International Conference on Management of Technology, Innovation, and Project (MOTIP) 2020
July 25th 2020, Institut Teknologi Sepuluh Nopember, Surabaya, Indonesia

A Combined AHP-GP for Maintenance Project Selection in Coal Power Plant

Hery Setiyawan[1] and Udisubakti Ciptomulyono[2]
[1]Department of BusinessTechnology Management, Institut Teknologi Sepuluh Nopember, Surabaya
[2]Department of Industrial and System Engineering, Institut Teknologi Sepuluh Nopember, Surabaya
e-mail: hsetiyawan888@gmail.com

***Abstract*—A proper maintenance project selection is a key to support performance of power plant. The issue of maintenance is allocation a limited budget to achieve the goals of various maintenance criteria and conflicting objectives. This paper presents an integrated AHP and goal programming. In the first step, since maintenance is measured in qualitative criteria, it is recommended to use AHP to weight and quantify criteria. Second step utilize GP which uses the criteria weights and alternative priorities calculated with AHP to optimize multiple objectives without exceeding available resource constraint. The results show that the approach can aid in selection optimal projects within available budget.**

***Keywords*—Analytic Hierarchy Process, Goal Programming, Performance, Project Selection.**

I. INTRODUCTION

THE growth of electricity generation in Indonesia is increasing at this time. This is to meet the National electrification program and meet customer growth. In the last 5 years (2012-2016) PLN's electricity sales have increased an average of 6.7% per year [1].

PT XYZ is a company that provides operation and maintenance (O&M) services for power plants. The management of power plants has a target to achieve key performance indicators that are included in O&M agreements with customers. Some of key performance indicator in power generation as follow [2]; (1)Availability can be measured in EAF (*Equivalent Availability Factor*) is the fraction of a given operating period in which a generating unit is available without any outages and equipment or seasonal deratings; (2)*Reliability* can be measured in some ways. Based on study and review show that Forced Outage Rate (EFOR) is the best measure of generating unit reliability [4].A measure of the probability that a generating unit will not be available due to forced outages or forced deratings; (3)*Efficiency* or expressed in Net Plant Heat Rate (NPHR) refers to increasing the efficiency of the unit or minimizing the occurrence of energy losses in the process equipments; (4)*Safety* refers to preventing the occurrence of unsafe conditions and hazards in the workplace that cause harm or injury to the worker.

Generating Availability Data System (GADS) [3] state that there are five key factors affected availability are maintenance and upgrade spending, unit aging, plant duty or cycling, availability incentive, and individual unit performance. Its important that operation and maintenance company achive the performance indicator in power generating unit by maintain the equipment performance. Some project improvement and rehabilitation on the equipment is needed because of ageing or plant duty cycle. Proper maintenance of plant equipment can significantly reduce the overall operating cost and increase productivity [5].

In literature, there are so many research project utilize AHP – GP approach in wide aplication. Study by Ciptomulyono (2000) [6], in such situations the project selection process will relate to the multi-criteria and multi-objective decision problems with quantitative and qualitative criteria which are difficult to measure, as well as project objectives in financial and non-financial terms. Therefore an integral decision model is needed that can accommodate multi-criteria and multi- objective decision problems. Multi Criteria Decision Making (MCDM) model based on Analytic Hierarchy Process (AHP) and Multiobjective Decision Making Model (MODM) in the form of 0-1 Goal Programming is integrated into a decision model for project evaluation / selection as well as optimizing the resources of the project.

Bertolini and Bevilacqua [5] applied the combined AHP - GP approach to define the best strategies for the maintenance of critical centrifugal pumps in an oil refinery. AHP approach to identified priority levels for the different maintenance policies with respect to the FMECA criteria and the GP method used to identify the best set of maintenance type for the equipment failure modes considered. Ho [7] appiled the combined AHP - GP approach to design the logistics distribution network for selecting the best set of warehouses without exceeding the limited available resources. Rusli and Ciptomulyono [8] applied the combined AHP – GP approach to select the contractors for turbine rotor repair of power plant with criteria and subject to avaialable budget. Badri [9] applied AHP – GP approach to help selecting the best set of quality control instruments for customer data collection purpose which AHP approach to weighting of service quality criteria and utilize GP approach to select optimal service quality control instruments with respect to resource limitation (i.e., budget, manhour, labor).

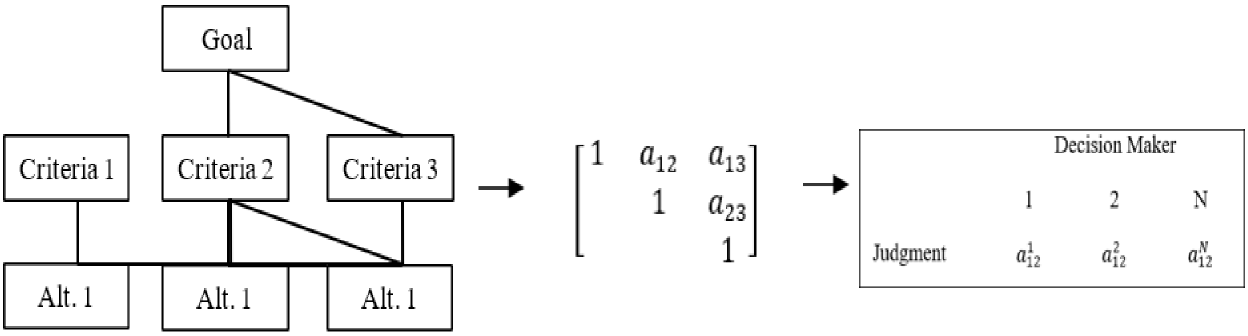
II. METHOD

A. AHP

The Analytic Hierarchy Process (AHP) provides the objective mathematics to process the inescapably subjective and personal preferences of an individual or a group in making a decision.Fundamentally, the AHP works by developing priorities for alternatives [10]. AHP is applied to support many types of multi-criteria decision problems. It has particular application in group decision-making, and it has recently become increasingly popular around the world in a

Table 1.
The fundamental scale

Intensity of importance	Definition	Explanation
1	Equal Important	Two factor contribute equally to the objective
3	Moderate importance	Experience and judgment slightly favour one over the other
5	Strong importance	Experience and judgemnet strongly favour one over the other
7	Very strong importance	An activity is strongly favored and its dominance demonstrated in practice
9	Extreme importantce	The evidence favoring one over the other is of highest possible validity
2, 4, 6, 8	Intermediate value	When compromise is needed



(a) (b) (c)
Figure 1. (a) Hierarchy structure in AHP; (b) individual judgment; (c) Group decision from individual judgment.

Table 2.
Conversion of LP Constrain to Goal Constrains

LP Constrain	Goal Constrain	Minimized in objective Function
$g_i(x) \geq b_i$	$g_i(x) + n_i - p_i = b_i$	n_i
$g_i(x) \geq b_i$	$g_i(x) + n_i - p_i = b_i$	p_i
$g_i(x) \geq b_i$	$g_i(x) + n_i - p_i = b_i$	$n_i + p_i$

wide variety of decision situations, in fields such as public policy, business, industry, healthcare, shipbuilding and education. This method helps people to set priorities between alternatives, sub-criteria and criteria in the decision-making process. Also, it helps making better decisions by taking into account the qualitative and quantitative aspects of the decision [11].AHP application steps are as follows [6,11]:

Step 1: Determine the problem, determined goal and develop model in structure hierarchy, determine criteria and alternative.

This step contains aim of decision-maker and strurtured hierarchical of goal, criteria and alternatives. Structure the decision hierarchy from top with goal, intermediate level of criteria, and lowest level set of alternatives (Fig.3 a).

Step 2: Make pairwise comparisons of criteria and comparisons of alternatives for each criterion. Make a set of pairwise comparison matrices. Each element in an upper level is used to compare the elements in the level immediately below with respect to it. The pairwise comparison is conducted by doing survey to decision maker expert which is more important by making comparison according to 1-9 scale as shown in table 2.

Step 3: Calculation of priority vector. By using the comparison matrixes, the vector of weights (w) is computed in two steps. First, the pairwise comparison matrix, then the weights are computed.

Step 4: Calculate and check the consistency ratio (CR). In the AHP, the pairwise comparisons in a judgement matrix are considered to be adequately consistent, if the corresponding CR is less than 10%. The CR coefficient is calculated after Consistency Index (CI). CI is defined and numerical calculation is made as follows:

$$(\mathrm{CI}) = (\lambda_{max} - \mathrm{n})/(\mathrm{n} - 1) \quad (1)$$

Next the CR is obtained by dividing the CI value by the Random Consistency Index (RCI). RCI values are shown in Table 2. Then, the CR value is calculated by using the formula:

$$(\mathrm{CI}) = \mathrm{CI}/\mathrm{R} \quad (2)$$

The test of consistency is completed when the CR is numerically calculated. If CR < 10%, achieved data is consistent If CR≥10%, achieved data is inconsistent, the original values in the pairwise comparison matrix should be reconsidered and revised.

Step 5: Analysis of the AHP scores.After all 4 steps, if the model is consistent, the best alternative byAHP score is chosen. The fundamental scale can see Table 1 [10].

1) AHP Group Decision

According Saaty there are two ways to generate entries: (1) consensus vote and (2) individual judgements. By using individual judgement and check the consistency ratio in each participant. If result > 10% then use revise the answer [10]. The survey was conducted on seven experts consisting of 2 managers, 3 assitant managers, and 3 engineers.

The individual's judgment with CR <10% is then combined using the geometric mean for each pairwise comparison (Figure 2b). The geometric mean is an appropriate rule for combining AHP because it maintains the

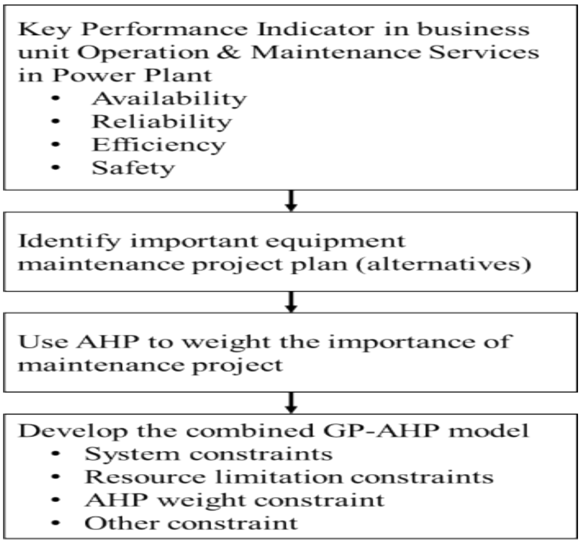


Figure 2. Combined model AHP-GP.

Table 3.
AHP Model for maintenance project selection

Goal (selecting projects)			
Availability	Reliability	Efficiency	Safety
X1	X1	X1	X1
X2	X2	X2	X2
X3	X3	X3	X3
X3	X3	X3	X3
X4	X4	X4	X4
X5	X5	X5	X5

X1 Boiler refractory rehabilitation X2 Line cooling water replacement X3 Valves replacement
X4 Houseload modification
X5 Air Preheater tubes replacement

Table 4.
Resulting priority value on each alternative by each criterion

Project Alternative	**Performance Indicator Criteria**			
	Availability	**Reliability**	**Efficiency**	**Safety**
x1	0.345	0.403	0.088	0.289
x2	0.194	0.163	0.148	0.194
x3	0.073	0.069	0.313	0.300
x4	0.252	0.239	0.097	0.110
x5	0.136	0.126	0.354	0.107
Total	1	1	1	1
Inconsistency Ratio	0.005	0.006	0.003	0.006

reciprocal property in the pairwise pairwise comparison matrix (Figure 1c.) [10]. Combined judgment

$$a_{12} = \ [a_{12}^1 \ _x \ a_{12}^2 \ x \ldots \ldots x \ a_{12}^N]^{1/N} \qquad (3)$$

B. Goal Programming

The Goal Programming model is used to solve problems more broadly than other approaches to solving multi-objective problems. Previous research, Ciptomulyono (2000) [6] stated that the advantage of goal programming is that this method contains fewer aspects of subjectivity compared to other multicriteria methods such as the Utility Theory Method or ELECTRE and has more effective procedures in weighting. The weakness of the goal programming method is that it does not have a systematic method of weighting, setting aspirations of goals and normalizing variable deviations. Goal programming is not able to overcome the selection of decisions if there are qualitative criteria. To improve these two deficiencies, it is proposed to use the AHP method. The integration of AHP and Goal Programming can complement the shortcomings of each method. The combined AHP-GP development model step shown in Figure 2. Steps in Goal Programming [6]:

1. Formulate a mathematical model consisting of objective functions, goal constraints. Because the decision process is accepting and rejecting, the model is Zero One Goal Programming (ZOGP).
2. Determine the qualitative decision attributes of the AHP process to be transformed into a decision variable and an objective function parameter.
3. Conduct analysis and test of model sensibility that enables obtaining an adequate level of validation.

The form of transforming the constraint / goal function into an equation in Goal Programming can be formulated as Table 2.

III. RESULT AND DISCUSSION

Input data from AHP in this study from group decisions for criteria and alternative maintenance projects are shown in

Table 5.
Resulting priority value on each criteria

Criteria	Weight
Availability	0.221
Reliability	0.140
Efficiency	0.100
Safety	0.539
Total	1
Inconsistency Ratio	0.006

Table 6.
Overall AHP weighs of project alternative

Projects alternative	AHP weighting	Decision Preference
x1	0.297	1st
x2	0.185	3rd
x3	0.219	2nd
x4	0.158	4th
x5	0.141	5th
Total	1	

Table 7.
Estimated budgetary

Resource item	Maintenance Project (decision alternatives)					Total available
	x1	x2	x3	x4	x5	
Estimated cost	2.8	9.5	4.7	7.6	3.2	20

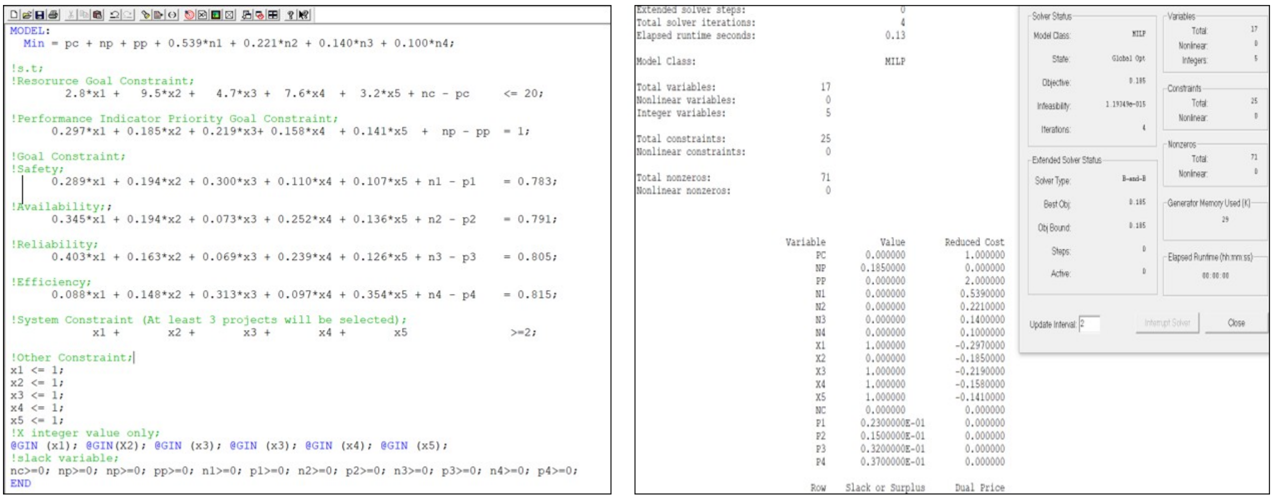


Figure 3. Input model and result report.

table 3 and then compute using Superdecisions V3x [13]. Table 3 shows the Superdecisions result on calculation relative priority each alternatives decision towards criteria. Researchers use an inconsistency ratio of 0.10 or less as guidelines in evaluating consistencies [12]. The power plant XYZ consist of two unit no. 1 and unit no. 2 and common system facilities. The description of projects improvement and upgrade will be planning in area as follow: project boiler refractory rehabilitation (x_1) for 2 units, project line cooling replacement (x_2) for common system, project valves replacement (x_3) for valve in turbine and boiler area in 2 units, project houseload modification (x_4) for 2 units, and project air preheater tubes replacement for 2 units.

Table 4 show the result of weights of alternative comparison for each performance indicator criteria in aggregate group decision. Inconsistency ratio is accepted ≤ 0.1.

Table 5 show the result is an overall prioritization of the performance indicator decision criteria of aggregate grup decision with inconsistency ratio ≤ 0.1. The results of this step are the overall rankings (in terms of weights) of the five maintenance projects candidate preference. From AHP result will be combined in GP as step shown in Fig. 3. Table 6 show the result overall weights or projects (alternatives).

A. Formulation of Goal Programming

Goal programming formulation determine function: decision variable, priority, goal constraint and goal function. Table 6 show estimation budgetary limitiation as use for resource constrain.

1) Decision Variable

xi = decision variable for select project ith

1. i = 1, 2, 3, m
2. $0 \leq xi \leq 1$

2) System constraint

Priority 1 : Prevent repeated select same project ith

$Xi \leq 1$ (for i = 1, 2, . . . 5) (4)

Priority 2 : At least select three projects

$x1 + x2 + x3 + x4 + x5 \leq 3$ (5)

Table 8.
Combined AHP-GP model solution

a. Decision variable			
x1 =	1	Select boiler refractory project	
x2 =	0	Do not select line cooling water replacement	
x3 =	1	Select Valve replacement project	
x4 =	1	Select Houseload modification project	
x5 =	1	Select Air Preheater tubes replacement project	
(b) slack in resource system constraint			
Constraint	**Usage**	**Total Available**	**Slack**
Budget	Rp. 18.3 B	Rp. 20 B	Rp.1.7 B
(c) Deviation in performance indicator constraint			
Constraint	**Obtained**	**Target**	**Under achievement**
Safety	0.806	0.783	0
Availability	0.837	0.791	0
Reliability	0.852	0.805	0
Efficiency	0.806	0.815	0.009

Table 9.
Sensitivity analysis of model with available budget

Budget constrain	Project selection	Slack
20%	X1, X3, X4	0.9
10%	X1, X2, X3	1.0
0	X1, X3, X4, X5	1.7
-10%	X1, X2, X3, X5	1.8
-20%	X1, X2, X3, X5	3.8

(b) Goal Constraint	**Priority under achievement**				
	-20%	-10%	0%	10%	20%
Safety	0.113	0.171	0	0.035	0.035
Availability	0.08	0.156	0	0.03	0.03
Reliability	0.307	0.256	0	0	0
Efficiency	0.116	0.032	0.009	0	0

3) Resource constraint

Priority 3: Keep cost within the budget Rp. 20 M. Table 7 show estimated cost for maintenance project. Resource constraint will be use as goal constraint to know the effect on this model.

$$2.8x_1 + 9.5x_2 + 4.2x_3 + 7.6x_4 + 3.2x_5 + n_C - p_C \leq 20 \quad (6)$$

4) Goal constraints

Goal constrain is needed to ensure that maintenance project with the highest weight obtained from AHP analysis will be selected in Table 5. Such goal constrain will attemp to maximize the weights by selecting the manitenance project with high priority.

$$0.297x_1 + 0.185x_2 + 0.219x_3 + 0.158x_4 + 0.141x_5 + n_P - p_P = 1 \quad (7)$$

Maximize project that have highest score for each criteria weights. Righ hand side is sum of three highest scores of project alternative from Table 3 (i.e the most project give useful contribution to achive EAF). The ordering goal constraint according criteria weights result from AHP process: Safety (0.539), Availability (0.221), Reliability (0.140), Efficiency (0.100).

Maximize Safety:

$$0.289x_1 + 0.194x_2 + 0.300x_3 + 0.110x_4 + 0.107x_5 + n_1 - p_1 = 0.783 \quad (8)$$

Maximize Availability:

$$0.345x_1 + 0.194x_2 + 0.073x_3 + 0.252x_4 + 0.136x_5 + n_2 - p_2 = 0.791 \quad (9)$$

Maximize Reliability:

$$0.403x_1 + 0.163x_2 + 0.069x_3 + 0.239x_4 + 0.126x_5 + n_3 - p_3 = 0.805 \quad (10)$$

Maximize Efficiency:

$$0.088x_1 + 0.148x_2 + 0.313x_3 + 0.097x_4 + 0.354x_5 + n_4 - p_4 = 0.815 \quad (11)$$

and $x_i = 0$ or 1; $n_k, p_k \geq 0$

The objective function to minimize the overall deviation in each of the goal constraints.

$$\text{Min } Z = P_1(p_c) + P_2(n_p + p_p) + P_3(0.539n_1 + 0.221n_2 + 0.140n_3 + 0.100n_4) \quad (12)$$

B. Solution of the goal programming.

The goal programming model was solved using LINGO [14], Figure 3. LINGO (Linear, Integer, Nonlinear, and Global Optimization) is a mathematical modelling language designed particularly for formulating and solving a wide variety of optimization problems, including linear programming, nonlinear programming, and integer programming.

IV. RESULT AND DISCUSSION

Table 8 present the result from goal programming for project selection are boiler refractory rehabilitation (x_1), valves replacement (x_3), houseload modification (x_4), and air preheater tubes replacement (x_5). The budget goal constraint can be achieved and 3 target performance indicators priority (safety, availability, reliability) can be achieved except for efficiency is under achievement. The project line cooling water replacement were not selected because limitation value by system constraint, goal constraint, and priority. The result of this model can be proposed to management to support the decision making of selecting equipment maintenance project in power plant XYZ.

A. Sensitivity Analysis

Sensitivity analysis used to know the effect of increasing and increasing resource constraint budget in this model from -20%, -10%, and +10%, and 20%. The results show in table 9 project selection and no of project change with variance of available budget. Goal constraint keep cost bellow available budget, with lowering budget has effect -10% to -20% on fewer project to be chosen and change project to its optimal solution. Sensitivity analysis can be used to analyze the effect of constraint or goal target to the model and result. This analysis can help management or maintenance planner to select project for optimal result based on available budget.

V. CONCLUSION

This paper proposes combined AHP and goal programming to the selection of maintenance project for equipment in power plant XYZ. The approach can handle the multiple and conflicting goal and constraints characteristic such as performance indicator criteria, budget constraints, and system constraint. This AHP-GP model consist of two stages: first stage using the AHP to find weights of criteria and alternatives and second stage find optimal problem solving by goal programming for selecting maintenance project. These model can be studied further for adding resource constraint such as management work hour, labor work hour, and project duration.

ACKNOWLEDGMENT

I would like to express my special thanks of gratitude to my research supervisor Prof. Udisubakti Ciptomulyono M.Eng.Sc as well as Head Department of MMT ITS Prof. Ir. I Nyoman Pujawan., M.Eng., Ph.D., CSCP, MMT ITS academic staff, commite of MOTIP 2020 and colleague. Secondly i would also like to thank family and friends who helped me a lot in finalizing this project.

REFERENCES

[1] PT PLN (Persero), "Rencana Usaha Penyediaan Tenaga Listrik PT Perusahaan Listrik Negara (Persero) Tahun 2018 s.d 2027', Kementrian Energi dan Sumber Daya Mineral, Jakarta, 2018.

[2] PT PLN (Persero). "Protap Deklarasi Kondisi Pembangkit dan Indeks Kinerja Pembangkit, PT PLN (Persero), Jakarta, 2017.

[3] NERC, "Predicting Unit Availability Top-Down Analyses for Predicting Unit Availability, " North American Electric Reliability Council, 1991.

[4] NERC," Predicting Generating Unit Reliability," North American Electric Reliability Council, North American Electric Reliability Council, 1995.

[5] Bertolini M., Bevilacqua M., "A combined goal programming - AHP approach to maintenance selection problem," *Reliability Engineering and System Safety*, vol. 91, pp. 839–848, Oct. 2005.

[6] Ciptomulyono U.,"Pengembangan Model Optimasi Keputusan Multi Kriteria MCDM (Multi Criteria Decision Making) untuk Evaluasi dan Pemilihan Proyek," Institut Teknologi Sepuluh Nopember, 2000.

[7] Ho, W, "Combining Analytic Hierarchy Process and Goal Programming for Logistics Distribution Network Design, *IEEE International Conference on Systems, Man and Cybernetics*, pp. 714-719, 2007.

[8] Rusli A, Ciptomulyono U," Pemilihan Kontraktor Perbaikan Rotor di Pembangkit Listrik PT XYZ Dengan Menggunakan Metode Analytical Hierarchy Process dan Goal Programming," *Prosiding Seminar Nasional Manajemen Teknologi*, XVIII, pp. 111-119, Jul 2013.

[9] Badri M.A, " A combined AHP - GP model for qualitycontrol systems," Int. J. Production Economics, vol. 72, pp. 27-40, Jun. 2000.

[10] Saaty T.L, Vargas L, "*Models, Methods, Concepts and Applications of the Analytic Hierarchy Process*," Springer New York, 2001.

[11] Özcan E.C., S. Ü., Eren Tamer, "*A combined goal programming – AHP approach supported with TOPSIS for maintenance strategy selection in hydroelectric power plants*," Renewable and Sustainable Energy Reviews, vol. 78, pp. 1410–1423,

[12] Saaty T.L, "Group Decision Making and the AHP," in The Analytic Hierarchy Process Applications and Studies, Bruce L. Golden Edward A. Wasil, Patrick T. Harker, Eds, Springer-Verlag, 1989, pp. 59-67.

[13] CDF, "Manuals Superdecisions V3x," CDF. [Online] Available: http://www.superdecisions.com/ . [Accessed: 15 May 2020]

[14] Schrage L., Optimization Modelling with LINDO," Lindo System Inc., Fifth edition, 2002.

Mahasiswa Pendidikan Matematika dengan Regresi Logistik," *J. Kegur. dan Ilmu Pendidik.*, 2014.
[20] D. R. Gujarati, *Dasar-Dasar Ekonometrika*, 1st ed. Jakarta: Erlangga, 2006.
[21] N. R. Draper and H. Smith, *Applied Regression Analysis, Third Edition*. New York: John Wiley & Sons, 1998.