Estimation of Workload for Aircraft Design Projects By Using Fuzzy Logic

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In this study, it is aimed to estimate workload for aircraft design. Actual values of variables are not always reachable due to subjectivity, lack of data, and so on. In this case, forming the model by incorporating fuzzy logic can be a satisfactory solution. In this study, the results obtained by fuzzified aircraft design data from literature were compared with the actual results of the literature. According to comparison results, it is seen that the results of the fuzzy estimation method are close to the actual results. As a conclusion, estimation is practicable by fuzzy variables and satisfactory results can be achieved when inputs are uncertain in aircraft design.

Keywords: Aircraft, Design, Workload, Cost estimation, Fuzzy logic, Fuzzy Estimation

1. INTRODUCTION

An aircraft is defined as a machine that the air provides flying. Designing an aircraft is a crucial process and needs to be managed carefully and meticulously. Through this process, cost and workload are two of the most important issues to be managed and also to be estimated. In estimating the cost and workload of aircraft design projects, the major difficulty is the complexity of measuring the components, which are considered as the inputs of the estimation models. The motivation of this study is the need of dealing with this complexity, caused by lack of information or uncertainties.

Once handling the complexities, there are many estimation techniques that are classified as qualitative and quantitative methods. Qualitative methods generally depend on heuristic principles like complexity, quality, etc. and works with similarities or comparable things of a product previously manufactured whereas quantitative models depend on statistical analysis, deep research about a product, its features or processes [1]. Fuzzy logic is one of the qualitative methods, introduced by Lotfi Asker Zadeh in 1965 to bring an optional perspective to traditional analyses. This method briefly provides problems including uncertainty and vagueness to model with linguistic variables in any system [2].
In this study, fuzzy logic is implemented on aircraft design projects' workload estimations, by using performance and size variables. Cost estimation techniques for aircraft design projects are taken into consideration and by considering workloads as costs of related projects, workloads are estimated. Selected crisp variables about performance and size variables such as aircraft unit weight, aircraft empty weight, speed and climb rate are defined by using linguistic fuzzy variables. After that, an appropriate Fuzzy Inference System is generated and a comparison of current outcomes gathered from literature and fuzzy outcomes is presented.

2. COST ESTIMATION FOR AIRCRAFT DESIGN PROJECTS

The first successfully flying aircraft was designed by Wright Brothers, in 1903 even if there were some trials for flying in anywhere on earth until that time. Then, once again Wright Brothers has improved an upgraded version by 1905 [3]. This development was source of inspiration to many people and countries for designing new and improving the existing ones.

Design concept can differ in terms of using methods or can be differentiated as tangible or intangible such as product, place, information, and so on [4]. During design process for anything there are many unknown obstacles. Since, it is usually encountered while doing it. Villecco and Pellegrino [5] stated that it is always faced with vagueness in engineering design and Daalhuizen et al. [6] emphasized also the source of uncertainty as lack of knowledge and proficiency, variances in design changes and its complexity in any given task because of inadequacy of data and knowledge. Moreover, MacCormack [7] evaluated that changing conditions can appear normally or appear slowly and Bstieler [8] explained that uncertainty in customer side leads to vagueness in project execution which no one is unable to understand. Because of the complexity in design process, cost estimation or prediction of effort during this period is very remarkable.

2.1. Cost Estimation Methods

Cost estimation methods may be classified as qualitative and quantitative [1]. Qualitative methods are ordered as *intuitive* and *analogical methods* that are mainly used in early stage of design because of lack of knowledge [9]. Case-Based Reasoning, Rule-Based, Fuzzy Logic and Expert Systems are the techniques used in intuitive methods. Analogical techniques use Regression Analysis or Back-Propagation Neural-Network in cost estimation. Quantitative cost estimation methods use parametric cost estimation, operation-based, break-down approach, feature-based approach, tolerance-based approach or activity-based approach.

2.2. Aircraft Design

An aircraft design consists of three phases which are conceptual design phase, preliminary design phase and detail design phase that are also shown in Figure 1.

Conceptual design is a kick-off for design but the most crucial one. The major responsibility of this phase is to prepare a guide for bringing together requirements and expected design and system configuration. The decisions about material type, structural design requirements, and support activities are determined [11]. Preliminary design phase is the phase that optimized design alternatives are handled in terms of cost effectiveness or practicability of design. Design geometry begins to form and system and sub-system of the aircraft also is shaped. Provided that the concept design phase is definite the only minor changes are made for aircraft in this part of the design [12]. The last stage of the design is the detail design phase which systems, sub-systems and parts are defined and designed in all details to be fabricated or sub-contracted. During this phase, whole system and design components are evaluated and analyzed in detail. Manufacturing documentation is released [13]. After finishing the design, manufacturing activities begin for maiden product. Followed by these activities first flight, flight testing, and certification operation proceed.

In any project, workload, defined as effort for one who works for the specific task, is considered at each stage. Therefore, workload is a crucial issue that should be estimated at the beginning of the projects. In terms of design projects, to spend time as working for a task in design activity can be expressed as design workload for the activity [14].

3. FUZZY LOGIC AND FUZZY INFERENCE SYSTEM

Fuzzy logic was first introduced by Lotfi Asker Zadeh in 1965 in order to model complex and uncertain problems that have lack of data or knowledge [2]. Hence, fuzzy logic is an alternative approach to find solution for vagueness in systems. It can be expressed as enlargement of the conventional set theory by adding belongings of elements to fuzzy sets. In classical set theory, element either belongs to a set or not (either zero or one), where fuzzy logic defines membership degrees in defining the belonging of each element to a fuzzy set, where there is no strict boundaries according to fuzzy theory [15].

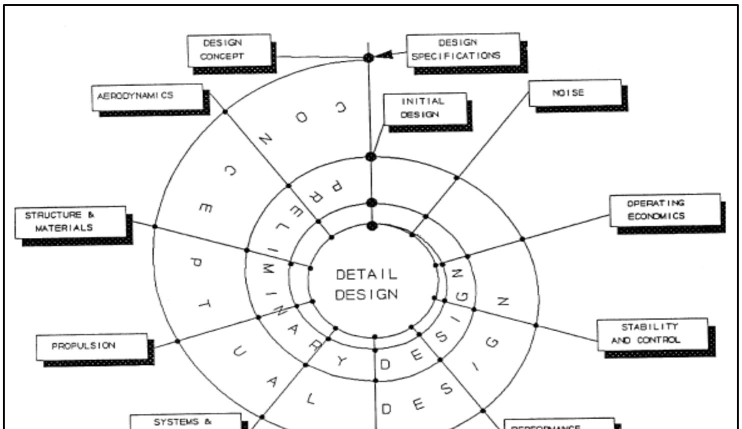

Figure 1. The Design Spiral [10]

There are many applications of fuzzy logic for aircraft. Dobrescu and Balazinski studied environmental control on cabin and cockpit of aircraft [16]. Atlı and Kahraman used fuzzy logic for aircraft maintenance planning as decision making tool [17]. Lo et al. implemented for finding system failures in aircraft. [18]. Liu et al. proposed a model using fuzzy logic about durable flight control system to explore Mars [19].

Fuzzy inference system can be expressed in three major steps which are fuzzification, fuzzy inference engine and defuzzification shown in Figure 2.

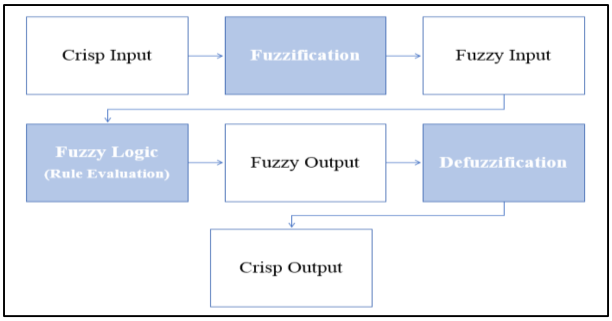

Figure 2. Process of Fuzzy Model

Fuzzification is a process that crisp inputs are converted into linguistic variables. Then, linguistic variables are defined with their fuzzy membership functions using fuzzy sets. Linguistic variables are the input or output terms of the system whose values are differ from numeric values, they are denoted as words or sentences from daily language [20].

Although various membership functions such as singleton, gaussian, trapezoidal and triangular can be defined in fuzzy logic [21], the mostly used types are triangular and trapezoidal fuzzy numbers because of their simplicity in calculation and linearity on membership functions. General mathematical notation of triangular fuzzy number is defined by three real numbers (l,m,u) and they are expressed lower, mid and upper bounds of triangular fuzzy number [22]. The next step is the ***fuzzy inference engine*** with IF-THEN rules. IF-THEN rules provide conditional situations between inputs and outputs for any model [23]. The last step of process is ***defuzzification*** where fuzzy values are converted to crisp value by using some methods such as center of gravity (COG) or center-of-area (COA), mean of maximums (MOM), smallest of maximum (SOM) and largest of maximum (LOM) [24].

4. PROPOSED MODEL

As stated in earlier chapters, if there is uncertainty and lack of data in any stage of the process, fuzzy logic can be used in achieving reliable results. In this study, an aircraft database including 34 military aircraft will be used from literature. These aircrafts' type is examined in 6 categories such as fighter, bomber, transportation, attack, training and business jet.

There are several cost factors that affect aircraft manufacturing. Basically, engineering, tooling, staffing, material, development and manufacturing support, flight test operations and quality control are cost levels of an aircraft development process. Especially, the design phase is more invisible comparing with others. That's why variable selection is important to make model visible. Aircrafts considered in this study are examined according to their characteristics and some dependent variables are determined in terms of size and performance features.

4.1. Inputs for Aircraft Design Workload Estimation

During the modeling phase of this study, many characteristics were considered according to elements of aircraft as possible variables. However, it was important that variables had to satisfy the requirements that are related to cost of aircraft and also had to embody all aircraft' design methodology. Determined variables are; **Climb Rate (CR),** the vertical maximum climb of the aircraft; **Aircraft Unit Weight (AUW),** calculated as excluding wheels, brakes, tires, engines propellers, avionics and other systems and sub-systems, (it can also be thought structural weight of the aircraft); **Empty Weight (EW),** defined as the weight of the aircraft without fuel, ammunition and crew; **Maximum Speed (MS),** the speed of the aircraft that reaches at any altitude.

4.2. Fuzzification of Proposed Model

Since it is not always possible to achieve actual (crisp) values of variables in real life, it is recommended to substitute them by fuzzified data, which are easier to obtain. In this study, the success of estimations done by using fuzzified data is investigated. Therefore, linguistic data is defined in fuzzifying the inputs in the model. In this process, equal intervals are used and converted to linguistic variables. The determination of intervals depends on the decision maker's choice. Because of the length of range of data, 11 fuzzy linguistic variables, defined as Extremely Low (EL), Very Low (VL), Low (L), Moderate Low (ML), Slightly Low (SL), Moderate (M), Slightly High (SH), Moderate High (MH), High (H), Very High (VH), Extremely High (EH) are used. Table 1. shows fuzzy values of inputs used in this study.

Table 1. Fuzzy Inputs

Linguistic Variable	AUW (lb)	EW (lb)	MS (kn)	CR (ft/min.)	EDH (hr)
EL	[0, 5072, 32479]	[0, 7410, 38677]	[0, 304, 436]	[0, 3400, 8210]	[0, 315934, 784842]
VL	[5072, 32479, 59886]	[7410, 38677, 69945]	[304, 436, 569]	[3400, 8210, 13020]	[315934, 784842, 1253750]
L	[32479, 59886, 87293]	[38677, 69945, 101212]	[436, 569, 701]	[8210, 13020, 17830]	[784842, 1253750, 1722658]
ML	[59886, 87293, 114701]	[69945, 101212, 132480]	[569, 701, 834]	[13020, 17830, 22640]	[1253750, 1722658, 2191567]
SL	[87293, 114701, 142108]	[101212, 132480, 163747]	[701, 834, 966]	[17830, 22640, 27450]	[1722658, 2191567, 2660475]
M	[114701, 142108, 169515]	[132480, 163747, 195015]	[834, 966, 1099]	[22640, 27450, 32260]	[2191567, 2660475, 3129383]
SH	[142108, 169515, 196923]	[163747, 195015, 226282]	[966, 1099, 1231]	[27450, 32260, 37070]	[2660475, 3129383, 3598291]
MH	[169515, 196923, 224330]	[195015, 226282, 257550]	[1099, 1231, 1364]	[32260, 37070, 41880]	[3129383, 3598291, 4067199]
H	[196923, 224330, 251737]	[226282, 257550, 288817]	[1231, 1364, 1496]	[37070, 41880, 46690]	[3598291, 4067199, 4536107]
VH	[224330, 251737, 279145]	[257550, 288817, 320085]	[1364, 1496, 1629]	[41880, 46690, 51500]	[4067199, 4536107, 5005015]
EH	[251737, 279145, 1000000]	[288817, 320085, 1000000]	[1496, 1629, 1000000]	[46690, 51500, 1000000]	[4536107, 5005015, 1000000]

4.3. Rule Evaluation for Proposed Model

Using Matlab software's fuzzy logic toolbox, fuzzy inference system (FIS) is executed by using triangular fuzzy numbers. The FIS process chart for proposed model is presented in Figure 3. In order to clarify the structure of fuzzy variables, triangular membership functions for "very low (VL)" level the first input AUW is given in Eq. (1). The rest of the inputs and output variables are defined similarly and presented in Figures 4-8.

$$\mu_{VL}(x)=\begin{cases}\frac{(x-5.072)}{(32.479-5.072)}, & 5.072\leq x\leq 32.479\\ \frac{(59.887-x)}{(59.887-32.479)}, & 32.479\leq x\leq 59.887\\ 0 & o.w.\end{cases} \quad (1)$$

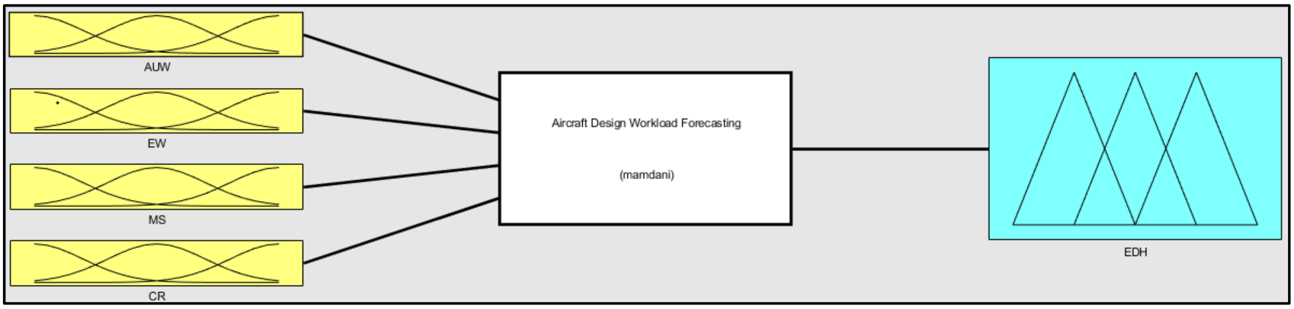

Figure 3. FIS (Fuzzy Inference System) Process Chart

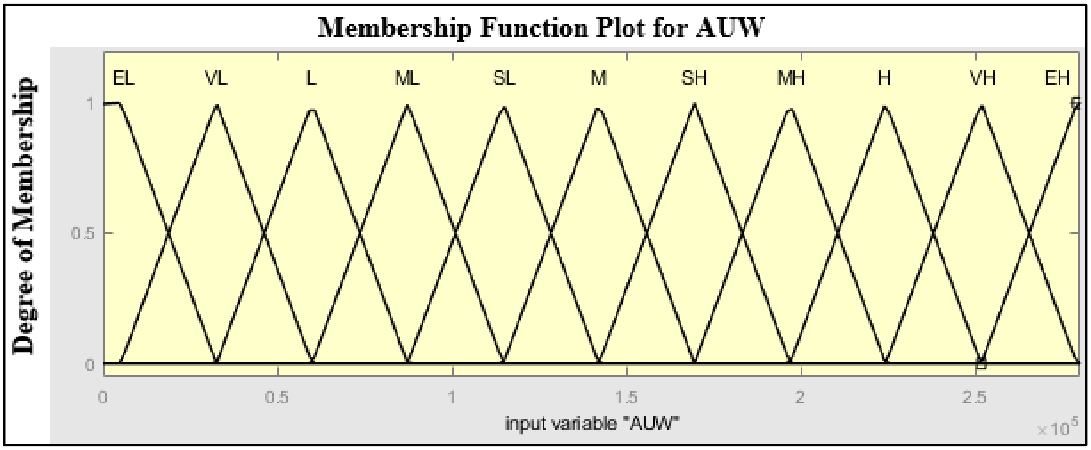

Figure 4. Aircraft Unit Weight (AUW) Membership Function

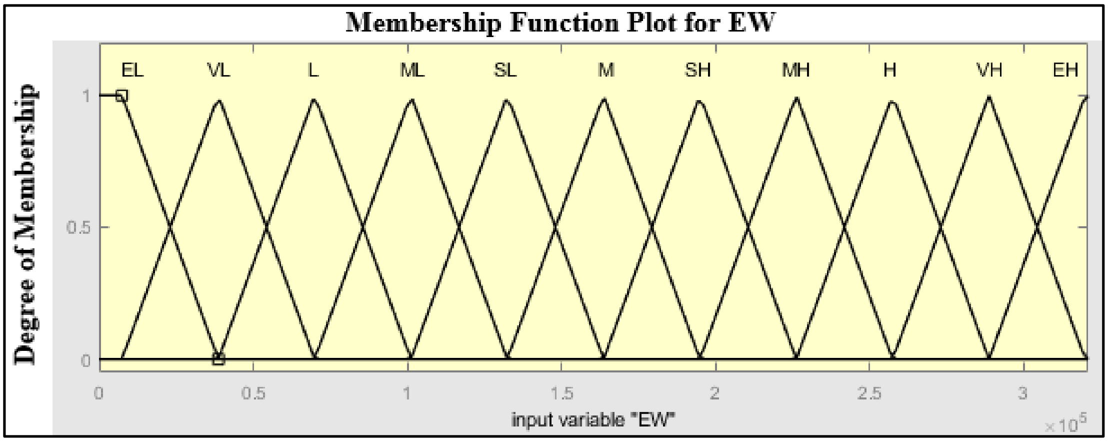

Figure 5. Empty Weight (EW) Membership Function

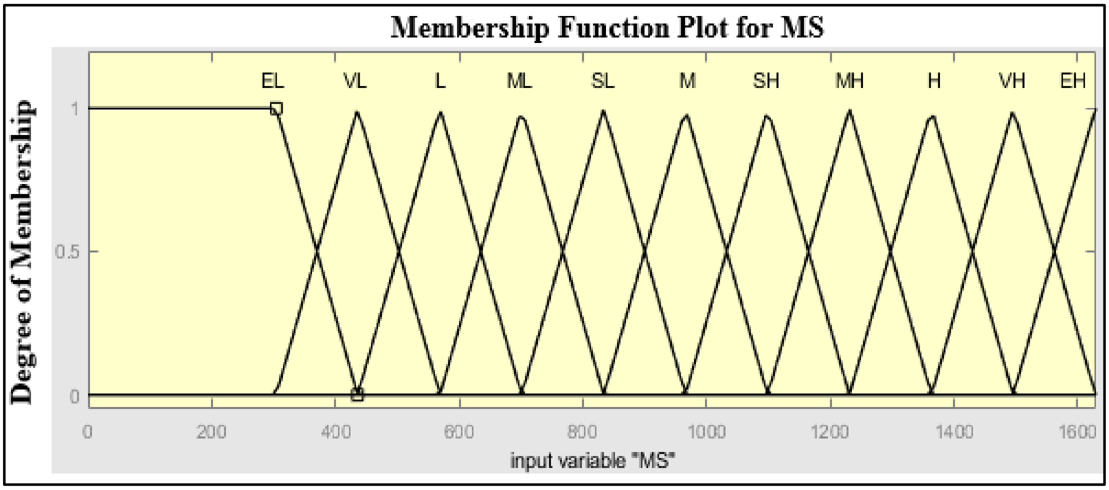

Figure 6. Maximum Speed (MS) Membership Function

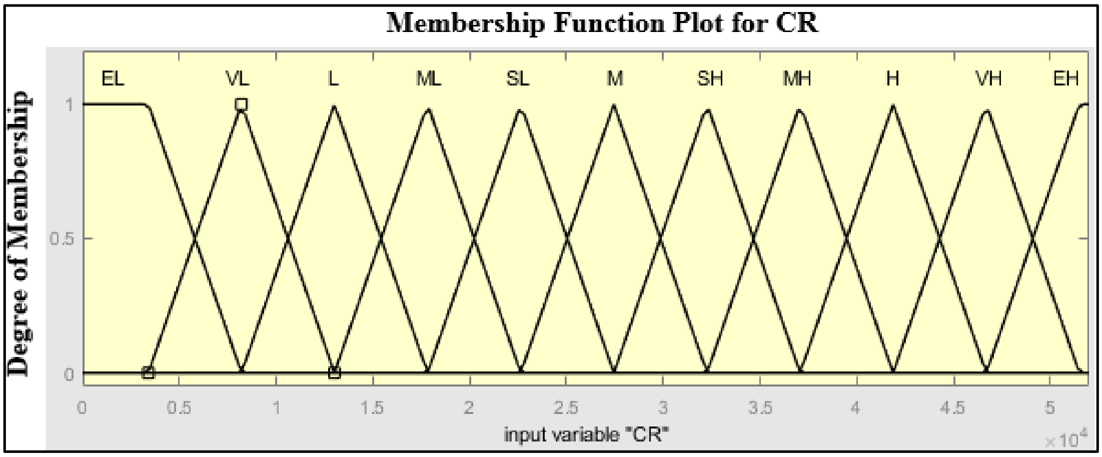

Figure 7. Climb Rate (CR) Membership Function

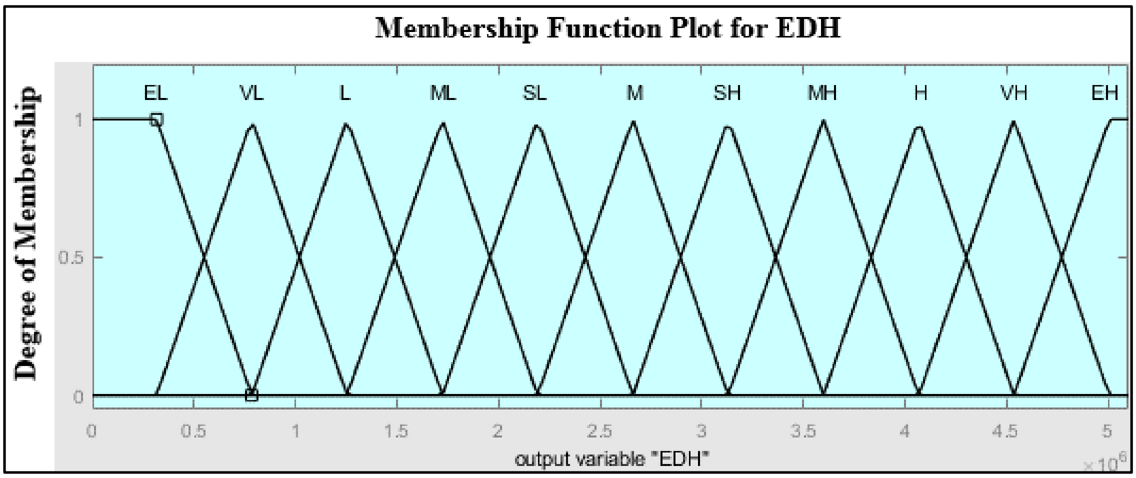

Figure 8. Engineering Design Hours (EDH) Membership Function

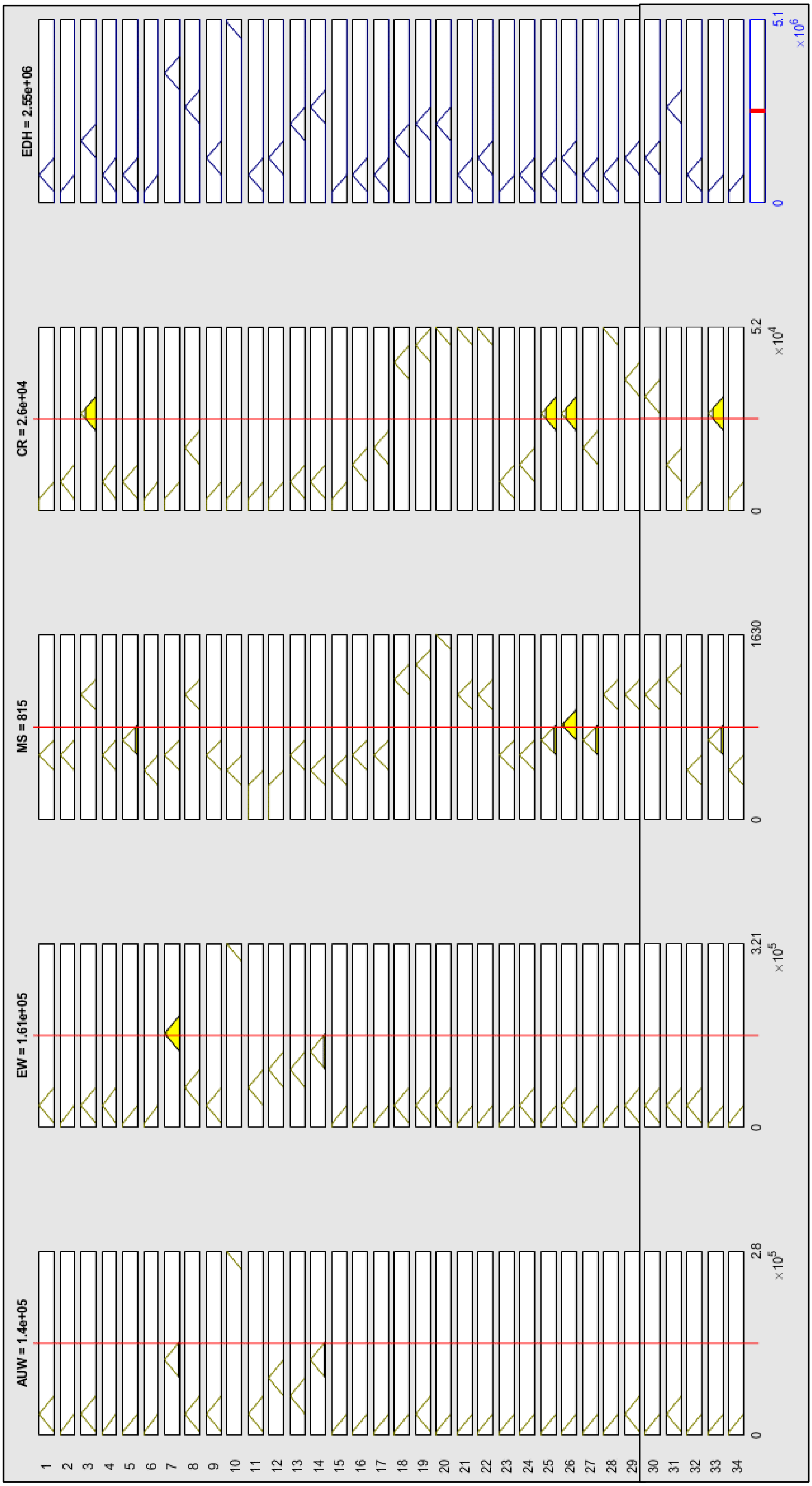

Figure 9. Fuzzy Rule Design

After constructing the fuzzy membership functions for inputs and outputs for the given values in Table 1, totally 34 fuzzy rules are defined. A selected list of the fuzzy rules is as follows:

1) If (AUW is VL) and (EW is VL) and (MS is L) and (CR is EL) then (EDH is VL)
2) If (AUW is EL) and (EW is EL) and (MS is L) and (CR is VL) then (EDH is EL)
3) If (AUW is VL) and (EW is VL) and (MS is SH) and (CR is M) then (EDH is ML)
4) If (AUW is EL) and (EW is VL) and (MS is L) and (CR is VL) then (EDH is VL)
5) If (AUW is EL) and (EW is EL) and (MS is ML) and (CR is VL) then (EDH is VL)

A complete list of rules can be found in [25]. The next step is the defuzzification process, where a crisp value based on fuzzy numbers and associated membership degrees are calculated. Center of Gravity (COG) is used as defuzzification method to get the crisp value. It determines the center of the area of the integrated membership functions. That means it calculates the centroid or COG of integrated output membership functions. Fuzzy rule design is shown in Figure 9.

5. RESULTS AND CONCLUSION

The current design hours and calculated fuzzy outputs are shown in Table 2. and Figure 10.

Table 2. List of workloads (Current Values and Fuzzy Outputs)

Data	Current Values (hr)	Fuzzy Outputs (hr)	Data	Current Values (hr)	Fuzzy Outputs (hr)	Data	Current Values (hr)	Fuzzy Outputs (hr)
1	1.000.288	983.000	12	1.458.067	1.250.000	23	397.490	430.000
2	355.668	316.000	13	2.093.929	2.190.000	24	726.907	652.000
3	1.803.163	1.660.000	14	2.568.323	2.890.000	25	785.891	709.000
4	779.127	590.000	15	439.897	559.000	26	1.135.161	1.250.000
5	644.754	762.000	16	746.726	783.000	27	754.682	785.000
6	465.280	508.000	17	605.156	785.000	28	805.956	1.020.000
7	3.488.623	3.600.000	18	1.668.815	1.670.000	29	1.400.996	1.330.000
8	2.721.242	2.660.000	19	2.274.788	2.090.000	30	1.386.136	1.250.000
9	1.142.757	1.020.000	20	2.112.966	2.190.000	31	2.566.799	2.660.000
10	5.005.016	4.890.000	21	934.204	1.020.000	32	637.010	596.000
11	915.080	785.000	22	1.146.608	1.020.000	33	365.299	527.000
						34	315.935	416.000

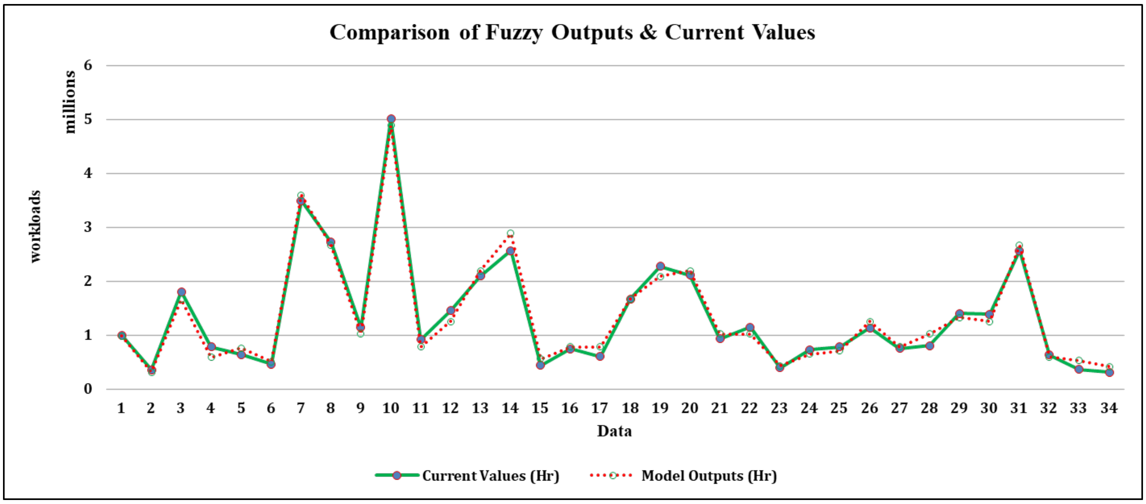

Figure 10. Comparison of Model Outputs and Current Values

Table 2 and Figure 10 present both the current (real) workloads and estimated fuzzy workloads. Comparisons show that fuzzy estimations are closed to actual values. Therefore, in cases where it is hard or impossible to achieve the actual values of components of workload estimation, if the inputs can be classified as linguistic variables such as "extremely low, very low, …, very high, extremely high", then a satisfactory estimation can be obtained.

Adding new variables to the model can make more precious results for future studies. Aircrafts'weight can change in terms of material used in the structures. The samples used in this study have mostly metallic material in their structures, where today's aircraft manufacturers mainly use composite material and even lighter for decreasing cost. Therefore, for future aircraft cost estimation models, material will be a meaningful variable for model.

ÖZET

Bu çalışmada hava aracı tasarımında iş yükünün tahmin edilmesi amaçlanmıştır. İş yükü tahmininde değişkenlerin gerçek değerlerine, sübjektiflik, veri eksikliği ve benzeri durumlar nedeniyle ulaşmak her zaman mümkün olmamaktadır. Bu durumda, modeli bulanık mantık dahil ederek oluşturmak tatmin edici bir çözüm yöntemi olabilmektedir. Bu çalışmada, literatürde bulunan hava aracı tasarım verileri bulanıklaştırılarak sağlanan sonuçlar, literatür sonuçları ile karşılaştırılmıştır. Yapılan karşılaştırma sonucunda, bulanık tahmin yönteminin sonuçlarının, gerçek tahmin sonuçlarına yakın değerler olduğu görülmüştür. Buna göre, hava aracı tasarımında girdilerin kesin olmadığı durumlarda, bulanık değişkenler kullanılarak tahmin yapılabileceği ve tatmin edici sonuçlara ulaşılabileceği sonucuna varılmıştır.

Anahtar Kelimeler: Hava aracı, Tasarım, İş yükü, Maliyet Tahmini, Bulanık Mantık, Bulanık Tahminleme

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