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VERTICAL NETWORK ADJUSTMENT USING FUZZY GOAL PROGRAMMING

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ABSTRACT

In engineering, especially in Surveying Engineering, vertical network adjustment is made to find out the definite values of the unknowns and the measurements. Generally Least Square Method (LS) is used for vertical network adjustment. By this study, FGP method, proposed as an alternative method to LS Method for vertical network adjustment, is explained with an example, and results are compared. Results found by using these two methods, are close to each other. It is shown that FGP Method can be used in vertical network adjustment. Only the level differences between the points have been used. Approximate height values of the points that have been used in Least Square Method have not been used in Fuzzy Goal Programming Method.

Keywords: Fuzzy Goal programming; Least Squares; Vertical Network Adjustment

1. INTRODUCTION

The aim of the network adjustment is to find out the optimum values of the unknowns and the measurements, performed much more than needed. Through the sensitiveness and reliance of the surveys, certain values and their functions are set. In other words, the statistical analysis of mathematical model which is used is made. During the network adjustment, measurements are accepted as normally distributed. To perform this aim Least Squares (LS) method of Gauss is applied. This method is widely used in Surveying Engineering.

FGP method has been proposed instead of LS in this research for network adjustment. FGP is based on GP formed by Charnes and Cooper [8, 9]. GP is widely spread out by Iijiri [16], Lee [19] and Ignizio [18]. The principal concept for linear GP is to the original multiple objectives into specific numeric goal for each objective. The objective function is than formulated and a solution is sought which minimizes the weighted sum of deviations from their respective goal [7].

Nowadays, GP is one of the most important methods of Multi-Criteria Optimization methods. The main idea in GP is to determine goals for each constraint [30]. The GP is multi objective programming model based on the distance function concept where the decision-maker looks for the solution that minimizes the absolute deviation between the achievement level of the objective and its aspiration level [5]. GP is a common tool used in decision making, but providing crisp goals can be a problem for a decision maker. Since Zadeh [39] proposed the concept of fuzzy sets, Bellman and Zadeh [6] have developed a basic framework for decision making in a fuzzy environment. Thereafter, research followed [23, 33] in which Narasimhan [25] and Hannan [14] extended the fuzzy set theory to the field of goal programming [35]. A fuzzy programming approach for linear programming problems with several objectives was formed by Zimmerman [41]. Narasimhan [25] recommend a complex method for dealing with the GP problem with fuzzy goal and mentioned an approach to deal with fuzzy priority in 1980 [10].

2. LITERATURE REVIEW

There have been a number of works on FGP. Samples are: Transportation problem with multiple objective function [12, 21, 34, 40], production

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planning with multiple efficiency criteria [7, 17], input-output model for resource allocation, portfolio management [27], operation scheduling [13, 28] and equipment-purchasing problem [10] are only examples of these applications.

There have been a number of works on LS. Samples are: robust source localization [36], estimating regional deformation [11], smoothing and differentiation [29] and global positioning [2].

The vertical network adjustment has been performed by GP in research paper by Alp et all [4]. To see the application in Surveying Engineering by the application of FGP similar results, which are perceived in LS method, are observed. This shows that FGP may be used as an alternative method in Surveying Engineering. FGP is expected to give more effective results than GP, because the amount of deviation is used in the adjustment, and the results are within the limits of the amount of this deviation.

3. LEAST SQUARE

3.1. Generalized Least Square

Generalized least squares (GLS) is a method for estimating the unknown parameters in a linear regression model. The GLS is applied when the variances of the observations are unequal, or when there is a certain degree of correlation between the observations.

A set of N pairs of observations $\{Yi, X_i\}$ is used to find a function relating the value of the dependent variable (Y) to the values of an independent variable (X) In the standard formulation, With one variable and a linear function, the prediction is given by the following equation:

$$\widehat{Y} = a + bx \tag{1}$$

This equation involves two free parameters which specify the intercept (a) and the slope (b) of the regression line. The least square method defines the estimate of these parameters as the values which minimize the sum of the squares between the measurements and the model. This amounts to minimizing the expression:

$$\varepsilon = \sum_i \left(Y_i - \widehat{Y}_i\right)^2 = \sum_i \left[Y_i - \left(a + bX_i\right)\right]^2 \tag{2}$$

The estimation of the parameters is gotten using basic results from calculus and, specifically, uses the property that a quadratic expression reaches its minimum value when its derivatives vanish. Taking the derivative of ε with respect to a and b and setting them to zero gives the following set of equations.

$$\frac{\partial \varepsilon}{\partial a} = 2Na + 2b\sum X_i - 2\sum Y_i = 0 \tag{3}$$

and

$$\frac{\partial \varepsilon}{\partial b} = 2b\sum X_i^2 + 2a\sum X_i - 2\sum Y_i X_i = 0 \tag{4}$$

The following least square estimates of a and b are obtained by solving the normal equations:

$$a = M_Y - bM_X \tag{5}$$

M_Y: Denoting the means of Y
M_X: Denoting the means of X

and

$$b = \frac{\sum \left(Y_i - M_Y\right)\left(X_i - M_X\right)}{\sum \left(X_i - M_X\right)^2} \tag{6}$$

LS can be extended to more than one independent variable and to non-linear functions [1].

3.2. Network Adjustment According to Least Square

Mathematical model in network adjustment is formed of two constituents. One of them is called functional model and the other is called stochastic model [31]. These constituents form the base of adjustment account. These models are formed before the adjustment.

Geometric height difference between the points A and B,

$$\Delta h_{AB} = \sum_A^B dh \tag{7}$$

by adding orthometric correction to this expression *(db_{AB})*

$$\Delta H_{AB} = \Delta h_{AB} + d_{AB} \tag{8}$$

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orthometric height differences are calculated. Heights of the points *(H_p)* are selected as unknowns in survey networks. Orthometric height differences are adjusted by the method of Least Square Adjustment. We can form the functional model that is between the measured height differences between the points P_i and P_j and the adjusted heights H_i and H_j as below,

$$h_{ij} + v_{ij} = H_j - H_i \quad (9)$$

According to this model, the correction equations v_{ij}, formed for the height differences h_{ij}

$$v_{ij} = -dh_i + dh_j - l_{ij} \quad (10)$$

and the constant terms *($-l_{ij}$)*;

$$-l_{ij} = H_j^{\circ} - H_i^{\circ} - h_{ij} \quad (11)$$

In this equation, H_i^0 and H_j^0 are approximate heights of the points P_i and P_j. Stochastic, model that is formed by the definition of weights of the measurements, is;

$$P_{ij} = \frac{1}{S_{ij}} \quad (12)$$

Normal equations, formed by correction equations formed by equation (9) and the weights calculated by stochastic model (12), are solved using modernized Gauss Algorithm.

Adjustment unknowns dh_i and invers weight matrics Q_{hh} of those are calculated. Adjusted heights of the points are calculated using below equation.;

$$H_i = H_i^{\circ} + dh_i \quad (13)$$

Adjusted values of height differences are calculated using below equation

$$\bar{h}_{ij} = h_{ij} + v_{ij} \quad (14)$$

$$\bar{h}_{ij} = H_j + H_i \quad (15)$$

and result equations are calculated using above equation Mean square root error value (a posteriori) of unit measurement.

$$m_0 = \mp\sqrt{\frac{[Pvv]}{n-u}} \quad (16)$$

n: number of measured height differences
u: number of unknowns

Mean error of height difference

$$m_i = \mp m_0 \sqrt{S_i} \quad (17)$$

S_i: length of alignment (km)

Mean errors of adjusted heights

$$m_{H_J} = \mp m_0 \sqrt{qh_i h_i} \quad (18)$$

qh_ih_i: diagonal term of matrics Q_{hh}

A priori value of mean error of unit measurement that is obtained from differences of departure and return measurements.

$$S_0 = \mp\sqrt{\frac{[Pdd]}{4n}} \quad (19)$$

Integrity of variance is calculaced by the help of experimental tests

$$T = \frac{m_0^2}{s_0^2} \quad (20)$$

Meaning full of the results is tested choosing the possibility of error as α=%5 [20, 26].

4. FUZZY GOAL PROGRAMMING MODEL

Goal Programming Method is not only a technique to minimize the sum of all deviations, but also a technique to minimize priority deviations as much as possible [4].

The general form of a multi objective programming is as follows;

$$\left.\begin{array}{l} \max/\min Z = Cx \\ Ax \le b \end{array}\right\} (21)$$

$Z = (z_1, z_2, \ldots, z_k)'$ is vector of objectives,
C is a *(KxN)* matrix of constants,
X is an *(Nx1)* vector of decision variables,

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A is an (MxN) matrix of constants,
b is an $(Mx1)$ vector of constants [24].

Goal Programming is a common tool used in decision making, but providing crisp goals can be a problem for decision makers [35].

Linear membership functions are used in literature and practice more than other types of membership functions. For the above three types of fuzzy goals linear membership functions are defined and depicted as follows (Figure 1):

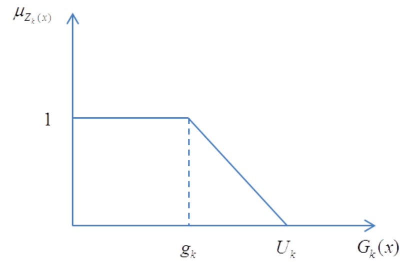
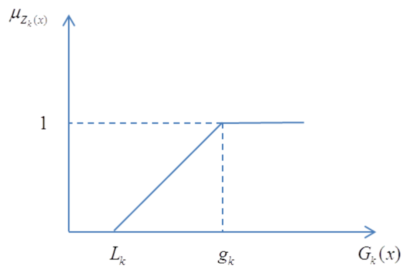
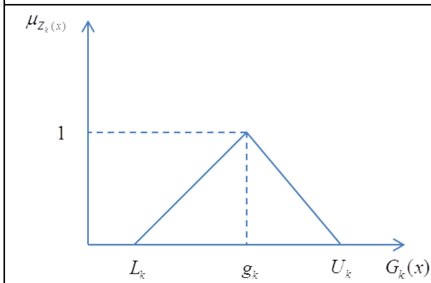
Membership Function	Analytical Definition
	$\mu_{Z_k(x)} = \begin{cases} 1 & if \;\; G_k(x) \le g_k \\ \dfrac{U_k - G_k(x)}{U_k - g_k} & if \;\; g_k \le G_k(x) \le U_k \;\; k = 1,...m \\ 0 & if \;\; G_k(x) \ge g_k \end{cases}$
	$\mu_{Z_k(x)} = \begin{cases} 1 & if \;\; G_k(x) \ge g_k \\ \dfrac{G_k(x) - L_k}{g_k - L_k} & if \;\; L_k \le G_k(x) \le g_k \;\; k = m+1,...n \\ 0 & if \;\; G_k(x) \le L_k \end{cases}$
	$\mu_{Z_k(x)} = \begin{cases} 1 & if \;\; G_k(x) \le L_k \\ \dfrac{G_k(x) - L_k}{g_k - L_k} & if \;\; L_k \le G_k(x) \le g_k \;\; k = n+1,...i \\ \dfrac{U_k - G_k(x)}{U_k - g_k} & if \;\; g_k \le G_k(x) \le U_k \\ 0 & f \; G_k(x) \ge U_k \end{cases}$

Figure 1. Linear membership function and Analytical definition

The fuzzy programming approach for handling the multi-objective problems was firstly introduced but Zimmermann [41]. Starting from goal programming model (21) the adopted fuzzy version according to Zimmermann is

$$\left.\begin{aligned} & Cx \gtrsim Z \\ s.t. \quad & Ax \lesssim b \end{aligned}\right\} (22)$$

Where $\gtrsim$ and $\lesssim$ are the fuzzification of $\geq$ and $\leq$, respectively. $\gtrsim$ ($\lesssim$) means "essentially greater (less) than".

Since Narasimhan [25] had presented the initial FGP model and the solution procedure, a few studies have proposed FGP models for improving the computational efficiency. Hannan [14, 15] has introduced conventional deviation variables into the model, so that only a conventional linear programming formulation is required; although, this increases the number of variables in the formulation [32]. Zimmerman type member functions are used in the approaches that have been developed for the solution of Fuzzy goal programming models. Zimmerman's triangular member functions for fuzzy inequalities are as follows:

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$G_k(x)$: k^{th} fuzzy goal,

b_k: access value that is determined by decision maker for k^{th} goal,

d_{k1}: access value that is determined by decision maker for k^{th} goal,

d_{k2}: maximum positive deviation that is allowed from access value b_k .

$$G_k(x) \cong b_k \left\{ \mu_k = \begin{array}{ll} 0 & if\ G_k(x) \geq b_k + d_{k2} \\ 1 - \dfrac{G_k(x) - b_k}{d_{k2}} & if\ b_k \leq G_k(x) \leq b_k + d_{k2} \\ 1 - \dfrac{b_k - G_k(x)}{d_{k1}} & if\ b_k - d_{k1} \leq G_k(x) \leq b_k \\ 0 & if\ G_k(x) \leq b_k - d_{k1} \end{array} \right\} \quad (23)$$

$$G_k(x) \tilde{<} b_k \left\{ \mu_k = \begin{array}{ll} 0 & if\ G_k(x) \geq b_k + d_{k2} \\ 1 - \dfrac{G_k(x) - b_k}{d_{k1}} & if\ b_k \leq G_k(x) \leq b_k + d_{k2} \\ 1 & if\ G_k(x) \leq b_k \end{array} \right\} \quad (24)$$

$$G_k(x) \tilde{>} b_k \left\{ \mu_k = \begin{array}{ll} 0 & if\ G_k(x) \leq b_k + d_{k2} \\ 1 - \dfrac{b_k - G_k(x)}{d_{k1}} & if\ b_k - d_{k1} \leq G_k(x) \leq b_k \\ 1 & if\ G_k(x) \geq b_k \end{array} \right\} \quad (25)$$

Goal Deviations, The goals for each objective are considered for each objective functions namely under achievement and over achievement goals. Initially, the upper and lower bounds for each objective functions are estimated and then the goals are included as by adding the under achievement and removing the over achievement for each objective on the left hand side of the objectives as variables [34].

5. APPLICATION

5.1. Problem

The surveys made in leveling network to determine the height of the points of the earth is given in Table 1, and approximate elevations is given in Table 2.

Table 1: Level Differences

	From Point	To Point	h_{ik} (m)
1	1	0	6,782
2	2	1	5,116
3	2	3	3,553
4	3	4	2,944
5	4	0	5,402
6	2	0	11,907
7	3	0	8,364
8	3	1	1,575
9	4	2	6,500

As shown in Table 1, the measurement from point 1 towards point 0 was calculated and the value was determined as 6,782 m. Similarly, the measurement calculated from point 2 towards point 1, the value was determined as 5,116 m, and the measurement from point 2 to point 3 the value was determined as 3,553 m. Other measurements are as shown in the above Table.

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Table 2: Approximate Elevations

Point	H^0_i (m)
0^*	40,500
1	46,780
2	51,900
3	48,360
4	45,400

Table 2 shows the heights of the points. The height of point (0) has been fixed at 40, 500 m. The heights of the other points have been measured and the approximate heights, containing measurement error values, have been determined.

A software developed by Yavuz [38] is used to solve the problem according to LS adjustment and WinQSB is used to solve the problem according to FGP.

5.2 Using the Least Square in Network Adjustment

In Table 3, given correction equations listed below have been formed by using data in Table 1.

Table 3: Correction Equations

	v_{ij}		$-l_{ij}$
1	$v_{1,0}$	$+d_0-d_1$	$+H^0_0-H^0_1-h_{1,0}$
2	$v_{2,1}$	$+d_1-d_2$	$+H^0_1-H^0_2-h_{2,1}$
3	$v_{2,3}$	$+d_3-d_2$	$+H^0_3-H^0_2-h_{2,3}$
4	$v_{3,4}$	$+d_4-d_3$	$+H^0_4-H^0_3-h_{3,4}$
5	$v_{4,0}$	$+d_0-d_4$	$+H^0_0-H^0_4-h_{4,0}$
6	$v_{2,0}$	$+d_0-d_2$	$+H^0_0-H^0_2-h_{2,0}$
7	$v_{3,0}$	$+d_0-d_3$	$+H^0_0-H^0_3-h_{3,0}$
8	$v_{3,1}$	$+d_1-d_3$	$+H^0_1-H^0_3-h_{3,1}$
9	$v_{4,0}$	$+d_0-d_4$	$+H^0_0-H^0_4-h_{4,0}$

V_{ij} : Corrections
d_{ij} : Corrections Unknows
H_i^0 : Appoximate elevations
h_{ij} : Elevation Differences

The table below shows the results of the Vertical Network Adjustment equation that has been solved according to Least Square Method.

Table 4: LS Solution

Point	Value
x_0	40,500
x_1	46,881
x_2	52,003
x_3	48,454
x_4	45,503

5.3 Using the Fuzzy Goal Programming in Network Adjustment

The aim of network adjustment is to find out the optimum values by distributing the corrections of the measurements in a proper way. To implement this aim generally LS method is used.

In this study vertical network adjustment is made by using both LS and FGP methods. The height values of 5 points in the network are accepted as decision variables (X_i) in network adjustment by FGP. By FGP model, values of decision variables, in other words adjusted height values of points in network, are obtained.

9 level differences surveyed between two points (h_{ij}) in network are accepted as goal values. The level differences between the two surveyed points are equalized approximately to a measured level difference accepted as the goal value. 9 goals are obtained by adding the deviation variables to the equalities and 1 absolute constraint are given.

The height of the zero point is accepted fixed and the result is transferred as absolute constraint.

$$x_0 = 40,500 \qquad (26)$$

In this situation, goal programming model of given experiment,
Goals,

$$\left.\begin{aligned}
&Goal\,1: x_0 - x_1 \cong 6,782\\
&Goal\,2: x_1 - x_2 \cong 5,116\\
&Goal\,3: x_3 - x_2 \cong 3,553\\
&Goal\,4: x_4 - x_3 \cong 2,944\\
&Goal\,5: x_0 - x_4 \cong 5,402\\
&Goal\,6: x_0 - x_2 \cong 11,907\\
&Goal\,7: x_0 - x_3 \cong 8,364\\
&Goal\,8: x_1 - x_3 \cong 1,575\\
&Goal\,9: x_4 - x_2 \cong 6,500
\end{aligned}\right\} \qquad (27)$$

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Absolute constraint

$$x_0 = 40,500 \quad (28)$$

$$x_0, x_1, x_2, x_3, x_4 \geq 0 \quad (29)$$

Zimmerman's triangular member function and max-min approach of Bellman and Zadeh [6] are used in experiment of this study. Goals that have been used in the model are accepted as fuzzy, thus goals have been taken as flexible. Tolerance value has been taken as 0,2 for goals. The goals are shown in Table 5.

Table 5: Goals of FGP

	Points	Goals
1	(1-0)	$\lambda \leq 1 - \frac{(x_0 - x_1) - 6,280}{0,2}, \lambda \leq 1 - \frac{6,280 - (x_0 - x_1)}{0,2}$
2	(2-1)	$\lambda \leq 1 - \frac{(x_1 - x_2) - 5,120}{0,2}, \lambda \leq 1 - \frac{5,120 - (x_1 - x_2)}{0,2}$
3	(2-3)	$\lambda \leq 1 - \frac{(x_3 - x_2) - 3,540}{0,2}, \lambda \leq 1 - \frac{3,540 - (x_3 - x_2)}{0,2}$
4	(3-4)	$\lambda \leq 1 - \frac{(x_4 - x_3) - 2,960}{0,2}, \lambda \leq 1 - \frac{2,960 - (x_4 - x_3)}{0,2}$
5	(4-0)	$\lambda \leq 1 - \frac{(x_0 - x_4) - 4,900}{0,2}, \lambda \leq 1 - \frac{4,900 - (x_0 - x_4)}{0,2}$
6	(2-0)	$\lambda \leq 1 - \frac{(x_0 - x_2) - 11,400}{0,2}, \lambda \leq 1 - \frac{11,400 - (x_0 - x_2)}{0,2}$
7	(3-0)	$\lambda \leq 1 - \frac{(x_0 - x_3) - 7,860}{0,2}, \lambda \leq 1 - \frac{7,860 - (x_0 - x_3)}{0,2}$
8	(3-1)	$\lambda \leq 1 - \frac{(x_1 - x_3) - 1,580}{0,2}, \lambda \leq 1 - \frac{1,580 - (x_1 - x_3)}{0,2}$
9	(2-4)	$\lambda \leq 1 - \frac{(x_4 - x_2) - 6,500}{0,2}, \lambda \leq 1 - \frac{6,500 - (x_4 - x_2)}{0,2}$

When the multi-purpose fuzzy goal programming equations shown above (27), (28) and (29) are solved, the results are as shown in Table 6.

Table 6: FGP Solution

Point	Value
x_0	*40,500*
x_1	46,880
x_2	52,010
x_3	48,460
x_4	45,500

5.4. Comparison between Least Square and Fuzzy Goal Programming

Taking the height of point (0) as fixed, by the help of the measured heights of 5 points; adjusted heights are obtained in both methods.The conclusions obtained in both methods are given in Table 7.

Taking the height of point (0) as fixed, by the help of the measured heights of 5 points; adjusted heights are obtained in both methods.The conclusions obtained in both methods are given in Table 7.

H_0 : approximate heights of the points
H_E : adjusted heights of the points with LS
H_D : adjusted heights of the points with FGP

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Corrections related to measured level differences, received by both methods have been obtained in mm sensitivity. Level differences for both methods are obtained by adding the correction amount to the leveling measurements.

For both methods; comparing level differences between 7 different measured points and adjusted heights of the points, the result control of the adjustment in both methods is done. The comparisons obtained in both methods are given in Table 8.

Table 7: Leveling Adjustment with LS and FGP

Point	Approximate H_0 (m)	LS		FGP		Differences LS-FGP	
		Corrections	Adjusted H_E (m)	Corrections	Adjusted H_D (m)	m	mm
x_0	40,500	0,000	40,500	0,000	40,500	0,000	0
x_1	46,780	-0,101	46,881	-0,100	46,880	-0,001	-1
x_2	51,900	-0,103	52,003	-0,110	52,010	0,007	7
x_3	48,360	-0,094	48,454	-0,100	48,460	0,006	6
x_4	45,400	-0,103	45,503	-0,100	45,500	-0,003	-3

Table 8: Comparison between LS and FGP Results

	Level Differences H_0 (m)	LS		FGP		Differences (LS-FGP)	
		Corrections	Adjusted H_E (m)	Corrections	Adjusted H_E (m)	m	mm
(1-0)	6,280	-0,101	6,381	-0,100	6,380	0,001	1
(2-1)	5,120	-0,002	5,122	-0,010	5,130	-0,008	-8
(2-3)	3,540	-0,009	3,549	-0,010	3,550	-0,001	-1
(3-4)	2,960	0,009	2,951	0,000	2,960	0,009	9
(4-0)	4,900	-0,103	5,003	-1,100	5,000	0,003	3
(2-0)	11,400	-0,103	11,503	-0,110	11,510	-0,007	-7
(3-0)	7,860	-0,094	7,954	-0,100	7,960	-0,006	-6
(3-1)	1,580	0,007	1,573	0,000	1,580	-0,007	-7
(2-4)	6,500	0,000	6,500	-0,010	6,510	-0,010	-10

6. CONCLUSION

The functional and the stochastic models of the adjustment which are used are appropriate according to LS approach.

Close values to the values obtained by LS method are received by using FGP method which is a minimizing of deviation of the targets whose aims are determined.

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The highest difference between the results of two methods is 10 mm.

In FGP method, different from LS method, without using the approximate height values of the points, but using only the level differences between two points, the height of the points are calculated close to the height values obtained according to LS.

In addition, the study made by FGP has been more effective results than the work previously carried out with GP. In the case of height values are unknown or can not be measured, in this study, it has been shown that FGP can be used.

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