

# Economic Considerations for Photogrammetric Mapping

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by Gottfried Konecny, Emeritus Professor,  
Leibniz University Hannover, Germany

## Abstract:

Currently classical photogrammetric mapping operations are challenged by new effective technologies, such as GPS, satellite imaging and mobile mapping. It is important to compare the cost of producing photogrammetric products, such as digital orthophotos and line maps with those of alternate technologies for mapping and map updating. The paper will outline the basic pricing structures for different mapping tools. This is particularly of relevance for developing countries where the resources for mapping are scarce.

## 1. Introduction – the phases of photogrammetric mapping technology

In its more than 150 years history photogrammetry went through different phases in practical applications and commercial uses.

From its **first application** by Laussedat in 1851, mapping Paris from rooftops by terrestrial photographs to stereo photogrammetric mapping by Von Orel by the Austrian Military Photogrammetric Unit in the Pre Worldwar I period, photogrammetry was an experimental tool, which could be applied in special situations, where conventional terrestrial survey techniques had difficulties (e.g.in architecture by Meydenbauer, in glacier surveys by Sebastian Finsterwalder or in mountain areas by Deville in Canada or Von Orel in Austria). It was scientific interest, military necessity or governmental activity, not commercial drive, which supported the development.

In the **second phase** after World War I photogrammetry became a competitor to terrestrial ground surveys usually done by plane table or tacheometry for topographic surveys. In Europe photogrammetry always had the handicap, that it could not reach the sometimes irrational accuracy requirements mandated by classical surveyors. In the 1930's when the American Society for Photogrammetry was founded, it became clear, that photogrammetry was the tool to map the vast non-European parts of the globe. This was reinforced by the military efforts in the USA, in the USSR, in Germany and in Japan to map each other's territories of interest. Entrance of this technology to the developing world became possible, when the Netherlands, under former Prime Minister Willem Schermerhorn established the ITC in 1951, and the gained in momentum developing countries obtained access to photogrammetric mapping technology. This was still mainly a governmental activity, but a private mapping industry gained in momentum or was beginning to form.

The **third phase** was marked by the efforts of analytical photogrammetry (Duane Brown and Friedrich Ackermann) who proved, that photogrammetry was caüable of producing unprecedented accuracies, compatible to past ground surveys in the 1970's. This went hand in hand with the rapid evolution of computer technology, which permitted partial automation of photogrammetric restitution tasks.

In the **fourth phase**, starting in the 1980`s photogrammetrists began to automate Part of the restitution tasks. We know now, that line mapping, which is difficult to automate, is about 5 times more expensive and takes about 5 times longer than the automated process of orthophoto mapping. This has resulted in the tendency for international outsourcing of mapping activities, particularly of those mapping tasks, where a differential difference in labour cost was involved.

This has resulted in the tendency to create or to update base topographic mapping every 5 to 10 years, but to renew the information content of critical areas by orthophotos every 1 to 2 years.

This tendency has even been improved by the newly available high resolution satellite systems after 1999 (e.g. Ikonos, Quickbird and WorldView).

Google Earth has spread the worldwide interest in such images as a geolocation search tool.

The **fifth phase** is about to begin, in which further automation of further automation of feature extraction becomes possible using knowledge based image processing technology.

## 2. Cost Structure

The present cost structure for different types of photogrammetric operations in phase four are well established. Costs are of course image scale dependent, and the image scale determines the interpretability of features.

The following workflows have been characteristic of the process:

- 1) aerial photography
- 2) digital scanning of aerial photos (as digital stereo workstations are now considered state of the art)
- 3) aerial triangulation to determine position and orientation of the aerial photos
- 4) digital elevation model generation (digital image matching of overlapping images is now considered state of the art)
- 5) 5) digital ortho rectification based on aerial triangulation and digital elevation model
- 6) radiometric matching of adjacent orthophotos from map file to map file or better within a seamless geodatabase
- 7) vector digitization of topographic map features in 2D (on screen from the orthophotos) or in 2.5 to 3D (in stereo workstations).

### Accuracy of Aerial Photography Restitution

The parameters representing the accuracy of the restitution can be derived from the relation

$$x = \frac{z}{f} x'$$

$$y = \frac{z}{f} y'$$

$$z = \frac{b \cdot f}{x' - x''}$$

in which  $x'$  and  $y'$  represent the image coordinates in the first photo,  $x''$  the image coordinate in the second overlapping photo,  $b$  the air base,  $x$  and  $y$  the ground coordinates and  $z$  the flying height.

Differentiating these equations with respect to the image coordinates one obtains relations for the assessment of accuracy:

$$\sigma_x = \pm \frac{z}{f} \sigma_{x'}$$

$$\sigma_y = \pm \frac{z}{f} \sigma_{y'}$$

$$\sigma_z = \pm \frac{b \cdot f}{(x' - x'')^2} \sigma_{(x' - x'')} = \pm \frac{z^2}{bf} \sigma_{(x' - x'')}$$

$\sigma$  being the standard deviations of image coordinates,  $\sigma_{x'}$ ,  $\sigma_{y'}$  and  $\sigma_{(x' - x'')}$ , and  $\sigma_x$ ,  $\sigma_y$ ,  $\sigma_z$  the resultant accuracies on the ground.

$f$  is the focal length. For a camera of the image size 23 x 23 cm a wide angle camera has an  $f$  of 15 cm. A normal angle camera has an  $f$  of 30 cm.

The images overlap along the flight line by about 60 % to assure stereo coverage of the terrain. Thus the base

$$b = (23\text{cm} - 0,6 \times 23\text{cm}) \cdot \frac{z}{f}$$

The measurement accuracy  $\sigma_{x'}$ ,  $\sigma_{y'}$  or  $\sigma_{(x' - x'')}$ , is based on operational experiences in restitution from aerial photos.

$\sigma_{x'}$  and  $\sigma_{y'}$  is usually assumed as  $\pm 5 \mu\text{m}$  for symmetrically signalized points,  $\pm 10 \mu\text{m}$  for natural points.  $\sigma_{(x' - x'')}$  depends on the stereo measuring capability which is usually assumed as  $\pm 7 \mu\text{m}$ .

Using the above relations table 1 for different image scales and flying heights can be derived:

Table 1: Accuracy for different types of cameras and image scales

Wide angle camera f = 15 cm, format 23 x 23 cm			
flying height z	image scale f : z	$\sigma_x = \sigma_y$	$\sigma_y$
500 m	1:3333	± 3,3 cm	± 3,8 cm
1000 m	1:6666	± 6,6 cm	± 7,6 cm
5000 m	1:33 333	± 33 cm	± 38 cm
10 000 m	1:66 666	± 66 cm	± 76 cm
normal angle camera f = 30 cm, format 23 x 23 cm			
flying height z	image scale f : z	$\sigma_x = \sigma_y$	$\sigma_y$
500 m	1:6666	± 1,6 cm	± 3,6 cm
1000 m	1:3333	± 3,3 cm	± 7,1 cm
5000 m	1:16 666	± 16 cm	± 36 cm
10 000 m	1:33 333	± 33 cm	± 71 cm

### Resolution of Aerial Images

The ability to map from a certain scale of aerial photography depends upon the sample distance of the digitization of the film. Considering the existing film grain of the photographic imaging and development process a film is optimally scanned at 15  $\mu\text{m}$  pixels.

At a flight height of z the ground sample distance

$$GSD = 15\mu\text{m} \cdot \frac{z}{f}$$

This has resulted in the practical recommendations that feature recognition of the relevant features for 1:1000 scale mapping can be done from 1:6000 scale photography. For 1:10 000 scale mapping 1:45 000 photography is usually chosen.

### Cost of Aerial Photography Restitution

The cost of restitution is scale dependent. It depends on the model by model stereo restitution, which is nearly proportional to the number of photographs needed to cover a certain area.

The cost for the 7 mentioned characteristic processes according to international experiences, which can locally vary greatly, is about as follows:

- 1) aerial photography: mobilization 5000 € plus 10 € per image
- 2) scanning of film 15 € per image
- 3) aerial triangulation 25 € per image
- 4) digital elevation model depending on the need to include manually observed break lines 10 to 100 € per image
- 5) digital orthophoto production 15 € per image
- 6) radiometric adaptation of orthophotos 10 € per image
- 7) vector digitization of features. This is the highest cost factor. As steps 1) to 6) are mostly automatic operations the processing of DEM's and orthophotos has a raster homogeneous cost factor over the globe.

In vector digitization there are, however, huge regional price differences depending on the local labour cost and depending on the desired feature content at a certain scale, which depends on the terrain type and the mapping specification. There is furthermore a difference, whether the features are digitized in 2,5 or 3D in stereo workstations or only in 2D on a simple screen, resulting in different accuracies.

A rural stereo model or image may be digitized in about 10 hours, while a complex urban landscape may require 100 hours in 3D or 20 hours in 2D. The hours required are to be multiplied by the hourly labour rate (with overhead) which in Europe is at 40 €/hour, while the task may be done in China on subcontract at 20 €/hour.

In table 2 a calculation is made, at which costs orthophotos or line maps may be produced for an area of 250 km<sup>2</sup> using a photoscale of 1:6000 and 1:45 000. In case of wide angle photography the stated accuracies for position and height can be reached at the 67 % confidence level (standard deviation).

Table 2: Cost of orthophotos and line maps from aerial photography; area covered 250 km<sup>2</sup>

image scale	1:6000	1:45 000
photo dimension	1380 m	10 350 m
air base	552 m	4 140 m
strip width	966 m	7 245 m
neat area covered	0,533 km <sup>2</sup>	29,99 km <sup>2</sup>
number of photos for area	469	8,34
cost of orthophotos with automatic DEM	44 865 €	5 709 €
cost of orthophotos with semi-automatic DEM	87 075 €	6 460 €

additional cost of line maps (European prices)	rural 375 200 € urban 1 876 000 €	6 672 € 33 360 €
additional cost of line maps (Asian prices)	rural 187 600 € urban 938 000 €	3 336 € 16 680 €

It is obvious that standard orthophotography is by a factor of 6 cheaper than line mapping.

For cadastral purposes standard orthophotos, which have been differentially rectified based on a DEM at ground level will suffice. There is the option of producing “true orthophotos”, in which elevated portions of the images (bridges, building) are separately rectified and posted into the orthophoto. This is an interactive procedure and raises the cost of the true orthophoto by at least a factor of 2.

Standard orthophotos are an excellent means to verify eventual digitized vector maps of parcel boundaries by superimposition.

#### Digital Aerial Photography

During the past four years digital aerial mapping cameras have come on the market. While photographic images can at best be radiometrically digitized to 8 bit grey levels for each colour, of which maybe 6 can be identified, digital cameras offer digitization capabilities to 12 bit. They are thus radiometrically superior. While there may exist additional calibration difficulties for the digital cameras, these have now been generally overcome for the more expensive type of cameras in the 1 M € cost range.

Even though these cameras are of the normal angle type, the added resolution does not make the geometric result less accurate.

Digital mapping cameras are of two different types:

- digital frame cameras consisting of area arrays exposed by separate objectives (Intergraph DMC, Vexcel Ultracam D or X, Applanix)
- scanning systems as they have been originally designed for operation from satellites (Leica ADS 40).

In particular the scanners rely on obtaining the orientation of each imaged pixel in real time. This is why scanners, especially when used from aircraft, must be combined with airborne inflight GPS positioning of the exposure stations and with the camera attitude orientation determined by an inertial monitoring unit IMU. As GPS signals can only be measured at rates of 1 Hz (1 second/measurement) and IMU data at rates of 10 MHz (1/10 second/measurement) there is a dependency on air turbulence during the flight, as the positions and altitudes of the exposures need to be interpolated between the received signals.

### Restitution from High Resolution Satellite Images

Since satellites became operational for imaging with the US-NOAA meteorological satellites and the US Landsat program of 1972 the images obtained have been used for various mapping tasks. The usability of these images very much depended on the GSD achieved by a particular satellite system, shown in table 3 for the most significant satellite mapping systems. (see fig.22)

Table 3: Satellite Imagery

Program	Country	GSD	year	use
NOAA satellites	USA	1 km		meteorology, global vegetation studies
Landsat MSS	USA	80 m	1972	
Landsat	USA	30 m	1982	general remote sensing
Spot 1-4	France	10 m	1986	land use studies
Spot 5	France	2,5 m	2002	
Alos	Japan	2,5 m	2006	
Ikonos 2	USA	1 m	1999	
Quickbird 2	USA	0,6 m	2001	stereo option
Orbview 3	USA	1 m	2003	
Topsat	UK	0,5 m	2005	
IRS-P5 Cartosat 1	India	2,9 m	2005	
Formosat 2	Taiwan	2,5 m	2004	
Eros A 1	Israel	2 m	2000	
Eros B	Israel	1,9 m	2006	
Resurs DK 1	Russia	1 m	2006	
World View 1	USA	0,5 m	2007	

What has been said about resolution of aerial images is equally valid for satellite images.

The GSD determines the capability of resolution for mapping and of geometric accuracy: For example, a 0,6 m GSD of the Quickbird satellite can give nearly equivalent mapping results to those from image scale 1:45 000 aerial photography.

In the meantime the geometric restitution accuracy with help of appropriately modelled software can be achieved in planimetry at about 2 GSD.

When it comes to elevations these must be determined from stereo images. But only few satellite systems, such as Ikonos, Spot and Alos permit to take stereo images from the same orbit. The stereo images must be restituted into digital elevation models to permit orthorectification of the satellite images.

There are alternate ways to obtain digital elevation models:

- existing topographic maps with contours; the digitization of contours permits to generate DEM's in raster form to be utilized in orthorectification;
- Radar interferometry from aircraft (Interra) or from satellites (SRTM) is another possibility to derive a DEM;
- a third possibility is to generate DEM's by laser scanning.

The accuracy of the DEM varies greatly with the method used. Ikonos stereo images (with only a small stereo-base) or Spot and Alos (with a wider stereo-base) are capable of deriving a DEM with 5 m accuracy. This also compares to the digitization of existing topographic maps from 10 or 20 m contours. Airborne radar interferometry has demonstrated country wide 1 m (or 0,5 m priority area) accuracy in Nextmap Britain.

The Shuttle Radar Topographic mission has been able to generate 5 m accurate DEM's for the flat areas of the globe at 90 m grid posting. Only over the USA 30 m posting has been processed.

Airborne Laser Scanning can generally provide the most accurate DEM data. Depending on the height of the flights (500 to 3000 m) DEM accuracies of  $\pm 0,15$  to 0,5 m can be obtained.

The cost of the DEM data obtained from digitization of existing maps is usually the lowest (e.g. 2 €/km<sup>2</sup>).

Nextmap Britain prices were at 4 €/km<sup>2</sup> when sold to several customers. SRTM data at 30 m posting in the US or at 90 m posting worldwide were essentially free of charge. Laser scanner data are the most expensive and amount to at least 80 €/km<sup>2</sup>. In addition to that come the costs for the satellite images required, which for 1 m to 0,6 m GSD data amount to at least 4000 € per image plus the processing of the orthophotos, as stated per image for aerial photography. Spot 5 and Alos images can be obtained at about 2 € per km<sup>2</sup>. Stereo processing cost has to be added.

This means that the restitution via satellite images is limited in performance and accuracy, and it is not necessarily less costly, if aerial images can be obtained without complications and exaggerated costs.

### 3. Threats to Photogrammetric Mapping

Airborne or satellite based photogrammetric mapping operations have the disadvantage, that they depend on intervals at which aerial or space imaging becomes possible and affordable. The USGS topographic mapping system did not



succeed at shorter mapping intervals than 5 to 10 years at the scale 1:24 000. In Germany the topographic ATKIS system at the scale 1:5000 (or 1:10 000) cannot be updated faster than every 5 years.

On the other hand the Ordnance Survey of Great Britain maintains its topographic mapping series 1:1250 or 1:2500 with a 6 month update commitment. This is only possible, because DGPF technology is being used. The terrestrial surveys are conducted on change reports by government departments or citizens.

Germany finds alternate means to cope with changes regarding a limited number of features. The ALKIS system is a Germany wide cadastral mapping system including Parcel boundaries and buildings, which is transaction and almost real time based, while other topographic features await updates by photogrammetry.

CORS systems have made it possible to conduct local DGPS surveys to cm accuracy, while photogrammetric survey methods usually restrict themselves to dm accuracy.

#### **4. Current Reorganization of Photogrammetric Production and Photogrammetric Instrument Industry**

In making comments to this topic I am aware, that I may be subject to legitimate criticism from the commercial sector, which has other aims than those of a professional photogrammetrist. But as a senior member of the photogrammetric community, who has no other interest than to preserve our photogrammetric heritage, I may nevertheless describe my observations:

In the described fourth development period of photogrammetric mapping there were recognized national photogrammetric enterprises, who were the pillars of worldwide photogrammetric activity:

e.g. PASCO, Kokusai Kogyo and Asia Airsurveys in Japan, Hansa Luftbild in Germany, Maps in the UAE, Kampsax in Denmark, BKS in Northern Ireland and many more in various countries and regions.

Nowadays such companies are in part being bought up by international consortia, e.g. BLOOM Info in Norway or Fugro. These consortia have partners in low labour cost countries, such as China, India, Indonesia and Georgia.

There is no more a professionally based local approach, but a market oriented product approach at the disadvantage of the traditional local and professional photogrammetric industry.

Furthermore, the traditional photogrammetric equipment industry is no more. It formerly concentrated in Germany since the 1920's with Zeiss; in Switzerland since 1925 with Wild and later with Kern; in Italy with Galileo and OMI; in France with Poivilliers; in Britain with Watts; and in the USA with Bausch and Lomb.

Hardware has become less significant, and software dominates. Software documentation does not reveal its real content, as it is produced like a blackbox. The European core software enterprises at Zeiss and Inpho, Wild and Leica, Vexcel have all been sold to US enterprises (Intergraph, Trimble, Leica Geospatial merged with ERDAS in Atlanta, Microsoft). Photogrammetric software enterprises now belong to

global decision makers. It appears to be a sign of excellence to create a high tech company in Europe and to offer it globally for sale.

Would we not have a motivation to generate open source software instead for the photogrammetric community?

I still remember the words of a Zeiss managing board member who said: "photogrammetric hardware and software is a business of only 100M\$ per year. We at Zeiss have 60%. This is too small to keep it". It is strange that the only major European hardware and software producer, where developments take place inhouse, is RACURS in the Russian Federation.

It is even worse. Some enterprises have patented slight modifications or applications of photogrammetric technology and try to protect its use from competition. Often the patents have been issued haphazardly and could be fought in court. But this is a lengthy procedure and the competitors are not strong enough to sustain a yearlong legal struggle, so that they restrict themselves not to fight the patent, but try to prove, that their methodology is different from that, which the patent states.

In Germany a patent has been issued to apply orthophotography for cadastral purposes. In the USA a patent has been granted to apply oblique imagery. In Germany and Japan a patent has been issued to apply stereo sensor technology by aircraft, which has been successfully operated on satellites. The legal profession usually does not understand the technical issues.

## **5. What to do now?**

It is probably true, that the photogrammetric market is too small to make an economic impact. But in 1980 the International Society of Photogrammetry became the International Society for Photogrammetry and Remote Sensing. This gives ISPRS the mandate for global monitoring. We need additional tools such as GNSS for geocoding our data and GIS tools for their use. We need to supplement our data by additional sensors such as laser scanning and radar imaging. Our potential has grown. We must find new structures to carry on, and the comments raised in the paper can perhaps help as a retrospective.

In 2010 we will celebrate 100 years of ISPRS. Our discipline has contributed to phenomenal achievements: the landing on the moon, the exploration of planets, and most of all the monitoring of our own natural and socio-economic earth environment. In this broad context we will be able to prepare for a continuation of ISPRS beyond 2010.