Comparison of Classical Terrestrial and Photogrammetric Method in Creating Management Division

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Abstract:
Constant development of modern remote sensing methods, primarily digital photogrammetry, opens new possibilities for their application in forest management, with the aim of faster, simpler and cheaper ways of collecting data. Since the remote sensing methods have not yet reached wider practical application in Croatian forestry, focus of our work was on researching the potential application of digital photogrammetry on the tasks of creating management division.
For selected part of the privately owned, multi-aged forests of 'Donja Kupčina - Pisarovina' management unit, comparison of results obtained by classical terrestrial (stand mapping) and photogrammetric method (strata delineation) of creating management division were performed, as well as comparison of costs of their application. Terrestrial stand mapping was conducted within regular inventory of the management unit. Strata delineation, i.e. photointerpretation was carried out in the stereomodels of colour infrared digital images of spatial resolution (GSD) of 30 cm and 10 cm, using digital photogrammetric workstation and PHOTOMOD software.
Comparison between results (subcompartments area) obtained by different methods showed no statistically significant difference. In comparison to terrestrial mapping of stands, greater number of strata and subcompartments were delineated when using the photointerpretation of aerial images. That indicates the possibility of very detailed stands delineation by photointerpretation of aerial images. Regarding the costs of application, digital aerial images of GSD 30 cm proved to be the most favourable method. In contrast, all performed calculations revealed the application of aerial images of GSD 10 cm as financially the least favourable method. Finally, it can be concluded that photointerpretation of digital images GSD 30 cm has proven to be the most suitable method for operational use in creating management division, i.e. the method that provides the most favourable ratio of costs and accuracy of obtained results.

Keywords: strata delineation, photointerpretation, digital aerial images, digital photogrammetric workstation, cost comparison

1 Introduction

Creating management division, i.e. dividing of management unit (m.u.) into compartments and subcompartments is an important step of each forest inventory. For this purpose, terrestrial stand mapping (stands exclusion) is performed which is very labour and time consuming work, especially when there is no previously established management division of m.u.

In order to reduce labor field work as well as its costs, a significant amount of research of application of remote sensing methods in forest stand mapping (delineation) were conducted, primarily focusing on aerial photographs (Sullivan 2009). In Croatia, most of these studies (Tomašegović 1956a, Tomašegović 1961b, Vukelić 1984, Ćurić 1986, Benko 1993, Pernar 1997, Seletković 2006) were carried out by photointerpretation of the classical analogue aerial photographs with analogue stereo instruments.

During the last thirty years, photogrammetry has developed from analogue, over analytical to digital photogrammetry (Lapaine and Frančula 2001). Through that period, analogue aerial photographs as well as analogue or analytical stereo instruments were replaced by digital aerial images and by digital photogrammetric workstations (Magnusson et al. 2007, Linder 2009). Development of digital photogrammetry opened new possibilities for its application in forest management, with the aim of faster, simpler and cheaper ways of collecting data. Since the remote sensing methods have not yet reached wider practical application in Croatian forestry (Balenović et al. 2011), focus of this paper is to research the potential application of digital photogrammetry on the tasks of creating management division.

For selected part of the privately owned, multi-aged forests of 'Donja Kupčina - Pisarovina' m.u., comparison of results obtained by classical terrestrial (stand mapping) and photogrammetric method (strata delineation) of creating management division were performed, as well as comparison of costs of their application. Terrestrial stand mapping was conducted within regular inventory of the m.u. Strata delineation, i.e. photointerpretation was carried out in the stereomodels of colour infrared digital images of spatial resolution (GSD) of 30 cm and 10 cm, using digital photogrammetric workstation and PHOTOMOD Lite software.

2 Material and methods

2.1 Terrestrial stand mapping

Terrestrial stand mapping (stands exclusion) was carried out within regular inventory of the m.u. in the spring of 2009.

Before starting the field measurements, the temporary management division into compartments was created for the researched area, based on the existing artificial borders (motorways, roads, canals). Detailed field survey was conducted and the description was created for cadastral particles that are registered as privately owned forests or forest land. Described and mapped forest stands were then grouped into management classes, compartments and subcompartments in respect to the rules of the Regulation on forest management (NN 2006, 2008), but also in respect to the particularities of privately owned forests.

Work group involved in terrestrial stand mapping consisted of two people, forestry engineer and auxiliary forest worker. Materials used included a compass, GPS receiver for recording borders of compartments and subcompartments, detailed topographic map (DTK25) and ortophoto map of the area at a scale of 1:20000, created during the cyclic survey of the Republic of Croatia in 2003.

After the field work was finished, data obtained through terrestrial stand mapping was vectorized using the ArcGIS 9.1 software. Obtained data was corrected (adjusted) with cadastral data. Cadastral particles that are not registered as privately owned forests or forest land were excluded from management division. DTK25 of the researched area was used as the basis for the performed work.

Number of work days used for terrestrial stand mapping, stands description and vectorization was measured for the purpose of conducting cost analysis.

2.2 Aerial surveys

Two aerial surveys of research area were conducted by Vexcel UltraCamX digital aerophotogrammetric camera in July 2009. Focal distance of camera lenses was 100.5 mm, while radiometric resolution was 12 bit. Forward overlap (endlap) of images was 60%, while lateral (sidelap) was 30%.

First, so called "high" aerial survey were conducted at flying height of about 4400 m above ground level and with approximate scale of 1:1000. Along two flight lines, 10 colour infrared (CIR) digital aerial images of spatial resolution, i.e. ground sample distance (GSD) of 30 cm were acquired.

Second, "low" aerial survey were conducted at flying height of about 1400 m above ground level and with approximate scale of 1:1000, product of which was 23 CIR digital aerial images of GSD of 30 cm acquired along two flight lines.

Aerial surveys of research area and post-processing of acquired digital aerial images were performed by Geofoto Ltd, Zagreb.

2.3 Strata delineation (photointerpretation)

Strata delineation, i.e. photointerpretation of research area was carried out in the stereomodels of CIR digital images of GSD 30 cm and 10 cm using digital photogrammetric workstation (DPW) with photogrammetric software PHOTOMOD Lite 4.4 and GIS software ArcGIS 9.1 installed. Strata delineation method used in this research was developed and presented by Balenović et al. (2011).

Used photogrammetric software PHOTOMOD Lite 4.4 is a free version which has all features as full version of PHOTOMOD digital photogrammetric system, but it can handle only limited number of images, vector objects, TIN nodes, breaklines etc. Within one created project, the Lite version supports up to 10 digital aerial images in the central projection and extraction of vector objects up to 1000 points, and allowing the performance of various photogrammetric tasks (vector objects collection, orthomosaics, DTMs and vector maps creation) (Racurs 2010a). For strata delineation two modules of PHOTOMOD Lite software were used: (I) PHOTOMOD Montage Desktop - the core module of the digital photogrammetric system used to create and manage projects and operate different PHOTOMOD modules for further photogrammetric processing (Racurs 2009), and (II) PHOTOMOD StereoDraw - module for 3D feature extraction, i.e. creating, editing and measuring 3D vector objects in stereomode (Racurs 2010b).

Beside mentioned software and powerful hardware, the most important part of used DPW is stereo-viewing system that consisted of graphic card (NVIDIA GeForce 9800 GT), high resolution stereo monitor (Hyundai IT W220S) as well as a monitor suitable stereo-glasses (Hyundai 'interlaced').

In order to acquire a photointerpretation key, as well as to train the photo-interpreter, field survey of the research area was performed. Since it is difficult to set a strict written set of rules for photointerpretation, particularly in diverse forests such as ours, and because photo-interpretation was performed by only one person (forestry engineer) we decided not to make a written photointerpretation key. We used the approach where photointerpreter was first “trained” at the smaller part of the forest area, in order to perform photo-interpretation tasks on the remaining area.

Before the delineation, classification categories of forests were defined. Through preliminary review of acquired digital aerial images of the research area and photo-interpretation training with field survey, as well by using certain rules from Regulations for Forest Management (NN 2006, 2008), 4 main categories divided into total of 19 subcategories were identified (Table 1).

Table 1: Categories for forest and forest land classification for photo-interpretation of digital aerial images

Category	Subcategory	Subcategory code
Cover	High forest – Young	HF-Y
	High forest – Middle-Aged	HF-MA
	High forest – Old	HF-O
	Harvested Area	HA
	Coppice (degraded, shrub)	COPP
	Land In Succession	SUC
	Land Without Vegetation	WV
Mixture	Pure	P
	Mixed	M
	Not applicable	NA
Canopy closure	Complete (91-100%)	1
	Incomplete (76-90%)	2
	Rare (50-75%)	3
	Broken (< 50%)	4
	Not applicable	NA
Main tree species	*Quercus petraea*	QP
	Fagus sylvatica	FS
	Carpinus betulus	CB
	Alnus glutinosa	AG
	Populus sp.	POP
	Other	OTH
	Not applicable	NA

Strata were delineated on the basis of observable differences on digital images, according to predefined categories: crown size and tree height (cover), tree species mixture, canopy closure and tree species (Figure 1).

After delineation in StereoDraw module, vectorized polygon objects were loaded in ArcGIS 9.1 software for further processing (adjustment with cadastral data) where topographical map was used as background layer for easier orientation.

Since delineation was performed for privately owned forests, it was necessary to perform 'overlapping' of delineated strata with cadastral register data of private forests (in particular, overlapping and adjustment with polygons of cadastral particles which are registered as privately owned). In our case, delineated strata was corrected (adjusted) with cadastral data in order to delete strata or its parts which in cadastral are not registered as privately owned forests.

Finally, grouping of strata into management classes and then into subcompartments was conducted according to: (I) categories (Table 1) which are assigned to each strata during delineation (cover, mixture, canopy closure, main tree species), (II) insight into the spatial distribution of delineated strata inside the compartment, and (III) with respect to the rules of the Regulation on forest management (NN 2006, 2008).

As with the terrestrial stand mapping, time spent for strata delineation on digital images of GSD 10 cm and 30 cm was measured.

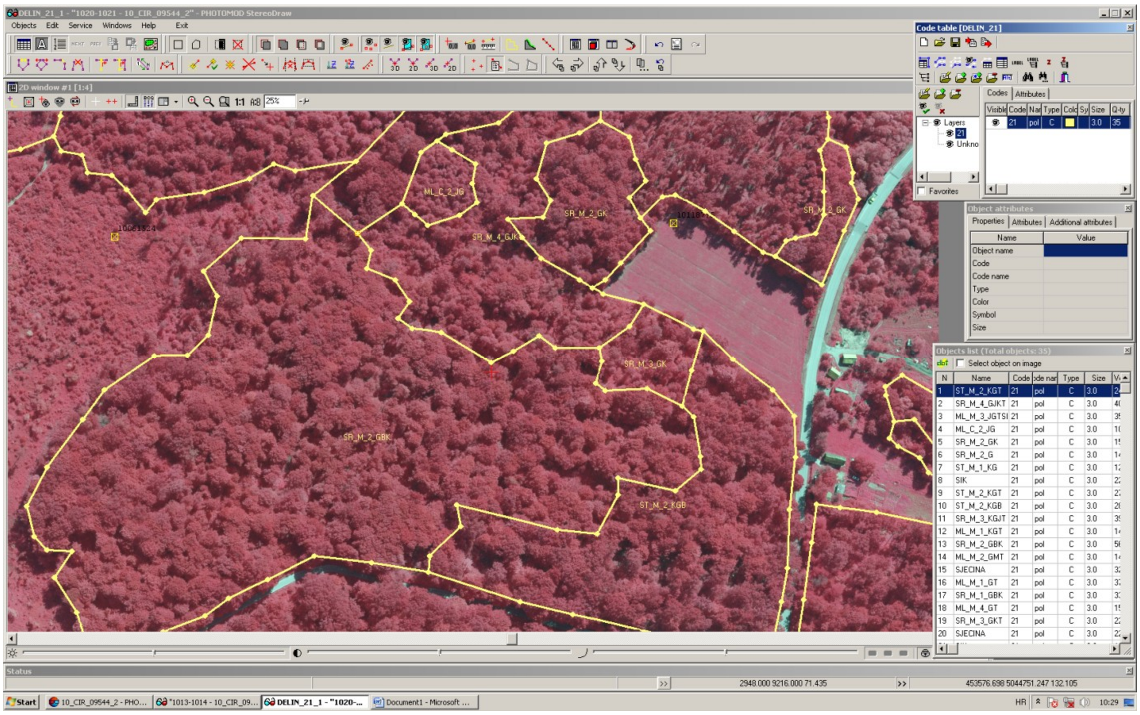

Figure 1: An example of strata delineated on digital aerial images of GSD 10 cm shown in 2D window of StereoDraw module at mitigation of 25 %

2.4 Statistic analyze and cost comparison

Data obtained from strata delineation by visual interpretation on digital images of GSD 10 cm and 30 cm, as well as data from terrestrial stand mapping was exported from ArcGIS attribute tables into MS Excel 2007 data bases.

Results (subcompartments area) obtained by different methods of creating management division were compared by t-test (pair test) for dependent samples (Sokal and Rohlf 1995) using STATISTICA 7.1 software (StatSoft Inc. 2011). Confidence level of 95% was considered as statistically significant.

In the process of costs analysis and costs comparison between different methods, all costs were specified into four basic groups: human labour costs, equipment costs, material costs and outsourcing costs (aerial photogrammetric images). Conversion into Euros was conducted in accordance with Croatian National Bank central exchange rate on 28th June, 2012.

3 Research area

Research was carried out on the selected part of multi-aged, privately owned forest of "Donja Kupčina - Pisarovina" m.u. which covers total area of 480 ha (Figure 2). The dominant tree species are Sessile oak (*Quercus petraea* L.), Common beech (*Fagus sylvatica* L.), Hornbeam (*Carpinus betulus* L.), Black alder (*Alnus glutinosa* (L.) Gaertn.) and poplars (*Populus* sp.).

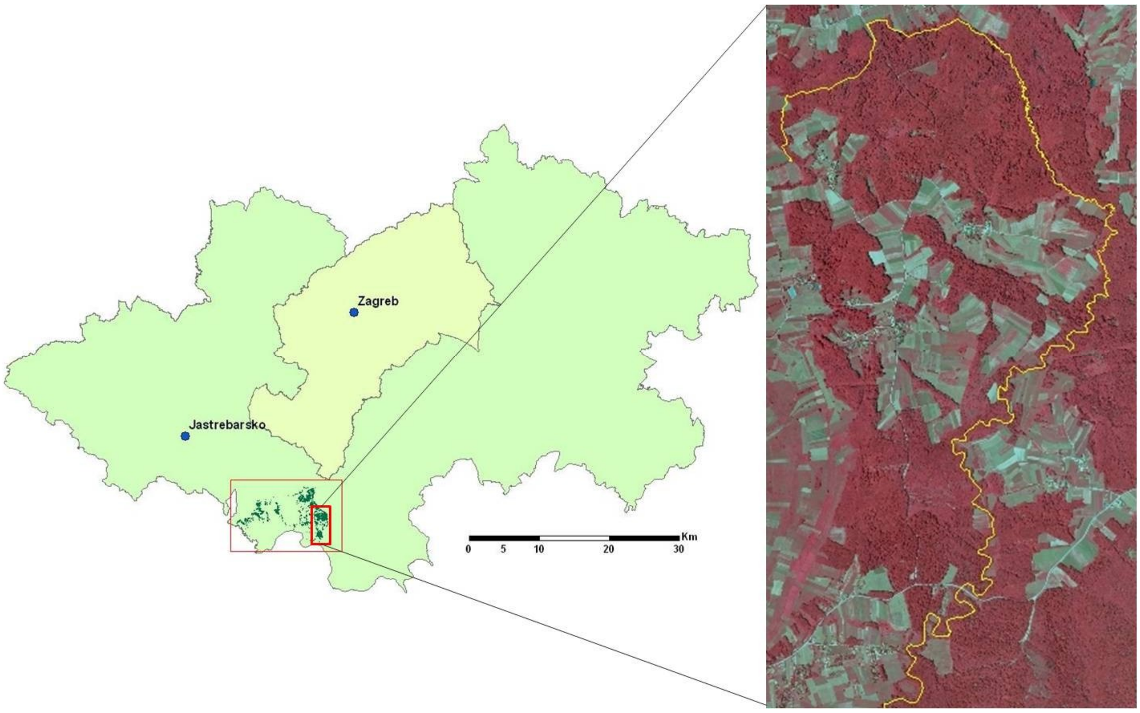

Figure 2: Location of the "Donja Kupčina – Pisarovina" m.u. in Zagreb County (left) and selected research area (yellow line – boundary) (right)

4 Results and discussion

4.1 Statistic analysis

Results of creating management division by each method are shown in Table 2.

Through terrestrial stand mapping 95 stands that formed 6 management classes or 24 subcompartments within 6 compartments were excluded. By photointerpretation of digital aerial images of GSD 30 cm 410 strata that formed 27 subcompartments were delineated, while by photointerpretation of digital images of GSD 10 cm 645 strata that formed 29 subcompartments were delineated. Same as with terrestrial stand mapping, by photointerpretation in both cases 6 management classes and 6 compartments were formed. Researched area, beside forests and forest land, also includes individual farm households, plough-fields, meadows and other 'non-forest' land. Total excluded area was therefore smaller (288.89 ha) than the total research area (≈ 480 ha).

Test results (t-test for dependent samples) on subcompartments area, obtained by using different methods, are shown in Table 3. Three t-tests were conducted: (I) comparison between subcompartments area obtained by terrestrial stand mapping and photointerpretation of digital aerial images of GSD 30 cm, (II) between subcompartments area obtained by terrestrial stand mapping and photointerpretation of digital aerial images of GSD 10 cm and (III) by photointerpretation of digital aerial images of GSD 30 cm and GSD 10 cm. All test results showed no statistically significant difference.

Results of the conducted tests indicate the possibility of applying photointerpretation of digital aerial images in the process of creating management division. Furthermore, number of delineated strata and average area of delineated strata (GSD 30 cm = 0.70 ha, GSD 10 cm = 0.45 ha) indicate the possibility of a very detailed stands exclusion by using the photointerpretation of digital aerial images of GSD 30 cm, and especially of GSD 10 cm. In other words, aerial images of GSD 30 cm, and especially of GSD 10 cm, enable a clear distinction of forest stands and tree species and a successful and reliable photointerpretation. In comparison, by terrestrial stand mapping (stands exclusion) 95 polygons with average area of 3.04 ha were excluded. Furthermore, by photointerpretation of digital aerial images in both cases a larger number of subcompartments were formed (Table 2).

Table 2: Results of creating management division by terrestrial stand mapping (stands exclusion) and by photointerpretation (strata delineation) of digital images of GSD 10 cm and 30 cm

Subcom-partment	Management unit	Area (ha)			Number of excluded stands/delineated strata		
		Terrestrial stand mapping	Photoint. GSD 30 cm	Photoint. GSD 10 cm	Terrestrial stand mapping	Photoint. GSD 30 cm	Photoint. GSD 10 cm
16a	Beech_MA	44.07	37.82	38.50	3	39	65
16b	Hornbeam_MA	1.57	5.41	4.69	4	20	31
16c	Alder_MA	0.90	1.23	1.17	2	3	4
16d	Coppice	1.80	1.18	1.82	4	5	14
16e	Oak_EA_older	-	2.70	2.17	-	5	9
17a	Beech_MA	40.50	40.18	38.36	2	35	66
17b	Beech_MA	28.71	26.84	26.37	2	42	70
17c	Hornbeam_MA	11.15	9.59	8.76	5	18	34
17d	Oak_EA_older	-	-	3.36	-	-	10
17f	Alder_MA	-	1.40	1.39	-	7	7
17g	Coppice	-	2.35	2.11	-	12	16
18a	Oak_EA_older	6.39	6.32	7.57	5	10	13
18b	Beech_MA	21.91	17.86	15.51	3	9	10
18c	Coppice	0.60	2.64	2.41	2	5	6
18f	Hornbeam_MA	-	2.08	3.41	-	9	11
19a	Oak_EA_older	2.70	1.82	3.12	4	5	10
19b	Beech_MA	7.11	6.92	6.58	3	5	12
19c	Hornbeam_MA	17.61	13.08	12.93	15	28	40
19d	Populus_MA	5.04	0.66	2.30	4	4	11
19e	Coppice	5.50	13.01	10.75	5	32	35
19g	Alder_MA	-	2.13	1.91	-	6	9
19DA	Transm. line	-	0.34	0.38	-	2	2
20a	Oak_EA_older	15.57	11.68	10.81	6	12	21
20c	Beech_MA	11.38	12.54	13.84	4	15	23
20d	Hornbeam_MA	20.46	22.63	21.94	8	34	49
20e	Coppice	1.62	2.03	2.31	1	17	22
20DA	Transm. line	0.54	0.69	0.67	2	2	2
21a	Oak_EA_older	9.91	8.98	8.83	4	7	11
21b	Hornbeam_MA	29.82	32.15	29.00	2	18	24
21c	Coppice	4.03	2.63	2.67	5	4	6
21e	Alder_MA	-	-	3.36	-	-	2
	Total	288.89	288.89	288.89	95	410	645

MA: multi-aged, EA: even-aged, Trans. line: transmission line.

Table 3: T-test of compartments area obtained by different methods of creating management division

t-test	Method	Mean	Std. deviation	N	Mean diff.	Std. dev. diff.	t-value	Degrees of freedom	p-value
I	Terrestrial	9,32	12,37						
	GSD 30 cm	9,32	11,42	31	0,0000	2,78	<0,0001	30	1,0000
II	Terrestrial	9,32	12,37						
	GSD 10 cm	9,32	10,76	31	-0,0036	2,85	-0,0069	30	0,9945
III	GSD 30 cm	9,32	11,42						
	GSD 10 cm	9,32	10,76	31	-0,0036	1,42	-0,0140	30	0,9890

4.2 Costs comparison

Comparison between costs of creating management division by using different methods, with all costs calculated, including the initial investment costs (equipment costs), are shown in Table 4. In this case, terrestrial stand mapping (stands exclusion) proved to be financially most acceptable method with the average cost of 19.67 €/ha. Costs of creating management division by using the photointerpretation of digital aerial images proved to be higher in comparison to terrestrial method. In the case of using aerial images of GSD 30 cm costs were higher by 26.03% (24.79 €/ha), and in the case of using aerial images of GSD 10 cm by 74.19% (34.26 €/ha).

Since the purchased equipment can be used for a long time, and eventually pays off, costs of different methods were also compared without calculating the initial costs (equipment costs). In this case, photointerpretation of digital aerial images of GSD 30 cm proved to be the most financially acceptable method with the average cost of 4.03 €/ha. Costs of terrestrial stand mapping proved to be higher by 56.59% and amounted to 6.32 €/ha. Once again, the least financially acceptable method proved to be strata delineation on aerial images of GSD 10 cm with costs higher by as much as 234.87% in comparison to the most favourable method (photointerpretation of aerial images of GSD 30 cm), higher by 113.84% than terrestrial stand mapping and amounted to 13.51 €/ha.

Conducted calculations proved that delineation method by using the aerial images of GSD 10 cm was the least financially acceptable. Besides, statistical analysis determined that there was no statistically significant difference between subcompartments areas delineated on aerial images of GSD 10 cm and GSD 30 cm (Table 3, t-test III). Based on these results we can conclude that photointerpretation of aerial images of GSD 30 cm provides just as good results as the photointerpretation of aerial images of 10 cm, while being significantly more financially acceptable. That is why we only used photointerpretation of aerial images of GSD 30 cm in further costs analysis and when comparing costs to terrestrial stand mapping (stands exclusion).

For the needs of further cost analysis and discussion, relation between research area ($A_{a.s.}$=480 ha) and the given forest area ($A_{m.u.}$=288.89 ha) was defined as aerial survey coefficient ($k_{a.s.}=A_{a.s.}/A_{m.u.}$) which was, in this case, 1.66. Therefore, due to heterogeneity specific for privately owned forests, it was necessary to survey 66% larger area to include complete targeted forest on the aerial images.

As the previous calculation showed that photointerpretation of aerial images of GSD 30 cm is financially more acceptable than the terrestrial stand mapping when the calculation does not include initial investment costs, it was necessary to determine at what point initial equipment investments pay-off when using photointerpretation method.

Table 4: Comparison between costs of terrestrial stand mapping (stands exclusion) and photointerpretation (strata delineation) of digital aerial images (GSD 10 cm and 30 cm) including initial investment costs (equipment costs)

Group of costs	Cost	Unit	€/unit	Spent	Method Terrestrial	 GSD 30 cm	 GSD 10 cm
						€	
External service	'Low' aerial survey (GSD 10 cm)	ha	6,98	480			3.352.60
	'High' aerial survey (GSD 30 cm)	ha	1,40	480		670.52	
Human labour	Forestry engineer	day	54.57	T=12+3, F10=6+1, F30=5+1*	818.59	382.01	436.58
	Auxiliary forest worker	day	28.85	T=12	346.15	28.85	28.85
	Fee for field work	day	22.62	T=6	271.40	22.62	22.62
Equipment	GPS receiver	piece	358.1	1	358.14		
	Compass Sunto	piece	97.78	1	97.78		
	PC computer	piece	532.16	1	532.16		
	ArcGIS 9.1	piece	2,869.61	1	2,869.61	2,869.61	2,869.61
	DFS PHOTOMOD (+software)	pieces	3,126.43	1		3,126.43	3,126.43
Material costs	DTK25	sheet	39.91	1	39.91	39.91	39.91
	$DOF5_{cs}$ black-white	sheet	26.61	2	53.22		
	$DOF5_{cs}$ colour	sheet	39.91	1	39.91		
	Car	km	0.27	T = 960 F10 = 80 F30 = 80	255.44	21.29	21.29
	Total	€			**5,682.31**	**7,161.23**	**9,897.88**
	Average	€/ha			**19.67**	**24.79**	**34.26**

Initial investment costs i.e. purchasing DPW and PHOTOMOD Lite 4.4 software used in this research becomes cost effective at the creating first management division if the m.u. area is larger or equals 950 ha (with $k_{a.s.}$=1.66). By applying the norms for stands exclusion and delineation, amount of individual costs (Table 4) recalculated for m.u. with the area of 950 ha, average costs for creating management division by using terrestrial stand mapping amount to 9.69 €/ha, while costs of using photointerpretation of aerial photos of GSD 30 cm amount to 9.64 €/ha.

In the case of buying the commercial version of PHOTOMOD 4.4 software (16,400.00 US $ according to Racurs catalogue from 2010) it becomes cost effective in privately owned forest at the start of creating seventh management division of m.u. with the area of 950 ha (with k_A=1.66). Total cumulative costs after seven created management divisions by using terrestrial stand mapping amount to 44,662.16 €, and costs of using photointerpretation of digital aerial images of GDS 30 cm amount to 42,691.73 €. With each following inventarization the advantage of using photointerpretation as a preferred method increases (Figure 3). In the case of m.u. with larger area software purchase would pay off even sooner. For example, in the case of m.u. with the area of 1300 ha, buying PHOTOMOD 4.4 software would financially pay off during the creation of fifth management division.

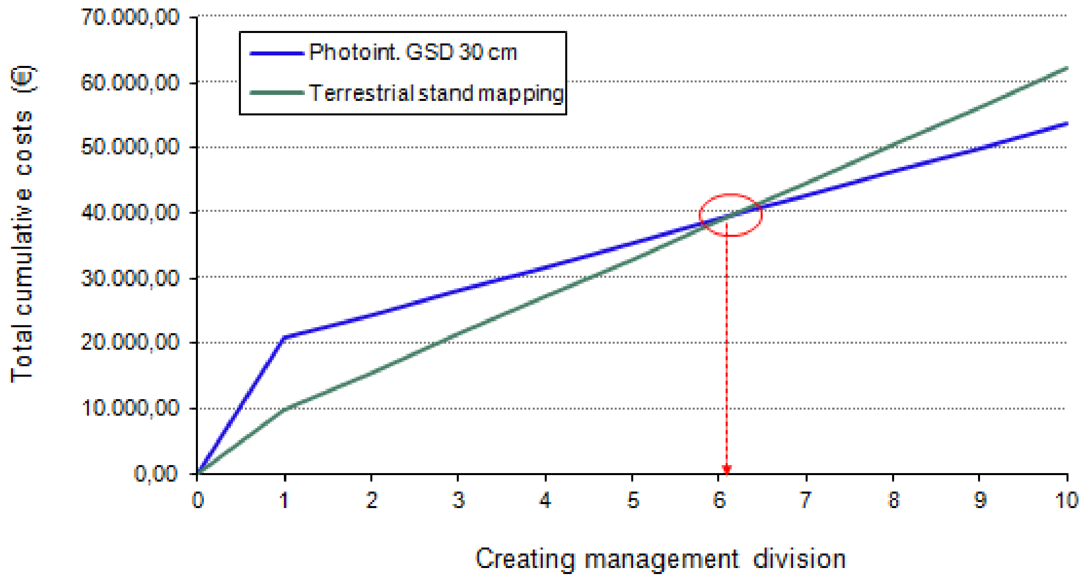

Figure 3: Comparison between total cumulative costs obtained by terrestrial stand mapping and by photointerpretation of digital aerial images of GSD 30 cm during ten conducted creations of management division (for $A_{m.u.}$=950 ha, $k_{a.s.}$=1.66)

As Table 3 shows, aerial survey costs, along with initial investments costs, have the largest influence on the total costs of photointerpretation method. Figure 4 shows average costs of creating management division by using terrestrial stand mapping (stands exclusion) in privately owned forests, as well as the change in average costs of photointerpretation of digital aerial images of GSD 30 cm, in dependence to changing aerial survey costs. With the assumption that costs of terrestrial stand mapping in certain conditions are constant, cost of aerial survey determines the most favourable method of creating management division. Obtained results showed that creating management division by using photointerpretation of aerial images is financially more favourable than using the terrestrial method when aerial survey cost does not exceed 2.77 €/ha. Since the real average cost of 'high' aerial survey conducted in this research was 1.40 €/ha, we can conclude that photointerpretation method used in our research was considerably more favourable financially than the terrestrial stand mapping method. In the case where aerial survey coefficient ($k_{a.s.}$) is lower than 1.66, or in the case of spatially more homogenous stands (which was not the case in this research), cost-effectiveness of using the photointerpretation method would be even higher. Calculation was done based on data ($A_{m.u.}$ = 288.89 ha; $k_{a.s..}$ = 1.66), average daily effects (norms) of terrestrial stand mapping (24.07 ha/day) and photointerpretation of aerial photos of GSD 30 cm (57.78 ha/day), and including all other research costs (Table 4) except initial investment (equipment purchase).

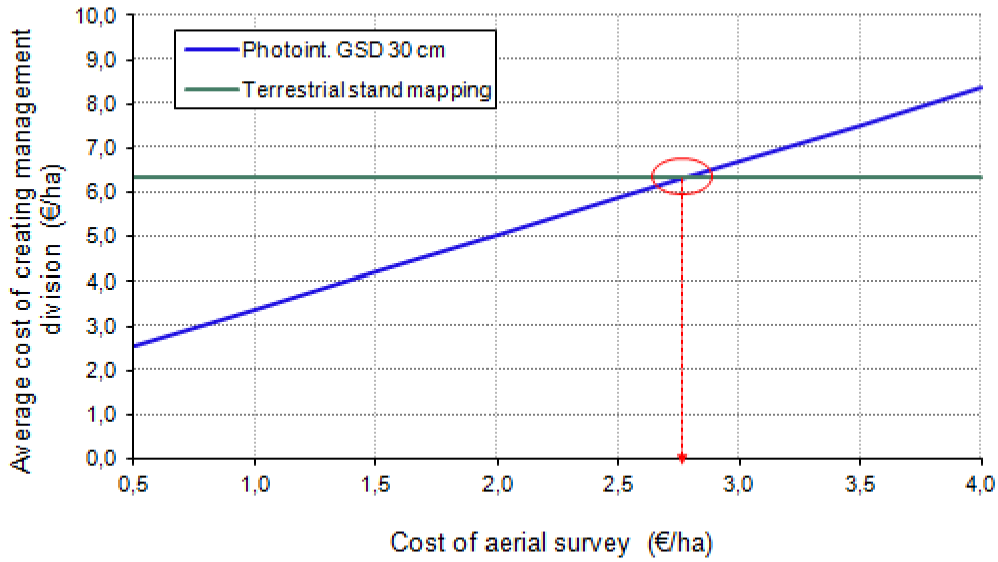

Figure 4: Comparison between average costs of creating management division by terrestrial stand mapping and by photointerpretation of digital aerial images of GSD 30 cm. Photointerpretation costs are shown in dependence on changing aerial survey costs

If we compare the above mentioned daily effects, i.e. average daily excluded or delineated areas, it becomes clear that delineation (photointerpretation) of digital aerial images of GSD 30 cm took the least time to complete, with the average daily delineated area of 57.78 ha/day. Photointerpretation of aerial photos of GSD 10 cm followed with 48.15 ha/day, while terrestrial stand mapping took the most time to complete, with average 24.07 ha excluded per day. If we add to that the fact that terrestrial stand mapping method requires two workers, while photointerpretation of aerial images only requires one, the advantage of photointerpretation method becomes even more obvious.

Further advantage of using the photointerpretation method is the fact that after conducted delineation (vectorization) in PHOTOMOD StereoDraw software most of work on creating management division is done. All that is left to do is to perform some lesser corrections of delineated strata, using ArcGIS (or any other software package for managing spatial data), and grouping delineated strata into potential subcompartments. Opposed to that, when using the method of terrestrial stand mapping, it is necessary to perform the complete vectorisation of excluded areas and to adjust the polygons in accordance with cadastre after the field work is finished.

Besides, existing digital aerial images and conducted delineation strata remain permanently stored, so finished work can be controlled multiple times. Also, the same images can be used for photogrammetric stand measurements which enables further costs reduction.

Former researches (Benko 1993, Pernar 1997, Klobučar 2004) indicated the possibility of applying remote sensing methods (visual interpretation of analogue aerial images or digital orthophoto) in stands exclusion, with conclusion that their application does not exclude field work, but rather reduces its volume and rationalizes it. Since then, remote sensing methods and techniques have considerably improved, especially in technological sense. Consequently, certain progress was expected in their application in stands exclusion and management division creation, which this research confirmed. Considering the obtained results, we can conclude that the application of contemporary photogrammetric tools or, to be precise, application of strata delineation i.e. photointerpretation of CIR digital aerial images on stereomodel using DPW for creating management division, reduces field work to a minimum. It may only take a few field surveys of individual stands to acquire a photointerpretation key for specific stands and tree species.

5 Conclusions

From obtained results of this research, following conclusions can be derived:

⇒ Conducted research indicated the possible application of digital aerial images of high spatial resolution (GSD 10 cm and GSD 30 cm) in creating management division by photointerpretation (strata delineation) using DPW.

⇒ Comparison between results (subcompartments area) obtained by different methods (terrestrial and photogrammetric) showed no statistically significant difference. In comparison to terrestrial stands mapping (stands exclusion), greater number of strata and compartments were delineated when using the photointerpretation of aerial images. That indicates the possibility of very detailed stands delineation by photointerpretation of aerial images.

⇒ Regarding the costs of application, photointerpretation of digital aerial images of GSD 30 cm proved to be the most favourable method. In contrast, all performed calculations revealed the application of aerial images of GSD 10 cm as financially the least favourable method.

⇒ Finally, it can be concluded that photointerpretation of digital images GSD 30 cm has proven to be the most suitable method for operational use in creating management division, i.e. the method that provides the most favourable ratio of costs and accuracy of obtained results.

6 References

Amending of Regulation on forest management (2008) Official Gazette of the Republic of Croatia, NN 141/2008.

Balenović, I., Seletković, A., Pernar, R., Marjanović, H., Vuletić, D., Paladinić, E., Kolić, J., Benko, M., 2011: Digital Photogrammetry – State of the Art and Potential for Application in Forest Management in Croatia, SEEFOR 2(2): 81-93.

Benko, M., 1993: Procjena taksacijskih elemenata sastojina na infracrvenim kolornim aerosnimkama (Assessment of stands elements on colour infrared aerial photographs), Glasnik za šumske pokuse 29: 199-274.

Ćurić, T., 1986: Fotointerpretacijsko izlučivanje sastojina. Bachelor's thesis, Faculty of Forestry, University of Zagreb, p. 22.

Klobučar, D., 2004: Izlučivanje sastojina prema sklopu na digitalnom ortofotu i usporedba s terestičkim izlučivanjem (Exclusion of stands according to the canopy on a digital orthophoto and comparison with terrestrial exclusion), Radovi Šumarskog instituta, Jastrebarsko (39)2: 223-230.

Lapaine, M., Frančula, N., 2001: O pojmovima analogno i digitalno. Bilten Znanstvenog vijeća za daljinska istraživanja i fotointointerpretaciju HAZU 15-16: 135-144.

Linder, W., 2009: Digital photoogrammetry - A practical course. Springer, Berlin, p. 220.

Magnusson, M., Fransson, J.E.S., Olsson, H., 2007: Aerial photo-interpretation using Z/I DMC images for estimation of forest variables, Scandinavian Journal of Forest Research 22(3): 254-266.

Pernar, R., 1997: Application of results of aerial photograph interpretation and geographical information system for planning in forestry, Glasnik za šumske pokuse 34: 141-149.

Racurs, 2009: PHOTOMOD 4.4. Module Montage Desktop, User Manual. Racurs, Moscow. <http://www2.racurs.ru/docs/en/md.pdf> (Accessed 25 October 2010).

Racurs, 2010a: PHOTOMOD Lite. <http://www.racurs.ru/?page=705> (Accessed 20 October 2010).

Racurs, 2010b: PHOTOMOD StereoDraw. <http://www.racurs.ru/?page=555#SD> (Accessed 20 October 2010).

Regulation on forest management (2006) Official Gazette of the Republic of Croatia, NN 111/2006.

Seletković, A., Pernar, R., Benko, M., 2006: Višefazni uzorak u inventarizaciji šumskog prostora (Multi-stage sample in forest inventory), Radovi Šumarskog instituta, Jastrebarsko, Special issue 9: 297-306.

Sokal, R. R., Rohlf, F. J., 1995: Biometry. Third edition, Freeman and Company, New York, p. 880.

StatSoft, Inc., 2011: Statistica, Electronic Statistics Textbook (Electronic Version). <http://www.statsoft.com/textbook/> (Accesed 15 November 2011).

Sullivan, A. A., McGaughey, R. J., Andersen, H.-E., Schiess, P., 2009: Object-Oriented Classification of Forest Structure from light Detection and Ranging Data for Stand Mapping, Western Journal of Applied Forestry 24(4): 198-204.

Tomašegović, Z., 1956: Razmatranja o fotoplanu Turopoljskog luga, Šumarski list 80(5-6): 154-166.

Tomašegović, Z., 1961: Sterefotogrametrijska linearna taksacija, Šumarski list 85(1-2): 36-45.

Vukelić, J., 1984: Doprinos fotointerpretacijske analize vegetaciji istraživanih šumskih zajednica Nacionalnog parka Risnjak. Master's thesis, Faculty of Forestry, University of Zagreb, p. 81.