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Choosing Intelligent Elevator Control System by Using Analytic Hierarchy Process in High-Rise Buildings

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ABSTRACT

In the last decades, improvements on the technology leads great improvements on the elevator sector and building sector. High-rise buildings have become more common and elevator systems have been improved relatively with the needs of the people who live or work in high-rise buildings. Finding the optimal intelligent elevator control system according to the needs of the building is not an easy problem to solve for the administration of the high-rise buildings. In this paper eight criteria have been determined by the decision-makers in high-rise buildings. The most important criteria has been determined as being able to call for the elevator by using specified cards which enables specialize the use of the elevators with the weight of 0,294 and the least important criteria has been determined as having an option for guidance of the elevators to the pre-determined floor in an emergency situation with the weight of 0,019. As alternativse, three different intelligent elevator control system have been determined and Analytic Hierarchy Process (AHP) method has been used to determine the weights of the criteria and to choose the optimal intelligent elevator control system alternative.

KEYWORDS: Multi-Criteria Decision Making (MCDM), Analytic Hierarchy Process (AHP), Elevator Systems.

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INTRODUCTION

With the raise on the number of the high-rise buildings, needs and demands of the high-rise buildings are being changed. One of the most complex problem in high-rise buildings is to make the transportation between floors better. In high-rise buildings, the most important transportation tools are elevators and the goal of the elevator control system should be maximizing the capability of transportation and improve the service quality (Jamaludin, Rahim, & Hew, 2009). To improve the elevator performance, the most direct way is adding cabins to the elevator systems or enlarge the cabins to make capacity higher or to make shorter transportation time, speed of the cabins can be accelerated. However, chance of these approaches to happen is very low, because of the limited space, higher costs and other reasons.

Hence, Intelligent Elevator Control Systems have been developed and studied by many researchers (Chan, So, & Lam, 1996) (Inamoto, Tamaki, Murao, & Kitamura, 2003). These systems can be described as, systems that based on the principle of taking the passengers that are going to same floor in the same cabin and nowadays working principle that involved into minimizing elevator waiting time for the passengers and minimum waiting time in the cabin for passengers with the better algorithms, which systems that include multiple elevators. To accomplish this goal, in every floor specialized buttons to enter the floor number which passenger want to go are placed. This is called “hall call system”. Apart from this buttons, cards, fingerprint readers and iris readers can be used for personalized access authorities. The base point is to make it possible for people to travel from the same or similar floors to the destination floors in the same cabin.

Today, to improve the elevators’ performances, systems with destination hall call registration have been developed. With these systems, the information about destination floors of passengers are being utilized by the control systems and because of that number of the each elevator cabin’s stops become less. To make it clear with an example it can be assumed that six passengers are waiting at the entrance floor for the elevator which consists two cabins. Passengers can be called P1, P2, P3, P4, P5 and P6 and the floors that passengers aim to go are 3, 3, 3, 4, 4 and 4, respectively. Their destination floors are not known in the ordinary systems and elevator controller put the passengers into the cabins randomly. So, in this situation, it can happen that P2, P3 and P4 can be put in one cabin and P1, P5 and P6 can be put in the other cabin which causes each cabin to stop twice. But, in the destination hall call registration system, elevator controller knows the destination floors so put P1, P2 and P3 into one cabin and put P4, P5 and P6 in the other cabin to make both cabins stop once. This leads to reduce the time and effects overall performance of the elevator system positively.

Hence, it can bee seen that the best traffic scenario for the users of building is taking the passengers who will go to nearby floors into the same cabin and use this cabin with full capacity. Intelligent Elevator Control Systems are being used based on this principle.

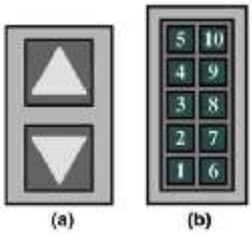

Figure 1: Two types of hall call buttons (a) the conventional system, (b) the destination entry system (Tanaka, Uraguchi, & Araki, 2005)

Nowadays, there are several models of destination entry Systems and several brands which produce them. Intelligent Elevator Control Systems. It is a complex decision making problem for the high-rise building managements to decide which model and which brand will be used. This paper concerns with the efficiency of the full configured Destination Entry Systems compared to the conventional old system and not full configured Destination Entry System by using one of the Multi Criteria Decision Making method, called Analytic Hierarchy Process.

Literature Review

Analytic Hierarchy Process has been used widely in the literature. Other than finance sector (Steuer & Na, 2003), AHP has been used in many different sectors such as logistics, manufacturing, business, environment. In logistics sector, application areas of AHP are transportation route selection (Chan & Chung, Multi-criteria genetic optimization for distribution network problems, 2004) (Chan & Chung, 2005) (Chan, Chung, & Choy, 2006),supplier selection (Korpela, Lehmusvaara, & Tuominen, 2001) (Tyagi & Das, 1997), facility location selection (Chuang, 2001) (Partovi, 2006) (Badri, 1999).

With the improvements on the technology, intelligent elevator control systems also took attention of the researchers. Sensor systems of the elevators in high-rise buildings (Marchesi, Hamdy, & Kunz, 2001), scheduling problem is considered as another topic for minimizing the waiting time for passengers (Hirasawa, Kuzuniki, Iwasaka, Kaneko, & Kawatake, 1979), predicting the traffic flows is another complex problem that determined in the elevators of high-rise buildings (Koehler & Ottiger, 2002). To solve these complex problems, authors developed mathematical methods.

In this paper, to solve the problem of choosing intelligent elevator system between the alternatives, AHP which is one of the Multi-Criteria Decision Making methods has been used.

Methodology

Analytic Hierarch Process is another Multi Criteria Decision Making Methods and one of the widely used methods in the literature. Analytic Hierarchy Process is developed in 1972 (Saaty T., 1972).

Analytic Hierarchy Process has been used in various sectors in the literature such as sustainable and renewable energy (Singh & Nachtnebel, 2016), agriculture (Abdollahzadeh, Damalas, Sharifzadeh, & Ahmadi-Gorgi, 2016), health (Nguyen & Nahavandi, 2016), nuclear power (Erdoğan & Kaya, 2016).

In this paper, Analytic Hierarchy Process have been used to making the decision of choosing the best elevator passenger routing alternative. Application of Analytic Hierarchy Process is shown step by step (Karaman & Akman, 2017).

Step 1: Starting process of the application of Analytic Hierarchy Process is determining the hierarchy model that can be seen as Figure 1. Option number is being shown as m and criterion number is being shown as n.

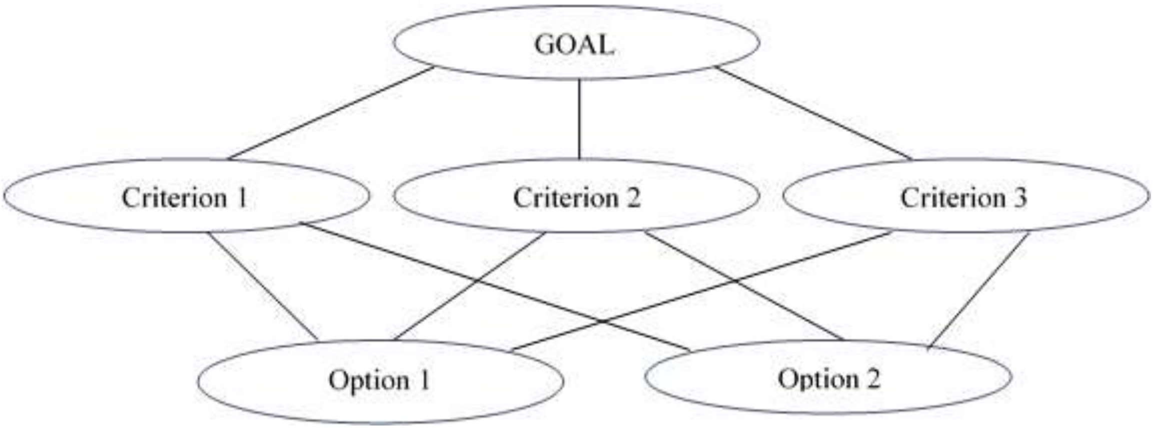

Figure 2 AHP Hierarchy Model

Step 2: Then, pairwise comparison matrix for each criterion is being determined, by the comparing each option by pairs for each factor. This matrix size is being shown as $n \times n$. When pairs are being compared linear scale is being used which can be seen in the table 2. The pairwise comparison matrix can be seen as:

$$A = \begin{bmatrix} a_{11} & a_{12} \dots & a_{1n} \\ a_{21} & a_{22} \dots & a_{2n} \\ \dots & \dots & \dots \quad \dots \\ a_{n1} & a_{n2} \dots & a_{nn} \end{bmatrix}$$

Because of the linear comparison, $a_{ij} = \frac{1}{a_{ji}}$. For example, if a is 7 times important than b, which means that a alternative has very strong importance over b alternative, then, b is 1/7 times important than a.

Table 1 Linear Scale (Saaty T. , 1972)

Intensity of Importance	Definition	Explanation
1	Equally strong	Two activities contribute equally to the objective
3	Marginally strong	Experience and judgment strongly favor one activity over another
5	Strong	Experience and judgement strongly favor one activity over another
7	Very strong	An activity is strongly favored and its dominance demonstrated in practice
9	Extremely strong	The evidence favoring one activity over another is of tile highest possible order of affirmation
2,4,6,8	Intermediate Values	When compromise is needed

Step 3: Factors' weights are being determined in this step. To determine the weights, column vectors of the pairwise comparison matrix are being used. At the end, n numbered B column vector is being determined. B column vector has n number of components. This B column vector can be seen as:

$$B_i = \begin{bmatrix} b_{11} \\ b_{12} \\ b_{13} \\ \dots \\ b_{1n} \end{bmatrix}$$

The formula that being used to calculate the column vectors can be seen as:

$$b_{ij} = \frac{a_{ij}}{\sum_{i=1}^{n} a_{ij}}$$

After, n number of B columns are obtained, these columns are being gathered for determining the C matrix.

$$C = \begin{bmatrix} c_{11} & c_{12} & c_{13} \dots & c_{1n} \\ c_{21} & c_{22} & c_{23} \dots & c_{2n} \\ c_{31} & c_{31} & c_{33} \dots & c_{3n} \\ \dots & \dots & \dots \quad \dots & \dots \\ c_{n1} & c_{n2} & c_{n3} \dots & c_{nn} \end{bmatrix}$$

Where;

$$c_{11} = b_{11}$$

$$c_{n1} = b_{n1}$$

$$c_{1n} = b_{1n}$$

$$c_{nn} = b_{nn}$$

Then, for the determining weights, w column vector is being determined which means arithmetic average of the values of lines of C matrix. It can be formulated as:

$$w_i = \frac{\sum_{j=1}^{n} c_{ij}}{n}$$

Weights vector is determined by using the w values.

$$W = \begin{bmatrix} w_1 \\ w_2 \\ w_3 \\ \dots \\ w_n \end{bmatrix}$$

Step 4: Consistency Ratio is being calculate in this step. Analytic Hierarchy Process is based on the comparison of decision maker and to apply the method successfully, comparisons should be consistent. Consistency ratio is based on the comparison between the number of factors and a coefficient called basic value which shown as λ. To calculate the λ, D vector column should be calculated by multiplying the A comparison matrix and W weights vector. It can be formulated as:

$$D = \begin{bmatrix} a_{11} & a_{12} & \dots & a_{1n} \\ a_{21} & a_{22} & \dots & a_{2n} \\ \dots & \dots & \dots & \dots \\ a_{n1} & a_{n2} & \dots & a_{nn} \end{bmatrix} \times \begin{bmatrix} w_1 \\ w_2 \\ w_3 \\ \dots \\ w_n \end{bmatrix}$$

Then, by using the D vector column, E values are determined with the formula:

$$E_i = \frac{d_i}{w_i}$$

After that, arithmetic average of the E values gives the value of λ and can be formulated as:

$$\lambda = \frac{\sum_{i=1}^{n} E_i}{n}$$

After λ is calculated, Consistency Indicator (CI) can be calculated by the formula:

$$CI = \frac{\lambda - \text{n}}{n - 1}$$

Then, Consistency Ratio (CR) is calculated by dividing Consistency Indicator (CI) to Random Indicator (RI). Random Indicator values are already determined and can be seen in Table 2.

Table 2 Random Indicator Values (Saaty R. W., 1987)

Number of n	RI
1	0
2	0
3	0.58
4	0.90
5	1.12
6	1.24
7	1.32
8	1.41
9	1.45
10	1.49
11	1.51

Consistency Ratio should be equal to or less than 0.10, to be the consistent, otherwise means that the comparisons are inconsistent and all the calculations are invalid.

Step 6: By doing the same steps for each factor to the options, standardized decision matrix is calculated. Standardized decision matrix can be seen as K matrix where s_{ij} represents the standardized value of decision point:

$$K = \begin{bmatrix} s_{11} & s_{12} & s_{13} & \cdots & s_{1n} \\ s_{21} & s_{22} & s_{23} & \cdots & s_{2n} \\ \cdots & \cdots & \cdots & \cdots & \cdots \\ s_{m1} & s_{m2} & s_{m3} & \cdots & s_{mn} \end{bmatrix}$$

Step 7: Multiplying the K matrix with W weights column vector, L column vector is being gathered. L column vector represents the scores of the options and can be formulated as:

$$L = \begin{bmatrix} s_{11} & s_{12} & s_{13} & \cdots & s_{1n} \\ s_{21} & s_{22} & s_{23} & \cdots & s_{2n} \\ \cdots & \cdots & \cdots & \cdots & \cdots \\ s_{m1} & s_{m2} & s_{m3} & \cdots & s_{mn} \end{bmatrix} \times \begin{bmatrix} w_1 \\ w_2 \\ w_3 \\ \cdots \\ w_n \end{bmatrix} = \begin{bmatrix} w_1 s_{11} + w_2 s_{12} + w_3 s_{13} + \cdots + w_n s_{1n} \\ w_1 s_{21} + w_2 s_{22} + w_3 s_{23} + \cdots + w_n s_{2n} \\ \cdots \\ w_1 s_{m1} + w_2 s_{m2} + w_3 s_{m3} + \cdots + w_n s_{mn} \end{bmatrix}$$

The option has the highest score overall, is the best option to choose. There are some sofwares that are developed for application of Analytic Hierarchy Process, to make easier use.

Application

In this paper, AHP will be used for determining the passenger guidance system of a new building between 3 alternative systems. Elevator system will be assumed to have 4 cabins and 20 stops. Stops would be numbered as 0, 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16, 17, 18, 19. Elevator system would be at the 2.5 meters per second and car capacity at 1200 kg. In the European standards a passenger would be calculated as 75 kg so the passenger capacity of an elavtor cabin would be 16 persons. 8 criteria are determined for the decision, by the decision maker:

1) Elevator Guidance in the lobby: This criterion enables the passengers that make call for elevator in the lobby to see which cabin is coming for them.

2) Calling for the elevator by using card: Apart from the standard passengers, in the necessary times,

by using card elevator could be called.

3) Having an Elevator to floor option: In an emergency situation, pre-determined cabins could be guided to the floor that the elevator called.

4) Energy Saving Mode: At the low-traffic times, some of the cabins could stand in the parking mode for saving energy.

5) Giving a Call From Turnstile: This criteria enables the passengers that are using the elevator daily, to call the elevator when the user makes an entrance to the building automatically and save time.

6) Generating a Traffic Scenario: Elevator system should enable to direct the elevators, according to traffic, only upwards or downwards.

7) Being Trackable: This criteria eables to get report from the floors call buttons, and enables to analyze the traffic.

8) Having an Encodable Option: It is the option that gives the managers to encode some floors. For example, only authorized persons could enter the 15th floor and managers could write a special code for make the elevator go to the 15th floor.

The purpose is choosing the best option between 3 options according to these 8 criteria.

Elevator System Options are:

- 1) Advanced Conventional call system with card reader support
- 2) Full Configured Elevator Passenger Dispatching System
- 3) Lobby Supported Elevator Passenger Dispatching System

First of all weights of the criteria are determined by using an MS Excel Spreadsheet developed by Klaus D. Goepel. Pairwised comparisons can be seen in Figure 3.

		Criterion 1	Criterion 2	Criterion 3	Criterion 4	Criterion 5	Criterion 6	Criterion 7	Criterion 8
Criterion 1	1	1	1/5	6	1	2	4	1/2	3
Criterion 2	2	5	1	8	2	2	7	1	6
Criterion 3	3	1/6	1/8	1	1/9	1/9	1/4	1/5	1/5
Criterion 4	4	1	1/2	9	1	2	2	1/2	3
Criterion 5	5	1/2	1/2	9	1/2	1	5	1/2	1
Criterion 6	6	1/4	1/7	4	1/2	1/5	1	1/2	1/4
Criterion 7	7	2	1	5	2	2	2	1	2
Criterion 8	8	1/3	1/6	5	1/3	1	4	1/2	1

Figure 3 Pairwise Comparison

According to the comparisons, calculated weights can be seen in Table 3.

Table 3 Weights of the Criteria

Criterion	Weight
Elevator Guidance in the lobby	13,3%
Calling for the elevator by using card	29,4%
Having Elevator to Floor option	1,9%
Energy Saving Mode	14,0%
Calling From Turnstile	10,9%
Generating a Traffic Scenario	4,5%
Being Trackable	18,0%
Having an Encodable Option	7,9%
Total	100%
Consistency Ratio	8,1%

It can be seen that, consistency ratio is 0,081 which is below 0,01 which shows that the comparisons of the decision maker is consistent. Also it can be seen that for the decision maker, “Calling for the elevator by using card” criterion is the most important criterion with

29,4% weight and "Having Elevator to Floor Option" criterion is the least important criterion with 1,9% weight.

After this step, alternatives are compared by pairs for each criterion. And overall values of the alternatives can be seen in Table 4.

Table 4 Values of Alternatives

Criteria	Alternatives			Weight of Criterion
	Alternative 1	Alternative 2	Alternative 3	
Elevator Guidance in the lobby	0,443	0,443	0,114	0,133
Calling for the elevator by using card	0,429	0,429	0,143	0,294
Having Elevator to Floor option	0,200	0,260	0,106	0,019
Energy Saving Mode	0,633	0,260	0,106	0,140
Calling From Turnstile	0,388	0,388	0,224	0,109
Generating a Traffic Scenario	0,229	0,563	0,280	0,045
Being Trackable	0,098	0,532	0,370	0,180
Having an Encodable Option	0,388	0,388	0,224	0,079
Overall Values of The Alternatives	0,378	0,420	0,195	

Based on the calculation, Alternative 2 which is Full Configured Elevator Passenger Dispatching System is the best option for the decision maker.

Conclusion

With the improvements on the building sector, buildings are becoming higher. One of the higher buildings' basic needs is, high-speed elevator systems. Elevator systems will be more improved and changed. These two sectors are connected with the improvements on each other.

With this paper, a model has been prepared for making selection between 3 elevator systems for which one is better to use according to the 8 criterias. As a result, it has been shown that Full Configured Elevator Passenger Dispatching System is better than the other alternatives based on the 8 criterias that determined by the decision maker.

Also, it has been proved that, Analytic Hierarchy Process can be used for making decision about the elevator passenger guidance system.

In the future, with the improvements on the elevator sector and building sector, new criteria would be developed and introduced, but by using the same model, it would be still possible to make a rational decision. Also, AHP can be used in different perspectives of the elevator sector, such as choosing the supplier of the elevator systems, raw material supplier etc.

REFERENCES

Abdollahzadeh, G., Damalas, C. A., Sharifzadeh, M. S., & Ahmadi-Gorgi, H. (2016). Selecting strategies for rice stem borer management using the Analytic Hierarchy Process (AHP). Crop Protection, 84, 27-36.

Badri, M. A. (1999). Combining the analytic hierarchy process and goal programming for global facility location-allocation problem. International Journal of Production Economics, 62(3), 237–248.

Chan, F. T., & Chung, S. H. (2004). Multi-criteria genetic optimization for distribution network problems. The International Journal of Advanced Manufacturing Technology, 24(7), 517-532.

Chan, F. T., Chung, S. H., & Choy, K. L. (2006). Optimization of order fulfillment in distribution network problems. Journal of Intelligent Manufacturing, 17 (3), 307–319.

Chan, F., & Chung, S. (2005). Multicriterion genetic optimization for due date assigned distribution network problems. Decision Support Systems, 39 (4), 661–675.

Chan, W. L., So, A. T., & Lam, K. C. (1996). Dynamic zoning for intelligent supervisory control. International Journal of Elevator Engineering, 1, 47-59.

Chuang, P. T. (2001). Combining the analytic hierarchy process and quality function deployment for a location decision from a requirement perspective. International Journal of Advanced Manufacturing Technology, 18 (11), 842–849.

Erdoğan, M., & Kaya, I. (2016). A combined fuzzy approach to determine the best region for a nuclear power plant in Turkey. Applied Soft Computing Journal, 39, 84-93.

Hirasawa, K., Kuzuniki, S., Iwasaka, T., Kaneko, T., & Kawatake, K. (1979). Hall call assignment in elevator supervisory control. Trans. Inst. Electr. Eng. Jpn. C, vol. 99, no. 2, pp. 27–32.

Inamoto, T., Tamaki, H., Murao, H., & Kitamura, S. (2003). Deterministic Optimization Model of Elevetor Operation Problemsand An Application of Branch-and-Bound Method. IEEJ Transactions on Electronics, Information and Systems, 123, 1334-1340.

Jamaludin, J., Rahim, N. A., & Hew, P. W. (2009). Development of a self-tuning fuzzy logic controller for intelligent control of elevator systems. Engineering Applications of Artificial Intelligence, 22(8), 1167-1178.

Karaman, A. S., & Akman, E. (2017). Taking-off corporate social responsibility programs: An AHP application in airline industry. Journal of Air Transport Management, 1-11.

Koehler, J., & Ottiger, D. (2002). An AI-based approach to destination control in elevators. AI Magazine, 23(3), 59-78.

Korpela, J., Lehmusvaara, A., & Tuominen, M. (2001). Customer service based design of the supply chain. International Journal of Production Economics, 69 (2), 193–204.

Marchesi, E., Hamdy, A., & Kunz, R. (2001). Sensor systems in modern high-rise elevators. O. Gassmann, H. Meixner, J. Hesse, J. W. Gardner, & W. Gopel içinde, Sensor Application Vol. 2: Sensors in Intelligent Buildings (s. pp. 261– 291). Weinheim: Wiley-VCH.

Nguyen, T., & Nahavandi, S. (2016). Modified AHP for Gene Selection and Cancer Classification Using Type-2 Fuzzy Logic. IEEE Transactions on Fuzzy Systems, 24(2), 273-287.

Partovi, F. Y. (2006). An analytic model for locating facilities strategically. Omega, 34 (1), 41–55.

Saaty, R. W. (1987). The Analytic Hierarchy Process - What it is and how it is used. Math Modelling,, 9(3-5), 161-176.

Saaty, T. (1972). An eigenvalue allocation model for prioritization and planning. Energy Management and Policy Center, University of Pennsylvania.

Singh, R. P., & Nachtnebel, H. P. (2016). Analytical hierarchy process (AHP) application for reinforcement of hydropower strategy in Nepal. Renewable and Sustainable Energy Reviews, 55, 43-58.

Steuer, R. E., & Na, P. (2003). Multiple criteria decision making combined with finance: A categorized bibliographic study. . European Journal of operational research, 150(3), 496-515.

Tanaka, S., Uraguchi, Y., & Araki, M. (2005). Dynamic optimization of the operation of single-car elevator systems with destination hall call registration: Part I. Formulation and simulations. European Journal of Operational Research, 167(2), 550-573.

Tyagi, R., & Das, C. (1997). A methodology for cost versus service trade-offs in wholesale location-distribution using mathematical programming and analytic hierarchy process. Journal of Business Logistics, 18 (2), 77–99.