Computational steps:

1) Apply corrections to the linear (distance) measurements (e.g. temperature & pressure for EDM, possibly map grid corrections too to fit with coordinates on a map projection).

2) Compute the angular misclose of the traverse and the adjusted bearing of each line.

3) Calculate the coordinates of the stations, and the linear misclose (in coordinates) of the traverse.

4) If misclose is small enough then adjust the traverse to obtain the final coordinates. If misclose is not small enough then investigate to find the error.

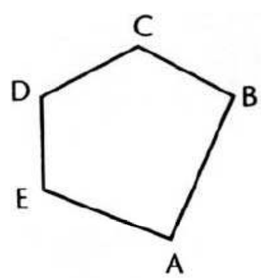
TRAVERSE MISCLOSE CALCULATION

ANGULAR MISCLOSE

Loop traverse with n points

If no errors in angles then:
Σ interior angles = $(n-2) \cdot 180°$
Σ outer angles = $(n+2) \cdot 180°$

Misclose = Σ internal angles - $(n-2) \cdot 180°$

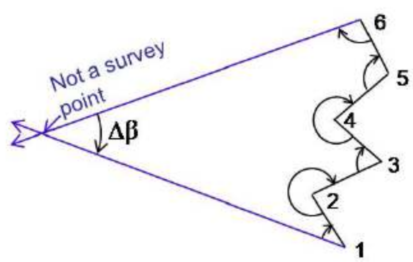


Closed-line traverse

Σ angles + $\Delta\beta = (n-2) \cdot 180°$ (in this figure: n = 7 !)

where $\Delta\beta$ = starting bearing – closing bearing

Misclose = Σ angles + $\Delta\beta - (n-2) \cdot 180°$

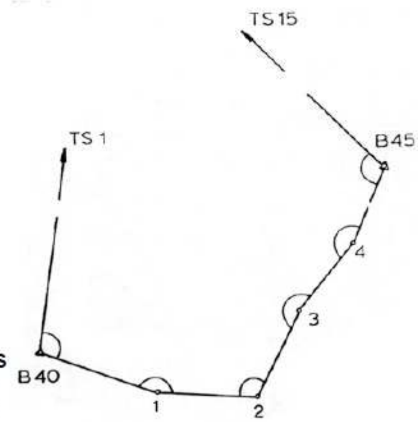


DISTRIBUTION of ANGULAR MISCLOSE

- If the angular misclose is acceptably small then it is usually distributed evenly to all observed angles.
- Correction to each angle: $\alpha_c = -\frac{\text{angular misclose}}{n}$ where n = number of observed angles
- The bearings are then calculated using the adjusted angles: $\beta_{forward} = \beta_{back} + adj\ angle \pm 180°$
- Alternatively, the bearings of lines calculated from unadjusted angles, can be corrected sequentially. i.e. first bearing gets + α, second bearing gets + 2* α, third bearing gets + 3* α, etc

Example 1: TRAVERSE with measured angles

A traverse was observed from B40 to B45 (which have known coordinates) as shown in the figure below. The angles were derived from mean of FL and FR directions and reduced to zero on the backsight. The distances have been corrected for slope, atmosphere etc and are the mean of forward and backward observations.



Observations:

	Angle	From - To	Dist m
B40	94° 10' 00"	B40 – 1	103.402
1	178 19 00	1 – 2	157.225
2	118 21 45	2 – 3	143.369
3	194 42 25	3 – 4	169.087
4	158 07 30	4 – B40	176.743
B45	89 03 55		

Given data:

Coordinates (E, N)	Bearings from coordinates
B40: 406.347, 423.509	B40 – TS1: 10° 12' 35"
B45: 992.415, 713.229	B45 – TS15: 302° 57' 43"

Step 1 – Angular misclose and adjusted bearings

This step can be done by:

(A) summing the angles, distributing a portion of the misclose as a correction to each angle, then calculating the adjusted bearings, or

(B) calculating bearings of each line, then the misclose, then distribute a sequentially increasing portion of the misclose to the bearings.

We show both methods here and assume the misclose is acceptably small. If the misclose is large then the angles and bearings should not be adjusted and the error should be found. More details on how to do that later.

(A) Adjusting Angles:

- $\Delta\beta$ (starting brg – closing brg) = 67° 14' 52"   Note: bearings <u>from</u> terminal <u>to</u> target control station.
- For a loop traverse, $\Delta\beta$ is zero.
- Angular misclose $m_\alpha = \Sigma$ angles - (n-2) ·180°   with n = number of angles.
  = 832° 44' 35" + 67° 14' 52" – (7-2) * 180°   here n=7 (6 traverse stations + $\Delta\beta$)
  = 899° 59' 27" - 900° → m_α = -33"
- Correction to angles = $-m_\alpha / n$ = +5.5"
- Bearings from corrected angles: $\beta_i = \beta_{i-1} + \alpha_i \pm 180°$

Pt	Angle	Cor	Adj Angle	Adj Brg
TS1				
				190°12'35" Known
B40	94°10'00"	5.5"	94°10'05.5"	
				104 22 41
1	178 19 00	5.5	178 19 05.5	
				102 41 46

2	118 21 45	5.5	118 21 50.5	
				41 03 37
3	194 42 25	5.5	194 42 30.5	
				55 46 07
4	158 07 30	5.5	158 07 35.5	
				33 53 42
B45	89 03 55	5.5	89 04 00.5	
				302 57 43
TS15				
	Misc -33”	33.0		**302 57 43** Known

- Check: last bearing calculated = given bearing

(B) Adjusting Bearings Method:

Bearings are calculated from unadjusted angles. Then each bearing is corrected by a sequentially increasing component of the misclose.

Correction to i^{th} bearing $= -\frac{i \cdot \text{ang. misclose}}{n} = i \cdot \frac{33''}{6}$

n = number of bearings to be corrected = number of observed angles.

So in this example the first bearing is increased by 5.5”, then next bearing by 2*5.5 = 11”, then next by 3*5.5, etc

Pt	Angle	Brg	Cor	Adj Brg
TS1				
				190°12’35” Known
B40	94°10’00”			
		104°22’35”	5.5”	104°22’41”
1	178 19 00			
		102 41 35	11.0	102 41 46
2	118 21 45			
		41 03 20	16.5	41 03 36
3	194 42 25			
		55 45 45	22.0	55 46 07
4	158 07 30			
		33 53 15	27.5	33 53 42
B45	89 03 55			
		302 57 10	33.0	302 57 43
TS15				
		Misc -33”		**302 57 43** Known

COMPUTATION of COORDINATES

- The coordinates of the traverse stations are calculated from the adjusted bearings and distances (P→R):

  $\Delta E = d \sin\beta$ and $\Delta N = d \cos\beta$

- The sum of the ΔE and ΔN is compared to the given values obtained from the known coordinates of the start and end control station:
  misclose in ΔE: $m_E = \Sigma\Delta E$ – given ΔE
  misclose in ΔN: $m_N = \Sigma\Delta N$ – given ΔN

- Or, calculate coordinates along the traverse and compare last station coordinates with given values:
  misclose in ΔE: m_E = Calc E – given E (of last point)

misclose in ΔN: m_N = Calc N – given N (of last point)

- The linear misclose is calculated from: $m = \sqrt{{m_E}^2 + {m_N}^2}$

- The proportional misclose is obtained by: m_p = 1 : (D / m)

where D = total traverse length, by simply summing the observed distances for each line.

BLUNDER DETECTION in TRAVERSES

Remember: Preventing errors is much better than trying to find and correct errors later!

During a traverse gross errors can occur in the measurement of distances and/or angles. These errors may be due to a booking mistake, e.g.

- Transferring the wrong number from the display onto the field form.
- The booker mishearing the value that the observer is calling out.
- Swapping numbers (e.g. book 68.123 instead of 86.123).

Other error sources include errors in centring and levelling of the instrument, observing to a target other than the intended target (or using wrong target ID), setting scale factors, additive constants and atmosphere corrections incorrectly. There are even more possible error sources. Some methods to prevent or detect measurement errors as they occur are taught in other surveying courses. Methods include using instruments that allow direct download of measurements from instruments to computers, or doing calculations within the instrument. Another method is to check measurement consistency of the individual readings, e.g. comparison of two faces or two arcs of an angle, or comparison of forward and backward distance measurement of each traverse line.

A large misclose indicates that a gross error occurred in the traverse. How do we discover where the gross error occurred if we have one distance error or one angle error? Hopefully, you haven't made more than one error! Large errors are usually easier to find than small errors.

What is a large misclose? That depends on the equipment and procedures used. Generally any misclose that is significantly larger than the specified or required value or, by experience significantly larger than the values obtained in similar previous traverses. Specified or required values for traverses can be set by clients or for example by state legislation for cadastral surveys or national standards for control surveys. The standards for surveys governed by the NSW **Surveying Regulation 2006** (www.legislation.nsw.gov.au) are:

- Angular misclose < 20" +10√n or 2'
- Linear misclose < 15mm + 100ppm
- Measure lengths to 10mm + 15ppm or better at a 95% confidence interval.

In the past it was customary in NSW to apply tests the misclose ratio. The linear misclose, was not to exceed a specified value depending on the type of survey, e.g. Misclose < S / 8000, S = traverse length [km]. For a cadastral traverse in NSW the required accuracy used to be better than 1/8000, for example. For further reading on Traverse Design and Specifications such as mark types, accuracy etc see: www.lands.nsw.gov.au/publications/guidelines/surveyor_generals_directions (SG Directions 1, 2 and 11).

In Australia the Standards and Practices for Control Surveys, frequently referred to as Special Publication 1 (SP1), is produced by the Intergovernmental Committee on Surveying and Mapping. It is available for free download at http://www.icsm.gov.au/icsm/publications/sp1/sp1.html

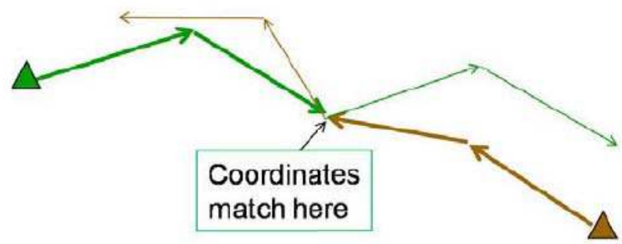
Student traverses at UNSW usually have miscloses less than 20" and 15mm.

ANGULAR ERROR

A large error in the measurement of an angle will cause a large angular misclose in a traverse.

Method 1

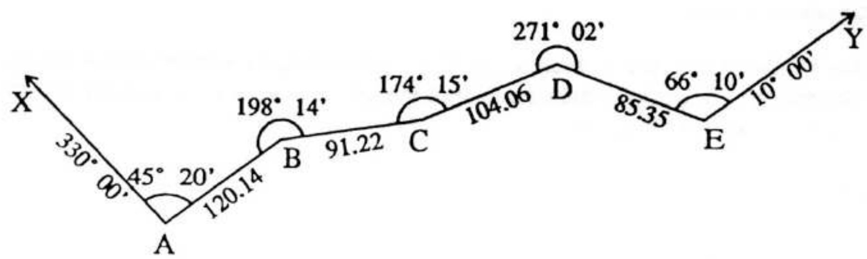
Compute the traverse coordinates from both ends of the traverse without adjusting the angular misclose. The station at which the coordinates from both computations agree closely (usually within a few cm) is the station at which the gross angular error occurred. This is because the erroneous angle has not been used to determine coordinates of points up to and including the point with the angle error. This method can be applied to closed line traverses or loop traverses. An angular error can also occur at the start or end point of the traverse, this method can detect that too.



A spreadsheet for traverse calculations can be modified to do these calculations. Alternatively, a surveying CAD program can do the calculations and provide a plan for visual identification of the likely error point. In the CAD program enter the control points by their coordinates, then enter two traverses one from each end.

Example:

Find the station at which a gross angular error occurred in the following traverse. The coordinates of control points A and E are known, A is (100.00, 100.00) and E is (309.50, 331.80). Figure below is not to scale.



Solution:

Forward Computation — Backward Computation

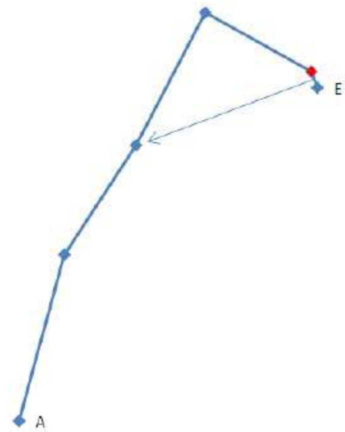
Station	Bearing	Distance	Easting	Northing		*Station*	Bearing	Distance	Easting	Northing
A			**100.00**	**100.00**		E			**309.50**	**331.80**
	15° 20'	120.14					303° 50'	85.35		
B			131.77	215.86		D			238.60	379.32
	33° 34'	91.22					212° 48'	104.06		
C			182.21	291.87		C			182.23	291.85
	27° 49'	104.06					218° 33'	91.22		
D			230.76	383.91		B			125.39	220.51
	118° 51'	85.35					200° 19'	120.14		
E			305.52	342.72		A			83.67	107.85
	5° 01'						334° 59'			
Y						X				

The angular misclose is about 5°. If only one angle was wrong then the angular error occurred at C because the two directions of computation yield differences of about 2cm in coordinates for C. The coordinates of the other points differ by 100s of metres. The angle at C should have been about 179°15'.

Method 2

The perpendicular bisector of the misclose vector will pass through the station at which the error occurred. This method is not reliable if the misclose is small.
Computational steps:

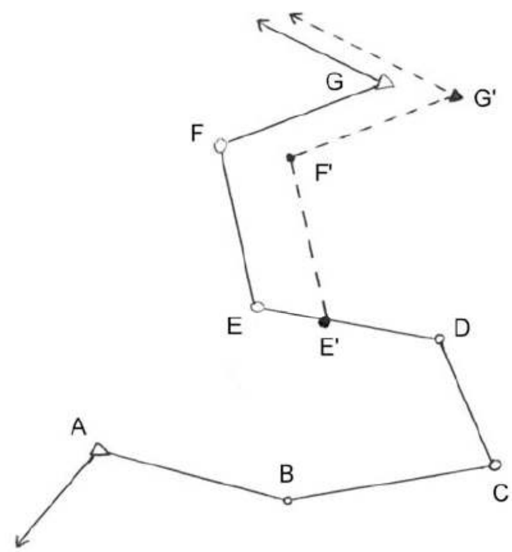
1) Calculate the coordinates of each traverse station.
2) Determine the bearing of the misclose vector.
3) Calculate the mid-point M of the misclose.
4) Calculate the bearings from M to all traverse stations.
5) The bearing that is approx perpendicular to the misclose vector indicates at which station the error occurred.



DISTANCE ERROR

I suggest you look for angular errors before distance errors, because angle errors are indicated by the angle misclose and distances are not involved. If the angular misclose is small then to detect distance errors we use the coordinate miscloses which depend on angles / bearings as well as distances.

An error in the distance measurement of a traverse line will cause a larger linear misclose. The bearing of the misclose will be approximately the same as the bearing of the line containing the error. This enables the erroneous line to be identified. This method can be applied to closed line traverses or loop traverses. In the figure below, an error in the distance DE will create an error in the coordinates of G the bearing of the misclose G'G will be close to the bearing of the line DE if the distance error is large.

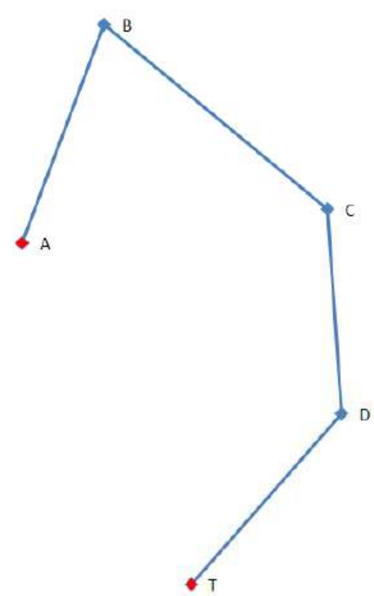


Example:

The bearing and distance of each traverse line has been measured. The coordinates of the control points on either end (A and T) are known.

	East	North
A	1043.216	2117.910
T	1112.492	1972.858

Line	Bearing	Distance
AB	20° 01' 30"	98.231
BC	130° 20' 40"	120.556
CD	176° 15' 50"	78.141
DT	220° 33' 40"	95.213



Computational steps:

1) Calculate the coordinates of each traverse station.
2) A large linear misclose (between the calculated and given coordinates of T) indicates a gross error.
3) Calculate the bearing and distance of the misclose (i.e. the line T'T).

4) The bearing of the misclose will identify the erroneous line and the distance will indicate the magnitude of the error.

Solution:

T' (calculated):	1111.916	1981.846
T (given):	1112.492	1972.858

→ line T'T: $\Delta E = 0.576m$ $\Delta N = -8.988m$ → $\beta = \tan^{-1}(\Delta E/\Delta N) = 176°19'59"$ $d = 9.006m$

This indicates that the error is probably in line CD that was β = 176°15'50", d = 78.141m.
The length of this line should probably be d = 87.141m.

Other blunders

Error in control point coordinates:

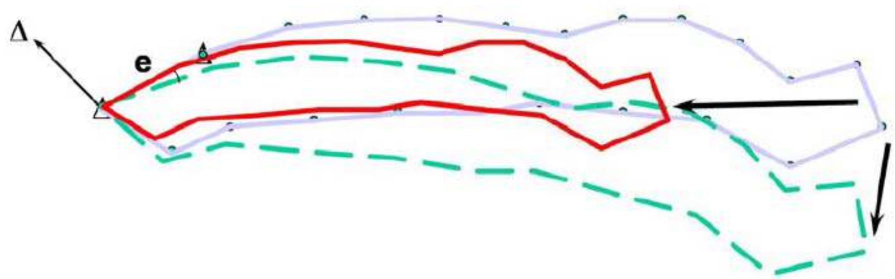
A large misclose could perhaps be caused by an error in one or more of the coordinates of the control points. In this case the bearing of the misclose will be close to 0/180° or 90/270°, if only one coordinate is wrong. If both E and N are incorrect (for example using the wrong survey mark) then the misclose could be large and the bearing may not be parallel to any of the traverse lines.

Scale error in distances:

There could be a scale error in your distances due to calculation errors or incorrect instrument calibration. For example, a map scale factor is wrong, or not applied or applied in opposite direction, so that lines are longer when they should have been shorter. A scale error in distances in a traverse between control points will cause a misclose.

Loop traverses:

Long loop traverses are risky because errors propagate and there is no warning about, or check for, scale errors or azimuth control in the miscloses.



DISTRIBUTION of MISCLOSE

The distribution of angular misclose has been discussed earlier. **IF** the misclose in E and N is small then it can be adjusted (i.e. distributed) using the Bowditch method or Transit or other methods. The Bowditch and Transit methods are described below and in many surveying textbooks. The adjusted ΔE and ΔN are then used to obtain the final coordinates of the traverse stations.

Bowditch's method causes the already adjusted bearings to be altered to a much greater extent than does the Transit method (particularly for N-S and E-W lines). The Transit method alters distances more than Bowditch. The Bowditch method has traditionally been more popular in NSW. A Least Squares adjustment is a much better way to adjust a traverse, but is taught in a following course not in this course.

Bowditch method

This method assumes errors in distance and angle cause equal displacement of a point.
The values of the adjustment are directly proportional to the length of the traverse lines.

$$\text{correction to } \Delta E = -\frac{\text{total error in } \Delta E}{\text{total length of traverse}} \cdot \text{length of side} = -\frac{m_E}{D} d_i$$

$$\text{correction to } \Delta N = -\frac{\text{total error in } \Delta N}{\text{total length of traverse}} \cdot \text{length of side} = -\frac{m_N}{D} d_i \qquad \text{where } D = \Sigma d_i$$

Transit method

The values of the adjustment are proportional to the values of ΔE and ΔN for each traverse line. The lengths of the traverse lines are not included in the calculations.

$$\text{correction to } \Delta E = -\frac{\text{total error in } \Delta E}{\text{sum of the } |\Delta E|} \cdot |\Delta E| \text{ of } i^{th} \text{ line} = -\frac{m_E}{\Sigma |\Delta E|} |\Delta E_i|$$

$$\text{correction to } \Delta N = -\frac{\text{total error in } \Delta N}{\text{sum of the } |\Delta N|} \cdot |\Delta N| \text{ of } i^{th} \text{ line} = -\frac{m_N}{\Sigma |\Delta N|} |\Delta N_i|$$

Example traverse 1 – Linear misclose and adjusted coordinates

Here we continue with the example traverse given near the start of this chapter, from B40 to B45.
Use the horizontal distances and adjusted bearings and to calculate coordinate differences.
Either use a calculator's P→R or computer's: $\Delta E = d \sin\beta$ $\qquad \Delta N = d \cos\beta$

Calculate misclose in Easting and Northing: $m_E = \Sigma\Delta E - \text{given } \Delta E$ $\qquad m_N = \Sigma\Delta N - \text{given } \Delta N$

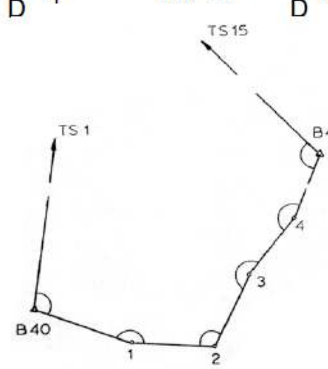
Use Bowditch's rule to correct ΔE and ΔN: $\text{corr } \Delta E = -\frac{m_E}{D} d_i$ $\qquad \text{corr } \Delta N = -\frac{m_N}{D} d_i$

Check: Σ corr $\Delta E = -m_E$ and Σ corr $\Delta N = -m_N$

Check: last coordinates calculated = given coordinates

Linear misclose: $m = \sqrt{m_E^2 + m_N^2}$

Proportional misclose $m_p = 1 : N$ where $N = \frac{D}{m}$



Pt	Adj Brg			Dist	DE	cor E	Easting	DN	cor N	Northing
B40	°	'	"				**406.347**			**423.509**
	104	22	41	103.402	100.163	-0.001		-25.676	0.003	
1							506.509			397.836
	102	41	46	157.225	153.381	-0.002		-34.555	0.005	
2							659.888			363.286
	41	03	36	143.369	94.172	-0.002		108.103	0.004	
3							754.058			471.393
	55	46	07	169.087	139.796	-0.002		95.118	0.005	
4							893.852			566.516
	33	53	42	176.743	98.565	-0.002		146.707	0.006	
B45							992.415			713.229
						Given:	**992.415**		Given:	**713.229**
			Σ	749.826	586.078			289.697		
				Known:	586.068			289.720		
					0.010	-0.010		-0.023	0.023	
				Linear Misclose:		0.025		Ratio 1:	29643	

Table. Bowditch traverse adjustment example. Distances and coordinates are in metres.

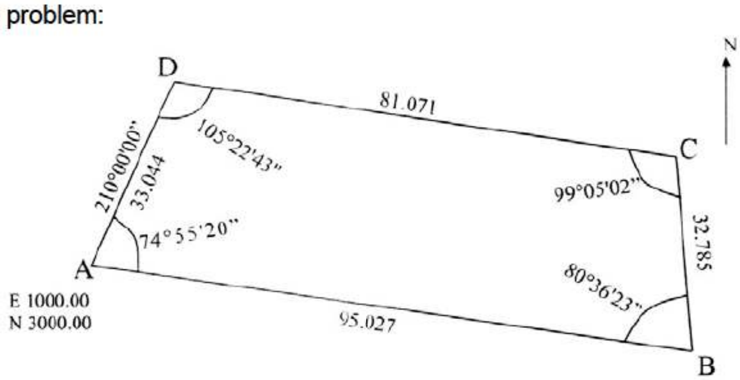
Example 2: Loop Traverse

A loop traverse ABCD was observed with the following data. Calculate the coordinates (easting and northing) of the points B, C, and D, of the traverse from the following data:

	Angle	Line	Distance (m)
A	74° 55' 20"	AB	95.027
B	80° 36' 23"	BC	32.785
C	99° 05' 02"	CD	81.071
D	105° 22' 43"	DA	33.044

Given coordinates of A: E 1000.00, N 3000.00   Given bearing of line D to A: 210°00'00".

1) Visualise the problem:



Calculator Calculations

2) Calculate the angular misclose: $m_\alpha = \Sigma \text{ angles} + \Delta\beta - (n-2) \cdot 180°$

with n = number of angles (incl. $\Delta\beta$)   For loop traverse $\Delta\beta = 0$.

3) Correct each angle for the angular misclose: $corr = -\dfrac{m_\alpha}{n}$ Check: Σ corr = - angular