AperTO - Archivio Istituzionale Open Access dell'Università di Torino

Performance of an electronic control system for hydraulically driven forestry tandem trailers

This is the author's manuscript

Original Citation:

Availability:

This version is available <http://hdl.handle.net/2318/1616653> since 2016-11-25T14:24:33Z

Published version:

DOI:10.1016/j.biosystemseng.2014.12.008

Terms of use:

Open Access

Anyone can freely access the full text of works made available as "Open Access". Works made available under a Creative Commons license can be used according to the terms and conditions of said license. Use of all other works requires consent of the right holder (author or publisher) if not exempted from copyright protection by the applicable law.

(Article begins on next page)

- 1 **Performance of an electronic control system for**
- 2 **hydraulically driven forestry tandem trailers**

3 **Abstract**

4 Timber transportation can be a complex operation because variations in
5 timber types and soil characteristics can require changes to the vehicles
6 and techniques used. Furthermore, this operation can be dangerous in
7 unfavourable soil conditions (e.g. frozen and muddy ground). A solution to
8 the problem is the use of mechanically or hydraulically driven trailers. The
9 object of this study was to determine whether an innovative electronic
10 control system for trailers equipped with motor axles, could be adapted to
11 the hydraulic transmissions usually mounted on the forestry tandem
12 trailers. The control system consisted of software that is able to modulate
13 the forward speed of the trailer to that of the tractor as a function of the
14 force presented on the hooked components. The control system mounted
15 on forestry tandem trailers was found to have good performance and the
16 versatility of the forestry tandem trailer was improved. Trailers equipped
17 with hydraulic drive and the control system performed similarly to trailers
18 fitted with mechanical drives normally used in forestry. However, unlike the
19 latter, they had a higher ground clearance and were lighter because the
20 absence of motor axle.
21 It was considered that the control system increased safety levels because
22 the tractor was protected from potentially dangerous oscillations generated
23 by the trailer whilst driving on poor roads.

24

25 **Keywords**

26 Timber transport, forestry trailer, motor axle, electronic control

27 **1. Introduction**

28

29 Timber recovery adds to the complexity of forestry operations, but it offers
30 a significant opportunity to increase efficiency, and reduce harvesting and
31 management costs (Windisch *et al.* 2013).

32 Forestry in Italy is characterised by steep terrains and high ownership
33 fragmentation (Spinelli *et al.*, 2009). These factors have tended to slow
34 down the introduction of mechanised harvesting and help explain the
35 current prevalence of labour-intensive operations (Magagnotti *et al.*,
36 2012). Thus, the introduction of mechanisation should be development of
37 versatile low-investment machinery that could offer a suitable balance
38 between capital and labour inputs (Spinelli *et al.*, 2013).

39

40 In terms of both energy (Antoniade *et al.*, 2012; Lindholm, & Berg, 2005;
41 Angus-Hankin *et al.*, 1995) and economics (Hamsley *et al.*, 2007) timber
42 transportation is most expansive part of the timber production process. In
43 addition, this operation can be complex because variations in timber types
44 and soil characteristics alter the vehicles and techniques that can be used.

45

46 Furthermore, timber harvesting is usually performed in winter and in spring
47 when transport can be difficult and dangerous because of the
48 unfavourable ground conditions (e.g. frozen and muddy). In order to obtain
49 high productivity it is necessary to use specifically designed forestry
50 machines. These machines are often heavy and when there is poor
51 traction, they can create deep rutting and soil compaction (Wästerlund,

1992, Nadezhdina et al. 2006, Sirén et al. 2013). The use of trailers could be a useful alternative because they have a low mass and therefore cause reduced pressure on the soil (Lindroos and Wasterlund, 2014).

Nevertheless, the use of trailers, in some cases, can be dangerous because, in presence of a little traction, they can push the tractor off the road because the tractor has a small mass compared to gross mass of the trailer.

A solution to this problem is the use of driven trailers. In this case, the gross mass of the trailer improves the traction of the combined vehicles (i.e. tractor plus trailer). At present, there are two methods to drive the motor axle of a forestry trailer: mechanical and hydraulic drives. With mechanical drive motion is provided by a cardan shaft that connects the synchronised PTO of the tractor to the motor axle of the trailer. With this transmission system, the drive ratio is constant and it is only possible to couple the trailer with the tractor for which it was designed.

Hydraulic transmission does not generally allow for the management of the speed of the tractor to match that of the trailer and, for this reason, such systems are usually only used in forests for transportation over short distances. Unlike mechanical transmission, this solution has the potential advantage of not causing damage to components during hard work, if viscous joint slippage is present. Unfortunately, for the same reason, hydraulic transmission cannot be used downhill where there is the necessity to have maximum tyre grip. Nevertheless, hydraulic systems are

77 frequently mounted on forestry trailers to permit coupling the trailer with
78 different tractors and they can be mounted on trailers with two axles in
79 tandem.

80

81 A traction roller powered, by a hydraulic motor has been inserted between
82 the two tyres of bogie (Spinelli, 2000). The roller has ribs which fit between
83 the lugs in the tyre and provide the traction at all positions of the bogie.

84 The traction roller does not slip on the tyre or cause damage and the
85 system has high ground clearance (up to 750 mm) because there are no
86 axles under the frame of the trailer.

87

88 Recently, in order to reduce the negative aspects of mechanical
89 transmissions, the University of Turin, has been developing an innovative
90 electronic control system for motorised axles (Manzone, & Balsari, 2015).

91 This system is able to correlate the forward speed of the tractor with that of
92 the trailer independent of the tractor to which it is coupled.

93

94 The object of this study is to determine whether the developed electronic
95 control system could be adapted to the hydraulic transmission system that
96 is mounted on the forestry tandem trailers.

97

98 **2. Materials and methods**

99

100 The system developed by the University of Turin consisted of specific
101 software that was able to modulate the oil flow to the hydraulic motors

102 mounted on the motor axle of the trailer using electronic control of
103 hydraulic pump as a function of the force presented to the hooked
104 components. The software is able to correlate the forward speed of the
105 trailer to that of the tractor through information provided by a potentiometer
106 fitted behind to the towing eye of the trailer. Therefore, independent of the
107 tractor used, the trailer following increases or reduces its forward speed as
108 function of the tensile or compressive force present on the drawing eye
109 (Manzone, & Balsari, 2015).

110 In detail, when the tractor pulls or pushes the trailer causes linear
111 movements of the drawing eye that are recorded from the potentiometer
112 and processed by the electronic control unit. In this way, the electronic
113 control unit modulates the oil flow inlet to the hydraulic motors mounted on
114 the motor axle until the forward speed of the trailer is equal to that of the
115 tractor. When the drawing eye reaches the neutral position (initial
116 position), the forward speed of the trailer is maintained constant. At this
117 point, the trailer follows the tractor without causing tensile or compressive
118 force on the drawing eye.

119
120 In order to minimize modifications to the hydraulic equipment usually
121 mounted on forestry trailers, the oil modulation was carried out using an
122 electro valve mounted on the primary pipes. The force present on the
123 towing eye was measured using disc springs made of carbon steel
124 interposed between the tightening nut and the bushing welded to the
125 trailer's towing arm. The internal diameter of the spring disc was larger
126 than that of the towing pin so that the latter could slide into the disc

127 springs. The potentiometer screwed behind the towing eye transformed
128 towing eye movements in the electrical signals and transmitted them to the
129 electronic control unit (Fig. 1). The electronic control unit processed the
130 data and powered the electric valves to modulate the force.

131 The choice of the number, sizes and arrangements (in series or in parallel)
132 of the disc springs can be varied depending on the total mass of the
133 trailers and the sensitivity that is assigned to the system.

134

135 During the tests, the control system was mounted on a typical forestry
136 trailer fitted with two axles in tandem (NOKKA® MV 1230HD) (Table 1).

137

138 This trailer was manufactured with a hydraulic transmission system able to
139 perform a pulling force of 17 kN with an oil pressure of 19 MPa. In the test,
140 the hydraulic system remained unchanged but was supplemented only
141 with the electrical proportional valve (EPV16B Eaton Corporation PLC,
142 United States).

143

144 The electronic control unit and the proportional valve were placed on the
145 tractor in order to have easy access and also to protect from possible
146 damage during use.

147

148 Four disc springs in series with 45 mm internal diameter and 100 mm
149 external diameter were mounted on the drawbar eye. Behind the eye a
150 potentiometer (317-780, RS Components, Milan, Italy) with 5 mm stroke

151 was placed. In order to record all the drawbar eye movements (back and
152 forth), the point zero of the potentiometer was set up in its half stroke.

153

154 Engaging and disengaging of the system was achieved automatically,
155 setting the lever of the hydraulic distributor of the tractor to which the
156 hydraulic pipe was linked.

157

158 When the system was activated, the driver was warned by an indicator.

159

160 The functionality of the developed system mounted on the forestry trailers
161 with two axles in tandem was assessed by determining the
162 synchronisation of the trailer forward speed with that of the tractor
163 (Manzone, & Balsari, 2015). The speed synchronisation was determined
164 through data acquisition from the potentiometer mounted behind the
165 towing eye. This is able to translate the towing eye position with respect to
166 “0 point” (neutral point) in different intensity current pulses (the further one
167 moves away from the “0 point”, the greater is the current intensity).

168 Specifically, when the values from the potentiometer were positive, the
169 tractor pulled the trailer, whilst when the values were negative the trailer
170 pushed the tractor. The displacement range of towing eye was of 5 mm (+
171 2.5 mm).

172

173 The tests were carried out using a 4WD tractor (Newholland® TS100) with
174 a nominal power of 74 kW and a mass of 4.4 t. In the tests, the trailer was
175 tested with a full mass of 2.290 t (trailer unloaded) and 4.5 t (trailer

176 loaded). To provide mass during the tests, the trailer was loaded with
177 concrete blocks.

178

179 The tests were carried out using two different itineraries traced on natural
180 soil with the presence of curves (Left and Right) and different slope
181 conditions. Itinerary 1 had a length of about 300 m on a flat area of turf
182 with two curves of 180° and a radius of curvature of 25 m; itinerary 2 had a
183 length of about 120 m and was realised in an area with an average slope
184 of 30% and bare soil. These itineraries were considered representative of
185 electronic control system testing because showing the main characteristics
186 of forestry roads (e.g. curves and a slope of 30%) (Epstein et al, 2006).

187 The tractor and trailer operated with three different forward speeds (2-3-
188 4 km h⁻¹), and for itinerary 2, they were operated in two directions (uphill
189 and downhill) and with constant forward speed (3 km h⁻¹).

190

191 During the test the tensile force exerted by the tractor to pull the trailer was
192 measured. This measurement was performed using a digital dynamometer
193 (FH50k, SAUTER, Basel, Switzerland) with a capacity of 50,000 N and a
194 resolution of 10.0 N.

195

196 **3. Results**

197

198 In the tests, the control system showed good results because it was able
199 to maintain the forward speed of the trailer similarly to that of the tractor. In

200 all tests the electronic control of the oil hydraulics kept the towing eye of
201 the trailer in "neutral" position (potentiometer's accuracy 0.2 mm).
202
203 Operating under normal conditions (i.e. with the control system
204 inactivated) and on flat ground, the towing eye tended to move forward
205 increasing the trailer forward speed. This situation was different when the
206 control system was activated. In this case, the towing eye movements
207 were limited and movements were mainly due to the unevenness present
208 on the road (Fig. 2).
209
210 A similar situation occurred during second itinerary where the ground had
211 different slopes. The values obtained highlighted that, independently from
212 the travel direction (uphill and downhill), the control system was able to
213 reduce the thrusts on the coupling pin of the tractor.
214 When the control system was disengaged the trailer pulled back the
215 tractor going uphill and pushed forward the tractor going downhill, but
216 when the control system was activated the towing eye remained in neutral
217 position (accuracy +/- 0.1 mm) in any operating condition without causing
218 significant disturbance to the tractor (Figs. 3, 4). The maximum
219 displacement range of the towing eye (1.42 mm) was obtained in uphill
220 direction with the control system disengaged (Fig. 4).
221
222 Similar dynamics were obtained when operating with a loaded trailer (Figs.
223 5, 6). In this case, the maximum displacement range of towing eye, again

224 with the control system disengaged was 2.27 mm (about 90% of
225 theoretical towing eye movement) (Fig. 6).

226

227 The peaks highlighted in all the performance figures were mainly due to
228 the unevenness on the itineraries.

229

230 With the control system disengaged, the tensile force necessary to tow the
231 trailer was proportional to the trailer full mass and to the road slope, but
232 with the system engaged, the maximum tensile forces required were
233 similar (between 2590 and 3750 N) for all the operating conditions (Table
234 2).

235

236 **4. Discussion**

237

238 The tests highlighted that by using the control system it was possible to
239 control the forward speed of the trailer to that of the tractor to which it is
240 coupled. In fact, tests showed that the electronic control system was able
241 to maintain the towing eye in the position "zero" properly modulating the oil
242 flow rate to the hydraulic motors. Good performance was found in all the
243 conditions tested (different slopes and itineraries).

244

245 Furthermore, the tests showed that independent from the trailer mass the
246 forces acting on the towing eye were limited. The force required to activate
247 the control system was always less than 4000 N, a value commonly
248 obtained by tractors operating in forestry yards.

249

250 Unlike the standard hydraulic drive system, that can be used only for short
251 distances, It is likely that the control system allowed the hydraulic drive to
252 be used long distances without compromising the life of the tyres or
253 mechanical parts involved. In addition, it is also possible to use the
254 hydraulic system going downhill because the control system is able to
255 reduce the forward speed of the trailer to limit the forces on the coupling
256 device.

257

258 The control system showed, therefore, a high level of versatility; it is
259 possible to mount all the parts of the control system either on the tractor or
260 the trailer. By mounting the system on the tractor, the trailer can be
261 changed easily making it possible to use different trailers with the same
262 tractor. By mounting all the control system on the trailer, it is possible to
263 limiting the investment of the forestry companies because it is possible to
264 share this investment and to use the same trailer with different types of
265 tractor.

266

267 The new developed system, working with the same tensile forces in
268 different operating conditions, should allow the general safety level of
269 tractor use to be increased because tractors are protected from dangerous
270 oscillations that can currently be generated by the trailer while driving on
271 forestry roads.

272

273 Furthermore, the device setup should be able to guarantee the same
274 performance with different oil temperatures because the electronic central
275 unit varies the oil flow rate until the towing eye returns to its initial position
276 (neutral point) regardless of oil density.

277

278 Finally, in some forestry operations, the trailer is not economically viable
279 compared to a conventional forwarder for its limited load (Eriksson 1998).
280 The use of this control system could permits to increased loads to be used
281 in a wider range of operating conditions.

282

283 **5. Conclusions**

284

285 The innovation system mounted on forestry tandem trailers guarantees
286 good performances and the improved versatility of the forestry tandem
287 trailer. On the bases of the results obtained in this work, it is possible to
288 assert that, trailers with hydraulic drive equipped with this innovative
289 system show performances similar to trailers with mechanical drive
290 normally used in forestry, but unlike the latter, they have a higher ground
291 clearance and are lighter because the motor axles are not present.
292 Furthermore, thanks to its control system, this also increases the general
293 safety level because the tractor is protected from the dangerous
294 solicitations generated by the trailer while driving on bad roads. For these
295 reasons, the innovative system tested can be considered a viable
296 alternative to the trailer traction systems currently available on the market.

297

298 **References**

- 299 Angus-Hankin, C., Stokes, B., & Twaddle, A. (1995). The transportation of
300 fuelwood from forest to facility. *Biomass Bioenergy*, 9, 191-203.
- 301 Antoniadu, C., Şlincu, C., Stan, C., Ciobanu, V., & Ştefan, V. (2012).
302 Maximum loading heights for heavy vehicles used in timber
303 transportation. Bulletin of the Transilvania University of Brasov, Series
304 II: Forestry, Wood Industry. *Agricultural Food Engineering*, 5, 7-12.
- 305 Eriksson, P., 1998. Påhängsvagn för skotare (Semi-trailers for
306 forwarders: potential exists for long extraction distances). Resultat
307 25. Skogforsk. Uppsala. 4 p.
- 308 Epstein, R., Weintraub, A., Sapunar, P., Nieto, E., Sessions, J.B.,
309 Sessions, J., Bustamante, F., & Musante, H. (2006). A Combinatorial
310 Heuristic Approach for Solving Real-Size Machinery Location and Road
311 Design Problems in Forestry Planning. *Operations Research*, 54(6),
312 1017-1027
- 313 Hamsley A.K., Greene W.D., Siry J.P., & Mendell B.C. (2007). Improving
314 timber trucking performance by reducing variability of log truck weights.
315 *Southern Journal of Applied Forestry*, 31, 12-16.
- 316 Lindholm, E.-L., & Berg, S. (2005). Energy requirement and environmental
317 impact in timber transport. *Scandinavian Journal of Forest Research*,
318 20, 184-191.
- 319 Johansson, J., Liss, J.E., Gullberg, T., & Bjorheden, R. (2006). Transport
320 and handling of forest energy bundles-advantages and problems.
321 *Biomass Bioenergy*, 30, 334-341.

322 Lindroos, O., & Wästerlund, I. (2014). Theoretical Potentials of Forwarder
 323 Trailers with and without Axle Load Restrictions. *Croatian Journal of*
 324 *Forest Engineering*, 35(2), 211–219.

325 Magagnotti, N., Spinelli, R., Güldner, O., & Erler, J. (2012). Site impact
 326 after motor-manual and mechanised thinning in Mediterranean pine
 327 plantations. *Biosystems Engineering*, 113, 140-147.

328 Manzone, M., & Balsari, P. (2015). Electronic control of the motor axles of
 329 the forestry trailers. *Croatian Journal of Forest Engineering*, 36 (in
 330 press).

331 Nadezhdina, N., Čermák, J., Neruda, J., Prax, A., Ulrich, R., Nadezhdin,
 332 V., Gašpárek, J., & Pokorný, E. (2006). Roots under the load of heavy
 333 machinery in spruce trees. *European Journal of Forest Research*,
 334 125(2), 111–128.

335 Sirén, M., Ala-Ilomäki, J., Mäkinen, H., Lamminen, S., & Mikkola, T.
 336 (2013). Harvesting damage caused by thinning of Norway spruce in
 337 unfrozen soil. *International Journal of Forest Engineering*, 24(1), 60–75.

338 Spinelli, R. (2000). *Meccanizzazione forestale intermedia*. Italy: Bologna,
 339 p.176.

340 Spinelli, R., Magagnotti, N., & Picchi, G. (2009). Deploying mechanized
 341 cut-to-length technology in Italy: fleet size, annual usage and costs.
 342 *International Journal of Forest Engineering*, 31, 21-23.

343 Spinelli, R., Magagnotti, N., & Facchinetti, D. (2013). Logging companies
 344 in the European mountains: an example from the Italian Alps.
 345 *International Journal of Forest Engineering*, 24(2) DOI:
 346 10.1080/14942119.2013.838376.

347 Wästerlund, I. (1992). Extent and causes of site damage due to forestry
348 traffic. *Scandinavian Journal of Forest Research*, 7(1), 135–142.

349 Windisch, J., Röser, D., Sikanen, L., Routa, J. (2013). Reengineering
350 business processes to improve an integrated industrial roundwood and
351 energywood procurement chain. *International Journal of Forest*
352 *Engineering*, 24, 223–248.

353

354 **Fig. 1.** System scheme to determine the force on the towing eye.

355

356 **Fig. 2.** Towing eye position with disengaged/engaged control system with
 357 different forward speeds.

358

359 **Fig. 3.** Towing eye position with disengaged/engaged control system in an
 360 uphill situation (trailer unloaded).

361

362 **Fig. 4.** Towing eye position with disengaged/engaged control system in a

363 downhill situation (trailer unloaded).

364

365 **Fig. 5.** Towing eye position with disengaged/engaged control system in an
 366 uphill situation (trailer loaded).

367

368 **Fig. 6.** Towing eye position with disengaged/engaged control system in
 369 adownhill situation (trailer loaded).

370 **Table 1**

371 Technical characteristics of the trailer used in the trials.

Nokka MV 1270HD		
Width	(m)	2.38
Length	(m)	6.10
Height	(m)	2.71
Loading area	(m ²)	3.00
Ground clearance	(m)	0.71
Tyres	550/45-22.5 ELS	
Loading capacity	(t)	12

372

373 **Table 2**

374 Maximum tensile force with control system engaged/disengaged

	Slope (%)	Trailer mass (kg)	Exerted force (N)
System disengaged	0	2300	1920
		4500	4200
	30	2300	9200
		4500	21000
System engaged	0	2300	2590
		4500	3200
	30	2300	2790
		4500	3750

375