SHORAN OPERATIONS IN CANADA

By J.E.R. Ross,

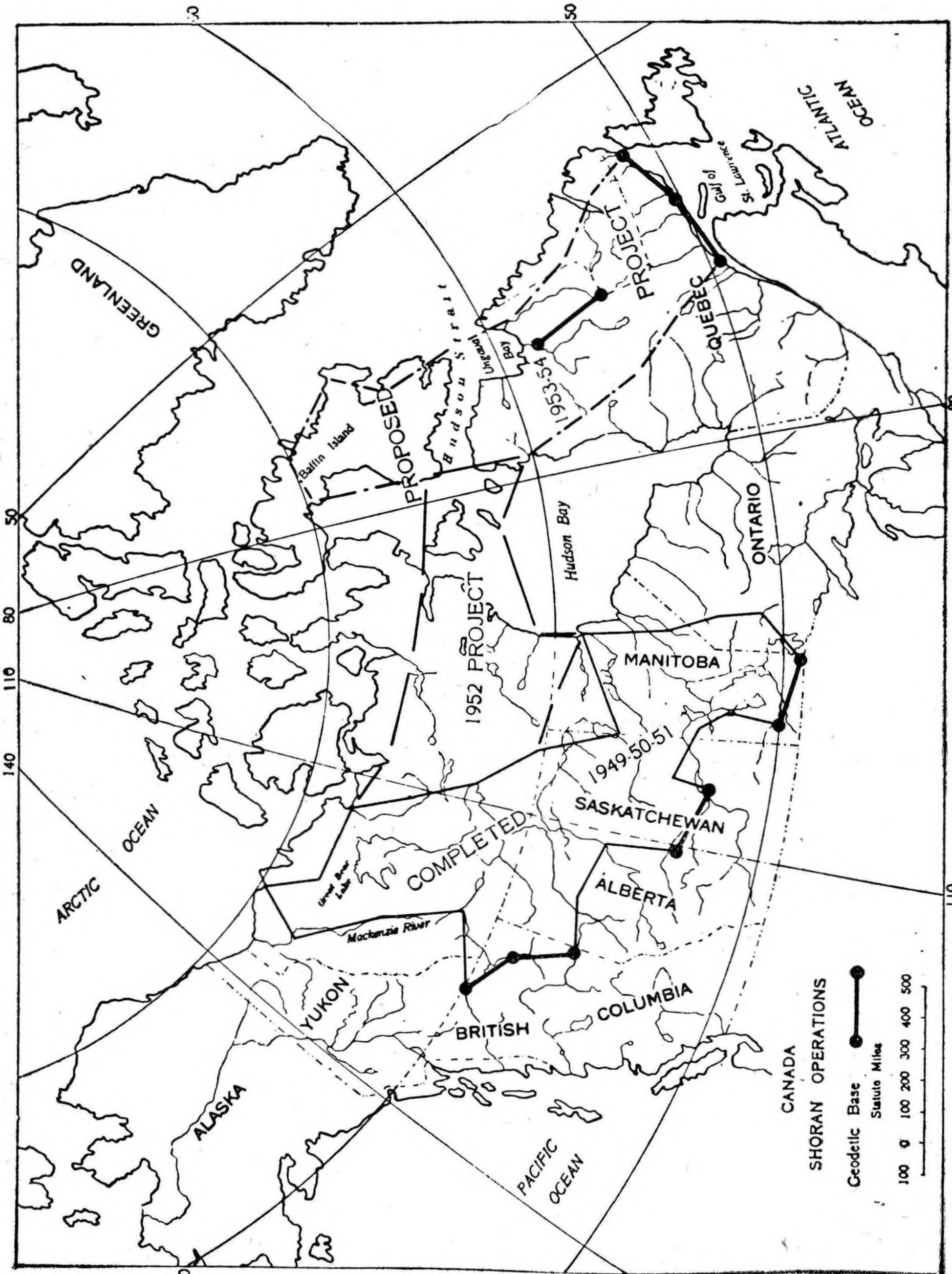
Dominion Geodesist, Department of Mines and Technical Surveys, Ottawa.

(Presented at the Twelfth Annual Meeting, American Congress on Surveying and Mapping, Washington, D.C., June 11-13, 1952).

Reprinted form « Surveying and Mapping », Vol. XII, No. 4, October-December, 1952, Washington).

Canadian operations with Shoran as applied to surveying and mapping may be regarded as having begun in 1947. During the next two winters experiments were conducted in the vicinity of Ottawa to asses the accuracy of Shoran positioning in comparison with that obtained by first-order triangulation. The results were encouraging enough to warrant consideration of Shoran as a means of establishing position in Canada's vast northland. First, it had to be demonstrated that a Shoran net of considerable length, starting at a base derived from the first-order triangulation, could give an acceptable closure when carried over the intervening distance to another geodetic base. In 1949 and 1950 such a Shoran net of 1,100 miles in axial length between geodetic bases was completed in Manitoba and Saskatchewan, with results which indicated that Shoran, with all details carefully supervised, could produce results with an accuracy superior to astronomic positions. This is the only reasonable alternative method of control at the present stage of development of the northern areas. More than 800 geographic positions have been determined in the last 10 years by the exploratory astronomic method. These have been satisfactory for control in the production of small-scale maps where displacements of as much as 400 feet are not plottable. Such astronomic determinations are not sufficiently accurate to use as control for the large-scale mapping which is essential and in demand now by the various agencies concerned in the development of oil and ore potentials, not only in local and relatively small areas but in regions of vast extent.

In the seasons of 1949, 1950 and 1951 the Shoran net has been advanced from the 49th parallel in southern Manitoba, northwestward through the provinces of Manitoba and Saskatchewan, and northward down the Mackenzie River basin to the Arctic coast in latitude 70°, over an axial length of 2,500 miles. In this net 40 Shoran stations have been established, and the 149 lines between stations, averaging 210 miles in length and forming the geometrical pattern of the net, each have been measured 16 times. In addition, 13 stations have been prepared in a 1,200 mile belt extending from Great Bear Lake eastward to Hudson Strait. These 13 stations form the basis of a Shoran net of 46 lines which will be measured in 1952.


CANADA
SHORAN OPERATIONS
Geodetic Base
Statute Miles
100 0 100 200 300 400 500
1952 PROJECT
1953-54
PROPOSED
PROJECT
1949-50-51
COMPLETED
GREENLAND
Baffin Island
Hudson Strait
Ungava Bay
Hudson Bay
QUEBEC
ONTARIO
MANITOBA
SASKATCHEWAN
ALBERTA
BRITISH
COLUMBIA
YUKON
ALASKA
Great Bear Lake
Mackenzie River
ARCTIC
OCEAN
PACIFIC
OCEAN
ATLANTIC
OCEAN
Gulf of
St. Lawrence

TRIANGULATION CONTROL IN NORTHERN AREAS

The existing high-order triangulation control is largely confined to the settled area which extends from coast to coast along the southern part of Canada. There is also a continuous arc of triangulation along the Pacific coast to Skagway, thence to Whitehorse, Yukon Territory, and thence westward astride the Alaska Highway to the 141st meridian and also eastward tho the vicinity of Fort Nelson, in the northeast part of British Columbia. In addition, there is minor triangulation control along the 141st meridian (the Alaska-Yukon boundary) and from Seven Islands, Quebec, northward to Ungava Bay, this latter not lying some 2,500 miles east of the former. The northern areas east of the Rocky Mountains thus lack accurate control in the form of either triangulation or levelling. In this vast region astronomic positions have provided what horizontal control we have. With the recent introduction of electronic methods of distance measurement, the use of astronomic positions for mapping control will decrease. Economic development has demanded better maps and, as time is a factor, electronic methods of establishing control furnish the answer with both speed and accuracy.

BASIC OPERATIONS

The operations involved in a Shoran-geodetic survey are not only extensive but complicated, and require the facilities and cooperation of many organizations. A reconnaissance is made by air and then by ground to select antenna sites of sufficient height to provide straight-line clearance of ray paths to the plane engaged in line measurement. For ease in transport these sites should be close to fairly large, deep lakes with good landing beaches, thus reducing the lengths of trails and providing safety for the supply planes. Each site is permanently marked by a monument or tablet, and in wooded areas a surrounding area 100 feet square is cleared. In the more northern interior regions basic elevations are nonexistent. It is thus necessary to determine the elevations of lake surfaces by barometric procedures during a period of 14 days with readings of wet-and-dry bulbs and barometer being taken every 3 hours at specified times to allow correlation of the data with weather information of the Meteorological Service. The elevation of each antenna site is obtained by spirit levelling from the lake surface. Radar altimetry would be of great assistance in this connection and it would also provide numerous spot elevations, but at present it is not in use. The approximate position of each antenna site is determined by astronomic observations. The azimuth is also calculated and marked on the ground for the antenna orientation. From these data, the navigator on line-crossing measurements is provided with information as to the approximate length and direction of each radiating line. Subsequent comparison of the astronomic position and the Shoran position of each station gives an approximate indication of the deflection of the vertical at that station.

An extensive organization is required to perform these operations and the work has been done as a cooperative venture by personnel of the Royal Canadian Air Force, National Research Council, Meteorological Service, and the Geodetic Survey of Canada. When it is realized that the field season lasts only about 3 months owing to lakes not being free from ice more than 4 months in the lower latitudes and progressively less as one approaches higher latitudes, one gains an appreciation of the necessity of personnel being highly trained in order to take full advantage of the short period of operation. The transportation of equipment and some 160 personnel 2,500 miles by air, the provision of food and shelter for them, the maintenance and operation of the antenna stations, and the servicing and operation of both line-measuring and supporting aircraft, coupled with the need for a high order of accuracy in the work, tend to make the operation a challenge to all concerned.

SHORAN PROJECT

It is expected that the Shoran operations south of latitude 66°, with a few extensions reaching to latitude 70°, will have an axial length of about 5,500 miles and will form a huge arc with connections to five geodetic bases available from the existing first-order triangulation. In three seasons we have now completed 2,500 miles of this arc, and from past experience it appears feasible to complete the rest of the arc in three more seasons to a junction with first-order triangulation in the East, on the north shore of the Gulf of St. Lawrence. The Shoran trilateration is necessarily the first step, but auxiliary stations will have to be established in any area for supplemental use in controlling the aerial photography. The principal shoran lines in general are too long to serve as the sole control aerial because signal reception in these circumstances is not feasible when farther than 150 miles from an antenna, and in many areas the sites are not properly placed to secure favourable intersection of position.

In geodetic suveying and mapping the sea-level distance between stations is required; therefore, it is necessary to consider Shoran trilateration sufficiently strong in a geometrical sense to give not only length to a certain accuracy but at the same time to give position to a relatively high degree of accuracy. Conventional triangulation requires the measurement of angles and, for a quadrilateral in which all angles are measured, four geometrical conditions must be satisfied. In trilateration the measurement of the six lines of a quadrilateral imposes only one condition and hence there is a decrease in the strength inherent in the method. To offset this, stations should be arranged in pentagon pattern so that extra lines of measurable length may be introduced from stations in one figure to stations in adjacent figures, thus giving overlap. We have endeavored to provide a standard of two more lines per station than are required to fix the station. There are practical limitations as to the maximum operating altitude of the line-crossing plane and to the distance at which the signals, due to lack of strength, may be received from the ground stations. With our present equipment these limits are 20,000 feet in altitude and some 165 miles in length. Thus the maximum length of measurement is approximately 330 miles.

LINE CROSSING AND LENGTH MEASUREMENT

The Shoran instrument in the plane flying at uniform ground speed, height, and direction, in the vicinity of the center of the line, emits pulses (20 per second) which are alternately sent to the terminal ground stations on frequencies of 230 and 250 megacycles and are then delayed a fixed amount and returned on a common frequency of 300 megacycles. The elapsed time between emission and reception is registered on mileage dials which, together with other dials, are photographed at 3-second intervals. It is evident that the true sum of the distances, plane to stations, is greater on each side of the actual crossing and is a minimum at the crossing. If time is plotted against sum, the plot approximates a parabola and a mathematical curve of best fit will determine the minimum sum distance corresponding to each line-crossing flight.

All lines of the project have been measured by a minimum of 16 line-crossings, of which 2 groups of 8 each were measured on different days to ensure a change of atmospheric and other conditions and to reveal unstable equipment.

As an example, let us now consider the results obtained for the line Fort Simpson-Peace (*see* tables 1 and 2). This is the longest line so far measured in our operation.

TABLE 1

Line: Fort Simpson—Peace
Indicator 1405 Aircraft 212 Recorder 2

June 30/51		Date	July 3/51	
20,000 feet		Flight height	20,000 feet	
329.5860 miles	329.5881 miles		329.5956 miles	329.5892 miles
.5795	.5884		.5841	.5847
.5853	.5850		.5924	.5856
.5876	.5889		.6008	.5898
329.5846 miles	329.5876 miles	Average of 4	329.5932 miles	329.5873 miles
329.5861 miles		Average for day	329.5902 miles	
Grand mean, reduced length : 329.5881 miles				

TABLE 2.—*Corrections to shoran measurements for first crossing of table 1*

Base value of computation	330.1500 miles	
Minimum of curve above base	.0071	
Minimum shoran distance ($R + D$)	330.1571 miles	
Minimum rate and drift station distance	165.8550 miles	164.3021 miles
	Rate	*Drift*
Corrected altitude of plane (H)	20,317 feet	20,317 feet
Antenna altitude (K)	619 feet	2,376 feet
Slope distance (R and D)	165.8550 miles	164.3021 miles
Delay	— .1669	— .1908
Velocity	+ .0082	+ .0082
Frequency	— .0006	— .0007
Indicator 1405	— .0015	— .0015
Slope distance (corrected)	165.6942	164.1173
To sea level	— .0827	— .0888
For slope	— .0420	— .0352
For curvature	+ .0116	+ .0116
	165.5811 miles	164.0049 miles
Reduced length (table 1)	329.5860 miles	
Grand mean (16 crossings) (table 1)	329.58810 miles	
Calibration constant	— .00446	
Correction from adjustment (v)	— .01336	
Adjusted length (1951 net)	329.57028 miles	

TABLE 3.—1949-50-51 *operations*

Range (feet)	0-10	10-20	20-30	30-40	40-50	50-60	60-70	70-80
Number of lines	42	29	28	18	15	8	4	3
Percentage of lines	28.6	19.7	19.0	12.2	10.2	5.4	2.7	2.2
Cumulative percentage	28.6	48.3	67.3	79.5	89.7	95.1	97.8	100.0

In table 1 the values of the 16 line-crossings reduced to sea level are given, and it may be seen that the means for the two flights agree within 21.6 feet. With reference to table 3 we see that an agreement within this range is obtained 50 percent of the time. The spread in each group of four is 40, 20, 84, and 25 feet, which reflects not only operator and other errors but also the elimination of certain instrumental errors due to the figure 8 line-crossing pattern. The agreement of the means for the 2-day operation is representative of the work in general and indicates good control of all factors insofar as they can be controlled. The variation in measurement from day to day is beyond control and the grand mean may thus be expected to contribute more highly to general accuracy than agreement of readings on any one day. No measurements of the intensity were taken but all flights were made at that altitude where the incoming pulses were most intense and least distorted. It is stressed that the consistency of values obtained for any one line in one day's operation of 8 line-crossings is an indication of relative accuracy but no clue is given of the extent of systematic error or of the effect of other conditions peculiar to the day's operation.

In table 2 the corrections to the shoran measurement, which lead to the value 329.5860 in table 1, are tabulated to indicate the relative size and sign of the various corrections needed to reduce the measured values, plane to stations, to the sea-level length from station to station. In the reduction, use is made of the best values obtainable for H, K, and the delay, but they are suspect to various degrees and this contributes to inaccuracy. Because levelling control is nonexistent, the antenna altitudes are determined by barometer, but they are believed to be accurate to within 25 feet on the average. The height of the plane, under certain atmospheric conditions, may be in error in length of some 15 feet. Because of calibration difficuties, the delay has been determined on a relative rather than on an absolute basis. Anderson's velocity of radio propagation is used, and a calibration constant is derived in the adjustement to cause the Shoran net to fit between triangulation bases. If the work is done uniformly, the net effect is a change in scale, thus taking care of both calibration and velocity difficulties which, unfortunately, we are not able to separate. The calibration constant and correction from the adjustment here indicated are obtained from the connection of the Shoran net to two geodetic points belonging to a loop not yet closed and thus subject to revision. Nevertheless, the accidental error of — 0.01336 mile, or 70.5 feet, the third highest in the operations, indicates an apparent accuracy of 1 in 24,670. Inasmuch as the line is the longest measured and no intensity measurements have been made, it is likely that a falling-off of intensity relative to that for an average line (210 miles) has occurred, and the relatively large minus correction to the observed values is supported on these grounds. For the 149 lines the average correction without regard to sign is 19.4 feet.

Table 3 has been compiled to illustrate the number of lines for which the means obtained on separate days fall in groups of 10-feet difference. Thus for 29 lines (19.7 percent) the means were not greater than 20 feet nor less than 10 feet apart. It may be inferred that 50 percent of the line measurements on separate days are in agreement within 20 feet and 75 percent within 35 feet for the entire operation. The remaining 25 percent are largely contained within the range 35 to 60 feet. Only occasionally are values beyond 80 feet obtained, and when this happens an overhaul of electronic equipment is immediately indicated.

FIELD ANALYSIS

A geodetic unit of 8 to 10 men, recently including a meteorologist, has been attached to the operation to compute the data and make the reductions immediately after the line-crossings. With a limited number of ground installations this has distinct advantages, as small adjustements can be made and information can be gained at once as to whether additional flights are necessary over certain lines.

The data were prepared for each unit set-up of ground equipment as the work progressed, and no movement of equipment was authorized until some 20 lines had been adjusted to check the over-all consistency of the measurements in forming geometrical patterns. If relatively large corrections were required for certain lines, this indicated that these lines needed to be remeasured to get better accuracy. Additional flights have invariably confirmed the conclusion based on the adjustment.

ACCURACY

A pertinent question is « What accuracy is being obtained ? » To answer this we must first rephrase the question so it reads « What accuracy do we believe is being obtained ? » for as yet we have no interior checks on position. The general picture may, however, be gathered from the results obtained in the first net of 74 lines, extended 1,100 axial miles between geodetic bases. This is summarized briefly as follows :

(a) Lines of average length, 210 miles, may be measured to give a mean accidental error of 18 feet.

(b) In a network in which there are twice as many surplus lines as stations to be fixed, the probable errors in latitude and longitude are about 25 feet.

(c) The closure in position at the geodetic base is better than 1 in 59,000, and this lends support to the belief that the intermediate stations are not likely to have a position error greater than the probable error, say 25 feet.

(d) The replacement of astronomic determinations by Shoran positioning has thus greatly improved the accuracy of control.

Shoran values of position have indicated areas in the north in which the positional effect of the deflection of the vertical is more than 1,000 feet.

The equipment in use was built during World War II but has been modified to improve its use in surveying. This equipment is gradually being replaced by new airborne and ground equipment, which will, no doubt, contribute to improved accuracy. Automatic gain control to offset variable signal strength has been tried, but so far without success. The attachment to the airborne recorder of an errorscope, by which irregularities in the matching of pulses may be assesed and corrected, is believed to be of more value in photographic missions than in the line-crossings and to date has not been used. Neither has radar altimetry been used.

Difficulty has been experienced with the calibration of the equipment. Nevertheless, the results so far obtained indicate that the accuracy is more than sufficient for the purpose in mind — that of Shoran-controlled photography. The Shoran net is not intended to replace ground triangulation in local areas, and future extensions northward of first-order work will make more connections to the Shoran net possible and thus improve its general over-all accuracy. It must be admitted that it is difficult to maintain direction over long distances with the present Shoran equipment and methods. Four Laplace azimuths have been introduced in the net to offset this tendency toward weakness in direction.

APPLICATION TO MAPPING

The application of the Shoran system to mapping depends upon the making of instantaneous length measurements from the airplane which is on a photographic mission to two established Shoran ground stations. In wartime bombing operations the system was used as a navigation aid to indicate the on-target and bomb-release position according to previous calculation. The timing unit is airborne and the slope distances from the aircraft to the two ground stations used as a base can be determined from the data. When the position and elevation of each ground station and the height of the aircraft are known, the projected position of each vertical photo may be computed.

The accuracy of these Shoran fixes cannot be greater on the average than the capability of the Shoran operator in matching the return pips with the marker pip on the oscilloscope screen. In line-crossing this operation is strenuous enough but on photo-flights when the aircraft may be on a flight line for 30 minutes or more instead of 5, fatigue may contribute very seriously to inaccuracy. In addition, there is but one value of each of the slope distances — that at the time of photo exposure. Delay values, goniometer errors, and other factors have an effect on scale as well as on direction of the plot, but as a rule it is possible to alter and shift the plot to give a very good placement.

More factors must be considered in planning a Shoran-controlled photographic flight than in the case of conventional flight missions. In the latter the spacing of flight-lines and the required overlap do not change for they are governed by the flying height and ground relief. In Shoran operations the location of the ground stations with respect to the flight area is very important. The airborne set must always be within the effective range of the ground stations, and for best results the angle subtended at the aircraft by these two points should be between 60 and 120 degrees. The path of the Shoran ray may be considered for all practical purposes a « line of sight ». In a certain sense this means that the ground station and aircraft must be intervisible for efficient operation. The effective range depends on the flying height, H. The expression, Range = $1.4 \sqrt{H}$, gives a fair approximation of its value. Here H is in feet and the range is in miles. All these factors must be considered when preparing the flight-line map.

Tests with Shoran-controlled photography in the Ottawa area in winter months have given excellent results, and an effort was made in 1951 to take some photography in the northern areas in conjunction with the line-crossings. Although the weather conditions were average, only a small amount of photography was obtained because of the limited number of ground sets with the necessity of movement immediately after line measurement. In an operation as extensive as ours is, we did not expect to produce more than incidental photography, the main effort being directed to advance the Shoran control as far as possible in the limited season.

There is an enormous amount of vertical and oblique photography of the northern areas available now for mapping purposes. Hitherto it has been used for small-scale mapping, but it is available for large-scale mapping as soon as more accurate control is established. Shoran has supplied this control in the areas so far covered. It is expected that a contract for Shoran-controlled photography will be let in 1952 for the aerial photography of an area of 172,000 square miles involving 14,000 lineal miles. Control flight lines over the existing vertical photography will be spaced at intervals of 20 minutes of latitude (23 miles) and 1 degree of longitude (30 miles).

CONCLUSION

A brief description such as outlined above may convey to the reader the extent to which electronics is equipping survey organizations with seven-league boots. Canada, with its northern areas over which the normal methods of control are slow and difficult, offers a wonderful field for the use of electronic methods. Doubts about the accuracy of Shoran control have been removed by the results of experience and further lines of improvement are indicated. Shoran has been made to work to our purpose.

As their frontier is being pushed back through air transportation, economic development is accelerated, mapping is claiming more attention, and the modern survey tool — Shoran — is making possible the realization of the fondest dream of geodesists and mappers — the dream of being ready with control data and maps previous to engineering developments. We have always pressed for this effective result, but not until recently has it been possible to achieve it.