.0103
Within groups	3,026,826.286	18	168,157.016		
Total	5,035,214.952	20			
Utilization					
	Sum of squares	df	Mean square	F	Sig.
Between groups	6,517.460	2	3,258.730	10.516	0.0009
Within groups	5,577.778	18	309.877		
Total	12,095.238	20			

These results were compatible with the distribution of moving time within predefined speed classes, as shown in Fig. 3. Almost 70% of forestry tractor-trailer moving time fell within the slowest speed class, compared to 40% for the forwarder and 5% for the articulated truck. In contrast, the percentage of moving time within the higher speed classes (2–10 km h^{-1}) was twice as high for the articulated truck as for the forwarder. The percentage of moving time in which the articulated truck traveled at a speed higher than 20 km h^{-1} was 66% of the total time monitored. Technically, both the articulated truck and the forwarder were capable of traveling at speeds higher than 20 km h^{-1}. The database even contained rare recorded speeds greater than 30–40 km h^{-1}, but these could have been the result of position errors. Table 5 shows the number of hours spent moving at a given speed for the whole seven-month study period. This was obtained by multiplying total moving time by the percent incidence of each speed class. During the whole study period, the articulated truck spent much more time moving at speeds greater than 20 km h^{-1}. In contrast, the forestry tractor and the forwarder moved at speeds less than 20 km h^{-1}. This may indicate that the articulated truck reached its highest speed only when traveling unloaded during relocations, whereas the forwarder and tractor were used for road transportation over short distances.

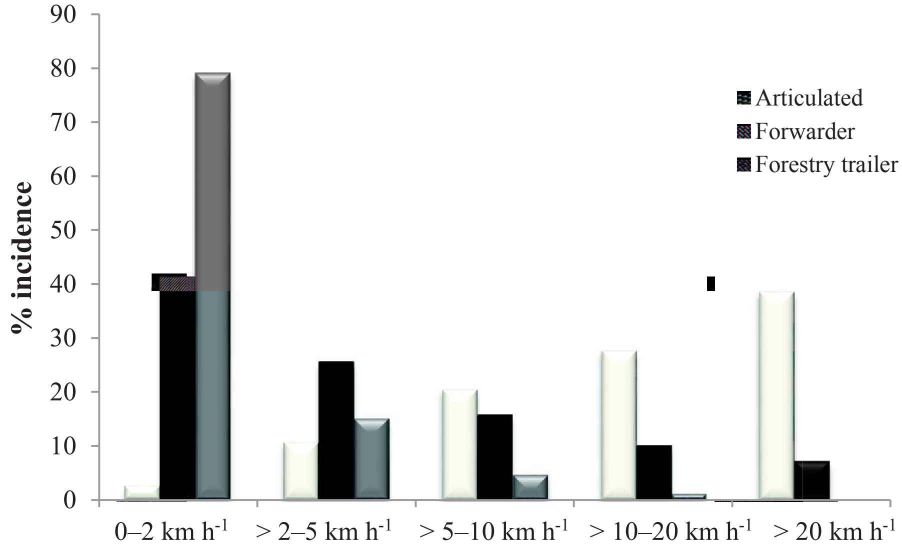

Figure 3. Breakdown of moving time within speed classes.

Table 5. Hours traveled within each speed class during the 7-month study period

Speed Class	Articulated truck	Forwarder	Forestry trailer
0–2 km h^{-1}	15	570	474
> 2–5 km h^{-1}	60	355	91
> 5–10 km h^{-1}	115	218	28
> 10–20 km h^{-1}	155	140	7
> 20 km h^{-1}	216	100	-
Total hours	561	1,383	600

The study showed that the three machines were used differently, which disproves the null hypothesis that the usage pattern did not change with machine type. The main difference in usage pattern was that the tractor was occasionally used for road transport, whereas the forwarder and the articulated truck were not. On the other hand, the forwarder and the forestry tractor-trailer both seemed equally capable of intermediate transport on lower-class roads, because the hours worked at speeds between 12 and 20 km h^{-1} were about the same for all machines. Indeed, the articulated truck spent much more time moving over intermediate and long distances. Annual usage was substantially higher for the forwarder and the articulated truck than for the forestry tractor-trailer, probably due to the combination of their better work capability and the need to depreciate their larger associated capital investment (Spinelli & Magagnotti, 2010). This study also highlights the substantial difference between worksite time and engine time, or hour-meter time. Differences between worksite time records and hour-meter records have already been noticed in a previous study by Spinelli & Magagnotti (2011). This is obviously related to the effect of machine utilization, which this study approximates by 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). This may result from including non-work time within engine time, which is bound to increase utilization. For this reason, further studies are planned to compare GPS and manual records.

These studies will also aim to determine productivity, which could not be estimated from the GPS records. These machines were capable of independent relocation, which made them suitable for small-scale forestry. All machine types were used intensively, but the annual usage of the forwarder and the articulated machine was almost twice as large as that of the tractor-trailer unit. Furthermore, the forwarders had 27% higher hourly productivity and 50% higher fuel consumption per hour than the tractor-trailer units.

CONCLUSIONS

The usefulness of articulated truck, forwarder, forestry trailer for extracting and transporting logs has attracted particular interest in the Calabrian forest industry. The transportation of timber has always been challenging, especially in mountainous environments where slopes cause processing limitations. This research has revealed that these machine types were used intensively, but that the annual usage of the forestry tractor-trailer was about half that of the other machines. The numerous observations recorded in this study confirm that the use of these different machines is influenced by the work site (Proto et al., 2016b). The forwarder is essential for efficiency in timber handling, thinning, and regeneration harvesting; the articulated truck for transport over intermediate and long distances; and the forestry tractor-trailer for extraction in gently sloping areas and transport over short distances. In terms of future road building, the position of these roads should minimize the extent of forwarding that may be economical. The models developed here provide a basis for site-specific costing of transportation operations and potentially a convenient and transparent means of negotiating contract timber extraction. Further research on extraction and transport system comparison could be based on the use of GNSS installed on carriage for supporting automatic or semi-automatic operational monitoring and for improving the quantity of acquired data reducing the engagement of the surveyor (Gallo et al., 2013).

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