A New Method for Aircraft Maintainability Allocation

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***Abstract*—Development of a civil aircraft maintenance program during early design stage has been carried out by Maintenance Steering Group, which is a team of manufacturer, authority and customers, according to a specified methodology which requires very high experience compare to other design steps. Main sources of maintenance design process are based on pilot reports, maintenance records, failure alerts and manufacturers' recommendations and requirements. During this process, one of the most important topic is task related items such as task types, intervals and durations. Maintenance task durations or repair time are very important for airline companies because availability of an aircraft directly related with this parameter. Aircraft maintainability allocation which is a process to identify the allowable maximum task time for each aircraft component or system is based on mostly experience and out of design office's control. In this study, a new method with two steps has been developed to create an alternative technic for experimental ones. At the first step an existing methodology developed for maintenance allocation has been improved by using a different technic. Improved method shows that newly established correlation between aircraft systems and task times has very high coefficient of determination compare to the existing method. At the second phase of the study several quantitative analysis have been performed by examining 1175 maintenance tasks which are accepted as standard maintenance actions by aviation industry, coming from Maintenance Steering Group methodology and six weight factors have been established for the new method. By using feed forward artificial neural networks for newly identified weight factors, maintenance task allocations has been established. Results shows that newly proposed method can be applicable for any maintenance process during early design stage. However since this study focused on system and component tasks in Maintenance Steering Group, a different perspective is required for structural and zonal tasks allocations.**

***Index Terms*—aircraft maintenance, neural networks, maintainability allocation**

I. Introduction

Aircraft are designed for safety, airworthiness and maintainability and at the beginning of design phase; designers may choose a design methodology. There could be more than one option so the designers must conduct trade-off analysis to arrive at a satisfying design that will meet customer expectations or required specifications. Some of those methodologies are design for manufacturing (DfM), design for assembly or disassembly (DfA, DfD) [1]-[11], design for quality (DfQ), design for reliability (DfR) [12]-[14], design for X (DfX) [15] and design for maintainability (DfM). Based on the commercial or technical requirements, more than one methodology can be used in the design process.

Design for maintainability which is the main topic of this paper, has been studied by several authors. However most of the related works focus on maintenance optimisation during life cycle of product. Desai [16] provided a set of guidelines to build maintainability into the design of product variants to reduce maintenance and service requirements. Wahab [17] studied on the maintainability of a coffee maker from the aspect of design modularity with clustering technique and proposed a new design which enhances maintainability and reliability. One study by Coulibaly [18] proposed an improvement of the maintainability indicators such as the disassembly time and the replacement time of failed components and a behavioral performance engineering algorithm for complex product families at the early design stage. To determine effect of artificial intelligence methods on maintainability Slavia [19] provided maintainability evaluation approach based on fuzzy logic in order to represent and handle the design data available early in the design process. Similarly, Zhong[20] proposed a maintainability fuzzy evaluation for airplane landing gears. Wani and Gandhi [21] proposed a procedure based on a digraph and matrix method for evaluation of maintainability index of mechanical systems and considered maintainability attributes and their interrelations are rudiment in evaluating the index. Chen and Chai [22] reported a new and convenient tool for Design for Maintenance and proposed a methodology, Vector Projection Method, to evaluate the maintainability of the mechanical systems. Lv and Zhang [23] offered TRIZ problem solving method for maintainability design by using work system and conflict matrix. Gillespie and Monaghan [24] developed a formulation for NASA's Ground Systems Development and Operations (GSDO) Program. In this study authors developed a reliability, maintainability and availability allocation techniques, along with system-based knowledge, to ensure the GSDO subsystems achieve the required launch availability goal. Waeyenbergh and Pintelon [25] proposed a new

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maintenance concept taking into considering of customer requirements and product spesifications. Based on the Reliability Centered Maintenance, Business Centered Maintenance and Total Productive Maintenance, the new concept consists of five new modules. Chipchak [26] provided a practical method for maintenance allocation and used 3 weighting factors namely Generic Modules Types (Kj1) which is given in Table I, Fault Isolation Techniques (Kj2), and Differences in M Design Characteristic (Kj3).

TABLE I. GENERIC MODULES (KJ1)

No	Module	Score
1	Lights	1
2	Digital	1
3	Low-level analogue	1.5
4	High-level analogue	1.5
5	Digital computers	2
6	Power Supplies	2
7	Electromechanical equipment	3
8	High-power/high-frequency components	4
9	Interconnections	4
10	Air conditioners	4
11	Liquid coolant systems	4
12	Mechanical structures	6
13	Rotating mechanism/engines	10

Wan[27] examined correlation between Chipchack's[26] weight factors and tasks and then performed several trend analysis. As it can be seen from Table II, the author found a relation between kj1 and task time with R^2=0,871.

TABLE II. TRENDLINES AND FORMULA

Trendline	Formula	R
Log	y=2.5681 ln(x)+4.2099	0.8171
Linear	y=1.4364x+1.769	0.7959
Power	y=3.3696x^0.6838	0.7418
Exponential	y=1.895e^0.3163x	0.4942

II. ENHANCING THE EXISTING METHOD

The main aim of this study is to enhance the existing method[8] and then develop a new one which establishes a correlation between generic modules and fundamental maintenance tasks. For this purpose, while the first step of this study uses artificial neural networks as an alternative to Wan's[27] trend analysis, the seconds one focuses on development of a new method to predict individual task times for each aircraft system or component by performing quantitative analysis and feed-forward neural network methods.

At the first stage of this study, relation between Chipchak's[26] Kj1 module and task times assigned by Wan [27] as per MIL-HDBK-472 [28] and DOD-HDBK-791 [29] is re-investigated by using feed-forward artificial neural networks. Computations of an neural networks are based on learning phases which make models suitable especially in cases when complex mathematical formulations are not possible, nor convenient to implement [30] For this purpose, Log-Sig, Tan-Sig and Pure-Lin transfer functions shown in Fig. 1 are examined for normalization of data. Because of required positive values in the analysis, Log-Sig function is selected and normalization procedure was carried out D_Min_Max rules [31] which is given in Equation (1).

$$x= [0.8*(x_i-x_{min})/(x_{max}-x_{min}) + 0.1] \quad (1)$$

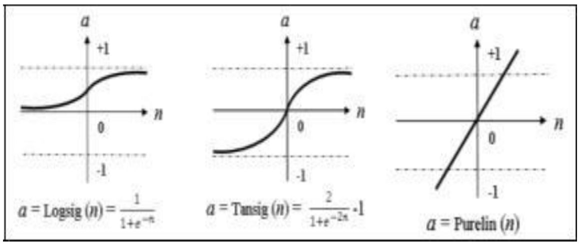

Figure 1. Normalization functions

A feed-forward neural network architecture which is chosen in this study is shown in Fig. 2 where two layers are used which are called hidden and output layer, respectively. Depending on the complexity of the system, more layers can be used, whereas in literature it is not recommended because generalization is reduced.

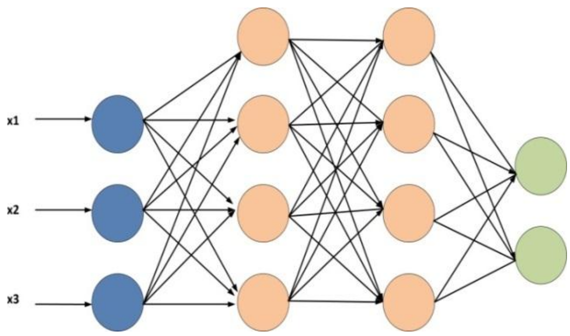

Figure 2. Feed-forward neural network architecture

To apply feed-forward neural network data are divided to 2 sub sets for training and test purpose. Levenberg-Marquardt algorithm[32] which is the fastest training algorithm for networks of moderate size has been used for training. For new vector wn+1 it can be calculated as in Equation (2).

$$w_{n+1} = w_n[J^T J + \eta I]^{-1} J^T e \quad (2)$$

In this equation while I shows unit matrix, η represents Marquard parameter. For learning learngdm which is the gradient descent with momentum weight and bias learning function has been selected from MATLAB. At the end of the training, a comparison between real values and test values has been performed. As it can be seen in Fig. 3 feed-forward neural network produced results which corroborates the findings of a great deal of the previous work[27] and it is also encouraging to compare R-squared value which is found as 1 with that identified by the author [27] as 0.8171. One of the main contributions of this study is the following polynomial function which can be used to evaluate new scores for new potential modules.

$$y = 0.8708x2 - 1.2698x + 0.9562 \quad (3)$$

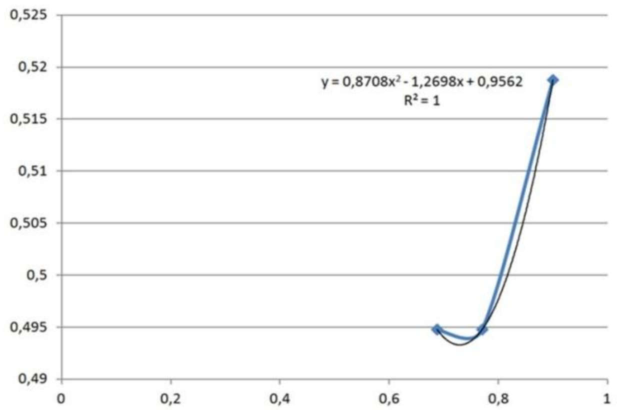

Figure 3. Result of feed-forward neural network

III. Development of the New Method

At the second part of this study, a new correlation is investigated between modules and task times to predict task times for each system or components. For this reason eight fundamental tasks coming from Maintenance Steering Group 3 (MSG-3) are examined in detail. MSG-3 is a voluntary structured process developed by the industry and maintained by Air Transportation Assosication to make decisions that are used to develop scheduled maintenance and inspection tasks and intervals for aircraft that will be acceptable to the regulatory authorities, the operators, and the manufacturers[33]-[35]. To define new weight factors, 1175 maintenance tasks are analysed and categorised into three different groups on the basis of task complexity as shown in Table III and Table IV.

TABLE III. Task Grouping

SİSTEM/KOMPONENT	TASK NO	TANIM	GRUP
MLG/NLG LUB.	XY536	LEFT MAIN LANDING GEAR FWD TRUNNION PIN LUBRICATIO	1
MLG/NLG LUB.	XY537	RGHT MAIN LANDING GEAR FWD TRUNNION PIN LUBRICATIO	1
MLG CLEANING AND CORR. INSP.	XY544	LEFT MAIN GEAR SHOCK STRUT CLEANING	1
MLG CLEANING AND CORR. INSP.	XY545	RIGHT MAIN GEAR SHOCK STRUT CLEANING	1
MLG CLEANING AND CORR. INSP.	XY546	CLEAN NOSE GEAR SHOCK STRUT	1
MLG/NLG LUB.	XY547	LH MLG FORWARD TRUNNION PIN LUBRICATION	1
MLG/NLG LUB.	XY548	RH MLG FORWARD TRUNNION PIN LUBRICATION	1
MLG/NLG LUB.	XY553	L MLG AFT FWD TRNNION PIN ASSY BEARING LUBRICATION	1
MLG/NLG LUB.	XY554	R MLG AFT FWD TRUNNION PIN ASSY BEARING LUBRICATION	1
CABIN INTERIOR(CLEANING)	XY563	REPLACEMENT OF THE PHOTOLUMINESCENT INSERT	1
CABIN INTERIOR(CLEANING)	XY568	VIS.CHK CLEANING OF PHOTOLUMIN.FLOOR PATH MARKING	1
WASTE SYSTEM INSP.&OPC.	XY607	SERVICE TOILET WASTE LINES	1
WASTE SYSTEM INSP.&OPC.	XY608	CLEAN OR REPLACE VACUUM BLOWER FILTER	1
WASTE SYSTEM INSP.&OPC.	XY609	WASTE TANK WATER SEPERATOR-REPLACE	1
WASTE SYSTEM INSP.&OPC.	XY610	FWD LAVATORY POTABLE WATER DRAIN VALVE-OPER CHECK	1
WASTE SYSTEM INSP.&OPC.	XY611	FWD LAVATORY POTABLE WATER DRAIN VALVE-OPER CHECK	1
WASTE SYSTEM INSP.&OPC.	XY612	TOILET WASTE LINES - SERVICING	1
WASTE SYSTEM INSP.&OPC.	XY613	TOILET WASTE LINES - SERVICING	1
WASTE SYSTEM INSP.&OPC.	XY614	WASTE TANK QUANTITY INDICATING SYSTEM-OPER CHECK	1
WASTE SYSTEM INSP.&OPC.	XY615	BLEED AIR IN-LINE FILTER-REPLACE	1
WATER SYSTEM FILTER REPL.	XY616	POTABLE WATER SYSTEM DISINFECTION	1
WASTE SYSTEM INSP.&OPC.	XY620	REMOVE AND CLEAN THE TOILET WASTE TANK RINSE FILTR	1
CABIN DOOR LUB.	XY649	FORWARD ENTRY DOOR-LUBRICATION	1
CABIN DOOR LUB.	XY650	FORWARD SERVICE DOOR-LUBRICATION	1
CABIN DOOR LUB.	XY651	AFT ENTRY DOOR-LUBRICATION	1
CABIN DOOR LUB.	XY652	AFT SERVICE DOOR-LUBRICATION	1

TABLE IV. Fundamental Tasks and Grouping

Abbreviation	Task Name	Group
SRV	Servicing	1
LUB	Lubrication	
RAI1	Rem.&Inst.	
SMP	Sampling	
DRN	Draining	
CLN	Cleaning	
RST	Rem. for Restoration	2
REP	Replacement	
LUB	Lubrication	
RAI2	Rem.&Inst.	
DIS	Discard	
CGK	Check	
GVI	General Visual Insp.	
OPC	Operational Check	
ADJ	Adjustment	3
CPC	Corrosion Control	
LUB3	Lubrication	
RAI3	Rem.&Inst.	
DVI	Detailed Visual Insp.	
FUC	Functional Check	

Weight factor k2 is established by examining labor skills and required certifications to perform maintenance actions by conducting a quantitative analysis. For example if only a task training is required to accomplish a certain task, k2 value is assigned as 1. When aircraft type training and maintenance license are mandatory for some complex tasks, k2 value will be 3. The Table V presents the summary of the whole scenario.

TABLE V. Summary of Weight Factor k2

Aircraft Mechanic				
Group(k2)	***Category***	***License***	***Type***	***Task Training***
1				√
2	**B1/B2**	√		√
			√	
3	**B1/B2**	√	√	
	B1/B2	√		√

Similarly, k3 is described as number of person for related task. If only one person is required for related task, k3 will be 1, for 2 persons, it will be 2 and so on.

TABLE VI. Summary of Weight Factor k3

Number of Persons	k3
1	1
2	2
i	i

Weight factor k4 shows requirement for tools or equipments. If any tool or equipment is required to perform related maintenance task, k4=1 otherwise it will be 0.

TABLE VII. SUMMARY OF WEIGHT FACTOR K4

Requirement for Tools/Equipment	k4
Yes	1
No	0

To apply some complex tasks, other relevant tasks or some preparation can be required. For example, to carry out a functional test of landing gears, aircraft jacking procedure which is raising the complete aircraft on jack must be performed. To simulate this situation a new factor is defined and characterized as k5.

TABLE VIII. SUMMARY OF WEIGHT FACTOR K5

Prerequist for Task	k5
Yes	1
No	0

Finally, k6 describes total man/hour to accomplish a task. All weight factors are listed in Table V.

TABLE IX. SUMMARY OF WEIGHT FACTORS

Weigh Factors	Definition
k1	Aircraft components/systems
k2	Tasks
k3	Number of persons
k4	Necessity of tool/equipment
k5	Prerequist
k6	AdaMan/hour

After all weight factors has been established, new modules and related score values have been produced by using the polynomial function given in (3) as shown in Table X and Table XI. Since the score is required an integer value, decimal numbers are rounded to the nearest whole number.

TABLE X. EVALUATED NEW MODULES

Module	Man/Hour	Equation	Value	Score
Landing Gears	3,63	$y = 0.8708x^2 - 1.2698x + 0.9562$	7,8	8
Hydromechanical systems	3,58	$y = 0.8708x^2 - 1.2698x + 0.9562$	7,56	8
Pitot	1,88	$y = 0.8708x^2 - 1.2698x + 0.9562$	1,64	2
Statik pors	2,0	$y = 0.8708x^2 - 1.2698x + 0.9562$	1,89	2

TABLE XI. LIST OF WEIGHT FACTORS

	k1	k2	k3	k4	k5	k6
ENGINE	10	2	1	0	0	0,5
	10	2	2	0	0	3,67
	10	3	5	1	1	20,25
	10	3	5	1	1	36,33
	10	1	1	1	0	0,42
MLG	8	1	2	1	0	1,5
	8	3	2	1	0	1
	8	2	1	1	0	0,58
	8	2	1	0	0	0,42
	8	3	5	1	1	6,75
NLG	8	1	2	1	0	1,17
	8	3	2	1	0	2,42
	8	3	1	1	0	0,33
	8	2	1	0	0	0,42
	8	3	5	1	1	6
AILERON	8	1	2	1	0	0,58
	8	2	1	0	0	0,42
	8	3	3	1	0	0,67
	8	2	1	0	0	0,25
STABILIZER	8	1	1	1	0	0,3
	8	3	2	1	0	1,33
	8	3	1	1	0	0,58
	8	3	3	1	0	1,25
LIGHTS	1	2	1	0	0	0,25
	1	3	1	0	0	0,42
	1	1	1	0	0	0,67
	1	3	1	0	0	2,17
PITOT	2	3	2	1	0	1,33
	2	3	1	1	0	0,25
STATIC PORTS	2	3	2	1	0	1,33
	2	2	1	0	0	0,5
OXYGEN SYSTEMS/MASKS	2	3	2	1	0	3
	2	3	1	0	0	3

Data for this study were retrospectively collected from a Boeing narrow-body fleet of an airline company. Subsequently feedforward neural network has been used to examine the correlation between score values and task times. While %80 of data were used for training, remaining ones were employed to compare both values. Similar to previous analysis, Levenberg-Marquardt training algorithm and learngdm learning function has been selected in MATLAB (Fig. 4.). Other parameters are given in Table XII and Fig. 4.

TABLE XII. SUMMARY OF NNA PARAMETERS

Network type	**Feed forward NNA**
Training function	Trainlm
Learning function	Learngdm
Performance function	MSE
Number of layers	2
Number of neurons	10
Activation function	Logsig

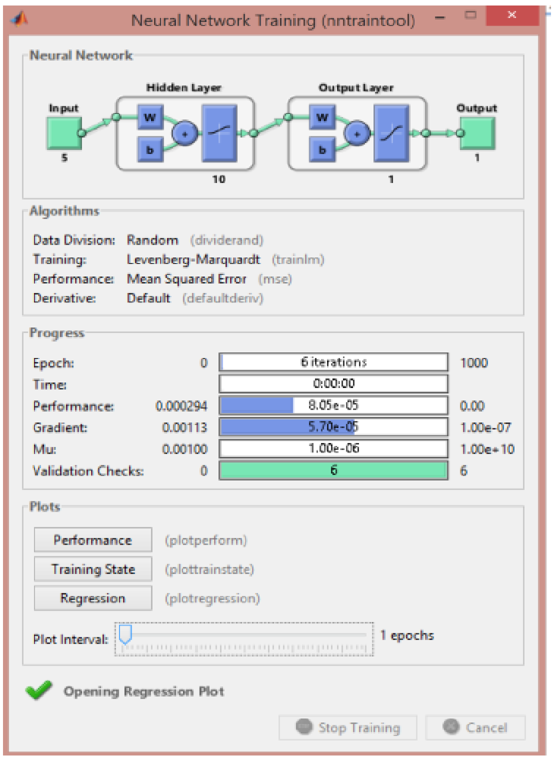

Figure 4. Matlab training screen

Evaluated R values for training, validation, test and overall are given in Fig. 5. As it can be seen, while all scores are above 0.90, overall value is found as 0.9565 which is very high for reliability.

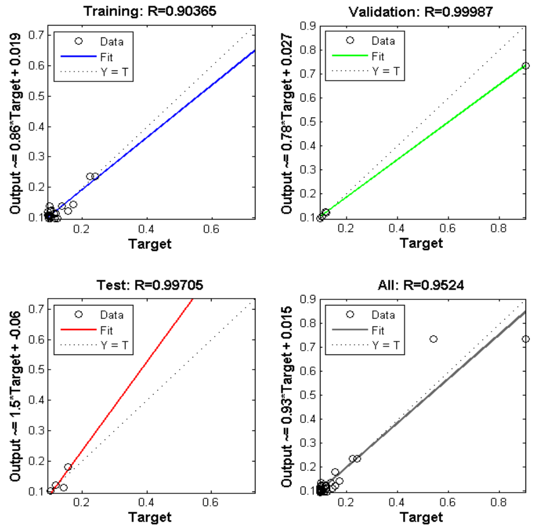

Figure 5. Matlab R values

The result obtained from the neural network analysis is shown in Fig. 6. It is apparent from this figure that there is a significant positive correlation between modules and related task time. Morever it shows that prediction of maintenance action time during early design stage can be possible for corrosponding part, system or component by using feed-forward neural network.

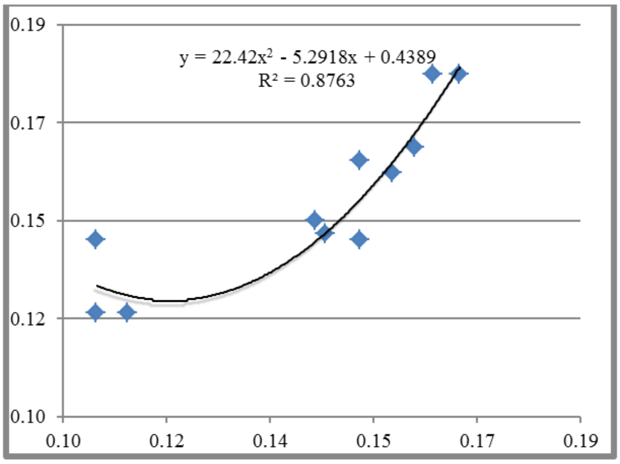

Figure 6. Comparison of training and test data

IV. CONCLUSION

The main focus of this research was to develop a new technique to predict the aircraft components maintainability in the early design stage. For this purpose, at the first step authors focused on an existing design methodology which found R^2 value as 0,8171. By usign feed forward neural network and quantitative analyses, proposed enhanced method increased R^2 value to 1 which means a perfect score. At the second stage of of this research, a new method based on artificial intelligence methods and several quantitave analysis has been proposed to initiate a correlation between aircraft components and allocated task times. Results show that new method can be very useful to provide a maximum allowable task time for newly designed aircraft. Furthermore, proposed technique offers the opportunies for academicians to use different inputs to predict other air platforms maintainability processes.

Since this study conducted by a limited data coming from an airline and getting more accurate results depends on available data, it is possible to extend this research by cooperating with airline industry for future works. In addition to this, Further research regarding prediction of aircraft structure tasks would be worthwhile.

REFERENCES

[1]. I. Bettles, "Design for manufacture & assembly (DFMA) - the Boothroyd & Dewhurst approach," *IEE, Stevenage*, UK, p. 316, 1992.

[2]. C. Kuo, H. C. Zhang, and S. H. Huang, "Disassembly analysis for electromechanical products: A graph-based heuristic approach," *International Journal of Production Research*, vol. 38, no. 5, pp. 993-1007, 2000.

[3]. E. Zussman, A. Kriwet, and G. Seliger, "Disassembly-oriented assessment methodology to support design for recycling," *CIRP Annals – Manufacturing Technology*, vol. 43, no. 1, pp. 9-14, 1994.

[4]. B. Gauthier, P. Dewhurst, and D. Japikse, "Application of design for manufacture and assembly methodologies to complex aerospace products," *AIAA/ASME/SAE/ASEE Joint Propulsion Conference and Exhibition*, 36th, Huntsville, AL; US; 16-19 July, vol. AIAA Paper 2000-3404, 2000

[5]. G. Boothroyd, P. Dewhurst, and W.A. Knight, *Product Design for Manufacture and Assembly*, 3rd Ed, *CRC Press*, New York, United States, 2010

[6]. T. C. Kuo and H. C. Zhang, "Design for manufacturability and design for "X": Concepts, applications, and perspectives," *Electronics Manufacturing Technology Symposium*. 'Manufacturing Technologies - Present and Future', Seventeenth IEEE/CPMT International, pp. 446, 1995.

[7]. A. J. Scarr and P. A. McKeown, "Product design for automated manufacture and assembly," *CIRP Annals-Manufacturing Technology*, vol. 35, no.1, pp. 1-5, 1995.

[8]. T. C. Kuo, "Disassembly sequence and cost analysis for electromechanical products," *Robotics and Computer-Integrated Manufacturing*, vol. 16, no. 1, pp. 43-54, 2000.

[9]. H. Bley, G. Reinhart, G. Seliger, M. Bernardi, and T. Korne, "Appropriate human involvement in assembly and disassembly," *CIRP Annals – Manufacturing Technology*, vol. 53, no. 2, pp. 487-509, 2004.

[10]. K. Lee and R. Gadh, "Computer aided design for disassembly: A destructive approach," *in Proc. 1996 IEEE International Symposium* on, pp. 173.

[11]. G. Boothroyd and W. Knight, "Design for assembly," *Spectrum, IEEE*, vol. 30, no. 9, pp. 53-55, 1993

[12]. NASA, 2000. Reliability Centred Maintenance Guide for facilities and Collateral Equipment. [Online]. Available: http://www.wbdg.org/ccb/NASA/GUIDES/rcm.pdf accessed at 11.05.2017.

[13]. L. C. Jaw, "Recent advancements in aircraft Engine Health Management (EHM) technologies and recommendations for the next step," *in Proc. Turbo Expo 2005 50th ASME International Gas Turbine & Aero engine Technical Congress*, Reno-Tahoe, Nevada, USA, 2005.

[14]. "American society of mechanical engineers, American Institute of Aeronautics and Astronautics and Society of Automotive Engineers," *in Proc. Reliability and maintainability conference*, [Technical papers presented] May 6-8, 1963, Washington, D. C.

[15]. M. C. Chiu and G. E. Okudan Kremer, "Investigation of the applicability of Design for X tools during design concept evolution: A literature review," *International Journal of Product Development*, vol. 13, no. 2, pp. 132-167, 2011.

[16]. A. Desai and A. V. Mital, "Design for maintenance: Basic concepts and review of literature," *International Journal of Product* Development, vol. 3, no. 1, pp. 77–121, 2006.

[17]. D. A. Wahab, K. E. Ching, T. A. Boay, R. Ramli, and A. V. Hussain, "Product redesign for ease of maintenance: A case study," *International Journal of Mechanical and Materials Engineering*, vol. 3, no. 2, pp. 153-159, 2008.

[18]. A. Coulibaly, R. Houssin, and B. Mutel, "Maintainability and safety indicators at design stage for mechanical products," *Computers in Industry*, vol. 59, no. 5, pp. 438-449, 2008.

[19]. C. A. Slavila, C. Decreuse, and M. Ferney, "Fuzzy approach for maintainability evaluation in the design process," *Concurrent Engineering Research and Applications*, vol. 13, no. 4, pp. 291-300, 2005.

[20]. L. Zhong and S. Youchao, "Research on maintainability evaluation model based on fuzzy theory," *Chin J Aeronaut*, vol. 20, no. 5, pp. 402-407, 2007.

[21]. M. F. Wani and O. P. Gandhi, "Maintainability design and evaluation of mechanical systems based on tribology," *Reliability Engineering & System Safety*, vol. 77, no. 2, pp. 181-188, 2002.

[22]. L. Chen and J. Cai, "Using vector projection method to evaluate maintainability of mechanical system in design review," *Reliability Engineering and System Safety*, vol. 81, no. 2, pp. 147-154, 2003.

[23]. C. Lv, M. Zhang, and M. Wang, "Application research of TRIZ in maintainability design," in *Proc. International Conference on Quality, Reliability, Risk, Maintenance, and Safety Engineering*, Chengdu, China, 15 - 18 July, 2013.

[24]. A. M. Gillespie and M. Monaghan, "Allocating reliability & maintainability goals to NASA ground systems," *Reliability and Maintainability Symposium*, Orlando, Florida, United States, 28-31 January, 2013

[25]. G. Waeyenbergh and L. Pintelon, "A framework for maintenance concept development," *International Journal of Production Economics*, vol. 77, pp. 299–313, 2002.

[26]. J. S. Chipchak, "A practical method of maintainability allocation," *IEEE Transactions on Aerospace and Electronic Systems*, vol. AES-7, no. 4, 1971.

[27]. H. Wan and M. S. Wan, "Maintainability prediction for aircraft mechanical components utilizing aircraft feedback information," *Applied Mechanics and Materials*, vol. 225, pp. 528-533, 2012.

[28]. MIL-HDBK-472 (1966). Maintainability Prediction, Department of Defense, Washington, DC.

[29]. DOD-HDBK-791 (1988). Maintainability Design Techniques, Department of Defense, USA

[30]. P. S. Rajpal, K. S. Shishodia, G. S. Sekhon, "An artificial neural network for modeling reliability, availability and maintainability of a repairable system," *Reliability Engineering & Systems Safety*, vol. 91, no. 7, pp. 809-819, 2006.

[31]. M. Deveci and S. Yavuz, İstatistiksel normalizasyon tekniklerinin yapay sinir ağın performansına etkisi, Erciyes Üniversitesi İktisadi Ve İdari Bilimler Fakültesi Dergisi, 40, pp. 167-187, 2012.

[32]. K. Levenberg, "A method for the solution of certain non-linear problems in least squares," *Quarterly of Applied Mathematics*, vol. 2, pp. 164–168, 1944.

[33]. Boeing, B737-600/700/800/900 Airframe & Engine Type Course Document, Seattle, America, 2014.

[34]. Airbus, Airbus A320 Family Airframe & Engine Type Course Document, Seattle, USA, 2013.

[35]. H. A. Kinnison, Aviation maintenance management, McGraw-Hill, New York, 2004.

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