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Research on the optimal picket sampling interval in automated digital terrain model creation by using digital photogrammetry

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Abstract. In the method of creating digital terrain model (DTM) by using digital photogrammetry, the picket sampling interval (PSI) plays an important role since it strongly influences on the production effectiveness and on the accuracy of created DTMs. The optimal value of PSI must be balanced between requirements of effectiveness and of accuracy.

This research is focused on the influence of PSI on root mean square error (RMSE) of created DTM and on the number of error pickets (caused by limitation of image matching technique) that must be checked and corrected manually. Based on the results obtained in four experimental areas of Vietnam (Co Loa, Duong Lam, Ba Vi, and Lang Son), the paper has proposed an empirical equation for choosing optimal PSI: $PSI = k\sqrt{P \times M_a}$, where P is the scan resolution (μm); M_a is the denominator of airphoto scale; k is a coefficient depending on the characteristics of topography.

Keywords: Digital terrain model (DTM); Picket sampling interval; Digital photogrammetry; DTM accuracy.

1. Introduction

Being known from 1950s, the Digital Terrain Models (DTM), as well as the Digital Elevation Models (DEM), are getting more and more popular. Nowadays, DTM becomes an important component of spatial data infrastructure (SDI) and to the creation of DTMs a special attention is given.

At present time, among available methods for creating DTMs, the method using airphoto and applying digital photogrammetry is the most popular one [1]. In DTM creation using digital photogrammetry, the key steps are placing a grid of pickets over the interested area and measuring these pickets automatically by using image matching technique. Since the image matching technique is still imperfect [2, 3], the choice of picket sampling interval (PSI), i.e. the distance between pickets in the measuring grid, is very important. The smaller the PSI, the more detailed DTMs are obtained. But in the same time, the number of error pickets that must be discovered and corrected manually is getting much higher.

Currently, the most common way to choose PSI is to use the following equation [4, 5]:

$$PSI = 30 \times P \times M_a, \qquad (1)$$

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where P is the scan resolution of airphotos; M_a is the denominator of airphoto scale.

The practical experiences show that Equation (1) usually gives PSI a smaller value than the optimal one. Thus, different researches are conducted to find the better way to determine optimal PSI by using high-quality airphotos of some areas in Europe [6-8]. Since the characteristics of topography and the quality of airphotos are important factors influencing on the choice of PSI, the results of these researches are hardly applicable for the conditions of Vietnam, which are different from European ones.

In this research, we investigated the influences of PSI on the number of error pickets and the accuracy of DTM by using airphoto database of Vietnam. On this basis, some recommendations on choosing optimal PSI are given.

2. Testing methodology

2.1. DTM creation

In this research, the workflow shown in Fig. 1 is used for creating and testing DTMs. Since the main purpose of the research is to assess the quality of automated picket sampling and measuring, some steps (additional breakline measuring, field checking,...) are intentionally omitted. The software used for airphoto measurement and DTM creation is PhotoMOD 3.51 - a softcopy photogrammetric system developed by Racurs Inc.

- *Photoscanning:* the airphotos are scanned at different resolutions from 800dpi (32μm) to 1600dpi (16μm) by using photogrammetric scanner ZEISS SCAI.

- *Project assembling:* the main purpose of this step is to distribute airphotos by strips as they were shot in the field.

- *Ground control measurement:* three GPS receivers Trimble 4600LS are used for ground control measurement. There are at least 5 ground control points in each of photostrips (4 at the corners and 1 in the center). The coordinates of control points are obtained by measuring GPS baselines to at least 3 points of the State Control Network. The overall accuracy of coordinates is 2-4cm in horizontal directions and 4-7cm in vertical direction.

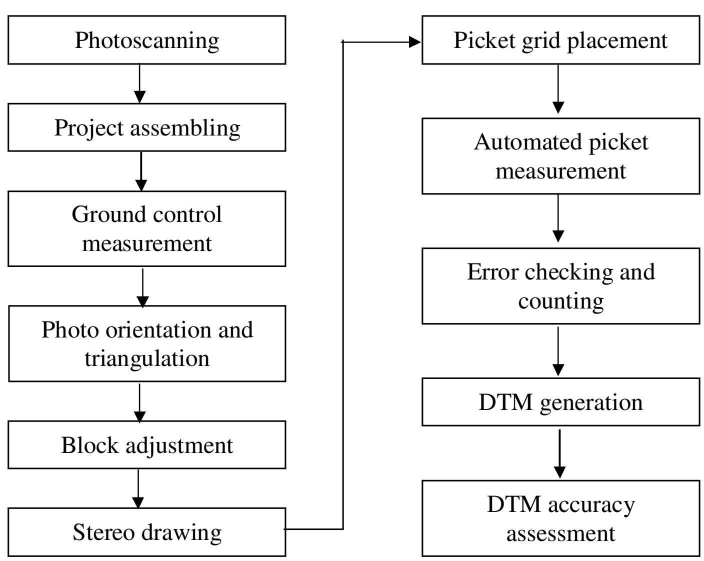

Fig. 1. The workflow for DTM creation and testing.

- *Photo orientation and triangulation:* Interior orientation of each airphoto is made by measuring fiducial points with an error of about 0.7 pixels. Exterior orientation is made by entering collected ground control points (absolute orientation) and measuring tie points between stereo pairs and between strips (relative orientation). The estimated error of relative orientation is about 4-6 pixels.

- *Block adjustment:* The method of adjustment is "Independent stereo pairs" in order to improve the accuracy comparing to "Independent strips" method. The fully constrained adjustment is preceded by minimally constrained adjustment in order to discover possible errors in the tie points measurement.

- *Stereo drawing*: The anaglyph method is used for drawing streomodels. Detailed information about this method can be found in [3].

- *Picket grid placement:* this step is done with the aim to determine the DTM area and the distribution of pickets, which will be measured in the next step. The grids are placed in the central area of the stereo models. The distances from grids to edges of airphotos are kept at more than 10% of the length (or width) of airphotos in order to reduce errors in the areas near edges of airphotos. The PSI, i.e. the grid cell size, is varied from 20 to 120m.

- *Automated picket measurement*: each node of the picket grid is measured automatically by using image matching technique. The correlation threshold is set to a relatively high value (0.90) in order to eliminate large errors in homogeneous areas. If the coordinates of a node are measured successfully, a picket is created. Otherwise, the software will move the node for a small distance and the process repeats until success.

- *Error checking and counting*: this step is made to discover the errors generated by the previous step since the image matching technique does not ensure 100% reliability. There are still some incorrectly measured pickets, especially in the areas on airphotos with homogeneous grey level [9]. The operator has three options to discover incorrect pickets:

+ Watch the grid of pickets placed on the stereomodel and visually find those pickets that are above or below the ground.

+ Compare the distance (parallax) between red and blue points representing the investigated picket on the stereo model with the same distance of nearby pickets or ground features. Since neighbour points usually have almost same elevation, they usually have almost same parallax in the stereo model. Any anomaly of parallax may point out an error.

+ Generate an intermediate DTM as a TIN (Triangulated Irregular Network) from current set of pickets and display it in 3D space. Any peak or abyss formed by one - two pickets may point out an error (see Fig. 2).

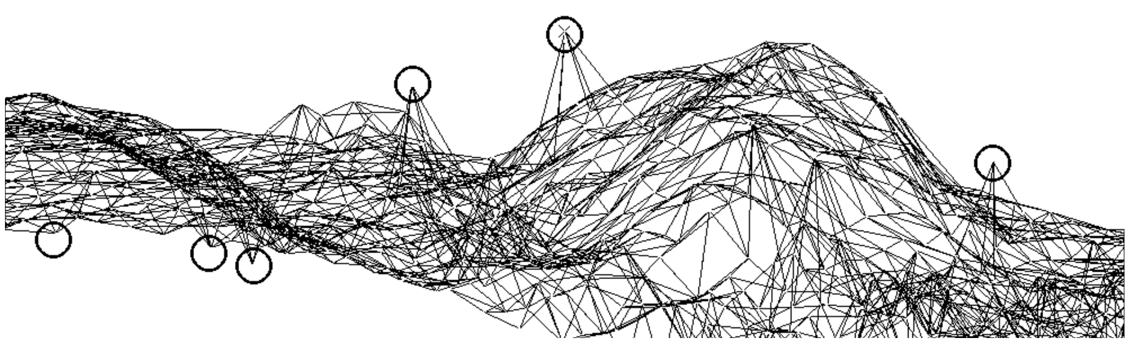

Fig. 2. An intermediate DTM displayed in 3D space. The small circles denote possible errors.

The number of error is registered for statistical analysis explained in the next session. After that, the incorrect pickets are corrected for the next step.

- *DTM generation:* this step is done automatically from the checked and corrected set of pickets measured in the previous steps by using module DTM.

- *DTM accuracy assessment:* the main purpose of this step is to compare the created DTM with a control DTM and compute root mean square error (RMSE) of the former. In this research, as the control DTMs we used high accuracy DTMs created manually from airphoto in combination with field survey. The method proposed by the author for DTM accuracy assessment is explained in the next session.

2.2. Method for computing error of DTM by using GIS

Since the sets of pickets used for generating testing DTM and control DTM are not coincided in both horizontal and vertical directions, the RMSE of the testing DTM can not computed directly picket by picket. So, in this research, we have developed a method using GIS for comparing two DTMs and computing RMSE.

The idea is to interpolate two DTMs (or corresponding sets of pickets) into two raster layers of high resolution, and then use the raster analysis capability of GIS for calculating the difference of values of each pair of coincident cells on these two raster layers. In this research, we use Raster Calculator and Raster Zonal Statistics tools of ArcGIS software for this purpose.

The workflow for computing error of DTM by using ArcGIS is presented in Fig. 3.

The testing and control sets of pickets (or DTM) are imported to point feature classes (or TIN) and opened as two layers in ArcGIS. After that, an interpolation is applied to convert

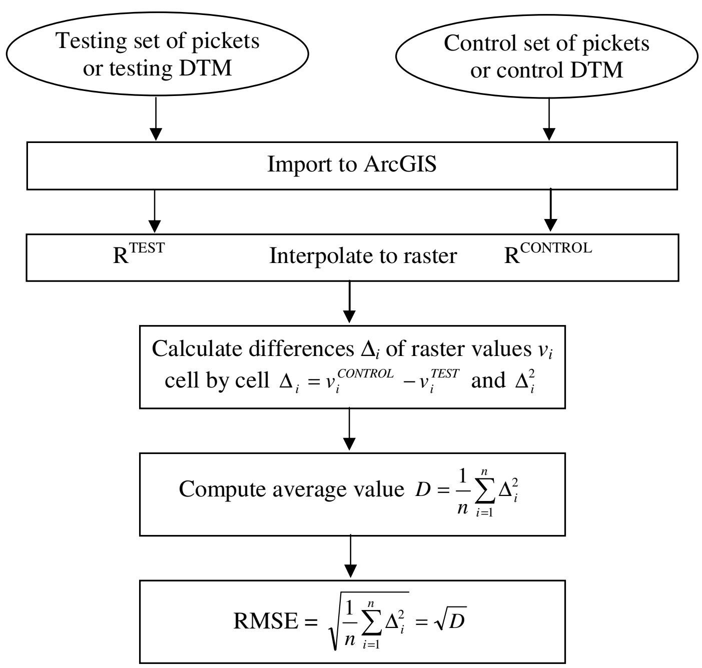

Fig. 3. The developed workflow for computing RMSE of DTM by using ArcGIS.

these feature layers into raster layers. There exist many interpolation algorithms, but the same algorithm must be applied for both feature layers. We prefer to use Spline interpolation since it is the most popular algorithm for interpolating topographic surfaces [10]. At this step, we have two raster layers, namely R^{TEST} and $R^{CONTROL}$. The values of their cells represent the heights of the surfaces interpolated from the testing DTM and control DTM.

The next step is to calculate differences Δ_i between the values $v_i^{CONTROL}$ and v_i^{TEST} of coincided raster cells:

$$\Delta_i = v_i^{CONTROL} - v_i^{TEST}, i = 1,2,...,n \qquad (2)$$

where n is number of cells inside the interested area.

The above calculation can easily be done by using Raster Calculator tool of ArcGIS software. For the sake of convenience, the squares of Δ_i are also calculated in this step:

$$\Delta_i^2 = \left(v_i^{CONTROL} - v_i^{TEST}\right)^2 \qquad (3)$$

In the next step, the average value D of Δ_i^2 inside the interested area is computed using Raster Zonal Statistics tool of ArcGIS:

$$D = \frac{1}{n}\sum_{i=1}^{n}\Delta_i^2 \qquad (4)$$

Finally, the RMSE of testing DTM is computed as follows:

$$\text{RMSE} = \sqrt{\frac{1}{n}\sum_{i=1}^{n}\Delta_i^2} = \sqrt{D} \qquad (5)$$

3. Test and discussion

The influence of PSI on the quality of automatically created DTM is investigated on four experimental areas. The main characteristics of these areas are shown in Table 1.

3.1. Co Loa experimental area

Co Loa is a commune of Dong Anh District, Hanoi City. This place is very famous in Vietnam thanks to the Co Loa Wall, which is built in the III Century B.C. Being located in 18km from center of Hanoi, Co Loa has an even and flat terrain, except for the above mentioned Co Loa Wall with height of about 2-4m. The population density is relatively high. There are many houses and traces of dykes in the central area, which make some difficulties in automated picket measurement by using image matching technique.

The experimental area covers about 200 ha in the Northwest of the commune. In this area, we tested four PSIs: 20, 30, 40, and 60m. The summarized results are shown in Table 2 and Fig. 4.

Table 1. Characteristics of the experimental areas

Area	Sub-area	Type of topography	Airphoto characteristics					
			Number of photo	Number of strips	Flying year	Scale	Flying height	Scan resolution
Co Loa		Plain, high building density	13	2	2003	1:7000	1050m	28µm
Duong Lam	Duong Lam 1	Residential area, similar to Co Loa	2	1	1997	1:33000	5000m	16µm
	Duong Lam 2	Hills, paddy-fields, many mounds						
Ba Vi	Ba Vi 1	Residential area	3	1	2004	1:32000	4900m	20µm
	Ba Vi 2	Mountainous area						
Lang Son		High mountains	3	1	2000	1:35000	5350m	32µm

Table 2. Results obtained in Co Loa experimental area

PSI *(m)*	Total number of pickets	Error pickets Number	Error pickets %	RMSE *(m)*
20	6634	552	8.32	0.55
30	2982	217	7.28	0.62
40	1642	141	8.59	0.68
60	700	34	4.86	0.75

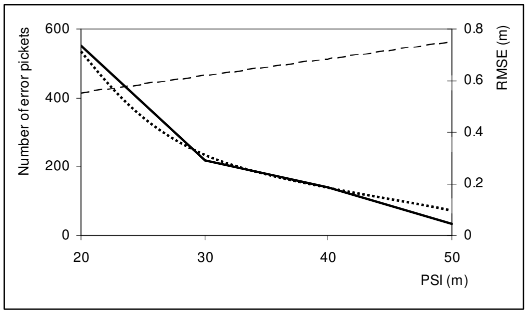

Fig. 4. Expected (dotted line) and actual (solid line) numbers of error pickets, and RMSE (dashed line) in Co Loa experimental area.

From the obtained results, some remarks can be made:

- The RMSE of DTM almost linearly increases with the increase of PSI.

- The errors are mainly occurred in the area with homogeneous grey levels (surface water, shadows of high objects, etc.). The similar remark was made by some researchers [2, 9].

- When PSI increases from 20m to 30m, the number of error pickets are significantly decreases (from 552 to 217). Further increase of PSI does not give such significant decrease of error pickets.

- The percentage of error pickets shows a tendency to decrease with increase of PSI. However, in Table 2 we can see an anomaly: the PSI of 40m has a larger percentage of error than the PSI of 30m. We suppose that this happens due to the random allocation of the pickets relatively to the ground objects. Note that this percentage is used only for reference: a more important parameter is the absolute number of errors.

- The hyperbola-like shape of the graph representing the actual number of error pickets in Fig. 4 is what we expected. It can be explained as follows:

Ideally, if the percentage p of error pickets remains unchanged then the number of error pickets e equals:

$$e = p\frac{S}{PSI^2}, \qquad (6)$$

where S is the area of DTM. Thus, the graph $e = e(PSI)$ theoretically should have a hyperbola-like shape (dotted line in Fig. 4). Some observed deviations of the actual number of error pickets are due to the errors of measurement and to the random allocation of pickets.

- Based on the obtained results, the optimal PSI for Co Loa experimental area can be chosen equal 30-40m since it gives an acceptable accuracy with relatively small number of error pickets.

3.2. Duong Lam experimental area

The old village of Duong Lam is a famous cultural heritage and historical monument of Vietnam. Located in 5km in the Northwest of Son Tay Town, Duong Lam has typical characteristics of the midland topography. The area has many mounds combined with low hills.

The experimental area covers about 335 ha, and it is divided into two sub-areas: the Duong Lam 1 is a residential sub-area (175 ha), and Duong Lam 2 is a hill and field sub-area (160 ha). We have tested four PSIs: 30, 50, 70, and 90m. The summarized results are shown in Table 3 and Fig. 5.

For Duong Lam experimental area, we have made the following remarks:

- With increase of PSI, the number of error pickets drops significantly at PSI = 50 ÷ 70m and then decreases slowly.

- The RMSE increases by 4-9% when PSI increases by 20m. The corresponding graph in Fig. 5 has a parabola-like shape with a very low curvature.

Table 3. Results obtained in Duong Lam experimental area

PSI (*m*)	Total number of pickets	Error pickets		RMSE
		Number	%	(*m*)
Duong Lam 1: residential sub-area				
30	1935	249	12.87	0.93
50	702	87	12.39	1.02
70	342	51	14.91	1.14
90	210	22	10.47	1.17
Duong Lam 2: hill and paddy-field sub-area				
30	1786	538	30.12	1.07
50	616	162	26.30	1.15
70	320	57	17.81	1.22
90	180	42	23.33	1.27

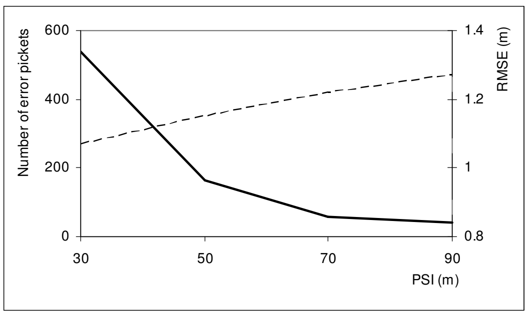

Fig. 5. Number of error pickets (solid line) and RMSE (dashed line) in Duong Lam 2 sub-area.

- The errors are concentrated in vegetable fields, ponds, mounds, hill bases and hill tops.
- The optimal PSI can be chosen equal 50-70m for both residential and field sub-areas.

3.3. Ba Vi experimental area

Located in 53km from Hanoi in the northwest direction, Ba Vi District is a half-mountain half-plain area. The topography is divided into three different sub-types: mountain, hill - mound, and plain. Our interested area covers about 720 ha around Ba Vi National Park. It has two sub-areas: Ba Vi 1 is a residential sub-area (330 ha) and Ba Vi 2 is a mountainous sub-area (390 ha).

In Ba Vi experimental area, we have tested four PSIs: 40, 60, 80, and 100m. The summarized results are shown in Table 4 and Fig. 6.

Table 4. Results obtained in Ba Vi experimental area

PSI (*m*)	Total number of pickets	Error pickets		RMSE
		Number	%	(*m*)
Ba Vi 1: residential sub-area				
40	2070	246	11.88	0.91
60	930	86	9.25	0.94
80	506	48	9.48	0.95
100	342	25	7.31	0.98
Ba Vi 2: mountainous sub-area				
40	2444	535	21.89	1.29
60	1120	218	19.46	1.44
80	650	154	23.69	1.58
100	420	101	24.05	1.68

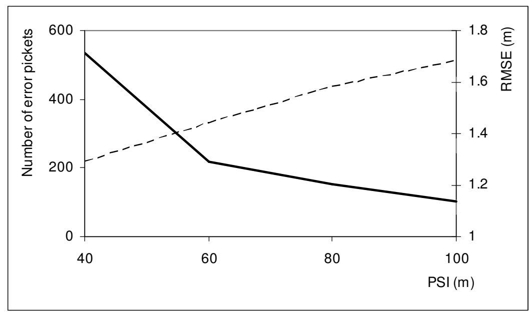

Fig. 6. Number of error pickets (solid line) and RMSE (dashed line) in Ba Vi 2 sub-area.

The following remarks are made for Ba Vi experimental area:

- The number of error pickets has the same distribution character as in Co Loa and Duong Lam, though the PSIs values are 1.5-2.0 times bigger.
- The percentage of error pickets in the mountainous sub-area is much large (2 times) than that is in the residential sub-area. Consequently, the RMSE in the mountainous sub-area is much higher.
- The errors pickets are concentrated on the tops of mountains, which appear as uniformly black blocks in the airphotos.
- The optimal PSI can be chosen equal 80-100m for the residential sub-area, and 60-80m for the mountainous sub-area. It is not a surprise that the mountainous sub-area has a

larger PSI than the residential sub-area, since the former has much more varying elevation than the latter.

3.4. Lang Son experimental area

Lang Son City is one of the important administrative centers of Vietnam in the Northeast region. The city is a valley at elevation of 250-500m relatively to the sea level.

The experimental area is located in the Southwest of Lang Son City. Most of the area is covered by high mountains, some peaks reach 550m and higher. The mountains make serious difficulties for automated picket measurement since they appear as large black blocks in the airphotos.

In Lang Son experimental area, we have tested four PSIs: 45, 60, 80, 100, and 120m. The summarized results are shown in Table 5 and Fig. 7.

Table 5. Results obtained in Lang Son experimental area

PSI *(m)*	Total number of pickets	Error pickets		RMSE
		Number	%	*(m)*
45	2392	499	20.86	1.78
60	1326	301	22.70	1.92
80	754	174	23.08	2.04
100	460	111	23.91	2.15
120	323	66	20.43	2.24

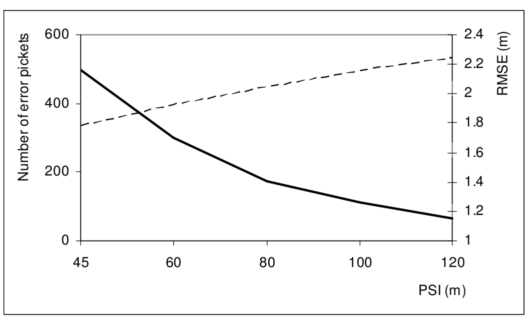

Fig. 7. Number of error pickets (solid line) and RMSE (dashed line) in Lang Son experimental area.

In Lang Son area, we have made the following remarks:

- The errors of DTMs are significantly larger than in the previous areas. The reason is that the topography of Lang Son is much more difficult to image matching technique than in the previous areas.

- The character of dependency of RMSE and the number of error pickets to PSI is similar to the previous cases, though it is less abrupt.

- The optimal PSI for Lang Son experimental area can be chosen equal 80-100m. Note that this PSI can be chosen only if the DTM error of about 2m is acceptable.

3.5. Some comments on choosing optimal PSI

From the results obtained in 4 experimental areas, some comments are made as follows:

- The optimal PSI is not linearly correlated to the scan resolution. Thus, Equation (1) is not very suitable. Moreover, it usually gives PSIs smaller than optimal PSIs discovered in this research.

- The larger the scale of airphotos, the smaller the optimal PSI. This relationship is consistent with the results of other researchers [6].

- We proposed to use the following empirical equation for choosing the optimal PSI:

$$PSI = k\sqrt{P \times M_a} \qquad (7)$$

where P is the scan resolution (μm); M_a is the denominator of airphoto scale; k is a coefficient depending on the characteristics of topography, $k = 0.08 \div 0.09$ for mountainous areas and $k = 0.095 \div 0.105$ for plain areas.

- For projects covering large areas, it is better to test some small sub-area to derive the optimal PSI instead of using Equation (7).

- In all cases, an additional manual breakline measurement is required for achieving better accuracy of DTM.

4. Conclusions

With increase of PSI, the accuracy of DTM is decreased almost linearly. In the same time, the number of errors caused by image matching technique is decreased too. However, this change is drastic at some smaller values of PSI, and then is moderate at larger values of PSI.

Based on the results obtained in four experimental areas of Vietnam, we have proposed an empirical equation for choosing optimal PSI: $PSI = k\sqrt{P \times M_a}$ where P is the scan resolution (μm); M_a is the denominator of airphoto scale; k is a coefficient depending on the characteristics of topography.

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