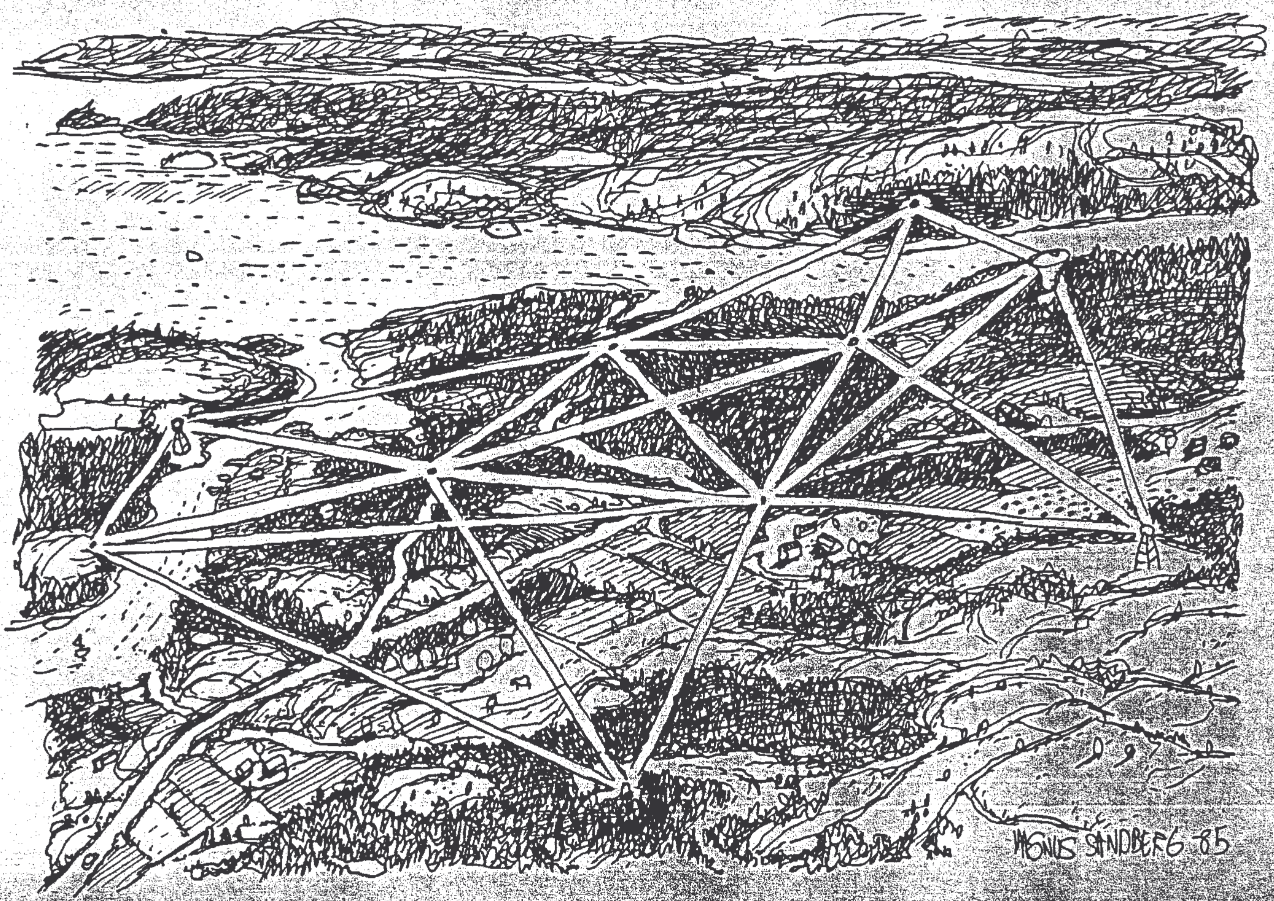
Lantmäteriet
Lantmäteriverket - National Land Survey
S - 801 12 GÄVLE · SWEDEN

Tekniska skrifter - Professional Papers LMV-RAPPORT 1986:1
ISSN 0280-5731

SUKK - a Computer Program for Graphic Presentation of Precision and Reliability of Horizontal Geodetic Networks

by Clas-Göran Persson



Gävle 1986

LMV-rapporter

1985-12-18

ISSN-0280 5731

Förteckning över utgivna rapporter år 1985

Rapport	Titel	Författare
1985:1	KP-85 Engelsk version	Ulf Andersson
1985:2	Några enkla metoder för noggrannhetsanalys av avvägningsnät	C-G Persson
1985:3	Fotoflygplan på 80-talet	
1985:4	Undersökning av elektroniska takymetrar	Ingmar Peterson
1985:5	Fältdatorer - utbud och egenskaper	T Cederholm, KTH
1985:6	Väggmarkerade stomnät - sammanställning av erfarenheter	Hellman, Källström Oldenmark, Virking C-G Persson
1985:7	The Swedish Experience with Motorized Levelling. New Techniques and Tests	Jean-Marie Becker
1985:8	Automatisering och motorisering av avvägningsarbeten	Jean-Marie Becker
1985:9	Erfarenheter av gemensamhetsskogar	Ulf Thorselius
1985:10	KP-85 Fransk version	Ulf Andersson/ H-F Wennström
1985:11	Översyn av det statliga lantmäteriets ADB-verksamhet Delrapport 1: Nuvarande verksamhet Delrapport 2: ADB-strategi	Statskontoret/ Lantmäteriet, Hans-Erik Wiberg m fl
1985:12	Storpolygonnät. Rapport från och utvärdering av Säffleprojektet	Rolf Löfqvist/ Bengt Karlsson
1985:13	Forest Inventory - Photo Interpretation	Per Johan Åge
1985:14	Superwide Ample Photography from Very High Altitude: Experiments and Experiences	Lars Ottoson
1985:15	Rättstillämpning inom skogsvärderingsområdet	Erik Åsbrink
1985:16	Förstudie - Atlas över Sverige	Bertil Jansson m fl

Lantmäteriet
Samhällsmätnings-
funktionen vid LMV

RAPPORT
Datum
1986-01-01

Rapport nr
1986:1
Dnr
Kg Mätningsteknik

Titel

SUKK - a Computer Program for Graphic Presentation of Precision and Reliability of Horizontal Geodetic Networks.

Huvudinnehåll

I denna rapport presenteras datorprogrammet SUKK, som är ett programsystem för undersökning och grafisk presentation av kvaliteten i plana geodetiska stomnät.

Clas-Göran Persson

KG - Geodetiska Utvecklingsenheten

Utarbetande av tekniska rapporter ingår som ett led i den s k Samhällsmätningsfunktionens verksamhet. Tillkomsten av denna funktion är ett uttryck för en ökad satsning på samhällsmätning vid LMV. Den utgörs av de enheter som har sitt verksamhetsfält inom detta område, och har som sin huvudsakliga uppgift att samordna och befrämja metodutveckling samt informera om metoder och instrument.

LDOK Kg Mätningsteknik Stommätning

Beställs hos

[X] Lantmäteriverket
Blankettförrådet
801 12 GÄVLE

[ ] Liber Förlag

[ ]

SUKK - a Computer Program for Graphic Presentation of Precision and Reliability of Horizontal Geodetic Networks

by Dr Clas-Göran Persson, National Land Survey, Gävle, Sweden.

Invited paper to be presented at:
XVIII International Congress of Surveyors
June 1-11, 1986, Toronto, Canada.

SUMMARY

This article comprises a description of the "SUKK" computer program, a program system for analysis and graphic presentation of the quality - precision and reliability - of horizontal geodetic networks. The precision is described in the form of error ellipses and different types of standard errors. The reliability is expressed in terms of marginally detectable errors (internal reliability) and the influence of undetected gross errors on the adjustment result (external reliability). The program is primarily intended to be used in conjunction with network simulation.

SUKK was originally developed at the Royal Institute of Technology in Stockholm but is now also available in a somewhat modified version on the National Land Survey's PRIME 850. The program language is FORTRAN-77.

INTRODUCTION

Access to extensive horizontal and vertical control networks - with high accuracy - is today a prerequisite for the different parts of the process of building up our society. The planning of these control networks is a complicated task, calling for experience, skill and knowledge. This is particularly true of network design, which is controlled by several factors which are often contradictory to each other.

When planning horizontal control networks, there are basically five different types of requirements to be considered:

1) The envisaged use of the network: location of and distance between control points.

2) Topography: certain measurements can perhaps not be performed on account of obstacles in the terrain such as high hills and dense forests.

3) Technical limitations - in instruments and other equipment: it is impossible, for example, to measure distances of any length whatsoever with an EDM-instrument.

4) Economic conditions: wage and salary costs, transport costs, costs for tower construction etc.

5) Accuracy requirements: the accuracy of the network depends upon the measuring method, the network geometry and the accuracy of the instruments used. As a rule, one is obliged to adhere to certain predetermined stipulated tolerances.

The "SUKK" program system is intended to serve as an aid during this introductory phase of a control survey project. Basically, the idea is to start off by permitting the user to draw up a proposal for a network on the basis of the prevailing external conditions (points 1-4 above) and his own professional skills. Once this has been done, one can use the SUKK program system to check how this initial proposal satisfies the requirements in accordance with point 5, and if necessary modify the proposal and try again. The whole thing, then, is a kind of iterative process, which gradually leads to an optimal design of the network - where all aspects have been duly observed.

Since the accuracy is actually checked before any measurements have been made, it is possible not only to avoid costly supplementary measurements but also to save money by dispensing with superfluous measurements.

SUKK is the Swedish acronym for "Simulation for Investigation of Coordinate Quality". (In Swedish, SUKK stands for "Simulering för Undersökning of KoordinatKvalitet".)

HISTORICAL REVIEW

The program system has been developed at the geodetic department of the Royal Institute of Technology in Stockholm. The program is written in FORTRAN-77 for a NORD-500 computer. The work has been carried out partly in the form of diploma work, which means that the subprograms have been developed separately and successively integrated into the system.

The purely numerical part - SIMON, the Swedish acronym for "Simulation and Network Optimization" (in Swedish: SIMulering Och Nätoptimering) - was written in 1982 by Staffan Berg (Berg, 1982). On the initiative of the writer of this article, the original level of ambition was raised so that instead of being simply any simulation program the program became a modern one based on the latest findings in this field.

The next step was development of control programs for the HP 7580 A plotter used in the department (Cramling et al, 1983). These routines comprise the PLOT-LIB (PLOTroutine-LIBrary) program library.

By this means, it became possible to develop the program for the graphic presentation - GRUS, the Swedish acronym for "Graphic Presentation of Output Data from SUKK" (in Swedish: Grafisk Redovisning av Utdata från SUKK) (Engberg, 1985). Only then did the system do itself full justice, enabling its possibilities to be utilized to the full.

In 1985, all of these programs were purchased by the National Land Survey and transferred there to the PRIME 850 computer - as one system with the collective name of SUKK. In conjunction with this, a number of additions and changes were also made, primarily with regard to the presentation of the reliability of a simulated network. It is this version of the system that is described below.

THEORETICAL FOUNDATION

SUKK is based on modern statistical methods. The intention here, however, is not to present details about the underlying theory, but is rather to show how this relatively complicated complex of formulae can be used - and be of great help - in solving everyday routine problems. The "interested reader" is therefore referred to the literature listed at the end of this article.

The fundamental concepts are described for the first time in Baarda (1968). The application of Baarda's theories to network simulation is described in, among other works, Persson (1982) and Benning (1984), while in Förstner (1979) an example is presented of an adjustment program designed in accordance with these principles. A suitable introduction may be Olofsson et al (1983), while for an elucidation of the algebraic aspects and the description of suitable numerical methods for design of computer programs, finally, reference should be made to Persson (1981).

A few terms and concepts nevertheless require an explanation.

According to the approach adopted by Baarda, the accuracy of a network adjustment can be divided up into precision and reliability. Precision relates primarily to the sensitivity to random errors and is defined in terms of standard errors, error ellipses etc. Reliability, in contrast, is a measure of the influence of gross errors. It is expressed in terms of marginally detectable errors (internal reliability) and the influence of undetected gross errors on the adjustment result (external reliability).

A rough measure of the reliability of the measurements are their so-called "redundancy numbers". These indicate how the total number of degrees of freedom in the adjustment is distributed and provide information on the extent to which the measurement in question is controlled by other measurements in the network. Redundancy numbers are normally expressed in per cent, where 100 per cent implies complete control and 0 per cent implies entirely uncontrollable measurement. With the aid of these quantities, both the internal and the external reliability can be estimated.

If the old and familiar rule of thumb "one overdetermination per unknown parameter" is applied, a control capability of 50 per cent throughout will be obtained in a network with both distance and direction measurements - well distributed and with comparable accuracy. For most applications, this gives an entirely satisfactory reliability and may be considered a suitable point of departure in design and simulation.

PROGRAM DESCRIPTION

Program structure

As the system has emerged and is built up, processing can easily be divided into three stages: the numerical calculation, generation of the plotter file and the actual drawing-up - see Fig. 1. Consequently, interruptions may take place between these stages, which on many occasions can be practical. For instance, large parts of the analysis can be performed solely with the aid of the numerical presentation, which takes place more rapidly, or else the plotter files of the different alternatives can be gathered together and drawn up later and in one swoop. The graphic presentation is particularly important for the overall picture, when extensive modifications - deletions and additions of measurements - have been made in the original network proposal.

SUKK in itself is intended for simulation studies, but the changes that would be required in order also to permit

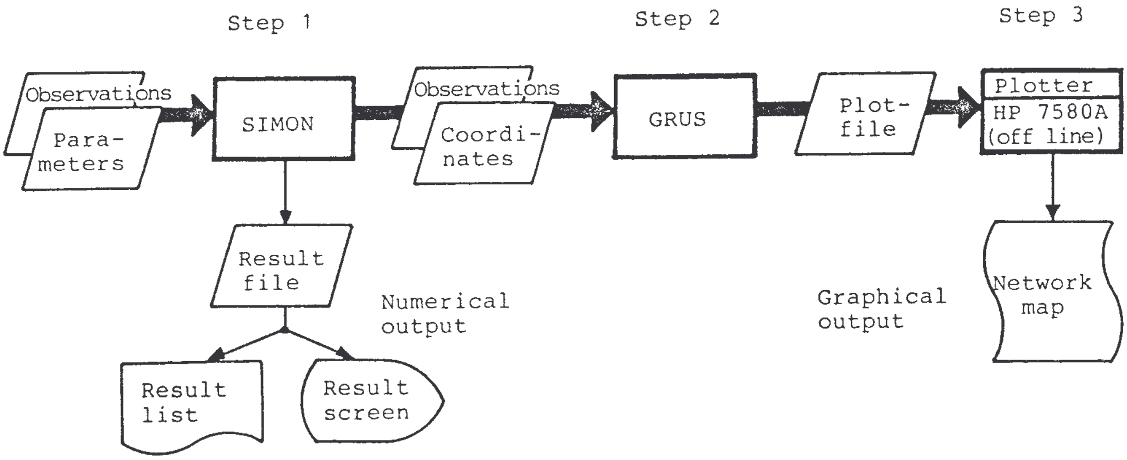


Fig. 1. Structural diagram of the SUKK program system.

adjustment are prepared in the program. For example, necessary variables have been declared and arrays dimensioned. Moreover, input files to SUKK can already contain measurement data.

Input data

Input data for a simulation are given in the form of two separate files - one for measurement program and one for various description parameters.

A measurement program is built up as follows:

* The numbers and coordinates of fixed points: these points are regarded as free of errors.

* The numbers and coordinates of new points.

* Planned distance measurements
  + point numbers
  + reference to a weight function in the parameter file.

* Planned direction measurements - arranged by station
  + station number
  + target number
  + reference to weight function.

The parameter file, in turn, must contain:

* The parameter values in the different weight functions.

* Distances for which standard errors (a posteriori) are to be calculated.

* Azimuths for which standard errors are required.

Output data

Output data consists both of a numerical account of the result of the analysis and of a graphic presentation of parts thereof in the form of a plot. The numerical account contains:

* Precision measures
  + standard errors of coordinates
  + error ellipse data
  + standard errors of distances and azimuths in accordance with the wishes in the parameter file; these are also expressed in ppm to simplify the evaluation.

* Reliability measures (see the section headed "Theoretical foundation")
  + redundancy numbers - for individual measurement as well as the average values for distances and directions
  + marginally detectable gross errors in each measurement (internal reliability)
  + maximum influence of undetected gross errors on the result of the adjustment (external reliability) - individually reported for each measurement.
  + Special marking is carried out both of uncontrollable measurements and of measurements that are "overcontrolled" - i.e. do not add to the accuracy but may be regarded as superfluous.

The graphic presentation, in turn, consists of a network map on an optional scale in which error ellipses and the external reliability in a colour-coded form are shown. The scale of the ellipses may also be selected freely, and the colouring of the reliability account is controlled by the user. As a rule, however, the following colour code is used:

Yellow = superfluous measurement - can be excluded

Green = measurement with a well attuned (external) reliability - should be retained

Red = uncontrollable measurement - must be "raised up" by modification of the measurement program (double measurements, addition of more measurements etc.).

The goal, then, is to create a network which satisfies the precision requirements and also has a completely "green" reliability. A plotter output from SUKK is shown in Fig. 2. The colour scale in this figure cannot be reproduced, however, for reasons relating to the printing technique used. For this reason, the reliability is illustrated separately in a slightly modified form in Figs 3a and 3b.

Notice particularly how the relatively small modification of the design made in Fig. 3b gives an extremely favourable influence on the reliability of the network!

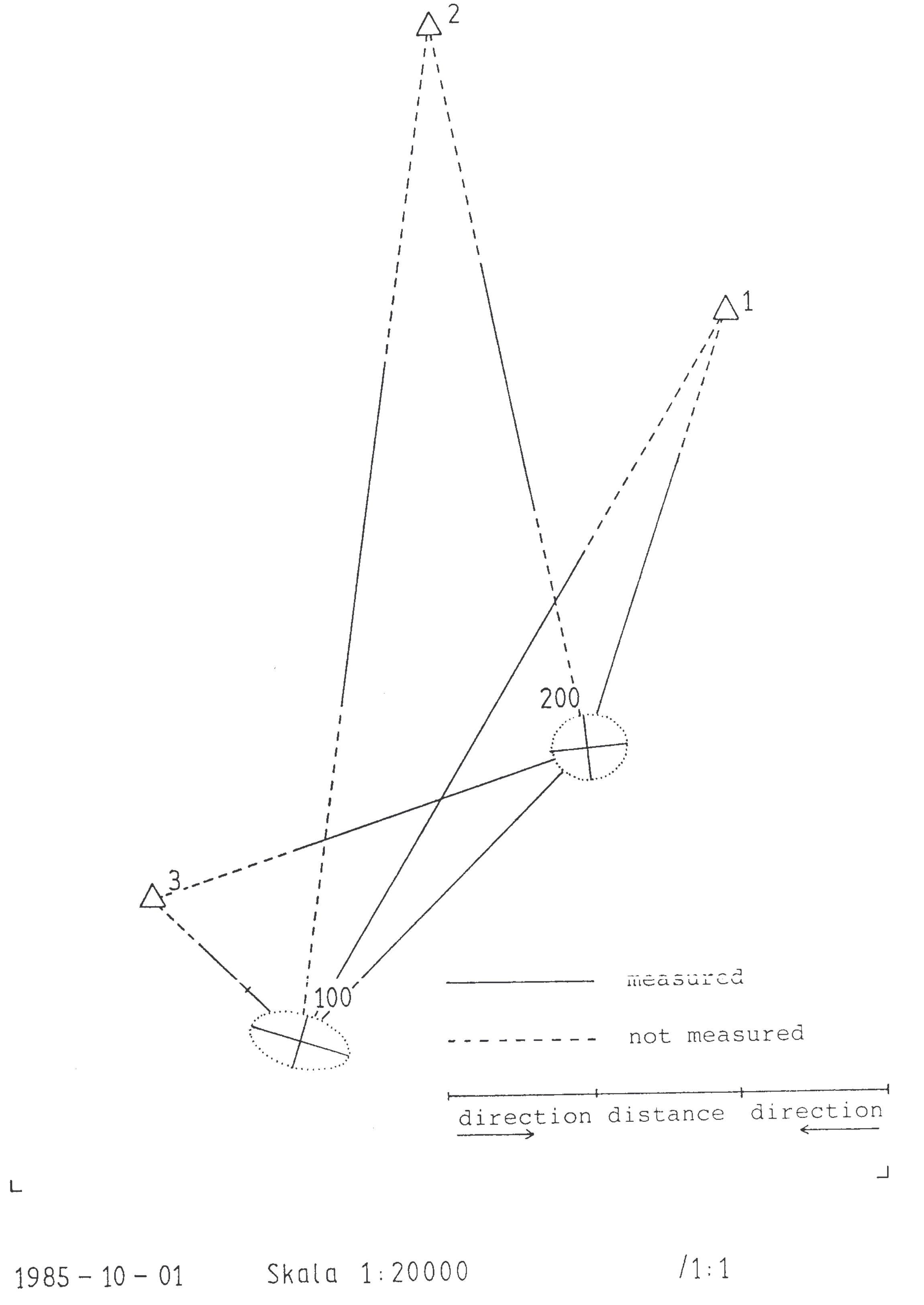


Fig. 2. Black/white reproduction of a plotter output from SUKK

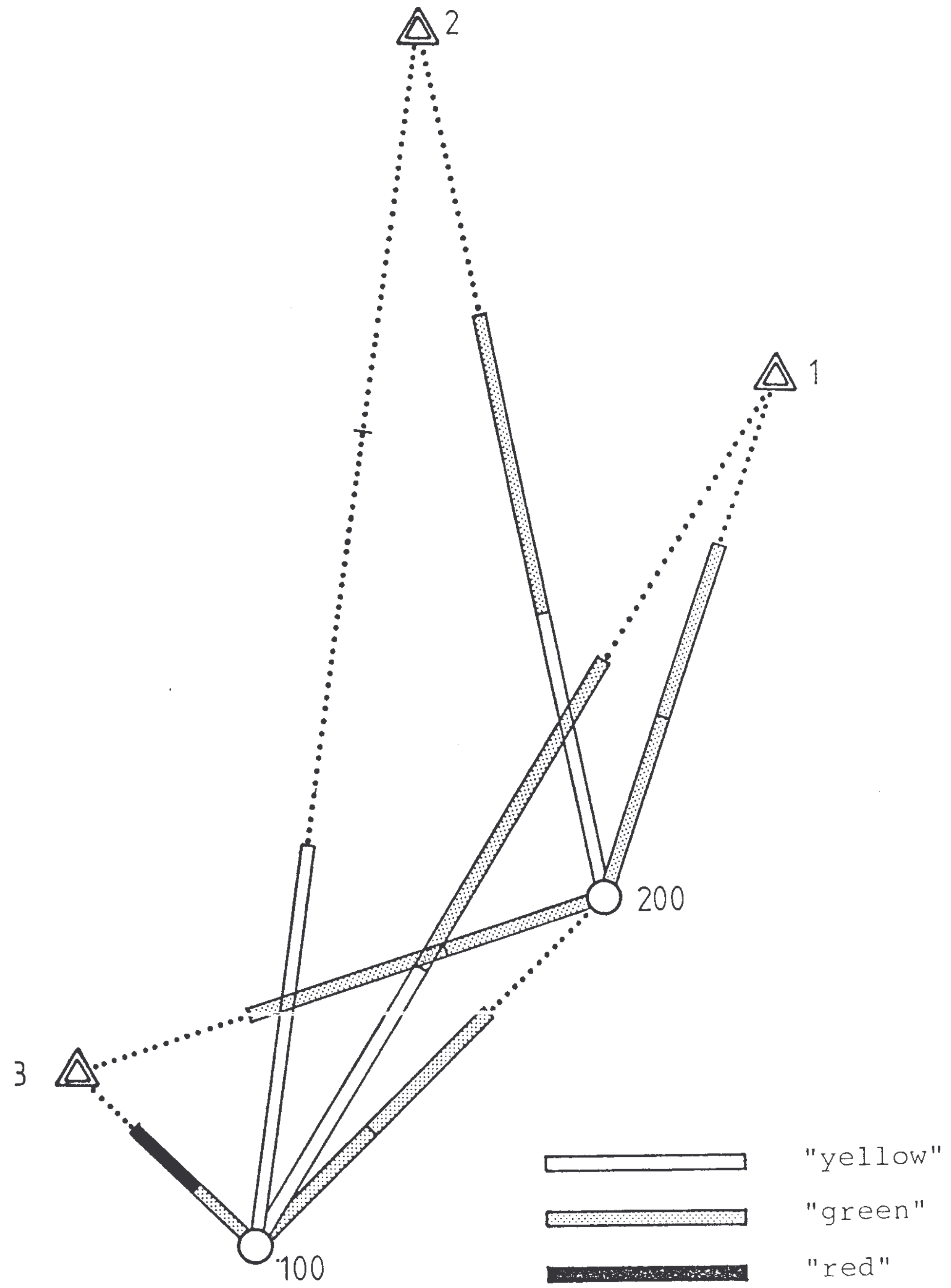


Fig. 3a. Separate presentation of reliability - initial proposal

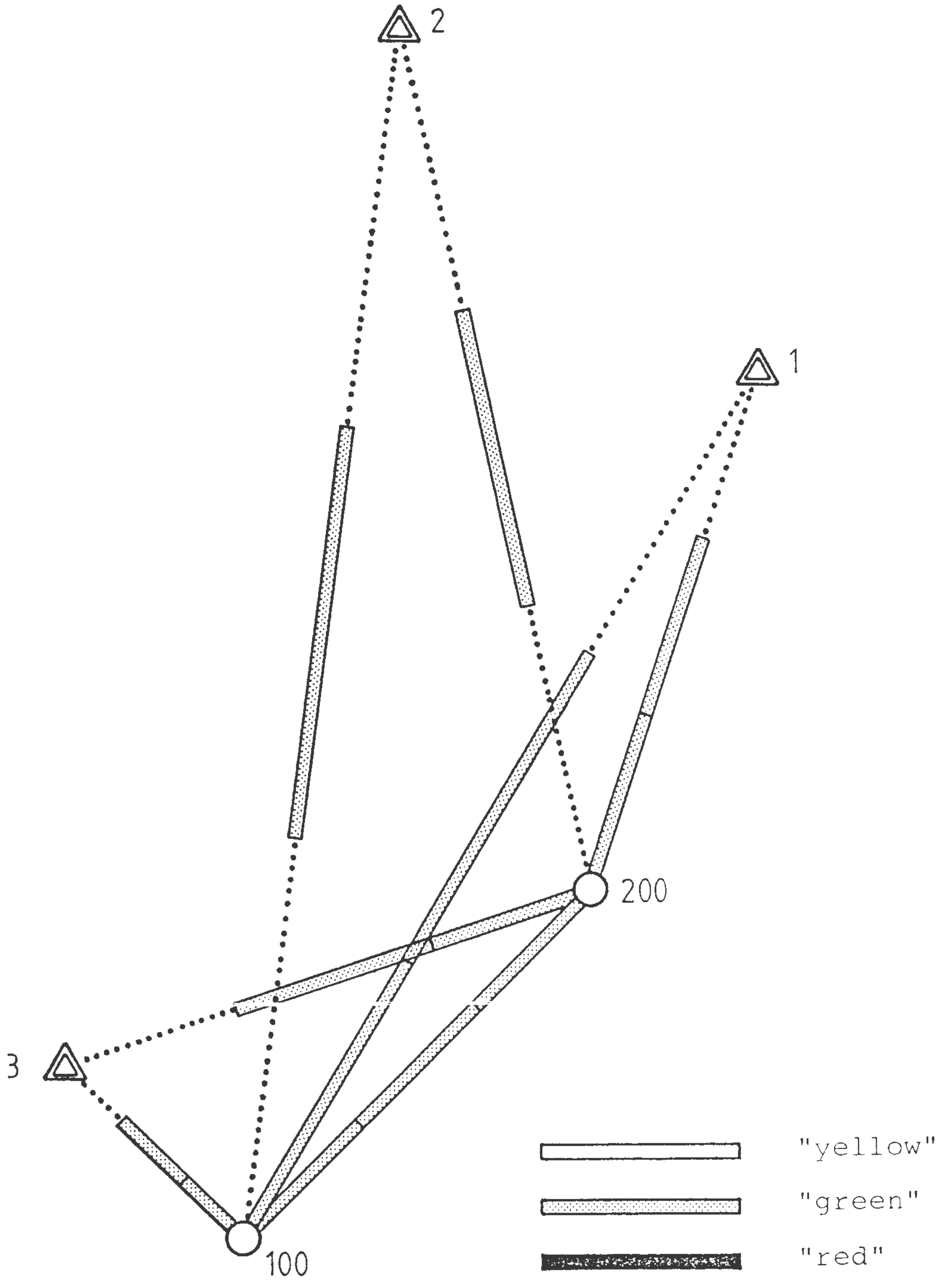


Fig. 3b. Separate presentation of reliability - modified proposal

The precision is not affected, however, to any particularly great extent by this modification. This is significative and is an indication that a simulation program based only on precision criteria is rather insensitive and gives less complete information about the effect of changes in network design than a program like SUKK.

SIMULATION METHODS

In principle, the design work can be carried out in accordance with the "trial-and-error" principle - i.e. measurements are added and excluded somewhat arbitrarily whereupon a check is made of the accuracy, continuing in this manner until a proposal has been arrived at that satisfies the stipulated requirements. This approach, however, can be somewhat time-consuming and occasionally leads to ending up in a "blind alley". That is why an attempt to draw up strategy has been developed. By and large, it agrees with the procedure described in Benning (1984), and is carried out in the following manner:

* To begin with, a "maximum proposal" is prepared, i.e. a proposal containing all the measurements that are performable and that are realistic for inclusion from the technical and economic standpoint.

* This proposal is simulated and if the precision is sufficient and the reliability well attuned the measurement program is approved - otherwise it is modified.

* If the requirements do not satisfy - for instance if the standard errors are too large and/or there are uncontrollable (red-marked) measurements - the program must be expanded or the measurement accuracy increased.

  A common problem is a lack of balance between direction and length measurements, i.e. "yellow" directions and "red" lengths. This makes it necessary to increase the number of rounds or to change to a more accurate theodolite. It may also be necessary to measure the distances twice.

  If it is rather a matter of minor local problems the solution is to add additional measurements if possible that provide help for the weak parts. These will then of necessity either be expensive or difficult to perform, since they are not included in the initial proposal.

* The program may also be overambitious. In this case, superfluous (yellow) measurements are simply excluded. It is essential not to make too many changes at the same time, but as a rule it is possible to modify in one swoop more than can be believed at first.

* Naturally, there may be both superfluous and uncontrollable measurements in one and the same network. Changes to remedy these problems can, however, take place simultaneously unless exactly the same part is affected in both cases.

* After the changes have been introduced, a new simulation is made and the whole thing is repeated until the design can be approved in its entirety.

EXPERIENCE

At the National Land Survey, SUKK has been used in the following contexts:

* In development of new measuring methods and for comparisons between different methods.

* In conjunction with training - as an introduction of the concepts on which the program is based.

* In assignment operations and activities - both in Sweden and elsewhere - to verify for the client that a presented proposal is thoroughly justified and satisfies the requirements imposed.

Since similar program systems are nowadays available that make use of interactive graphics - e.g. "INTRA" (Frank et al, 1980) and "CANDSN" (Mepham et al, 1984) - SUKK may appear to be slightly primitive. The program, after all, is not interactive and uses a far simpler solution for the graphic presentation. This very simplicity, however, has proved to be an enormous strength. Among the advantages, mention may be made of the following:

* We have not omitted ourselves with regard to the design: SUKK can be regarded as a "first draft" which is used to introduce the ideas. In the long-term view, this will provide opportunities for more people to present their views on the final elaboration of our simulation program.

* Knowledge of interactive graphics is limited, and a barrier may be encountered if those concerned are obliged to learn both new technology and new methods. Our solution with input files and batch-processing, in contrast, is the same as is used in the adjustment programs, which enables the "beginner" to recognize what he/she is doing.

* Graphic screens are expensive and not readily available within the organization - plotters, in contrast, are common.

* The program makes colour presentation, which we consider to be essential, possible without any need for graphic colour screens - which are even more expensive.

It is also doubtful whether the volume of the simulation operations carried out today justifies development of a complicated and expensive system. That is why we consider that programs such as SUKK are fully justified - perhaps in the future too.

FUTURE PLANS

Today's SUKK will not be further developed to any great extent. Nevertheless, there are some points on the "list of wishes" that should be dealt with.

Routines that enable extraction of coordinates through digitizing of maps are needed. This can, in itself, already be done, but not in a streamlined manner.

Drawing-out takes place today on an off-line plotter. It is desirable for this to be steered over instead to the directly connected drawing equipment of the production system.

In other respects, the system will probably retain its current elaboration. Instead, resources are being concentrated on gradually developing a similar, more powerful program which will be included in the next generation of geodetic adjustment system at the Swedish National Land Survey.

FINAL ASSESSMENT

A simulation program of this type gives far more information than one with a conventional design. This is valid both for the expert and - through the graphic presentation - for the less experienced user. The graphics complies an important means of communication - for instance during discussions between a purchaser and the surveyor.

SUKK has proved to be equally usable in method development as in pure production work and is also - through its simplicity - an excellent aid in the introduction of these "modern" methods and this partly new approach to a wider circle.

Note: A Swedish version of this paper has been published in Svensk Lantmäteritidskrift 1985.

LITERATURE

W Baarda	(1968)	A Testing Procedure for Use in Geodetic Networks. Netherlands Geodetic Commission, Vol. 2, No. 5.
W Benning	(1984)	Zur Strategie des Entwurfs geodätischer Netze aus optimierter Zuverlässigkeit. ZfV 109 (1984), pp. 563-569.

S Berg (1982) SIMON: Program for Simulation and Optimization of Geodetic Networks (in Swedish). Diploma work, Royal Institute of Technology in Stockholm.

D Cramling, P Hollander (1983) Control Programs for Drawing with HP Plotter - description of the programs in PLOT-LIB (in Swedish). Diploma work, Royal Institute of Technology in Stockholm.

L E Engberg (1985) GRUS - Program for Graphic Presentation of Output Data from SUKK (in Swedish). Royal Institute of Technology in Stockholm.

A Frank, C Misslin (1980) INTRA - a Programme for Interactive Design and Adjustment of Geodetic Networks. Eidgenössische Technische Hochschule, Bericht Nr. 43, Zürich, Institut für Geodäsie und Photogrammetrie.

W Förstner (1979) Das Programm TRINA zur Ausgleichung und Gütebeurteilung geodätische Lagenetze. ZfV 104 (1979), pp. 61-72.

M P Mepham, E J Krakiwsky (1984) CANDSN: A Computer Aided Network Design and Adjustment System. The Canadian Surveyor, Vol. 38, No. 2/1984, pp. 99-114.

T Olofsson, C G Persson (1983) Control of Gross Errors in Free Positioning (in Swedish). Svensk lantmäteritidskrift 1983:5, pp. 302-308.

C-G Persson (1981) On Weight-Estimation and Detection of Outliers within the Adjustment of Horizontal Control Nets. Royal Institute of Technology in Stockholm.

C-G Persson (1982) Adjustment, Analysis and Optimization of Triangulation Networks (in Swedish). Lecture held at the 9th meeting of the Nordic Geodetic Commission in Gävle 13-17 September 1982.