# THE SWEDISH PROGRESS FROM AN ANALOGOUS SYSTEM TO A DIGITAL PHOTOGRAMMETRIC SYSTEM IN ROAD DESIGN

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Abstract

As early as 1976 the Swedish National Road Administration published an investigation based on comparative studies of documentation methods available for road design. The studies showed that computer aided systems were the most credible, rational, effective and economical alternatives.

All the arguments favoured a future concentration on computer aided design technique in which photogrammetry would play an essential role in the collection of on-site landscape information and for direct studies of the actual planning area in a three-dimensional photogrammetric model.

The SNRA then reached two important decisions, namely:

- to build a nation-wide computer network and provide the designers with powerful computers suitable for CAD techniques;

- to convert entirely from analogous to digital production of basic plans for road design.

With the introduction of a digital design system a radical change in the technology and philosophy of the photogrammetric process takes place. The interpretation of aerial photographs with a computer aided system no longer results in one single final product.

The conventional final product, the map, is now merely one product among many and may be used as á key map of the project or as standard information material.

This presentation describes the experience acquired at the SNRA during the adoptation period following the transition from an analogous to a digital photogrammetric system.

## Background : History

In the mid-1950's some road designers at our then existing organisation began to use aerial photographs. These aerial photos were then studied in pairs in simple mirror stereoscopes equipped with measure micrometers and their first fields of application were for assessment, inventory and general planning. Designers also began to make simple trial preliminary design plans directly from these pairs of pictures and used the above-mentioned technique. To make the various phases of Swedish road design more comprehensible, I would like to explain the various stages by means of the following diagram:

Fig. 1

**PRELIMINARY DESIGN**

| | |
|---|---|
| ROUTE LOCATION | * Where in the terrain is it possible to place a road - in reality various different alternatives in the shape of terrain corridors |
| PRELIMINARY DESIGN PLANS | * Where in the corridor should the road be - in fact testing road alignments within the area as regards their horizontal and vertical alignments. |

(An on-going influence from other societys and civil-rights on the different alternatives.)

**FINAL DESIGN**

| | |
|---|---|
| DESIGN PLAN | * Testing the chosen centreline in the terrain - in fact producing technical and economic solutions for the highway. |

(A decision where in the terrain it is allowed to construct the road.)

| | |
|---|---|
| FINAL DESIGN PLAN | * Continued revision of the approved centreline - in fact the production of construction drawings for building the highway. |

| | |
|---|---|
| CONSTRUCTION | Building and construction of the highway in the terrain in accordance with the investigations made and whitin the technical and financial framework set up. |

As a result of these trials, a photogrammetry section was set up at the Swedish National Road Administration (SNRA) in May, 1957. In order better to meet the needs arising the various phase of highway planning, a BALPLEX-PLOTTER was purchased for each of the regional offices - 24 in all. The instrument was equipped with 4 picture projectors, making simultaneous observations of 3 stereo models possible. The aerial photographs were processed as a terrain model in this instrument. Terrain corridor alternatives were produced as a result of discussions. Since several people could look at the models at the same time - the system used the anaglyph method. (C/F Route location. fig. 1)

A Planimetric map was drawn in the scale of 1:4000 and using various measure rulers, so-called circle templates, a horizontal construction of the proposed alignment centreline was made on the map. The same measuring board used for making the map was now used to follow the centreline construction on the map and at 20-metre intervals the ground elevation was measured. The results were drawn graphically for every measured line in the form of terrain elevation profiles. This made it possible to include the vertical alignement of the highway and to obtain comparisons between various proposals and demands for various different road standards. This type of instrument was later replaced by the ortho photo based economic map with contour lines in scale 1:10000. In addition the improved topographical map in scale 1:50000 was used for the same purpose (C/F Preliminary Design Plan, fig. 1.)

In 1957 the SNRA purchased its first stereoautograph, serial no. 8, production no. 530, manufactured by WILD Heerbrugg. The instrument came later to be called just A8-530 and was a second order measuring device. Up to the mid-1960's five more such instruments were purchased. In this instrument a design map on a scale of 1:2000 around the road alignment analysed in the BALPLEX instrument or on the economic map was produced. The most common picture scale was initially 1:13000 (from 2000 m flying altitude). It changed in the 70's to 1:10000 (1500 m flying altitude). The design maps were later used as a basis for further detailed analyses of the road alignment horizontally and vertically and of where to set the road in the terrain considering the interests of the landowners affected by the undertaking, etc. These maps allowed the planner to interpolate with a relative high degree of exactitude from the map various different road alignment alternatives, both vertical and horizontal, which he then drew manually so as to determine more easily the profile standard of the road with respect to horizontal and vertical radii. He also used the map when presenting the highway proposal made. Presentation of a proposed highway in Sweden is an important legal process. The requirement is that the proposal shall be exhibited to the public and to other parties affected. After the expiration of the exhibition period and after all viewpoints have been considered, then a decision concerning the exact alignment of the road may be taken (C/F Design Plan, fig. 1).

The final design following this process - in fact the production of construction drawings and building plans, was largely carried out on site using terrestrial surveying methods. The road was set-out in the terrain at 20-metre intervals along the centreline. From these points a perpendicular cross section was made and the elevation break-points of the terrain were measured, usually with a levelling instrument. Later more modern measuring methods came to be used for example free stationing, using EDM instruments, so-called total stations linked to data acquisition equipment. Measurements of the cross sections were later fed into a computer to calculate volumes in relation to the horizontal and vertical profiles of the planned highway.

Some road projects, however, led to renewed aerial photography with ensuing photogrammetric processing. The scale selected for the new aerial photographs lay between 1:4000 (600 m flight altitude) and 1:6000 (900 m flight altitude), depending in the degree of exactitude demanded and the type of terrain the road would be built in. The road alignment was now drawn on a basic planimetric map on which its cross sections were also drawn. This basis was placed on the A8-drawing table and was aligned with the stereo model in the manner normally employed for this technique. By means of a profiloscope the instrument could now be guided by force indirectly via the table to the positions where the operator chose to record the ground elevation. The string of machine coordinates recorded was transformed into ground coordinates via another recording string of polygon points and elevation points. The results calculated was later used in the same manner when making the subsequent volume computations.

In 1972, one A8 was exchanged for a first order instrument of the same make, namely a WILD A10. The reason for the change was to increase the exactitude of the points measured in elevation mainly connected with cross section measurements (C/F Final Design Plan, fig. 1).

Numerical Photogrammetry on Analogous Instruments

In the early 1970's, when the small desk top computers made their entry into our organisation, digital numerical photogrammetry began to develop with us. By about 1973-74, we had program routines for relative and absolute orientation (outer orientation) and also programs to transform data into ground systems for further processing within the company. When the WILD company presented an electronically controlled drawing table in 1977, the TA-table, the idea of developing a digital drawing system came to us. The system developed was given the name, Digital On Line Stereo Plotting (DOSP). During 1977-78 linear encoders were installed on three of our A8's to register X and Y coordinates and a rotational encoder for the Z cordinate was mounted on the Z-axis.

In order to be able to register the py parallax also, a rotational encoder was mounted on the omega screw of all three instruments. A TA drawing table and a registering device, EK 20, was purchased for one of the instruments all linked to a Hewlett Packard desk top computer, model no. HP-9825. This made it possible to develop the needed programs. Program development of the DOSP system went on for about two months. The system was a semi-automatic drawing system working as follows: preselection of the manner of drawing desired was made on the desk top computer, after which the object was registered in the stereo model. The coordinates registered were transferred via the register device to the computer (HP 9835), where a computation was made, the result then was sent as a drawing instruction to the drawing table. On the drawing table there was basic material consisting of drawing film and a drawing pen in the pen holder. The information from the stereo model was now transferred in just a few seconds to the original map via the computer and with much greater precision. Data were not saved as yet, since our road designers had as yet no computers based solutions of their own in the form of planning systems. After this the system worked without further development until 1986. The DOSP system was also installed on the new WILD instrument, AMH, purchased in 1982. The instrument was acquired at the same time as our first analytical instument, a WILD AC1, was purchased. Both instrument systems with DOSP were sold in 1986 to a firm of private consultants in Sweden.

Digital Photogrammetry with Analytical Instruments

In 1982, our first analytical instument, an AC1, manufactured by WILD, was purchased together with a TA 2 drawing table. This quickly introduced us to the advantages of the new technology. The instrument showed a very high degree of precision and, later tests, e.g. at the University of Darmstadt, West Germany, has shown that the internal precision lies under 1 µm (0,7-0,8 µm). The problems was still that our customers, the road designers, could not yet accommodate our large amount of digital data. But they had begun to learn the new technology using a desk top computer based small planning system, Digital Road Design (DRD 80). The system can handle digital data transfered from geodetic data stacks directly via a cable into the computer. After this input data is edited and later drawn in the form of simple maps.

When the Road Administration decided in 1982-83 to invest for the future in total computerisation of the whole establishment, it was also decided that a new planning system should be produced (DRD 90). The investment was decided on in 1987 and the choice of hardware suppliers was made at the same time. The order, valued at 500 m SEK, went to two companies, Swedish Eriksson/Nokia and the American Digital Equipment (VAX/Vms). The planning system was not intended to be complete in its entirety until 1990. In order to win time and experience in the meantime, a Finnish planning system, with a similar system philosophy was purchased. The name of the system is Road Cad but it is not a real CAD system (Computer Aided Design) but resembles rather an IGS system (Interactive Graphic System), in which the various proposals are first produced by means of interactive work on a TEKTRONIX terminal and then processed in a computer (Data General MV-8000 or MV-2000). The results are presented in various tables and graphics and later drawn on a drum plotter (CALCOMP). What was completely new was that the supplier, (SITO OY), had the system linked directly to an analytical instrument, a BC2, manufactured by WILD. When the system was leased for assessment for six months as from 1 October, 1985, an analytical plotter was also leased. The choise fell on WILD and on a BC2:a since all the routines had been completed between these systems. On the advice of one of our stereo operators the instrument was equipped with a so-called instruction ocular. The system were connected and so the trials and assessments could commence.

The trials took place parallel with a training course on the various systems. Already after a month or so we registered a positive response from the participating designers. Their reaction to the speed and flexibility of the ROAD CAD system was very positive but the greatest reaction came when they were given the opportunity to sit at the instruction ocular and follow the operator making preliminary studies of the various road alignments considered. They realized at an early stage that there was no need first to gather in the terrain in the form they were previously accustomed to, on so-called road planning maps on a scale of 1:2000. They found, namely, that the terrain as it was represented in the oriented stereo model was superior to the map as a source of information. One thing that this led to was that geotechnical information, by means of interpretation on picture material, could influence the choice of road alignment in the terrain at an early stage. Furthermore, they could remeasure the position of the alignment before any actual measurements had been taken, which later resulted in more different road alignments being tested compared with the former technique. These positive results led to the purchase of three more Road Cad systems. To cope with the photogrammetric aspect all the analogous instruments were sold in 1986, and three more analytical BC 2 instruments were leased from WILD. We now had only analytical instruments and one of the reasons was to train the photogrammetric staff as quickly as possible in the new technology.

System Integration : Photogrammetry - User

The one big difference, compared with previous well-tried methods, is that the amount of data needed to reach a satisfactory basis for decision taking regarding the terrain has been considerably reduced. With previous methods the first step was for the customer to draw a preliminary outline of the area in question. This area resulted in maps, a rather large amount of data, in other words. From these data the planner sought one solution, which in effect meant that a large part of the data was only needed for preliminary studies. With the new method, the amount of data is built up according to the needs of the project for data, thus leading to a smaller volume of data and, with it a cheaper solution altogether. In spite of this the designer all the time has access to better information about the terrain, e.g. geotechnique.

To sum up, the work is carried out in the following manner. First, the aerial photos or aerial photostrip are orientated and measured. The measurements are then computed in a triangulation computation giving good monitoring of all aspects of the quality of the terrain model. The designer then produces various road alignments on, for example, key maps (scale 1:10000 or 1:50000) which will be computed in the Road Cad system; These alignments can also be produced directly in the stereo model. When the road alignments have been computed, they are transferred to the photogrammetry instrument in the shape of a longitudinal profile in X and Y coordinates along the proposed route. A preliminary study of the terrain can now be made: together with the planner a "journey" is made through the landscape and if changes are necessary, then new points are measured in. If changes are made, the route alignment is sent back to the Road Cad equipment for new calculations otherwise the operator can start measurements of the elevation for all the route alignments prepared. The measurement of the elevation profile of the route is returned to the Road Cad aquipment, where a preliminary volume computation is made, a so-called "volume check". The procedure is repeated until the designers is satisfied with one of the alternatives. The alternative which the designers now chooses to work further with is again returned to the BC 2 instrument. Here, a more exact measurement is made according to well established methods, so-called "cross sectioning" along the route alignment. When making cross section measurements, the operator adds codes for varios types of terrain, for example, open bed rock, earth, etc. But codes for the quality of the measurement are also fed in and may later result in, for example, certain complementary additions, by means of field measurements of the "uncertain" coded measurements. When all the sections have been measured, they are returned to the Road Cad equipment, where the next stage of planning takes over. A more exact volume computation than previously is made but the measurements are also displayed on the interactive screen in the shape of perspectives together with the normal section applying to the proposed route. If a proposal is to be presented in perspective on a perspective photomontage, the pass points can be measured in directly in the aerial photographs. When the designers is satisfied with the proposed route alignment, a simple digital map is produced along the centreline contemplated; this map is then used to support presentation of the proposal made.

What impressed our costumers most was the speed with which the systems could generate a fresh result. As a comparison I should remind you that we have no opportunity to make fields surveys during the winter season (3-6 months/year) as the terrain is snow-covered and other weather factors affect field surveying in a negetive way. To make a comparison in time between the various different methods of measuring, we may add that with the "fieldmethod" the time for a project was about 3-6 months, while with the new photogrammetric method, the same project takes anything from a few days to a few weeks. The comparison is not entirely correct, however, since the first method most often results in only 1-2 alternatives, while the second gives between 4 and 8 alternatives with complete presentation and comparable quality for all the route proposals.

New Analytical Instruments System

We chose merely to lease the 4 (four) BC 2 instruments as several suppliers had already advertised the advent of new, more powerful and more intelligent analytical systems. During 1987, we, therefore, negotiated the purchase of a new photogrammetric system. Systems from four different companies took part in our evaluation. The various different constituents, such as hardware and software, were examined but our main purpose was to look at the systems as entities and especially their philosophy. Once again, our choice fell on WILD and their new system, SYSTEM 9, and the analytical plotter forming an integral part of it. The most essential point of all was that this system was built up round a relational data base and, in addition, was connected to an image injection system in STEREO.

Other reasons influencing us were WILD's unique measuring precision, the construction of the measuring system, in fact. Installation of this system started in the spring of 1988 and will replace entirely the BC 2 instruments. We made an initial order of 4 (four) S9/AP systems and one so-called file server station. All the work stations are connected via a local data network (Local Area Network, Ethernet), which in its turn is linked to the SNRA's data network (Decnet). Using this system we can now measure in 3D without making any errors when linking and coding the objects measured, for example, houses and their roofs.

## Summing up and Visions

What we have achieved is a solution which resembles in part the BALPLEX solution of 1957, but now that computer technology has caught up with the excellence of photogrammetry, we have a very strong argument in that we are now able to deliver to our customers the right amount of data at the right price. Another idea coming to us is to inject a road construction into the system as an experiment and, in that way, be able to test directly how the road fits into the terrain. Another idea is that when a terrain model has been computed using one of the measuring methods and, for example, contour lines have been generated from it, we can now check its correctness very simply. We inject the computed result back in the shape of contour lines superimposed on the terrain and we have not as yet come across any rival method for testing a terrain model.

A third vision is to build the user's application program round a photogrammetric system of the S9/AP type together with the data base and the stereo superimposition technique. In this way today's problems with unwieldly (too BIG) data base could easily be solved while avoiding some time problems. It takes quite a lot of time first to gather in a large model when the client then most often uses only a fraction of the mass of data. Such a solution as proposed makes sense economy-wise also. The customer pays as the data base is built up and from his own need for data. In such a way the data bases are built up from the bottom upwards with full financial cover for investments and production. As some of you may have noticed earlier in the text, our customers have already accepted the fact that an actual map is not really needed but they may as a side product receive a drawing as a final result and that will be a map.