Original scientific paper – *Izvorni znanstveni rad*

Using On-Board GPS to Identify Training Needs of Helicopter Pilots

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Abstract – Nacrtak

In forest harvesting, helicopter extraction systems are incredibly versatile due to their ability to avoid many of the obstacles that encumber ground based and skyline systems. Helicopter yarding is used for a variety of reasons including site sensitivity, urgency to remove or deliver the product, lack of access, and slope of the terrain. Because of the high cost of helicopter yarding, maximizing productivity is critical. There are many site and stand factors that affect productivity, but pilot experience and skill is also known to be important. Job training of new pilots can be very expensive, including the loss of productivity during the training phase. Basic time studies can be used to show differences in productivity between pilots. This project shows that by using an on-board GPS system to capture elemental time study data, that is geo-referenced, it becomes possible to isolate in detail during what phase of the turn cycle a trainee is not efficient. Using data collected at three different sites in the Pacific Northwest region of the USA, basic productivity curves were developed for each yarding element and indicated that inexperienced pilots produced between 33 and 43 tons less per productive machine hour. For these case studies, the trainee pilot was losing most of his time positioning the helicopter when hooking trees, although reduced acceleration and maximum top velocity was also noted. With detailed feedback, the trainee pilot and/or trainer can focus efforts to improve training effectiveness and reduce productivity loss during the training period.

Keywords: helicopter yarding, on-board GPS system, pilot training, productivity

1. Introduction – *Uvod*

Helicopter yarding is incredibly versatile due to its ability to avoid many of the obstacles that encumber ground based and skyline systems (Stampfer et al. 2002; Conway 1976; Burke 1973). Today this yarding system is used for a variety of reasons including site sensitivity, urgency to remove or deliver the product, lack of access, and slope of the terrain. The use of helicopters in forestry continues to expand. Where there were only a few firms offering helicopter logging services in the early 1970's (Conway 1976), today the Helicopter Association International estimates almost 175 forestry or logging companies use helicopter logging as a principal means of yarding timber (Bruce 2003).

Helicopters have various designs and abilities, and the variety of helicopters used is also fairly extensive. The type of helicopter used will influence speed, angle of ascent, and maximum payload (Conway 1976). For example Dunham (2003) lists 14 manufacturers and models used in British Columbia, Canada. Helicopters are typically rated by payload capacity that ranges from 1134 kg for the Eurocopter Lama to 12727 kg for the Boeing CH234 for machines commonly used in helicopter yarding.

Helicopter yarding is a relatively high cost extraction method (Keegan et al. 1995). While Hartsough et al. (1997) found ground based skidding to account for approximately 20 – 25% of the stump to truck operation costs, helicopter yarding ranged between 65 and 78% of the stump to truck costs (Krag and Evans 2003; Dunham 2003). Currently helicopter operating costs are at least US$ 500 per hour for the smallest machine, up to approximately US$ 4500 per hour for the larger machines.

Optimizing the payload is a key factor in achieving efficient yarding (Burke 1973; Hartsough et al. 1986). The location and layout of the log landing is also a crucial factor. The primary concern is the yarding distance, which generally is the distance from the hook point to the log landing (Burke 1973). Weather not only limits when operations may occur, but it also influences helicopter capability during operations. The density of the air impacts both the ability of the helicopter to achieve lift and the horsepower of the engine (Wagtendonk 1996).

Other operation dependent factors that may influence productivity are the pilots themselves. When a helicopter yarding organization employs a pilot new to logging work, they are likely to experience higher costs (Sloan and Tollenaere 1994; Warren 1996; Stampfer et al. 2002). Stampfer et al. (2002) shows that an experienced pilot delivered 59% more volume to the landing than a trainee-pilot did.

With the high cost and wide range of factors affecting helicopter yarding, the application of new technology to improve and evaluate training systems will be very beneficial. New technology allows us to more accurately measure the helicopter yarding process and better predict the production rates in different conditions. Recent forest operation research has used ground based equipment with on-board Geographic Positioning Systems (GPS) to conduct more precise production and site impact analysis (McDonald et al. 2002, McDonald et al. 2000). GPS is also being used more extensively to monitor, manage and optimize harvesting operations (Flisberg et. al 2007). Heinimann and Caminada (1996) recommend using GPS to gather more precise data on helicopter operations.

This study aims to test the application of on-board GPS to aid the helicopter yarding industry by measuring the impact of pilot experience on productivity. Knowing where a trainee-pilot is likely to need the most improvement may assist the industry in selecting optimized training routines.

2. Describing the Helicopter Yarding Process – *Iznošenje drva helikopterom*

The process of helicopter yarding can be broken into yarding cycles, turns, and elements. The basic definition for a cycle is leaving the service landing, flying a number of turns and returning to the service landing. The basic definition for a turn is leaving the log landing and traveling to the location of the payload (outhaul), picking up the payload (hooking), returning to the log landing with that payload (inhaul), and releasing the payload at the log landing (unhooking). Each segment of the turn just described is an element.

Beginning at the service landing, the helicopter will fly to the harvest area and begin yarding logs. During the hooking element there will often be a person, the hooker, on the ground with pre-choked logs ready to be connected to the hook at the end of the helicopters long line. The pilot locates the hooker and maneuvers the hook near the hooker. Then the hooker slides the chokers into the hook. The pilot then lifts the logs off of the ground and clear of the forest canopy.

The inhaul element begins and the pilot flies toward the log landing. At the landing the pilot sets the logs on the ground in the drop zone and releases the chokers from the hook. With the load released, the pilot clears the log landing and enters the outhaul element and flies back to the woods for another load of logs. The entire process, hook, inhaul, unhook, and outhaul is referred to as a turn. If no problems occur, this continues for 60 to 90 minutes, until the helicopter must be refueled. The pilot must then return to the service landing for fuel. When the helicopter is in the hooking, inhaul, unhooking, or outhaul elements, this is called the yarding cycle. When the helicopter is flying to or from the service landing or being fueled or repaired, this is called the service cycle.

3. Methodology – *Metodologija*

The data used for this paper is part of a larger comprehensive study into measuring helicopter productivity using GPS and GIS analyses (Horcher 2008). It includes over 35 days of helicopter data gathered at nine different sites on three different helicopters.

3.1 Study Sites – *Mjesto istraživanja*

At three locations the operation included an inexperienced pilot, who for the purpose of this study is defined as a pilot with less than 100 hours flying in logging operations. The sites were located in the Pacific Northwest, the operations were harvesting conifer trees on rolling terrain, and all operations were studied in the summer. At each site (Table 1), an attempt was made to capture at least 30 turns for a cycle, whereby the inexperienced and experienced pi-

Table 1 Site descriptions for pilot experience data
Tablica 1. *Mjesto istraživanja*

Site *Mjesto istraživanja*	Paired Cycles *Broj radnih turnusa*	Yarding Method *Način prihvata drva*	Harvest Type *Vrsta sječe*
A	1	Grapple *Hvatalo*	Seed Tree/Salvage *Naplodni sijek Sanitarna sječa*
B	4	Chokers *Uže za vezanje*	Thinning *Proreda*
C	5	Chokers *Uže za vezanje*	Thinning *Proreda*

Table 2 Description of the numerical variables and time components
Tablica 2. *Opis brojčanih varijabli i vremenskih sastavnica rada*

Type *Tip*	Name *Ime*	Description – *Opis*	Unit *M. jedinica*
Dependant variables *Zavisne varijable*	FlyOut *Let neopterećenoga helikoptera*	Time for the helicopter to fly from landing to hook point *Vrijeme leta helikoptera od stovarišta do mjesta utovara*	sec
	Hook *Kopčanje tereta*	Time at hook point, which is defined by a radius of 20 meters around the actual hook point *Vrijeme provedeno za kopčanje drva, uključujući područje od 20 m promjera oko mjesta kopčanja drva*	sec
	FlyIn *Let opterećenoga helikoptera*	Time for the helicopter to fly from hook point to landing *Vrijeme leta helikoptera od mjesta utovara do stovarišta*	sec
	Landing *Slijetanje*	Time at landing, which is defined by a radius of 30 meters around the actual landing *Vrijeme provedeno na stovarištu, uključujući područje od 30 m promjera oko stovarišta*	sec
	TurnVol *Obujam tovara*	Sum of the tree volumes extracted in one turn *Obujam tovara iznesen unutar jedne sastavnice rada*	kg
Covariables *Kovarijable*	TreeVol *Obujam drva*	Average tree volume *Prosječan obujam komada drva*	kg
	ExtDist *Udaljenost iznošenja*	3d extraction distance – *Udaljenost iznošenja drva*	m
	ElvChange *Promjene u visini leta*	Change in Elevation – *Promjene u visini leta tijekom iznošenja drva*	m
	Slope *Nagib*	Slope between landing and hook point *Razlika u nagibu između stovarišta i mjesta kopčanja drva*	%
Factors *Čimbenici*	PilotEx *Iskustvo pilota*	Pilot experience, as defined by 100 flying hours in logging *Iskustvo pilota (100 radnih sati iznošenja drva)*	0/1
	ChokDrop *Ispuštanje užadi*	Turn that includes picking up and dropping off a bundle of chokers *Podizanje i otpuštanje užadi za kopčanje*	0/1
Time *Vrijeme*	Vel *Brzina*	Max velocity (Flyout and FlyIn) *Najveća brzina (opterećenoga i neopterećenoga helikoptera)*	m/sec
	Accel *Ubrzanje*	Max Acceleration (Flyout and FlyIn) *Najveće ubrzanje (opterećenoga i neopterećenoga helikoptera)*	m/sec^2
	Decell *Usporavanje*	Max Deceleration (Flyout and FlyIn) *Najveće usporavanje (opterećenoga i neopterećenoga helikoptera)*	m/sec^2

lot flew consecutively yarding cycles ensuring consistency in stand and terrain factors. In all cases the inexperienced pilots flew fewer turns per cycle: in part because they took longer per turn, but were also deliberately replaced by an experienced pilot to reduce the productivity impact. During the study of the seed tree/salvage harvest with a grapple (site A) the inexperienced pilot only flew long enough once to obtain one cycle comparison with an experienced pilot. As the data is consistent with the other sites it has been included in this paper.

Helicopter yarding is a very competitive business and a confidentiality agreement required to collect research data prevents us from identifying the exact location of the operation, or specifically linking the make and model of the helicopter to a specific data set. The two machines used by the pilots in this experiment were the Boing Vertol BV 107 and the Sikorsky S-61A. Both are rated at approximately 4 ton payload.

3.2 Data Collection – *Prikupljanje podataka*

GPS data was collected with a WAAS enabled Trimble Geo XT with EVEREST technology mounted in the helicopter. Location information was gathered at one-second intervals, and downloaded from the GPS unit when possible.

Some basic programs were developed to aid the evaluation of the data, including auto location of landing and hook point within the GPS data using helicopter velocity (Horcher 2008). Using 35 meter

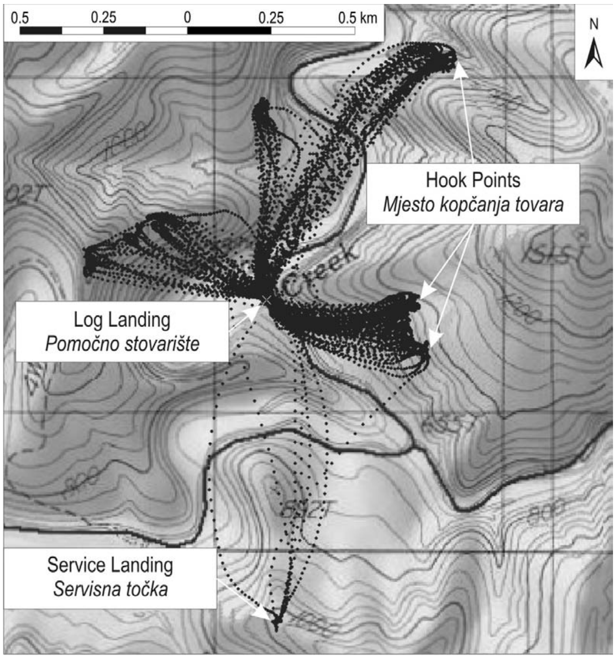

Fig. 1 Mapped helicopter yarding data for a full cycle from an on-board GPS unit

Slika 1. *Kartografski prikaz turnusa rada helikoptera pomoću sustava GPS*

radii around the landing and the hook point, the time was divided into the four phases that make up a typical turn cycle.

An overview of all of the time-study elements is presented in Table 2.

It is possible to present the GPS data from a helicopter yarder cycle graphically, for example as overlaid on a GIS based contour as shown in Fig. 1.

Processing the GPS data, and combining it with the payload data as recorded by the load sensor, allowed it to be converted to a more conventional time study form, as presented in Table 3. It includes four timed cycle elements (fly out, hook the load, fly in and releasing the logs at the log landing), and a measured turn weight that can be combined with the time elements to calculate productivity on a per turn basis. In addition, the extraction distance is recorded for each turn. The final column shows the pilot experience covariate.

Statistical analysis was carried out using SAS JMP 7.0, including basic mean comparisons as well as linear regressions to build the models. Scheffe's multiple comparison procedure was conducted on hook and unhook time for the trainee and experienced pilot data. Comparison of means was tested at

Table 3 A sample of a typical time study format for helicopter yarding

Tablica 3. *Uzorak podataka iz studija rada i vremena za iznošenje drva helikopterom*

Cycle *Turnus rada*	Time Elements – *Radni zahvati*				Factor – *Čimbenik*				Covariate *Kovarijabla*
	Out, sec. *Let, s*	Hook, sec. *Kopčanje, s*	In, sec. *Let, s*	Un-hook, sec. *Otkopčavanje, s*	Tot-Cycle, sec. *Ukupno, s*	Payload, t *Teret, t*	Prod, m^3/hr *Proizvodnost, m^3/h*	Extr-Dist, m *Udaljenost iznošenja, m*	Exper, 0/1 *Iskustvo pilota, 0/1*
1	36	44	32	25	137	3.0	75	671	0
2	29	69	37	16	151	3.1	70	687	0
3	27	58	36	15	136	3.1	78	667	0
4	28	40	33	13	114	3.3	99	672	0
5	28	37	36	14	115	2.3	68	674	0
Etc. *Itd.*	-	-	-	-	-	-	-	-	-

Table 4 Inexperienced pilot elemental time as a percent of experienced pilot elemental time

Tablica 4. *Usporedba vremena rada neiskusnoga i iskusnoga pilota pri radnim zahvatima*

Site *Mjesto rada*	Choker Drop *Ispuštanje užadi*	Outhaul *Let neopterećenoga helikoptera*	Hook *Kopčanje*	Inhaul *Let opterećenoga helikoptera*	Unhook *Otkopčavanje*	Total *Ukupno*
A	N/A *Nije primjenjivo*	156%	368%	175%	117%	181%
B	No – *Ne*	128%	209%	147%	147%	164%
	Yes – *Da*	189%	217%	147%	155%	194%
C	No – *Ne*	129%	200%	179%	204%	172%
	Yes – *Da*	176%	189%	179%	176%	180%

Table 5 Mean hook and unhook times excluding choker drop cycles
Tablica 5. *Srednje vrijeme kopčanja i otkopčavanja drva bez vremena ispuštanja užadi*

Site *Mjesto rada*	Element *Radni zahvat*	Pilot Status* *Iskustvo pilota*	Turns, n *Radne sastavnice, n*	Mean, sec. *Srednja vrijednost, s*	Scheffe Sign., 0.05
A	Hook *Kopčanje*	1	10	83.5	Yes *Da*
		0	38	22.7	
	Unhook *Otkopčavanje*	1	8	19.4	No *Ne*
		0	39	16.5	
B	Hook *Kopčanje*	1	44	109.0	Yes *Da*
		0	137	51.7	
	Unhook *Otkopčavanje*	1	44	30.8	Yes *Ne*
		0	139	16.9	
C	Hook *Kopčanje*	1	54	106.0	Yes *Da*
		0	152	52.8	
	Unhook *Otkopčavanje*	1	56	36.0	Yes *Da*
		0	153	17.6	

*Pilot Status; 0 = experienced, 1 = inexperienced – *Piloti : 0 = bez iskustva, 1 = s iskustvom*

the 0.05 level, whereby stepwise model development used a threshold of 0.10 for parameter inclusion.

4. Results – *Rezultati*

The full data set showed highly significant differences in almost all elements when comparing the impact of pilot experience. An example to show how improvement potential can be assessed compares relative times for the total turn, as well as individual elements within a turn. Table 4 provides a summary of all the data, showing the percent of time an inexperienced pilot spends relative to an experienced pilot. 100 percent indicates performance equivalent to an experienced pilot.

For these case studies, the total time column indicates that a trainee pilot takes at least 64% longer to complete a single turn, and this is exacerbated to 80 or even 90% when adding complexity such as requiring chokers to be picked up and dropped off, or when using a grapple. For the individual elements, both the highest and lowest percentages occur within site A: 368% for hook and 117% for unhook. This indicates that grapples may require minimal experience for unhooking, but significant experience for actually grabbing a log. Overall, the greatest room for improvement usually occurs in the hook element.

Table 5 provides a more detailed look at just the Hook and Unhook phases of the yarding cycle. It indicates how readily significant differences can be found between pilots, even if the inexperienced pilot flies very few turns.

To better understand the reason for the additional time required for a trainee pilot to complete either the inhaul or the outhaul phase of a cycle, it was possible to look at maximum velocity, as well as the acceleration and deceleration, of the helicopter. For example, at site A maximum inhaul velocity is significantly higher with the experienced pilot, at 99 km/hr, than it is with the inexperienced pilot, 59 km/hr. Site C exhibits a similar situation, where the experienced pilot achieves a higher mean maximum outhaul velocity of 139 km/hr compared to the inexperienced pilot's mean maximum outhaul velocity of 107 km/hr. The mean outhaul acceleration and deceleration rates at site C are more extreme for the experienced pilot as well, with 3.0 m/s^2 and –3.0 m/s^2, compared to 1.9 m/s^2 and –1.8 m/s^2 for the trainee pilot.

Regressions for turn time and productivity (tons/hr) all show a strong correlation. In general, turn time had stronger correlations compared to productivity, adjusted R^2 = 0.70 to 0.79, and adjusted R^2 = 0.50 to 0.64 respectively. The lower multiple coefficient of determination for productivity relative to turn time is expected to be a result of the variability in wood availability and arrangement at each hook point, which is not described with the explanatory variables. From a production perspective, on average in these studies the inexperienced pilots reduce production from 75.9 to 42.8 tons/hr. This equates to a 44% decrease in productivity.

Pilot experience (PilotEx) and extraction distance (ExtrDist) were significant for all regression models. Turn volume (TurnVol) was significant in all turn cycle time models, but not used in the productivity models as it is the quotient component of productivity. Specifically, the turn time and productivity regression equations for the grapple operation (Site A) were:

$$\text{SiteA: Turn(sec)} = 22.1 + 112.8(\text{PilotEx}) + 0.0281(\text{TurnVol}) \quad (1)$$

Adjusted $R^2 = 0.70$

$$\text{SiteA: Prod(tonnes/hr)} = 90.0 - 42.8(\text{PilotEx}) - 0.0094(\text{ExtrDisc}) \quad (2)$$

Adjusted $R^2 = 0.50$

For sites B and C, the need to pick up and drop off chokers during a production cycles has a significant influence on both turn time and productivity. Specifically;

$$\text{SiteB: Turn(sec)} = 51.8 + 123.4(\text{PilotEx}) + 0.0358(\text{ExtrDist}) + 96.7(\text{ChokDrop}) + 0.0200(\text{TurnVol}) \quad (3)$$

Adjusted $R^2 = 0.75$

$$\text{SiteB: Prod(tonnes/hr)} = 90.6 - 33.1(\text{PilotEx}) - 0.0105(\text{ExtrDist}) - 28.1(\text{ChokDrop}) \quad (4)$$

Adjusted $R^2 = 0.64$

For site C an autocorrelation component also became significant in the regression equation for turn time. Autocorrelation would indicate that cycles are not independent of each other. In this case it suggests that as the pilot returns to a hook point, the accumulation of prior knowledge of the site helps decrease the overall cycle time. The effect of slope was also picked up in the regression equation for productivity at Site C.

$$\text{SiteC: Turn(sec)} = 58.5 + 122.4(\text{PilotEx}) + 0.0407(\text{ExtrDist}) + 63.3(\text{ChokDrop}) - 0.58\,(\text{Turn of Cycle}) + 0.0111(\text{Payload}) + 3.9(\text{Logs}) \quad (5)$$

Adjusted $R^2 = 0.79$

$$\text{SiteC: Prod(tonnes/hr)} = 87.4 - 33.4(\text{PilotEx}) - 0.0176(\text{ExtrDist}) - 0.21(\text{Slope}) - 14.0(\text{ChokDrop}) \quad (6)$$

Adjusted $R^2 = 0.58$

This analysis showed that not only can pilot differences be quickly evaluated using GPS technology, but productivity factors identified. Here onboard GPS shows strong promise in evaluating performance.

5. Conclusions – *Zaključci*

Integration of new technologies can provide significant opportunities to improve productivity of existing timber harvesting operation. This study has demonstrated the opportunity for using onboard GPS for the benefit of identifying training needs for inexperienced helicopter pilot flying in logging operations. It identified turn time and productivity differences at both the cycle and elemental level. This not only allows a true opportunity cost for operating with trainee pilots to be established, but also allows for targeted training by indicating the specific phases where a trainee pilot is less efficient compared to an experienced pilot. General regression equations that identified key factors that affect productivity are also readily developed. Although some automation of the data interpretation was achieved during this study, opportunities exist for improved data synthesis.

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Sažetak

Korištenje sustava GPS za unaprjeđenje obuke pilota helikoptera

Iznošenje drva helikopterom pokazalo se kao višestruko upotrebljiv način primarnoga transporta drva zbog svoje sposobnosti svladavanja mnogih terenskih prepreka s kojima se susreću po tlu kretni te užetni sustavi prilikom privlačenja drva. Iznošenje drva helikopterom najčešće se koristi u ekološki osjetljivim sastojinama, pri hitnim isporukama veće količine drva, zbog nemogućnosti pristupa sječini (manjak šumskih cesta ili žičnih linija) ili zbog izrazito nepovoljnoga nagiba terena. Postoje razne vrste helikoptera za iznošenje drva te će vrsta letjelice utjecati na brzinu, kut uspona i najveću dopuštenu nosivost tereta. Zbog visoke cijene iznošenja drva helikopterom najvažnije je postići najvišu moguću proizvodnost takva sustava rada. Trenutačno se troškovi rada helikoptera (ovisno o vrsti letjelice) kreću od najmanje 500 US$ po satu pa sve do 4500 US$ po satu.

Postoje mnogi sastojinski čimbenici koji utječu na proizvodnost sustava rada, ali iskustvo i vještina pilota helikoptera pokazali su se također vrlo značajnima. Obuka novih pilota neposredno u sječini može biti vrlo skupa, pa je studijem rada i vremena lakše i jeftinije uočiti razlike između pilota s različitim radnim iskustvom. Utvrđivanjem gdje će pilot vježbenik (pilot s manje od 100 sati leta iznošenja drva) najvjerojatnije trebati dodatnu obuku pomoći će u cjelokupnom sustavu rada te ubrzati vrijeme obuke pilota vježbenika.

Korištenjem sustava GPS, uklopljena u vozilo radi snimanja georeferenciranih podataka tijekom studija rada i vremena, moguće je u detalje izdvojiti dijelove turnusa rada odnosno uočiti radne zahvate u kojima pilot vježbenik nije dovoljno učinkovit.

Podaci korišteni u ovom istraživanju dio su opsežnijega mjerenja proizvodnosti rada helikoptera analizom pomoću GPS-a i GIS-a. To uključuje više od 35 radnih dana rada triju različitih vrsta helikoptera i podatke s devet različitih mjesta istraživanja. Podaci GPS-a prikupljeni su sustavom Trimble Geo XT sa WAAS ispravljanjem (korekcijom) i tehnologijom EVEREST postavljenima u helikopteru. Informacije su prikupljene u vremenskim razmacima od 1 sekunde. U tri sječine radio je i neiskusan pilot (pilot vježbenik). Istraživanje je provedeno ljeti, u sječinama četinjača u sjeverozapadnom SAD-u (tablica 1). Korišteni su helikopteri Boing Vertol BV 107 i Sikorsky S-61A, oba nosivosti do 4 tone.

Zabilježene su značajne razlike u gotovo svim radnim zahvatima s obzirom na iskustvo pilota (tablica 4). Pilotu vježbeniku trebalo je najmanje 64 % više vremena za dovršetak jedne radne sastavnice, što je dodatno povećano na 80 ili čak 90 % kada je dodana složenost u radnim elemenatima (npr. podizanje ili otpuštanje užadi za kopčanje, korištenje hvatala). Osnovne su krivulje proizvodnosti izađene za svaki od radnih zahvata. Neiskustvo je pilota smanjilo proizvodnost sustava rada od 75,9 do 42,8 t/h, odnosno 44 %. Uočene su razlike u vremenu potrebnom pilotu vježbeniku pri letu opterećenoga ili neopterećenoga helikoptera (najveća brzina leta, ubrzanje i usporavanje letjelice). Ipak, pilotu vježbeniku najviše je vremena bilo potrebno prilikom postavljanje helikoptera u sječini za kopčanje tereta.

Korištenje novih tehnologija može pružiti značajne mogućnosti za poboljšanje proizvodnosti postojećih sječnih sustava. Ovo je istraživanje pokazalo mogućnost korištenja sustava GPS uklopljenoga u vozilo za bolje buduće osposobljavanje neiskusnih pilota helikoptera. Omogućena je kvalitetnija obuka novih pilota jer su ustanovljene kritične točke rada (tijekom turnusa rada, radnih sastavnica i radnih zahvata) na koje treba obratiti više pažnje pri obuci pilota.

Ključne riječi: iznošenje drva helikopterom, sustav GPS, obuka pilota, proizvodnost

Received (*Primljeno*): August 04, 2011
Accepted (*Prihvaćeno*): September 5, 2011

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