MİLLİ SAVUNMA ÜNİVERSİTESİ
BARBAROS DENİZ BİLİMLERİ
VE MÜHENDİSLİĞİ ENSTİTÜSÜ

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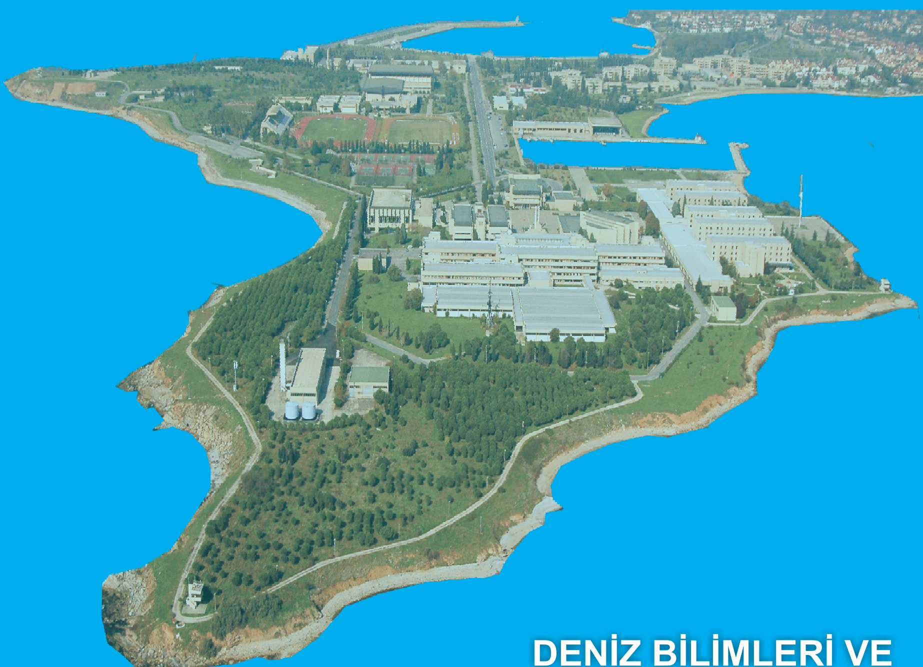

DENİZ BİLİMLERİ VE MÜHENDİSLİĞİ DERGİSİ

CİLT : 14 SAYI : 1 NİSAN 2018

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BARBAROS NAVAL SCIENCES AND ENGINEERING INSTITUTE
JOURNAL OF NAVAL SCIENCES AND ENGINEERING

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Dr.Mehmet Bilge Kağan ÖNAÇAN

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RESEARH ARTICLE

IMPROVING AN INEFFICIENT PRODUCTION LINE VIA AHP AND VALUE STREAM MAPPING

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ABSTRACT

Nowadays competition among companies is rapidly increasing with the progress of technology. In order to stand out in this competition environment, companies need to be renovated in their own fields. Many companies use lean manufacturing techniques to achieve this renewal.

This study was performed in a company operating in the automotive industry. In this study, the production line which will be improved is determined by using the Analytical Hierarchy Process method. Next, Value Stream Mapping has been applied to the determined product line. We revealed the current situation of the production line by drawing current state mapping. Second, the future state mapping is drawn up to solve the problems presented in the current state mapping, and an action plan was presented for improvements.

Keywords: *Analytic Hierarchy Process, Lean Manufacturing, Value Stream Mapping*

VERİMSİZ BİR ÜRETİM HATTININ AHP VE DEĞER AKIŞ HARİTALAMA İLE İYİLEŞTİRİLMESİ

ÖZ

Günümüzde şirketler arası rekabet teknolojinin ilerlemesiyle birlikte hızla artmaktadır. Bu rekabet ortamında pazarda öne çıkabilmek için şirketler kendi bünyesinde yenilenmeye ihtiyaç duymaktadır. Bu yenilenmeyi sağlayabilmek için birçok şirket yalın üretim tekniklerini kullanmaktadır.

Bu çalışma otomotiv sektöründe faaliyet gösteren bir firmada uygulanmıştır. Bu çalışmada, geliştirilecek üretim hattı Analitik Hiyerarşi Prosesi metodu kullanılarak belirlenmiştir. Sonrasında belirlenen hatta değer akışı haritalaması uygulanmıştır. İlk önce üretim hattının mevcut durumu mevcut durum haritası ile ortaya konmuştur. İkinci olarak mevcut durum değer akışında görülen problemlerin iyileştirilmesi için önerilen gelecek durum haritası çizilmiştir ve iyileştirmeler için aksiyon planı sunulmuştur.

Anahtar Kelimeler: *Analitik Hiyerarşi Yöntemi, Yalın Üretim, Değer Akışı Haritalama*

1. INTRODUCTION

In today's world, the price of the product is determined by the market. Therefore, companies can not increase the price of the product sold in order to make more profit. Firms choose to reduce the cost of the product instead of increasing the price in order to make more profit without losing its competitive power. To reduce the costs, improvements have to be made during the production phase. With this approach which employs lean production philosophy, many companies have increased their competitiveness levels.

Value is the critical starting point for lean philosophy and can only be identified by the end customer. The customer is now willing to pay for any operation that does not create a surplus value on the product he/she buys. These processes are defined as operations. To make the value concept meaningful, customer demands must be expressed in a product type that meets at a certain time and at a certain price [1].

Lean thinking is based on the removal of waste and refuse. It primarily begins with the Value Stream Mapping (VSM) method for detecting waste and refuse. By analyzing the current state with the VSM method, it is possible to determine the steps that are value added and non-value added in value stream.

In this study, we adopt the AHP (Analytical Hierarchy Process) methodology, one of the well-known multi criteria decision making methods to determine the product line for the VSM. Then, we apply the VSM method to the determined production line. The outline of this paper is as follows: In the second section, we present the related work on this topic. The third section deals with the VSM method used in the study and the fourth section presents the basics of the AHP methodology. In the fifth section, we discuss the details of our application. Finally, in the sixth section, we present the results and suggestions about our study.

2. LITERATURE REVIEW

In our literature review, we focus on a number of studies which incorporate VSM methodology in both the production and service sectors.

The first study on VSM was conducted by Rother and Shook in 1999. In the book "Learning to See" [2], Rother and Shook described the VSM in detail and provided a number of examples. In [3], Efe and Engin used the VSM method in the Numune Training and Research Hospital Emergency Service. They reduced the supply period obtained from the current state map from 132.5 minutes to 84 minutes. That is, they have achieved an improvement of 36.6%. In their study, it was observed that the VSM method provided significant improvements in the service sector.

In their study, Abdulmalek and Rajgopal [4] used the VSM method in a steel manufacturing company to identify opportunities for a variety of lean techniques. At the same time, they defined a simulation model to compare before and after performances. Seth and Gupta in [5] used VSM methodology to improve the supplier productivity of an automotive industry in their study. The current and future states of the supplier are discussed using the value stream concepts. In the study, per capita production volume was increased, and process time, flow time and finished product stock were reduced [5].

In [6], the authors used VSM methodology in a company that produces tractors. After the current state map is drawn, the proposed state is presented in the future state map. The authors stated that, the application of the proposed improvements would change the 21 days long manufacturing lead time to 3.5 days, hence the total inventory turnover would increase by 6 times.

[7] Considered improving the performance of aircraft maintenance services by using VSM. Considering the fact that customers expect a short delivery time from aircraft maintenance services, the authors analyzed service processes related to maintenance work to minimize the delivery time. Doing so, they revealed wastes and bottlenecks in the system. Next, with the help of the VSM methodology, they showed an improvement in the efficiency of the maintenance service.

3. VALUE STREAM MAPPING METHOD

The value is anything that the customer accepts to pay for the product. So first we have to understand what the customer wants. In a production system, operations that the customer is not willing to pay should be eliminated or minimized.

A value stream represents the sum of value-added and non-value added activities and works. In the value stream, the entire flow is examined and intended to improve the whole processes, instead of improving them individually [2].

VSM visually shows the value stream of the product using special figures and computations. This makes it easier for decision makers to understand the value stream. In the VSM, all material and information flow from the raw material to finished product is drawn with special symbols to the value flow. The map of the future is designed from this map drawn later [2].

In VSM, wastes become clearly visible and the links between the information flow and the material flow is displayed clearly. All operations from door to door in the VSM are drawn for the production of a single product group using a paper and pencil [2].

There are four basic steps in VSM: (1) The product family is selected, (2) The current state is drawn, (3) The future state is drawn, and (4) The business plan is prepared and applied. When the improvements designed in the future are completed, this future status map becomes the current status map. This is the logic of continuous improvement. Then a map of the state will be drawn again and so on [2].

When the current state is analyzed in the VSM, three kinds of operations are encountered;

1. The actions that add value to the product,

2. The actions that do not add value to the product,

3. The obligatory actions that do not add value to the product,

The processes that do not add value to the product are wasted and they should be destroyed. The obligatory processes that do not add value to the product should be minimized.

The VSM uses standard symbols for both the current state drawing and the future state drawing. These standard symbols form a common language in production. The symbols used are three kinds: material flow symbols, general symbols and information flow symbols. All of these symbols are shown in Figure 1 below [2].

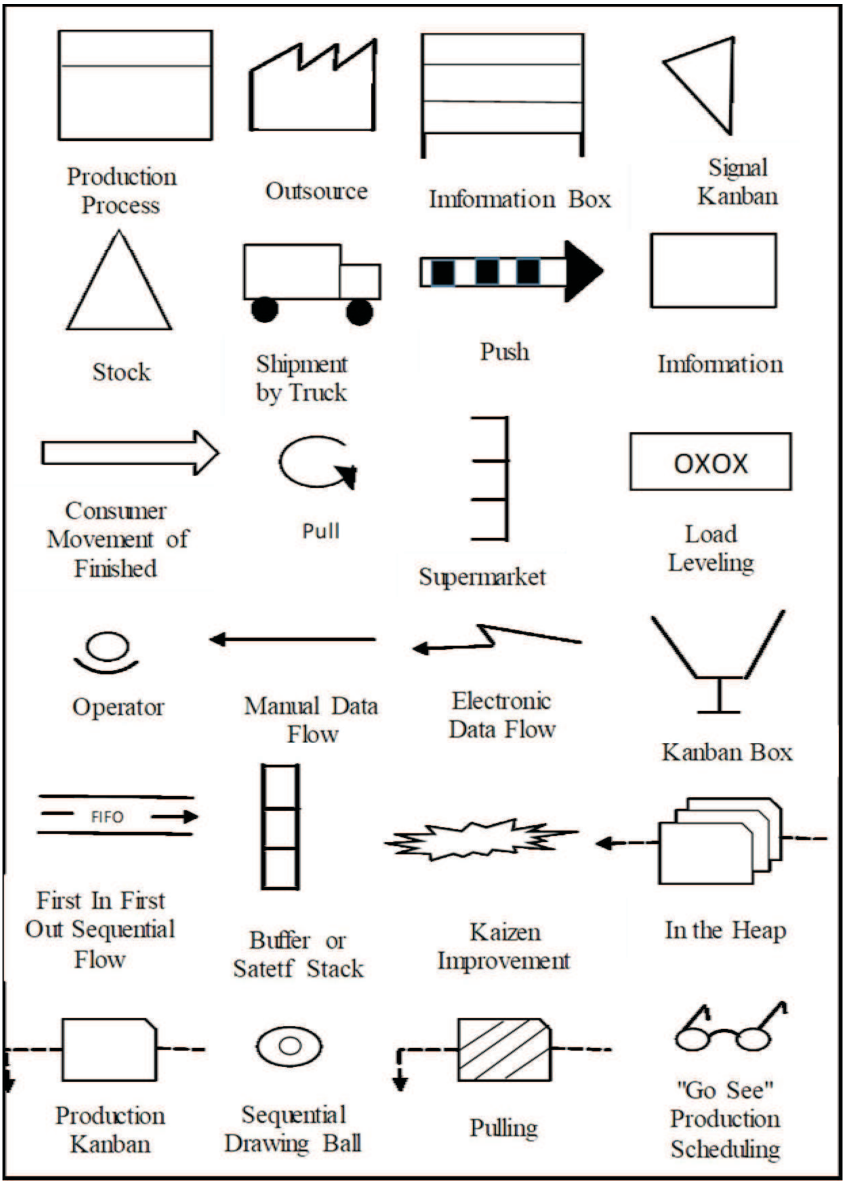

Figure 1. Symbols Used in Value Stream Mapping (from [2])

4. ANALYTIC HIERARCHY PROCESS

Decision making is very important in both daily and business lives. Making right decisions increases the competitive levels of companies. Decision theory provides guidance on the best alternative to take while aiming to maximize utility [8]. People can make their decisions by using their intuition or by taking advantage of their experience. In cases where multiple alternatives and assessment criteria exist, decision makers use Multi-Criteria Decision Making methods which aim to assist them by providing an analytic solution approach [9]. One of those methods is the Analytic Hierarchy Process (AHP), developed by Thomas L. SAATY in the 1970s with the intention of supporting decision makers during decision making [10].

The AHP is a method that allows a hierarchical model to include the objective, assessment criteria & sub criteria, and alternatives for the problem of interest. [11]. The AHP process decomposes the decision problem into a number of sub-problems, which are easier to evaluate and solve [12, 13]. There are 7 stages in the Analytic Hierarchy Process. These steps include creating hierarchical structure, determination of priorities, pairwise comparison matrix, creating priority vector, calculation of consistency ratio, determination of final sequence, and finally sensitivity analysis [10].

4.1. Creating Hierarchical Structure

First, the problem needs to be understood clearly. Then, the objectives (targets) and criteria should be determined by the experts [14]. Figure 2 shows a hierarchical structure consisting of targets, criteria and alternatives [15].

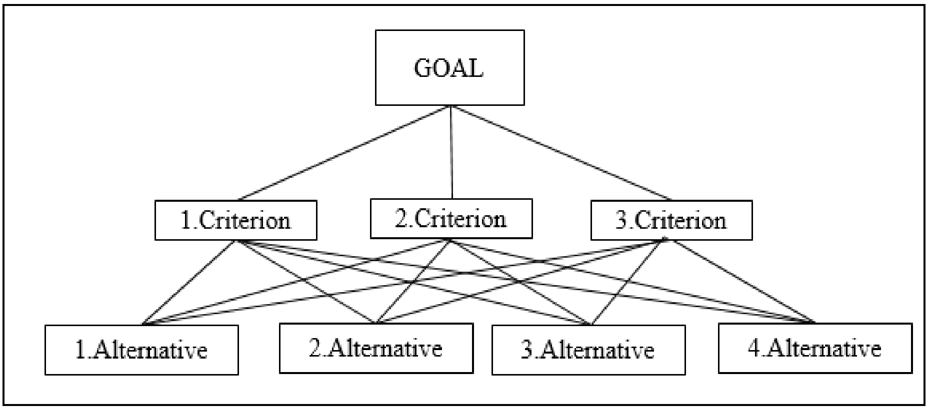

Figure 2. Example of a Decision Hierarchy (from [15])

4.2. Determination of Priorities

The elements forming the hierarchy are compared with each other and priorities are calculated relative to each other. In this comparison, "1-9 scale" is used to eliminate complexity in comments and minimize many errors [16]. Table 1 represents the "1-9 scale" [17].

4.3. Pairwise Comparison Matrix

The pairwise comparison matrix is the result of the decision maker's comparision of alternatives and criteria using the values in Table 1. This matrix is provided as a result of proportion of w_i to w_j which are weights or importance ratings according to the basic scale [18].

C_1, C_2, ..., C_n are the elements at any stage of the decision hierarchy. The A matrix is the nxn matrix of pairwise comparisons of C_i and C_j. a_{ij} are the values
of pairwise comparison matrix (i, j = 1,2, ..., n). Thus the matrix A consisting of pairwise comparisons is as follows [19].

$$A = \begin{bmatrix} 1 & a_{12} & \cdots & a_{1n} \\ 1/a_{12} & 1 & \cdots & a_{2n} \\ \cdot & \cdot & \cdots & \cdot \\ \cdot & \cdot & \cdots & \cdot \\ \cdot & \cdot & \cdots & \cdot \\ 1/a_{1n} & 1/a_{2n} & \cdots & 1 \end{bmatrix}_{nxn} \quad (1)$$

Table 1. Significance Ratings and Explanations Used in Pairwise Comparisons (from [17])

Importance Level	Definition	Explanation
1	Equally Important	Both parties have the same importance
3	Slightly Important	A factor according to experience and judgement is more important than the other.
5	Strongly Important	One factor is more important than the other
7	Very Strong Important	One factor is strongly preferred at a higher level than the other.
9	Absolutely Important	One of the factors is very important at a higher rate than the other.
2,4,6,8	Represents intermediate values	When compromise is needed
Mutual Values	i is assigned a value (x) as compared with j; when j is compared with i, the value to be assigned (1 / x) will be.	

4.4. Creating Priority Vectors

In this phase, the correlation matrices are first normalized to determine the priority or weight vectors. A normalized matrix is formed by dividing the value of each column by the sum of the respective columns. Subsequently, weights or priority vectors of the criteria, sub criteria and alternatives are obtained by taking the average of the row values of the normalized matrix [10]. This priority vector is defined as *w* column matrix.

4.5. Calculation of Consistency Ratio

The consistency of the decision is tested by the consistency rate determined at this stage. This rate is calculated as follows (for details, see [20]):

1. The pairwise comparison matrix *A* is multiplied by *w* matrix and the weighted sum matrix A_w is obtained,

2. The A_w matrix is divided into *w* matrices,

3. Calculate the maximum $\square_{max}$ by taking the arithmetic mean of the values in the matrix obtained from the second step,

4. Consistency index is found in the following formula:

$$CI = \frac{max - n}{n - 1} \quad (2)$$

5. Finally, the consistency rate is calculated using the following formula,

$$CR = \frac{CI}{RI} \quad (3)$$

RI (Random Index) is found in Table 2 for various *n*'s [21].

Table 2. Random Index Values (from [21])

n	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**
RI	0.00	0.00	0.58	0.9	1.12	1.24	1.32	1.41
n	**9**	**10**	**11**	**12**	**13**	**14**	**15**	
RI	1.45	1.49	1.51	1.48	1.56	1.57	1.59	

It means that the binary comparison matrix is consistent when the consistency rate is smaller than 0.10.

4.6. Determination of the Final Sequence

The priorities extracted from the pairwise comparison matrices are aggregated. Thus, result weights are found for alternatives in the lowest level. Decision makers can see the best alternative by ranking the alternatives with the results found [10].

4.7. Sensitivity Analysis

After the order of the alternatives is determined, the result should be checked. At this stage, it is discussed how the order of the alternatives and the determined decision are sensitive to the changes in the interpretations [10].

5. APPLICATION

The application was performed in a company operating in the machine manufacturing sector. The company seeks to improve its competitive power among other competitors performing in the sector. Therefore, the company intends to determine the wastes on the production line and to eliminate (or minimize) them. The VSM methodology is used for this purpose.

The company has multiple production lines. For this reason, it is desirable to identify the production line that will be improved by VSM. At this point we applied the AHP method to determine the line. In order to apply the AHP method, all possible alternatives and assessment criteria for selecting the most suitable line have been determined by the field experts.

In particular, there are six production lines in the company as alternatives. These are MT (Magnettopf), FT (Fitting), CP (Connecting Pieces), AP (Ankerplatte), RA (Rail) and Aktorfuss (AF). To assess the performances of these lines, six assessment criteria have been determined as: the distance traveled in the layout, stock amount, scrap rate, rate of turnover, shipment performance and proximity to Takt. These criteria are described below:

1. Distance travelled in layout represents the total distance of the route from the raw material to the final product.
2. Stock amount represents the area covered by the stock amount seen in the company's ERP (Enterprise Resource Planning) system. The system is checked at certain times.
3. Scrap rate represents an analysis of the last six months of determined scrap rates on a weekly basis.
4. Rate of turnover represents the shares of the products in total turnover.
5. Shipment performance is the rate of compliance with the prepared shipment plans by the production planning department.
6. Proximity to Takt; The takt time of the product is calculated by dividing the annual working time by the annual order. Subsequently, the cycle time information of all the process steps of the product was taken and the distance from the longest cycle time of the takt time is determined.

Figure 3 shows the AHP decision hierarchy to e select the production line according to the determined criteria.

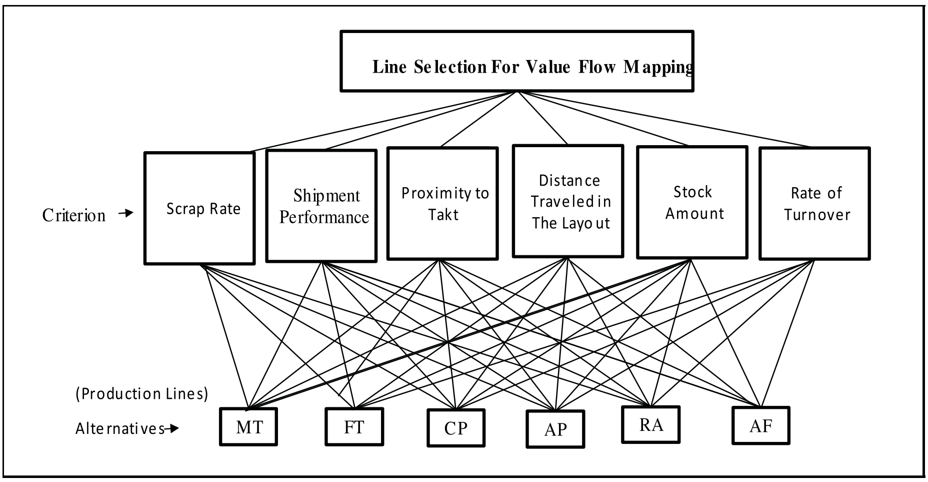

Figure 3. Decision Hierarchy

There are six alternatives in the AHP hierarchy in Figure 3. The pairwise comparisons for these alternatives are shown in the matrices in Table 3-Table 9. It is seen that the CR value of all pairwise comparison matrices is smaller than 0.10. So the comparisons are consistent.

Table 3. Pairwise Comparison Table for Criteria

	Scrap Rate	Shipment Performance	Proximity to Takt	Distance Traveled in The Layout	Stock Amount	Rate of Turnover
Scrap Rate	1	2	4	0.50	4	0.25
Shipment Performance	0.50	1	2	0.25	4	0.20
Proximity to Takt	0.25	0.50	1	0.20	2	0.14
Distance Traveled in The Layout	2	4	5	1	7	0.50
Stock Amount	0.25	0.25	0.50	0.14	1	0.11
Rate of Turnover	4	5	7	2	9	1
						CR= 0.02

Table 4. Pairwise Comparison of Alternatives for Scrap Rate Criteria

Scrap Rate						
	MT	FT	CP	AP	RA	AF
MT	1	0.13	0.33	2	2	0.20
FT	8	1	7	9	9	6
CP	3	0.14	1	4	4	0.50
AP	0.50	0.11	0.25	1	0.50	0.20
RA	0.50	0.11	0.25	2	1	0.25
AF	5	0.17	2	5	4	1
						CR=0.06

Table 5. Pairwise Comparison of Alternatives for Shipment Performance Criteria

Shipment Performance						
	MT	FT	CP	AP	RA	AF
MT	1	0.20	1	0.25	3	0.50
FT	5	1	5	2	5	4
CP	1	0.20	1	0.25	2	0.50
AP	4	1	4	1	5	3
RA	0.33	0.20	0.50	0.20	1	0.25
AF	2	0.25	2	0.33	4	1
						CR= 0.03

Table 6. Pairwise Comparison of Alternatives for Proximity to Takt Criteria

Proximity to Takt						
	MT	FT	CP	AP	RA	AF
MT	1	1	0.33	1	0.11	5
FT	1	1	0.33	1	0.11	4
CP	3	3	1	3	0.13	6
AP	1	1	0.33	1	0.11	4
RA	9	9	8	9	1	9
AF	0.20	0.25	0.17	0.25	0.11	1
						CR= 0.07

Table 7. Pairwise Comparison of Alternatives for Distance Traveled in Layout Criteria

Distance Traveled in Layout						
	MT	FT	CP	AP	RA	AF
MT	1	0.25	0.11	0.14	0.13	0.11
FT	4	1	0.11	0.20	0.17	0.13
CP	9	9	1	5	3	2
AP	7	5	0.20	1	0.50	0.25
RA	8	6	0.33	2	1	0.50
AF	9	8	1	4	2	1
						CR= 0.07

Table 8. Pairwise Comparison of Alternatives for Stock Amount Criteria

Stock Amount						
	MT	FT	CP	AP	RA	AF
MT	1	1	0.20	3	0.20	5
FT	1	1	0.20	3	0.20	5
CP	5	5	1	7	1	8
AP	0.33	0.33	0.14	1	0.14	3
RA	5	5	1	7	1	9
AF	0.20	0.20	0.13	0.33	0.11	1
						CR= 0.04

Table 9. Pairwise Comparison of Alternatives for Rate of Turnover Criteria

Rate of Turnover						
	MT	FT	CP	AP	RA	AF
MT	1	6	4	5	7	9
FT	0.17	1	0.33	0.50	2	4
CP	0.25	3	1	2	5	7
AP	0.20	2	0,50	1	3	7
RA	0.14	0.50	0.20	0.33	1	5
AF	0.11	0.25	0.14	0.14	0.20	1
						CR= 0.06

Each cell in each matrix is divided by the sum of the values in the cells in its column. Thus new values of the matrix are formed. Then the row average of each row is taken. A new matrix was created by combining the row averages obtained from the matrices consisting of Pairwise comparisons of alternatives for all criteria. This matrix and the row averages of the matrix obtained by comparing the criteria with each other are multiplied. The resulting sequence is shown in table 10.

As seen in Table 10, the CP has received the first rank. MT is located in the second rank. However, the two products have very similar ranking results. At this point, the VSM method has been applied for CP as a result of expert evaluation. It was decided by the experts to implement an implementation for MT later. At the end of the sorting, AF alternatives are seen.

Table 10. Ranking of Production Lines

Production Lines	Priorities	Percent	Ranking
MT	0.2313	23.1%	2
FT	0.1684	16.8%	3
CP	0.2334	23.3%	1
AP	0.1221	12.2%	5
RA	0.1236	12.4%	4
AF	0.1211	12.1%	6

The VSM method was applied for the CP line in the first rank. The stock values in the current situation map and the future situation map are shared by multiplying by a certain coefficient. Because, the company has privacy principles.

The raw material of CP is steel. The company announces the steel supplier details of the annual order with the annual forecast plan. In addition to, actual orders are weekly shared with the supplier. The supplier supplies steel twice a week. The CP's customer is a company that is working for the automotive main industry. The customer shares the details of the annual orders with the annual forecast plan. The customer gives actual orders once a week. According to given orders, the production planning department gives daily production knowledge (daily shipment schedule) to the production department.

Figure 4 shows the current state map for the CP line. As seen in the current state map, the CP line lead time is set at 25.5 days. The main reasons for the long lead time are;

1. At the end of the value stream, there is an eye control operation performed on the outsource. In the outsource, discarded products are sent back to the company. Because the company checks the scrap again. Approximately half of these parts are accepted pieces. So discarded parts need to be checked again in the company, but an operator is needed for it. Sometimes, if there are no extra operators, returning parts from outsource can not be checked again. This is why

there are excess stocks. This is the first reason why the lead time is long.

2. There is excess inventory after the first operation. It is seen that the machine in the second operation does not work efficiently. Moreover, although the two machines in the second operation are the same machine, the cycle times are different.
3. The flow in the production line flows in the form of pushing and it creates unnecessary stock.

On the CP line, the above mentioned problems have been encountered as a result of the studies for the drawing of the current state map. For the solution of the related problems, the future state map shown in Figure 5 is proposed. The details of the suggestions are following;

1. It is necessary to reduce the scrap rate in the outsource. So, the causes of discard must be analyzed. Pareto analysis should be performed and the most important causes should be identified. The discard rate should be reduced by making improvements on causes. Thus, there will be fewer scraps on the outsource and the outsource will send back less scraps to the company.
2. It is necessary to improve the efficiency of the two machines used for milling. Therefore, machine productivity needs to be regularly monitored. To determine the cause of machines inefficiency; operators should be given a form in which they can write daily production numbers and reasons for stopping. Subsequently, this form should be analyzed and calculated daily with three multiplications as productivity performance, employee performance and quality performance. The calculated performance values should be visualized. And it should be put in front of the relevant process. Efficiency values should be evaluated in front of these panels by the relevant persons on a daily basis and necessary actions should be taken.

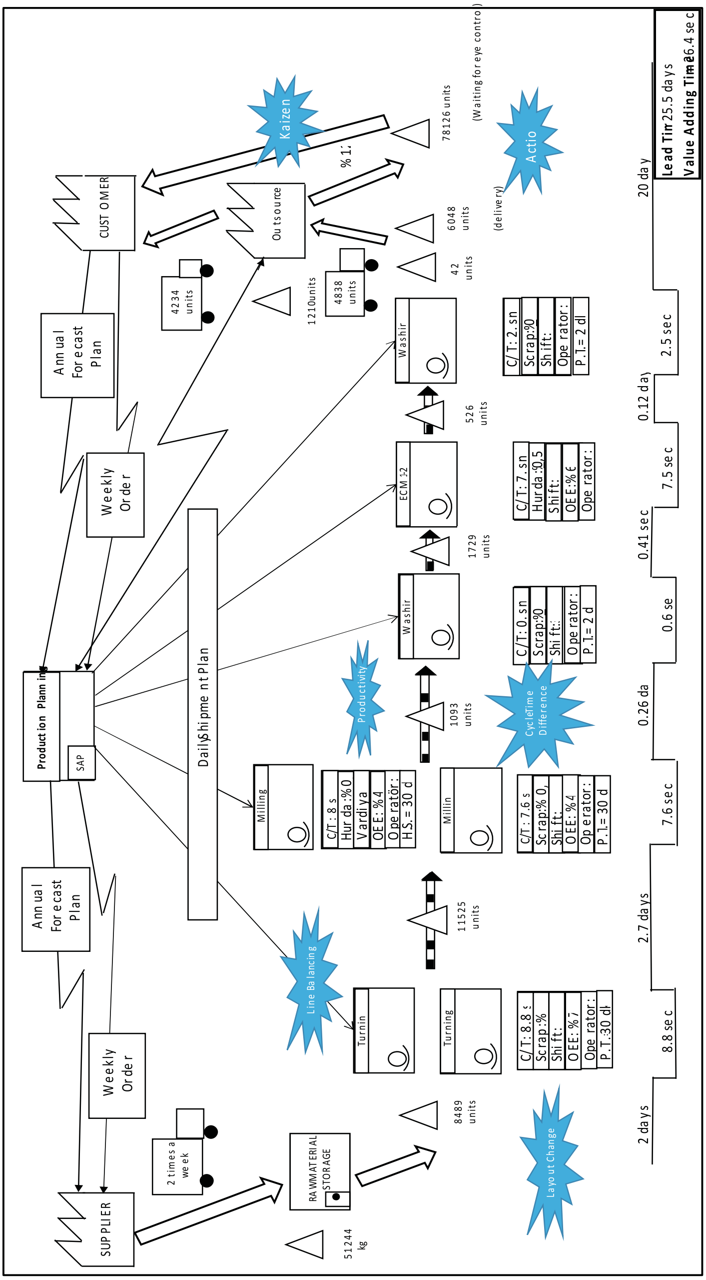

Figure 4. Current State Map

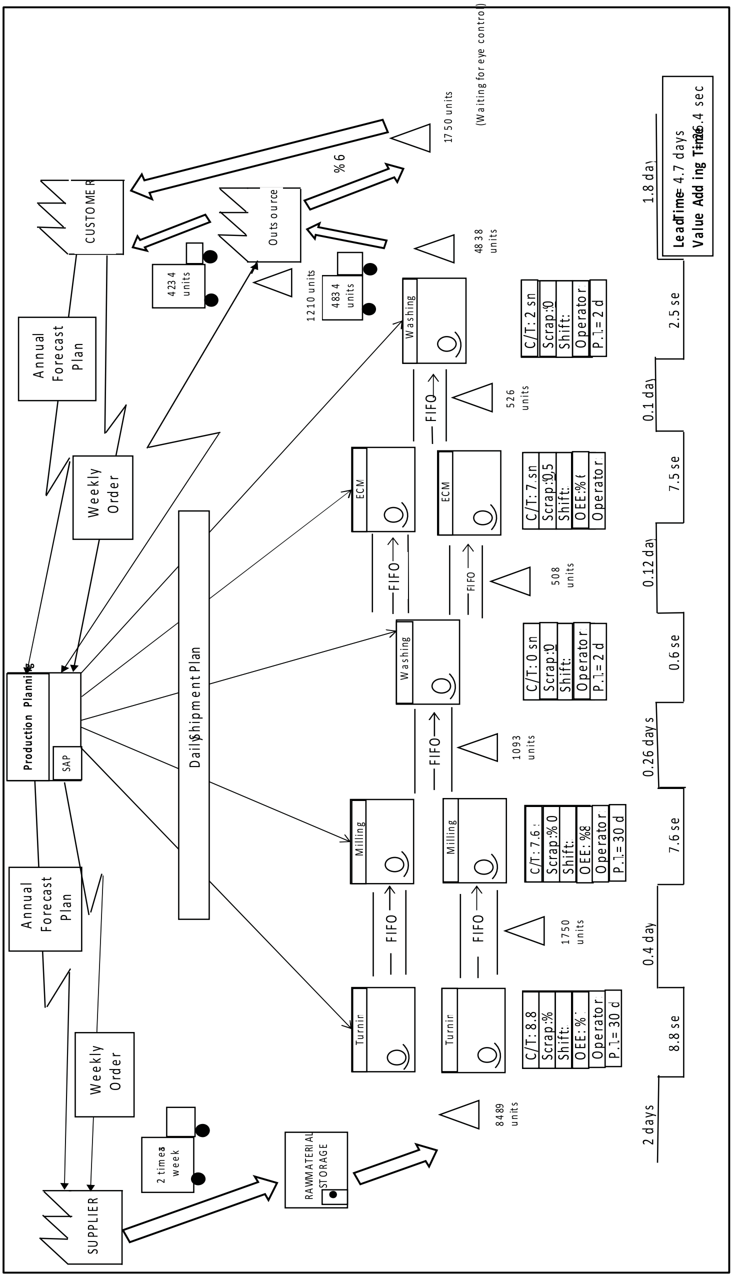

Figure 5. Future State Map

3. The reason why the cycle times of two machines in the milling operation are different should be investigated. If possible, the cycle times should be fixed by making the necessary adjustments.
4. The flow in the production line must flow with the principle of pulling with FIFO, not with pushing. It should flow with FIFO principle and take as much parts as necessary when necessary.

With the improvements described above, it can be seen that the flow period of 25.5 days in the current state map in Figure 4 is reduced to 4.7 days in the future state map in Figure 5.

6. RESULT AND RECOMMENDATIONS

In this study, our main objective was to apply the VSM methodology - the first step in lean production- in a company operating in the automotive sector. Since there are multiple production lines in the company, it was necessary to determine the line that needs most the VSM for an efficient use of time. For this purpose we implemented the AHP technique -one of the commonly used multi criteria-based decision making methods- and determined the CP line as the most suitable line.

Next, we prepared the current state map for the determined CP line and accordingly designed the future state map, and suggested a number of issues to improve the line. In the designed future state map, the lead time was reduced from 25.5 days to 4.7 days, resulting in an improvement by 81.57%.

We can summarize our contribution in two folds. First, we applied the VSM method to a real-world problem and improved the performance of a line in a company. Next, we applied the AHP methodology for selecting the appropriate line before employing the VSM. As a future work, we suggest implementing the VSM methodology to different production lines and to problems observed in different sectors.

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RESEARCH ARTICLE

AN ALTERNATIVE APPROACH TO GENERATE MAXWELL ALGEBRAS

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ABSTRACT

Symmetries are so important for explaining our universe. From this idea, one can get more knowledge about the universe using wider symmetries. Last century shows us that the Group theoretical methods provide very effective mathematical background to construct extended symmetries. Recent years there are a lot of studies on the Maxwell symmetry which is obtained by extension of Poincare symmetry. In this paper, we present an alternative method to produce the Maxwell algebras. We show that $D = 4$ *Maxwell algebras can be obtained by inducing from* $D = 6$ *Maxwell-Lorentz algebra. From this method, some Maxwell algebras are constructed.*

Keywords: *Lie Algebras, Tensors, Group Extension, Maxwell Algebra.*

MAXWELL CEBİRLERİNİN OLUŞTURULMASI İÇİN ALTERNATİF BİR YAKLAŞIM

ÖZ

Simetrilerin kullanımı kainatın açıklanmasında büyük bir önem arzetmektedir. Bu fikirden hareketle denilebilir ki, daha geniş simetrilerin kullanılmasıyla kainatın işleyişi hakkında daha fazla bilgi edinebiliriz. Geçtiğimiz asır bize gösterdi ki Grup teorik metotlar, simetrilerin genişletilmesinde çok kullanışlı bir matematiksel temel hazırlamaktadır. Son yıllarda, Poincare simetrisinin genişletilmiş hali olan Maxwell simetrileri hakkında pek çok çalışma yapılmıştır. Biz bu çalışmada Maxwell cebirlerinin oluşturulması için alternatif bir yöntem sunduk. $D=6$ *Maxwell-Lorentz cebrinin indirgenmesi ile* $D=4$ *Maxwell cebirlerinin elde edilebileceğini gösterdik. Bu yöntemi kullanarak bazı Maxwell cebirlerini oluşturduk.*

Anahtar Kelimeler: *Lie Cebirleri, Tensörler, Grupların Genişletilmesi, Maxwell Cebri.*

1. INTRODUCTION

The main role of Lie algebras in constructing of Supersymmetry and Gauge theory shows us that the Group theory is very important in physics. Lie algebras represent symmetries in physics, and so one can say if we extend given Lie algebra, we obtain extended symmetry, in other words new interactions or new interacting terms. Supersymmetry is a clear example of this motivation which is obtained from extension of Poincare symmetry.

Maxwell algebra is a non-central extension of Poincare algebra [1-6] in which momentum operators are no longer abelian and it satisfies the relation $[P_a,P_b]=iF_{ab}$, where F_{ab} is antisymmetric tensor under Lorentz transformations and $a,b=0,1,2,3$. Gauging this symmetry and supposing F_{ab} is electromagnetic stress tensor, one can get the equation of motion of charged particle which is moving along constant electromagnetic field [1].

In 2005 Soroka [7] derived new kind of Maxwell algebra by adding new six degrees of freedom into Poincare algebra. Soroka used the generator Z_{ab} instead of F_{ab} and new generator depends on new coordinate parameter

θ^{ab}. Thus, the space-time is extended as $\Phi(x^a) \rightarrow \Phi(x^a, \theta^{ab})$. This algebra is used to produce new symmetries [7-12], to obtain generalization of (super)gravity theories [13-25] and for applying higher spin field and Landau dynamics [26-28].

There are some methods about extension of Lie algebras in literature. The expansion [29-35], S-expansion [36-37], and Chevalley-Eilenberg (CE) cohomology [38-40] methods are used to obtain new algebras with changing group dimensions. If we don't need to change group dimensions it is enough to use contraction, deformation and extension methods [32-33].

In this paper, we present $D=4$ Maxwell algebras can be obtained from $D=6$ Maxwell-Lorentz algebra by dimensional reduction. After these notional preparations some Maxwell algebras are obtained.

2. GENERATING D = 4 MAXWELL ALGEBRAS FROM D = 6 MAXWELL-LORENTZ ALGEBRA

Commutation relationships of Maxwell-Lorentz algebra can be shown as,

$$\begin{aligned} [J_{AB}, J_{CD}] &= i(\eta_{AD} J_{BC} + \eta_{BC} J_{AD} - \eta_{AC} J_{BD} - \eta_{BD} J_{AC}), \\ [J_{AB}, Z_{CD}] &= i(\eta_{AD} Z_{BC} + \eta_{BC} Z_{AD} - \eta_{AC} Z_{BD} - \eta_{BD} Z_{AC}), \\ [Z_{AB}, Z_{CD}] &= i(\eta_{AD} Z_{BC} + \eta_{BC} Z_{AD} - \eta_{AC} Z_{BD} - \eta_{BD} Z_{AC}), \end{aligned} \tag{1}$$

where J_{AB} is the Lorentz generator, Z_{AB} is Maxwell generator in $D=6$, the Minkowski metric is $\eta_{AB} = (+,-,-,-,-,+)$ and capital Latin indices $A, B, \ldots = 0,1,2,3,5,6$. Then if we choose following relations,

$$M_{ab} = J_{ab}, \quad P_a = \alpha J_{5a} + \beta J_{6a} + \rho Z_{5a} + \sigma Z_{6a}, \quad Z_{ab} = Z_{ab}, \tag{2}$$

we get commutation of momentum generator as follows,

$$[P_a, P_b] = i(\alpha M_{ab} - \beta M_{ab} + \alpha\rho Z_{ab} - \beta\sigma Z_{ab}). \tag{3}$$

where M_{ab}, P_a, Z_{ab} are Lorentz, momentum and Maxwell generators respectively and $\alpha, \beta, \rho, \sigma$ are arbitrary constants. After that, choosing the constants as $\alpha = 1, \beta = 0, \rho = -1, \sigma = 0$ then the AdS-Maxwell algebra [17] is obtained as given below,

$$\begin{aligned}
&[M_{ab}, M_{cd}] = i(\eta_{ad}M_{bc} + \eta_{bc}M_{ad} - \eta_{ac}M_{bd} - \eta_{bd}M_{ac}),\\
&[P_a, P_b] = i(M_{ab} - Z_{ab}),\\
&[M_{ab}, P_c] = i(\eta_{bc}P_a - \eta_{ac}P_b),\\
&[M_{ab}, Z_{cd}] = i(\eta_{ad}Z_{bc} + \eta_{bc}Z_{ad} - \eta_{ac}Z_{bd} - \eta_{bd}Z_{ac}),\\
&[Z_{ab}, Z_{cd}] = i(\eta_{ad}Z_{bc} + \eta_{bc}Z_{ad} - \eta_{ac}Z_{bd} - \eta_{bd}Z_{ac}),
\end{aligned} \tag{4}$$

Also, if one changes the selection with $\alpha = 0, \beta = 1, \rho = 0, \sigma = -1$ then commutation relationship of momentum generators takes following form,

$$[P_a, P_b] = -i(M_{ab} - Z_{ab}), \tag{5}$$

thus, we get dS-Maxwell algebra. Lastly, taking the constants as $\alpha = 1, \beta = 1, \rho = \frac{1}{2}, \sigma = -\frac{1}{2}$ the semi simple Maxwell algebra presented in [21] is obtained by following relation,

$$[P_a, P_b] = iZ_{ab}. \tag{6}$$

One can generate different kind of Maxwell algebras by changing the choices given in Eq. (2) and also using simple Maxwell-Lorentz algebra,

$$\begin{aligned}
&[J_{AB}, J_{CD}] = i(\eta_{AD}J_{BC} + \eta_{BC}J_{AD} - \eta_{AC}J_{BD} - \eta_{BD}J_{AC}),\\
&[J_{AB}, Z_{CD}] = i(\eta_{AD}Z_{BC} + \eta_{BC}Z_{AD} - \eta_{AC}Z_{BD} - \eta_{BD}Z_{AC}),\\
&[Z_{AB}, Z_{CD}] = 0,
\end{aligned} \tag{7}$$

or Maxwell-General-Linear group [16] given below,

$$\begin{aligned}
&[L^A{}_B, L^C{}_D] = i(\delta^C{}_B L^A{}_D - \delta^A{}_D L^C{}_B),\\
&[L^A{}_B, Z_{CD}] = i(\delta^A{}_D Z_{BC} - \delta^A{}_C Z_{BD}).
\end{aligned} \tag{8}$$

4. CONCLUSION

We showed that $D = 4$ Maxwell algebras can be obtained by dimensional reduction from $D = 6$ Maxwell-Lorentz algebras. The (A)ds-Maxwell and semi simple Maxwell algebras were constructed by using presented method. For generating different Maxwell algebras two possible $D = 6$ algebras were given.

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RESEARCH ARTICLE

UNMANNED AERIAL VEHICLE DIGITAL FORENSIC INVESTIGATION FRAMEWORK

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ABSTRACT

The Unmanned Aerial Vehicle (UAV) technology is a rapidly emerging technology and it has found widespread usage. While UAVs are still in their development phase without any existing commonly accepted standards for their underlying technologies and their forensic investigation, they have an increasing record of criminal usage. This urges the research community to develop techniques to detect and prevent illegal usage of UAVs. With this work, we present a seven-phase UAV digital forensics investigation framework to standardize the investigation process for UAVs. We tested our framework on the DJI Phantom III Professional UAV which is one of the most popular commercial UAVs in the market. Three kinds of forensic artifacts are found on the sample UAV and these artifacts are examined deeply. Two of the artifacts are log files stored as binary files and the other artifact is the EXIF header of the images that are captured by UAV's onboard camera. As a result of our investigation, we are able to regenerate the flight path of the UAV. As a final step of our research, we compare our investigation framework with the existing framework on the literature and reveal the differences of both frameworks.

Keywords: *Digital Forensics Investigation, Embedded Devices Forensics, Unmanned Aerial Vehicle (UAV) Forensics.*

İNSANSIZ HAVA ARAÇLARI İÇİN ADLİ BİLİŞİM İNCELEMESİ ÇERÇEVESİ

ÖZ

İnsansız Hava Araçları teknolojisi günümüzün hızla gelişen teknolojileri arasında yer almaktadır. İnsansız hava araçlarının kullanımındaki hızlı artış, bu araçların yasadışı faaliyetlerde kullanımını da beraberinde getirmiştir. İnsansız hava araçlarının yasadışı kullanımlarının tespiti ve önlenmesi çözülmesi gereken önemli bir problem olarak ortaya çıkmıştır. Bu çalışmada insansız hava araçlarının adli bilişim incelemelerinde kullanılmak üzere yedi aşamalı bir inceleme sistemi ortaya önerilmektedir. Önerilen bu sistem şu an piyasada kullanılan en popüler ticari insansız hava araçlarından biri olan DJI Phantom III professional insansız hava aracı üzerinde uygulanmıştır. Yapılan incemeler sonucunda incelenen insansız hava aracında üç adet delil tespit edilmiştir. Bulunan bu delillerin iki adedi uçuş kayıt dosyası, diğeri ise araçta bulunan kamera tarafından çekilen görüntü dosyalarındaki metadata bilgileridir. Dosyalar üzerinde yapılan incelemeler sonucunda insansız hava aracının gerçekleştirdiği uçuşlara ait GPS koordinatları ve uçuş haritaları elde edilmiştir. Araştırmamızın son aşaması olarak ortaya önerdiğimiz inceleme sistemi şu anda literatürde bulunan diğer inceleme sistemi ile karşılaştırılarak farklılıklar belirtilmiştir.

Anahtar Kelimeler: *Adli Bilişim İncelemesi, Gömülü Sistemler Adli Bilişim İncelemesi, İnsansız Hava Araçları (İHA) Adli Bilişim İncelemesi.*

1. INTRODUCTION

Unmanned Aerial Vehicles (UAVs) have become increasingly popular to use, with a wide range of usage areas throughout the world. While the first UAVs were used as early as on 22 August 1849 in Austria to launch the first air raids in history to the Venice [1], UAVs have found widespread usage only in recent years. It is reported that there are 770,000 hobbyists and 80,000 commercial Unmanned Aerial System (UAS) pilots had registered as UAS pilots in the United States as of 2017 [2, 3]. By 2021, it is expected that there will be around 3,5 million UAVs used by hobbyists [4].

Due to their significantly reduced prices, it has become easier to own and fly a UAV, and some people have started using UAVs also for illegal purposes such as terrorism, plane watching, violation of private life, smuggling and delivery of drugs into prisons [5, 6]. Since the illegal usage UAVs, in violation of the Federal Aviation Administration (FAA) regulations [7], is increasing dramatically, it has become crucial to have the ability to detect and prevent illegal usage of UAVs. Furthermore, it is vital to have the ability to find and show evidence of illegal UAV usage when a case is brought in front of the court. The increasing number of illegal UAV usages has drawn closer public attention when a UAV crashed into a lawn at the White House [8, 9]. This incidence clearly reveals the necessity for standardized digital forensic investigation methods to obtain evidence for UAV related criminal incidences, so that they can be prosecuted in front of the court.

There is no standardized framework for digital forensics investigation of UAVs at the time of this study. With this work, we aim to fill this gap and propose a framework for the digital forensic investigation of UAVs. The proposed framework is applied on DJI Phantom III, one of the most popular commercial drones available in the market today. During the implementation of our framework, we kept in mind the well-known forensic investigation principles such as preserving digital evidence, preserving chain of custody, avoiding adding data and documenting actions [10].

In Section 2, we give a literature review on the digital forensic investigation of UAVs. In Section 3, we propose our UAV digital forensics investigation framework and apply this framework to the digital forensic investigation of the DJI Phantom III UAV. In Section 4, we implement the proposed framework on our sample UAS. In Section 5, we test and compare our framework with the other existing framework on the literature. Finally, in Section 6, we give our conclusions and propose future research directions.

2. RELATED WORK

A UAV is defined as a pilotless aircraft or a flying machine without an onboard flying pilot and passengers. In this definition, "unmanned" defines the complete absence of humans [11]. The related term UAS was first introduced by the U.S. Department of Defense (DoD), which was followed by FAA and European Aviation Safety Agency (EASA) [12]. According to its definition, a UAS contains not only the aircraft but also the whole system which is used for airworthiness such as ground control stations (GCS), mobile devices, communication links, etc. Moreover, the terms such as Remotely Piloted Aircraft (RPA), Remotely Piloted Aircraft System (RPAS) and Remotely Piloted Vehicle (RPVs) are also used to denote a UAS. A similar term “drone” is used to denote an autonomously or remotely guided vehicle. According to this definition, drones cover not only UAVs but also other remotely controlled devices such as remotely operated underwater vehicle (ROV). In other words, a UAV may be considered a drone, but a drone does not have to be a UAV [13].

Although the digital forensic investigation of UAVs is crucial for providing security and accountability related to the use of these systems, there are only few academic works focusing on this topic [14, 15, 16, 17, 18, 19].

The control technology embedded inside the Parrot Ar.Drone was investigated by Bristeu and others [20]. It was shown that the Parrot Ar.Drone has a main board embedded with a Parrot P6 processor (32-bit ARM9-core running at 468 MHz), a navigation board embedded with a 16-bit PIC microcontroller running at 40 MHZ, a Wi-Fi chip, a camera, ultrasonic sensors, accelerometers, gyroscopes and a GPS chip. The embedded P6 processor runs with a Linux based real-time operating system. Even though the Parrot Ar.Drone was one of the most popular UAVs at the time, its technology is considered inferior today.

Samland and others, analyzed the security threats of UAVs by using the Computer Emergency Response Team (CERT) taxonomy [19]. They examined the hardware and software components of the four popular drones of the time. They revealed the vulnerabilities of these components. They specifically investigated three different scenarios: "Hijacking the Ar.Drone", "Interception of the video signals of the Ar.Drone" and "Manual tracking of persons using the Ar.Drone". Their work is one of the first attempts in the field, however, as in every field of technology, the UAV technology has been advancing and some of the valuable information given in their work is now out of date. The technology of the UAVs used for this research is out of date and their UAVs are not on the market anymore. Therefore, the techniques used in this study is not applicable for the security threat analysis of the currently used UAVs. The UAVs that are used today have different and more complicated communication links. In the paper they benefit from the security weaknesses of known network protocols such as FTP and UDP protocols, however, UAVs of our days have their own proprietary communication protocols. For this reason, the vulnerabilities of the UAVs mentioned in their work do not exist on the UAVs used today.

The digital forensic analysis of a Parrot Bebop UAV was conducted by Horsman [15]. Parrot Bebop UAV was one of the most popular drones of 2015. The four main phases of their UAV forensic investigation implementation were identified as "Acquisition of data", "Establishing Flight Data", "Media Taken by the Device" and "Establishing Ownership". They established a wireless network connection to the UAV and, by using Telnet and the File Transfer Protocol (FTP), they were able to access the hidden folders in the UAV which contained evidential information such as flight log files.

Kovar presented the forensic analyses of both the DJI Phantom II and DJI Phantom III model UAVs [17]. He showed that DJI Phantom III contains two types of flight log files. One of these log files is created by the app on the mobile devices that are used to remotely control the UAV and the other log file is stored inside the 4 Gb micro SD card that is located at the bottom of the main board of the UAV. These log files are encrypted or obfuscated and cannot be read directly.

Clark and others performed Digital Forensic Investigation of DJI Phantom III [14]. In their research, they ascertain that DJI Phantom III series UAVs store two kinds of log files. One of these files is created by "DJI Go" Android application and stored on the Android device that is used for controlling the UAV. The other log file is stored on the UAV's internal nonvolatile storage. They correlate both of these log files and reveal that these log files are one to one match. In their research, they emphasize that both of these log files could be used as evidence in front of the court.

The digital forensic investigation of the DJI Phantom II model UAV was performed by Maarse and Sangers [18]. In their work, they focused on retrieving positional data and sequence work to build the flight path of the UAV. They used the flight logs stored on the remote controller of the UAV to retrieve the flight path. The flight log contains the coordinates of the

UAV's home point, the altitude of the UAV and the coordinates of the waypoints. All of these artifacts are stored in 16-bit character strings with UTF-16 little endian encoding.

Jain and Others proposed a UAV Digital Forensic Investigation Framework [16]. Their framework consists of twelve linear phases. Their framework contains Preparation, Identification, Class Identification, Weight Measurement, Check for Customization, Fingerprint, Bluetooth, Wi-Fi, Memory Card, Geo-Location, Onboard Camera and Documentation phases. They tested their framework on five commercial UAVs.

3. METHODOLOGY

In this research, we focus on the forensic analysis of a captured UAV. The UAV could be a suspect UAV that is captured by security forces by being shot by a shotgun (or by using any anti-UAV technique) or it could be a UAV that has crashed into a private property. In order to investigate a UAV forensically, its hardware and software components should be identified and investigated. Besides the investigation of the UAV components, collecting evidence, providing chain of custody and media/artifact analysis are important parts of the forensic investigation.

DJI Phantom III Professional packs all major parts required in a UAV into a small commercial drone. Furthermore, terrorist groups, such as ISIS, has been reported to use this UAV actively [24]. The use of the DJI Phantom III Professional UAV has been detected in several illegal activities such as bomb dropping, remote surveillance, plane watching, etc. For all these reasons, we decided to work on the forensic investigation of the DJI Phantom III Professional UAV in this study.

There has been no standardized investigation framework for the digital forensic investigation of a UAV at the time of this study. There is only one proposed framework [16] for the digital forensic investigation of UAVs in the literature. The proposed framework [16], has a complex structure and is highly dependent on platform types. To eliminate these deficiencies, we propose a UAV digital forensic investigation framework. And then we apply our proposed framework to the forensic investigation of the DJI Phantom III UAV and present our findings in detail.

3.1. UAV Digital Forensics Investigation Framework

In order to disclose any evidence to the court and get it approved, a standardized, or at least acceptable, investigation framework should be used by the investigator. There are numerous kinds of UAVs available in the market and each company uses different hardware and firmware packages. For this reason, although it is difficult to create a single tool for investigating all UAVs, finding a general investigation framework for all kinds of UAVs is a reasonable solution. With this work, we propose a seven-phased framework for the digital forensic investigation of UAVs. An outline of our framework is given in Table 1. Furthermore, we apply our framework to the forensic investigation of a sample UAS, namely the DJI Phantom III Professional drone. We explain our findings on DJI Phantom III Professional in detail in the later sections of the paper. We explain in detail the seven phases of our proposed framework in the rest of this section.

Table 1. Proposed Seven-Phased UAV Investigation Framework

UAV FORENSIC INVESTIGATION PHASES
1. Preparation
2. Scene Control
3. Customization Detection
4. Data Acquisition
5. Evidence Authentication
6. Evidence Examination
7. Presentation

3.1.1. Preparation Phase

An embedded system is a special-purpose computer system designed to perform one or a few dedicated functions. In this respect, MP3 players, mobile phones, PDAs, telemetric systems such as car navigation systems, etc., are all considered embedded systems [25]. Similarly, UAVs are also embedded systems. As it is the case with all embedded devices, the digital forensic investigation of UAVs requires special knowledge and preparation due to the huge diversity of UAV systems. A forensic investigator has to follow the developments in UAV systems available in the market and have knowledge about both their firmware and hardware components. An undue response on the incident scene could cause irreversible damage to the evidence. To avoid any data loss, the investigator should have knowledge about hardware and software properties of the specific UAV that is investigated.

3.1.2. Scene Control Phase

All kinds of investigation processes that take place on the incident scene form the scene control phase of the digital forensic investigation. During this phase, the investigator should take into consideration any equipment dropped from the UAV during the incidence. Moreover, maintaining chain of custody and protection of evidence from being altered is crucial in this phase. If only the UAV is captured and not the remote control unit, a circle with a radius of the range of the UAV should be explored to find the remote control unit and the owner of the UAV.

3.1.3. Customization Detection Phase

A UAS could be modified to perform specific missions. A forensic investigator should detect these modifications and create a report to be presented to the court. Possible modifications to a UAS could include the following:

a. Range extender usage for flying to longer distances,

b. Battery upgrades for increased flight time,

c. Attaching dropping gear for smuggling and dropping prohibited items to prisons,

d. Camera upgrades for surveillance,

e. Adding autopilot software for pilotless and critical missions such as flying over military units,

f. Deployment of explosives for terrorist activities,

g. Gun mounting for terrorist activities.

3.1.4. Data Acquisition Phase

The Data Acquisition phase of the digital forensic investigation is probably the most important phase in that it involves the collection of all evidence data based on approved forensic techniques. In this phase, all volatile and non-volatile data, such as network based data, live response data, and removable media evidence, should be acquired. In compliance with the "Avoiding Adding Data" principle of digital forensics [26, 27], a write blocker should be used during this phase. Moreover, the investigator should pay attention to the existence of any anti-forensics software laid dormant on the UAV.

3.1.5. Evidence Authentication Phase

Evidence authentication phase is significant for the approval of the collected evidence before the court. During the whole investigation process, the commonly accepted principles of digital forensic investigation, such as "Prevention of Data Loss", "Avoiding Adding Data" and "Chain of Custody" [26, 27], should be taken into consideration. Moreover, the forensic investigation process should be performed on the "Working Copy" of the "Best Copy" that belongs to the original evidence. In the following sections, we explain the evidence authentication techniques that we used during the forensic investigation of our sample UAS.

3.1.6. Evidence Examination Phase

In the evidence examination phase, the investigator probes into all data that is acquired from the UAS. The investigator tries to find evidence about specific cases. The rebuilding of the flight path for a suspicious flight is of vital importance as evidence before the court of law. Also, any kind of video or image file could be used as an evidence.

3.1.7. Presentation Phase

Last but not least, the presentation phase is the final step of a digital forensic investigation. All efforts made during the whole investigation process should be explained in detail, ready to be presented before the court. A report should be prepared that presents all evidence about the case at hand. While preparing the report, one should always keep in mind that the judge, or the jury, in the court does not have to be a technical person and therefore a plain and understandable language must be used.

4. Forensic Investigation of DJI Phantom III Professional

We applied our framework on the forensic investigation of the DJI Phantom III Professional Drone, the DJI Phantom III Professional Remote Controller and their associated app running on an Android tablet (Samsung Galaxy Tab 3 Lite). In the rest of this section, we explain the seven phases of our digital forensic investigation framework applied to this tested UAS.

4.1. Preparation Phase

The sample UAS used for this study (DJI Phantom III Professional) consist of two main components, aircraft and ground control station (GCS). From the outer appearance, the aircraft has four propellers, 4480mAH Li-Po intelligent battery, gimbal, 4K resolution camera, micro SD-Card mount on gimbal, a USB port, and Wi-Fi antennas. Inside the aircraft, there are four brushless motors and four electronic speed control units, one for each propeller, a single main board which contains all the modules of Inertial Measurement Unit (IMU), a gyroscope unit, a GPS sensor, a speed controller unit and a Wi-Fi unit. Last but not least, on the bottom of the aircraft, there is a 4GB capacity SD-card, which is used for recording all the flight data. The ground control station consists of a remote controller and a mobile device which runs the "DJI Go" application. The mobile device is connected to the remote controller through a USB port and the remote controller communicates with the aircraft via the Lightbridge protocol on the 2,400-2483GHz frequency [28].

The sample UAS uses Open WRT 14.07 "Barrier Breaker r2879, 14.07" built for the "ar71xx/generic" operating system, on both the aircraft and the remote controller. This firmware is a Linux based operating system used for embedded systems [29, 30]. Consequently, the OverlayFS, tmpfs, SquashFS, JFFS2, UBIFS, ext2 and mini_fo file systems, could be contained in the UAS. The DJI Go application runs on both Android and IOS devices. In addition to the drone's internal SD-card, the DJI Go application creates a very detailed flight record and stores it on the mobile device.

4.2. Scene Control Phase

Even though this phase is within other criminal discipline's field of interest, a digital forensic examiner should investigate the incidence area. On the incident scene, the examiner should search for any dropped items from the UAV. Since we conducted the flights in the scope of this paper, no dropping off item is detected. Since our sample UAV has an up to 5 kilometers of range, a circle whose center is the incident scene and with a radius of 5 kilometers is drawn. The remote controller and the owner of the UAV are probably located in this area.

4.3. Customization Detection

The investigator should take into account any customizations on the UAS. By the reason that our sample UAV contains no customization, we do not locate any customization.

4.4. Data Acquisition

As a first step in the data acquisition phase, in accordance with the "Prevention of Data Loss" and "Avoiding Adding Data" principles of digital forensic investigation, we applied the factory reset procedures to both the drone and the Samsung Galaxy Tab 3 Lite tablet before performing our tests. We formatted the drone by using the DJI Go application. This process deleted all of the nonvolatile files from the internal storage of the drone. Then we formatted the Android tablet to its factory settings by using its booting menu. After formatting, we updated the device to the latest Android version and the latest version of the DJI Go application. As a final precautionary step, we wiped the SD card located on the gimbal and that is used for video and picture storage. For this wipe operation, we used the "Disk Dump (dd) utility" with the "zero of" command which fills the whole disk with zeroes during the wipe procedure. We formatted the disks to the FAT32 file system.

After wiping and formatting the UAS to its factory settings, we planned and conducted ten different flights with it. We conducted these flights on different places, on different days and at different times of the day. We recorded the date, time, location and flight pattern information for these flights.

After conducting the flights, we started the data acquisition phase of our forensic investigation. During the data acquisition phase, we used the FTK Imager tool for getting the physical image. To follow the "preventing adding data" principle a "write-blocker" should be used. Firstly, image of the tablet is generated. The image is labeled as "*Evidence_storage_001*" Secondly drone's internal storage is imaged. The image is labeled as "*Evidence_storage_002*". Lastly, the same process applied to the SD card stored on the gimbal and labeled as "*Evidence_storage_003*". All of the images are copied and the investigations are conducted on the best working copy of the images.

4.5. Evidence Authentication Phase

This phase should be conducted right after the "data acquisition phase". In this phase, the "md5sum" utility was used for MD5 hash generation. The MD5 hash values of the Android device, the internal SD card of the aircraft and the SD card stored on the gimbal were calculated. The hash values which are created with the "md5sum" utility and the "FTK Imager" tool were compared and verified to be equal. Thus, the evidence was verified to be authentic. The evidence Authentication data is shown on Table 2.

Table 2. Evidence Authentication Data

EVIDENCE	EVIDENCE MD5 HASH (with FTK)	IMAGE OF THE EVIDENCE MD5
Evidence_storage_001	702aefc3bc17a7ae 0ae983021d3e0685	702aefc3bc17a7ae 0ae983021d3e0685
Evidence_storage_002	1309901b969b1bf7 898c9c1711fb2fd0	1309901b969b1bf7 898c9c1711fb2fd0
Evidence_storage_003	f5d18bd470399ac5 12392ef0771be315	f5d18bd470399ac5 12392ef0771be315

4.6. Evidence Examination Phase

During the Evidence Examination Phase, all of the examinations were conducted on the best working copy of the evidence images to prevent any alteration of the data.

We were able to locate three different digital pieces of evidence on the sample UAS. The first one of these evidences was a ".TXT" extended file that is created by the "DJI Go" application. This text file was stored on the smart device which is used for controlling the drone. The second evidence was a ".DAT" extended file that was created by the drone itself. This file was stored in the drone's internal memory. Finally, the third evidence found is the EXIF data files that are stored in the drone's internal memory for each picture taken by the drone. Finally, at the end of the "Evidence Examination Phase", we were able to regenerate the flight path of the flight by using GPS coordinates information located on the flight log files. We explain the details of these artifacts in detail below.

4.6.1. *DJI Go .txt File*

During the investigation of the Android tablet image, several directories were detected that pertain to DJI. The investigation on the Android tablet was mainly focused on these directories. In the data/dji.pilot/DJI/FlightRecords directory of the Android tablet, the file named as DJIFlightRecordyYYYY-MM-DD_[HH-MM-SS].txt caught our attention. This text file could not be opened by any text editor, however, we were able to convert this file to a readable .csv file using some online tools (https://airdata.com).

4.6.2. *.dat File Created by the DJI Drone*

DJI Phantom III drones contain a micro SD-Card with 4 GB storage capacity located on the bottom of the main board. To access this storage hardware, the aircraft had to be laid open and the main board must be removed from the drone. The SD-Card was glued to the card slot, therefore we had to scratch the glue to remove the SD-Card. After doing this, we took the image of the SD-Card to prevent any loss of data and then copied the image. We inspected this copy with scrutiny. During our inspection, we detected 10 files, named as FLY***.DAT. The numbers *** in the file names were consecutive numbers. We detected that these .dat extended files were in binary format. We used the tool DatCon (https://datfile.net/) to convert these .dat extended flight records into human readable .csv files.

4.6.3. *EXIF Data File*

DJI Phantom III drones store all their recorded videos and taken pictures in an SD-Card located in the gimbal. We exported a few pictures from the image of the SD-Card to analyze the metadata of these pictures. At first glance, we saw that the drone stores pictures as .jpg extended files and videos as .mov extended files. We read the EXIF headers of the images using the tool "ExifTool" and thus we were able to detect a lot of valuable information such as the creation dates of the images and the GPS locations where the images were taken.

4.7. Presentation Phase

Since the judge in the court is not necessarily a technical person, a plain and understandable language must be used in the forensic investigation report. In the report, all the steps of the investigation should be described properly. An example report template that could be used to present findings in front of the court is shown on Figure 1.

5. Testing and Comparison

There is only one proposed framework for digital forensics investigation of UAVs at the time of this study [16]. Digital forensics investigation of the sample UAS was conducted according to both our proposed framework and the framework proposed by Upasita et al [16].

5.1. Testing the Proposed Seven-Phased UAV Investigation Framework

Our proposed Seven-Phased UAV Investigation Framework was tested with the DJI Phantom III Professional UAS. During the investigation process, we always kept in mind the well-known digital investigation principles, such as preserving digital evidence, preserving chain of custody, avoiding adding data and documenting actions [10].

<table>
<tr><td colspan="4">Suspicious Incident :</td><td>Incident Date :</td></tr>
<tr><td colspan="5">Incident Scene Description and GPS Position:</td></tr>
<tr><td colspan="5">Incident Scene Investigation :</td></tr>
<tr><td colspan="5">Detected Customizations on Suspicious UAV :</td></tr>
<tr><td colspan="5" align="center">Evidence Acquisition and Authentication :</td></tr>
<tr><td colspan="2">Evidence :</td><td colspan="3">Acquisition Date and Time :</td></tr>
<tr><td colspan="2">Evidence Hash Value :</td><td colspan="3">Image of The Evidence Hash Value:</td></tr>
<tr><td colspan="2">Evidence :</td><td colspan="3">Acquisition Date and Time :</td></tr>
<tr><td colspan="2">Evidence Hash Value :</td><td colspan="3">Image of The Evidence Hash Value:</td></tr>
<tr><td colspan="5" align="center">Evidence Examination and Findings :</td></tr>
<tr><td>Evidence :</td><td colspan="2">Flight Date and Time :</td><td colspan="2">Flight Duration :</td></tr>
<tr><td colspan="2">The Closest GPS Position to Incident Scene :</td><td colspan="3">Altitude of the Closest GPS Position to Incident Scene :</td></tr>
<tr><td colspan="2">Distance Between The Closest GPS Position and Incident Scene :</td><td colspan="3">Duration on the Closest GPS Position :</td></tr>
<tr><td colspan="5">Examiners Judgement :</td></tr>
</table>

Figure 1. An Example Report Template

When the phases of our framework are applied in a forensic investigation, our framework significantly helps the investigators to detect any evidences in the incident scene (i.e. dropped items), locate any customizations for specific missions, present the data acquisition, authenticate the acquired data (crucial for proving that the evidence is authentic), analyze the acquired data with proper methods and lastly present all the findings in front of the court.

As a result of our investigation process, we were able to acquire evidence related to a specific suspicious incident to present them in front of the court. As it is mentioned earlier, we were able to locate three kinds of forensic artifacts on the sample UAS. At the end of our investigation, we were able to regenerate the flight path of any suspicious flight, thanks to the GPS coordinates information that was included in the obtained evidence.

5.2. Results of the Framework Proposed by Upasita et al.

The investigation by Upasita et al. is conducted according to their proposed framework in twelve steps. The twelve phases of their framework and the result of each phase are given below.

1. Preparation Phase: Assessment of the risks, threats, and vulnerabilities of the sample UAS are made. The sample UAS has a range of 3.1 nm (approximately five kilometers) with 25 minutes of flight time. The maximum operating altitude of the sample UAV is 19685 ft (6000m). The sample UAS can run some autopilot applications to conduct some specific missions.

2. Identification/Collection Phase: All data contained by the sample UAS is acquired by the techniques mentioned in Section 4.4 Data Acquisition.

3. Identify Class/Category Phase: The weight of the sample UAS is 1280 grams. According to UAV regulations of the Directorate General of Civil Aviation in Turkey, our sample UAS is in the UAV-0 class. According to the regulation, all UAVs in the UAV - 0 class have to be registered.

4. Measure Weight Phase: As it is mentioned in the previous phase, our sample UAS 1280 grams and it has to be registered.

5. Check for the Customization Phase: Same as our proposed seven-phased UAV investigation framework, we check for any customization on the sample UAS, and as it is mentioned hereinbefore we cannot locate any customization.

6. Fingerprint Phase: Since detecting and investigating the fingerprints located on a suspicious UAV is within the scope of not digital forensics but other criminal disciplines, we do not investigate the fingerprints.

7. Bluetooth Phase: The sample UAS does not have any Bluetooth modules.

8. Wi-Fi Phase: Even though the sample UAS communicates on the Wi-Fi frequency, it uses a proprietary protocol called "Lightbridge" and the communication between the aircraft and the remote controller cannot be exploited by ordinary Wi-Fi chips.

9. Memory Card: Our sample UAS has a 16GB capacity micro SD-Card located on the gimbal (camera mount of the UAV). The captured images and the videos are located on this storage equipment.

10. Geo-location Phase: The sample UAS has both GPS and GLONASS satellite positioning systems. Besides, it has a vision positioning system for flying in indoor areas.

11. Camera Phase: The sample UAS has a 4096 x 2160p (UHD) resolution camera on board. The camera is located on the gimbal which helps keep the camera stabilized during the flight.

12. Documentation Phase: The findings of the investigation are documented, corresponding with the report template which is mentioned hereinbefore.

5.3. Framework Comparison

Both our framework and the framework by Upasita et al. are implemented on the sample UAS, namely DJI Phantom III Professional. We have seen that the "Preparation" and "Customization Detection" phases are the common phases in both frameworks.

As a result of our comparison of both frameworks, we identify some differences. The most significant difference is that while our investigation framework is related to the investigation of the digital data stored on the suspicious UAV, the other framework mainly focuses on the hardware specifications of the suspicious drone. The framework proposed by Upasita et.al only investigates the Wi-Fi and Bluetooth modules of the UAV, however, some of the new generation, bigger and more complex UAVs use different communication frequencies and protocols for communicating at longer distances. Besides, our framework covers the investigation of the whole UAS and not just the aircraft, whereas the framework offered by Upasita et al. only investigates the aircraft and does not deal with the data stored on the GCS. The main purpose of our framework is to regenerate the flight path of a captured suspicious drone. We can achieve this in our framework thanks to the analysis results of the flight logs and other artifacts found on the UAS. The framework proposed by Upasita et al. focuses on finding evidence only in the captured image and video files.

In a forensic investigation, the investigator has to prove that, the evidence presented in front of the court are authentic. In the data authentication phase of our framework, we prove that we conduct our investigations on the authentic evidence. The framework offered by Upasita et al. does not prove the authenticity of the presented evidence.

The framework proposed by Upasita et al. detects the classification/category of the suspicious UAV. The detection of the classification/category of suspicious UAV helps the investigator to find the regulations related to the UAV. Most countries have regulations for registering UAVs according to their classification. This phase helps the investigator to identify the owner/pilot of the UAV. Since that our framework mainly focuses on the digital data, and owner/pilot identification of the UAV is in the scope of different criminal disciplines, this feature is not contained by our proposed framework.

Table 3. Comparison of the Proposed Framework and the Framework by Upasita et al.

Feature	Seven-Phased UAV Investigation Framework	Framework by Upasita et al.
Preparation Before Investigation	✓	✓
Customization Detection	✓	✓
Digital Data Investigation	✓	X
Hardware/Gear Investigation	X	✓
GCS Investigation	✓	X
Flight Path Regeneration	✓	X
Preserving Data Authentication	✓	X
Classification/Category Detection	X	✓

6. CONCLUSION, RECOMMENDATIONS AND FUTURE WORK

With this research, we aimed to create a framework for systematically detecting and classifying any criminal activity conducted with UAVs. The massive increase in the usage of UAVs has also led to a dramatic increase in the illegal usage of these devices. The illegal usage of UAVs has revealed a legal loophole in the current aviation regulations due to the lack of sufficient information and existing standards on the forensic investigation of these incidents.

We proposed a seven-phased UAV digital forensics investigation framework and tested its efficacy by implementing it on a sample UAS. We experienced that our framework works successfully and it significantly helps with the forensic investigation of UASs in a systematic manner. We believe that our proposed framework contributes to digital forensics investigators on the investigation of UAVs.

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RESEARCH ARTICLE

PREDICTION OF VIBRATION RESPONSE CAUSED BY ROTATING MACHINERY

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ABSTRACT

Excitation energy of rotating machinery propagates through the connection paths resulting in vibration responses at the structures such as machine foundations. Accurate prediction of these vibration responses at a point of a complex structure, where the operational behavior cannot be measured directly, is an important engineering problem for design optimization, component selection and condition monitoring. The main step of the prediction is to identify the internal forces acting on the connection paths of the machinery. At the circumstances where direct measurement is impossible or impractical due to physical constraints, an indirect approach is to identify the exciting forces based on multiplication of an inverted frequency response functions (FRFs) matrix and a vector of vibration responses measured at the points where the exciting forces are transmitted through. The aim of this paper is to present matrix inversion method to identify the exciting internal forces and hence predict the vibration response at the point of interest.

Keywords: *Vibration Response, Matrix Inversion, Cross-Coupling, Rotating Machinery.*

DÖNEL MAKİNE KAYNAKLI TİTREŞİM CEVABININ ÖNGÖRÜSÜ

ÖZ

Dönel makinelerin tahrik enerjisi makinenin bağlantı patikalarından yayılararak makine kaidesi gibi yapılar üzerinde titreşim cevabı ortaya çıkarmaktadır. Kompleks bir yapının titreşim cevaplarının doğru olarak öngörülmesi dizayn optimizasyonu, ekipman seçimi ve durum izlemesi açısından önemli bir mühendislik problemidir. Öngörünün ana aşaması makinenin bağlantı patikalarına etkiyen dahili kuvvetleri tespit etmektir. Doğrudan kuvvet ölçümünün mümkün veya pratik olmadığı durumlarda, frekans cevap fonksiyonları (FCF) matrisinin tersi ile tahrik kuvvetlerinin yayıldığı noktalarda ölçülen titreşim cevapları vektörünün çarpılması ile tahrik kuvvetlerinin tespit edilmesi endirekt bir yaklaşım olarak uygulanabilir. Bu makalenin amacı dahili kuvvetleri tespit etmek ve böylelikle ilgi noktasının titreşim cevabını öngörmek amacıyla kullanılacak matris evirme metodunu sunmaktır.

Anahtar Kelimeler: *Titreşim Cevabı, Matris Tersine Çevirme, Bağıl Etki, Dönel Makineler*

1. INTRODUCTION

A mechanical vibrating system can be divided into two main groups; active and passive. As shown in Figure 1, active part is the source creating the vibrational energy which can be defined as force or volume velocity. On the other hand, passive part consists of the receiver and the paths through which the vibrational energy is transferred. This part can be defined as acceleration/sound pressure and transfer functions, respectively.

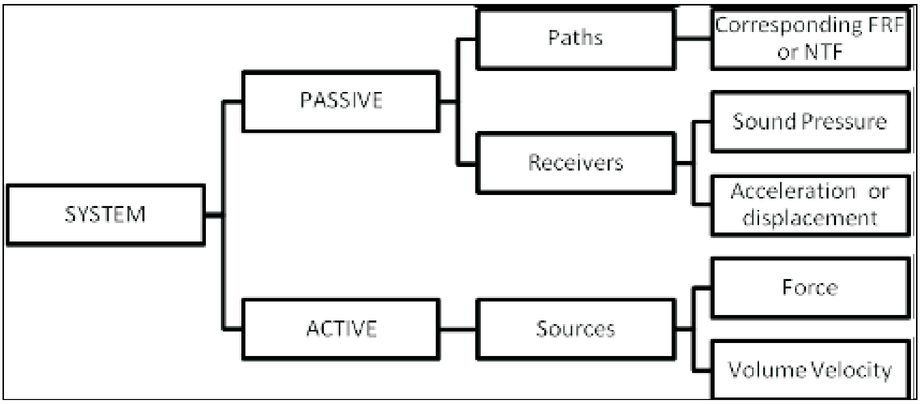

Figure 1. Description of a Mechanical Vibrating System

The major step of the vibration response prediction (VRP) is to identify the exciting internal forces acting on the structure through the connection paths. The most straightforward solution is to measure the forces directly. However, this may not be possible due to the complexity of the structure and the challenges of load cell applications. Consequently, indirect methods have been widely studied in the literature [1-20]. Dynamic stiffness method, introduced by Verheij [1], seems to be the most simple way, especially for the rubber linked structures. However, accurate complex dynamic stiffness data of the rubber mounts is seldom available and even if there is, it is only valid for a given load condition. Another approach, called transmissibility method, can be implemented to predict the vibration response at a point of interest. In this method, the forces are replaced by the measured responses at the force identification points and the propagation paths are represented by the transmissibilities. This approach is much simpler and faster but unconsidered potential cross-coupling between the paths lead to incorrect predictions [2, 5].

In the early 1980s, the matrix inversion method has been developed [6, 7]. This method basically involves multiplication of a vector of vibration responses with an inverted matrix constituted by the frequency response functions (FRFs).

In this study, prediction of the vibration response will be discussed for a structure excited by an electric driven pump. Dynamic stiffness method is commonly used for the rotating machinery. However, the machinery may be mounted without resilient elements. Even if it is connected with resilient mounts, the stiffness data of the mounts may not be available. This study investigates the application of direct inversion method for these cases and the effect of the cross-coupling terms.

2. MATRIX INVERSION METHOD

The vibration response of any point is related to the acting force and corresponding point transfer function. However, the response at a particular point is not only related to the force acting on the point but also the other forces acting on the structure. This contribution from the other forces is called cross-couplings. If the system consists of more than one source or path, the cross-couplings should be considered. Cross-coupling effects are focused on considering all transfer functions between the path inputs, as illustrated in Equation (1). It can be stated that a high dynamic response at any point does not indicate that the corresponding point force is the only exciter. Due to this reason, prediction of vibration response at a point results in errors if the cross-couplings are not taken into account. Biermayer et al. reported that the error can be up to 10 dB in case of not considering the cross-coupling terms [21].

$$\ddot{X}_1 = F_1\, H_{11} + F_2\, H_{21} + \cdots + F_n\, H_{n1} \tag{1}$$

Where n is the number of paths, F is the exciting force and H is FRF between the force and the path inputs.

In order to identify the exciting forces, the inverse procedure should be applied. In this presented approach, a square FRF matrix, $n \times n$, is constituted by measured FRFs between the path inputs to take the cross couplings into account. A vector of vibration responses is created by using the responses measured at the points. Thus, internal forces propagating through each path can be defined in matrix notation by applying matrix inversion as shown in Equation (2).

$$\{F_i(\omega)\} = [H_{ij}(\omega)]^{-1}\{\bar{X}_i(\omega)\} \tag{2}$$

Where *i* and *j* denotes the number of paths and forces, respectively.

Once the exciting internal forces are calculated, the vibration response at the point of interest, *k* can be predicted assuming that the system is linear. The contribution of each path to the total response can be found by multiplying the identified internal forces with the corresponding transfer functions or FRFs. Since the system is assumed to be linear, the response of the point of interest can be identified by adding up the partial contributions, as illustrated in Equation (3). Besides, the dominant transfer paths can be determined according to the partial contributions.

$$\bar{X}_k(\omega) = \sum_{i=1}^{n} \bar{X}_{ki}(\omega) = \sum_{i=1}^{n} F_i(\omega) H_{ki}(\omega) \tag{3}$$

Due to the defined partial contributions with Equation (3), main reasons for the high contributions of a transfer path can be determined such as high transfer function, high point mobility etc. Then, some remedial measures can be applied by means of reducing transfer function or increasing local stiffness.

3. CASE STUDY

A set-up composed of an electric motor driven pump and its foundation was created in order to predict the vibration response at the defined target on the foundation, as shown in Figure 2.

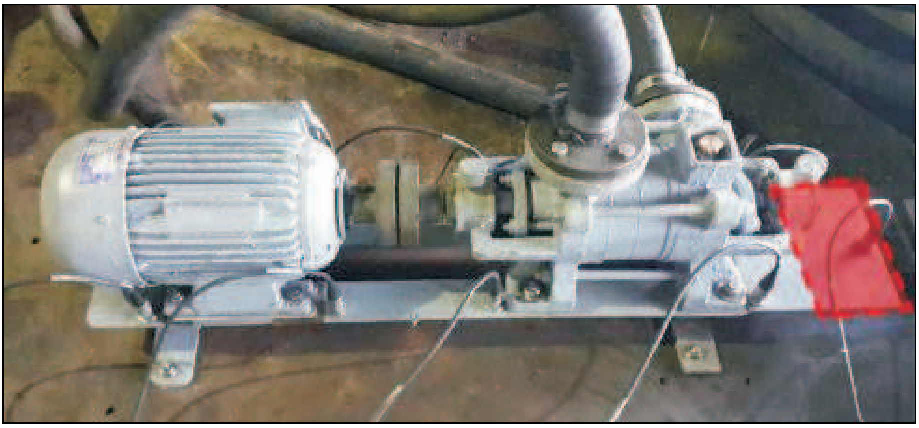

Figure 2. Electric Motor Driven Pump Set-up

Experimental study was composed of three parts. First, the pump ran at 3000 rpm and the acceleration was measured as the vibration response by means of accelerometers at the connection paths, S1 to S8, as shown in Figure 3. The measured responses should include complex quantities having magnitudes and phase information. They can be derived for each frequency by using auto- and cross-spectra as;

$$a_i = \sqrt{G_{ii}}\, e^{-j\angle G_{i1}} \tag{4}$$

where G_{ii} is the auto-spectrum of the response at point *i* and G_{i1} is the cross-spectrum between the reference position, 1 and point *i*. Equation (4) should only be implemented if the coherence function between a_1 and a_i is about one. Besides, the reference position should be one of the points at where the response is measured [16, 22].

Second part was measuring the transfer functions of the structure by means of an impact hammer. FRFs were measured from the path locations to the target location, S9. H1 was considered as the FRF and frequency range was selected as 0-300 Hz. Finally, in the third part, the mentioned methodology was implemented; the results were presented and compared with the measured ones.

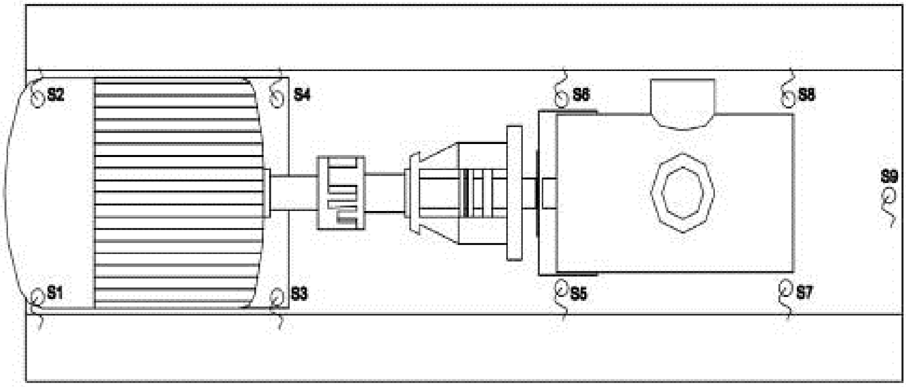

Figure 3. Schematic View of the Set Up

It is really challenging to perform a pure one dimensional excitation at the path connections because moments and lateral forces may be arisen. However, moments and rotations were neglected in the study since they are very hard to measure [23]. In this study, the vertical exciting forces were aimed to be identified and then the vibration responses were predicted assuming that the system is linear and time-invariant. By applying the matrix inversion method along with the cross-coupling terms (Equation (2) and (3)), the response at the target, S9 was identified.

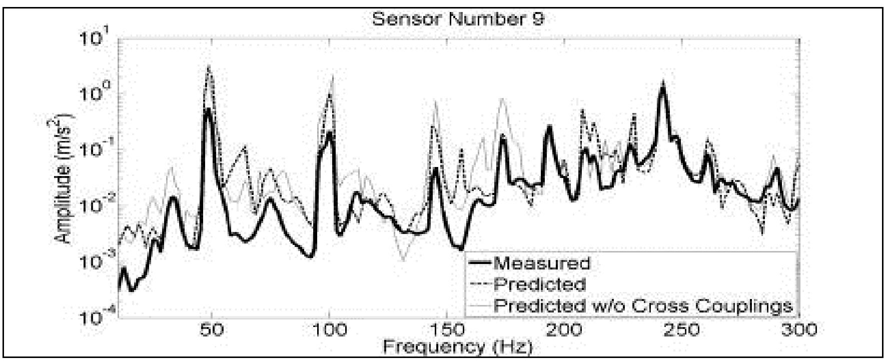

Figure 4. Vibration Response of S9

As shown in Figure 4, the predicted response catches the vibrational character of the measured response with admissible amplitude differences and it can be stated that there is an acceptable consistence between the measured and predicted result with 30 % average error in the frequency band. The internal forces were also identified such that cross-coupling terms were not included. Internal point force propagating through each path was determined by using its point FRF and the path input. As illustrated in Figure 4, it was identified that the prediction without considering cross-coupling terms increased the overall error with about a rate of 40 % in the frequency band.

In this methodology, there are some inevitable discrepancies, which can be occurred due to some assumptions and measurement errors. Neglected moment and lateral forces as well as the energy transmission loss through the paths result in error in the force identification. Besides, measurement errors are almost unavoidable in all experimental studies. The process of measuring vibration is prone to errors introduced by various factors based on the excitation, sensor, structure and environment [24-26]. Furthermore, measured vibration is usually contaminated with other unfavorable effects such as noise. These assumptions and measurement errors result in high condition number of the matrix to be inverted. Thus, the condition number of the accelerance matrix, which is basically the ratio of the largest singular value to the smallest one, can be used as a quality indicator for the response prediction based on the matrix inversion method. It is calculated by using Equation (5) and compared with the absolute error of prediction in Figure 5.

$$K_2([H]) = \frac{\sigma_{max}}{\sigma_{min}} \tag{5}$$

As shown in Figure 5, the absolute error increases with increasing condition number. Measurement errors, which usually occur in any FRF measurement, amplify the prediction errors due to the inversion of the FRF matrix. Thus, it can be stated that the condition numbers serve as the parameters influencing the error.

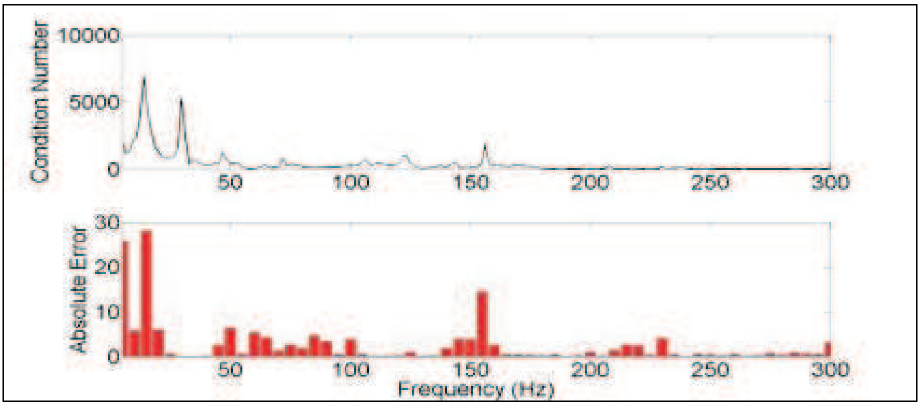

Figure 5. Condition Number of the FRF Matrix vs. Absolute Error

In addition to the vibration response prediction, the dominant paths with the corresponding frequency are the focus of interest. For that purpose, path contribution plot (PCP) was generated by using partial contributions for the paths as stated in Equation (3). According to the Figure 6, 50 and 100 Hz dominate the response since they correspond to the first and second order of the pump, respectively.

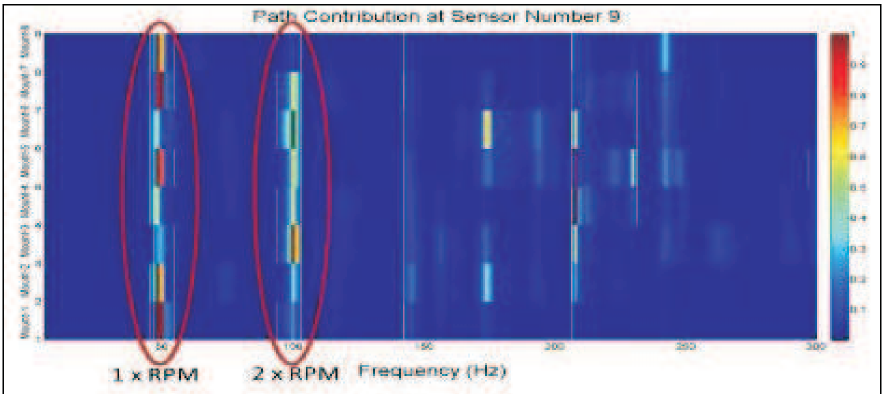

Figure 6. Path Contribution Plot (PCP) for S9

4. SUMMARY AND CONCLUSIONS

In this study, the prediction of vibration response caused by rotating machinery was discussed with the methodology of matrix inversion. An experimental case study composed of an electric motor driven pump and its foundation was performed. One dimensional and vertical exciting force was considered and assumed to be the sum of the vertical internal path forces by ignoring the lateral forces and moments. The vibration response of the target located on the foundation was predicted by including the cross-couplings between the paths and compared with the actual measured response. The results show that the predicted response fits well with the measured one in terms of character and magnitude. However, there are some acceptable discrepancies occurred due to the combination of assumptions and measurement errors. On the other hand, it can be determined that the including cross-coupling terms improves the results with a rate of about 40 %. In conclusion, the matrix inversion method including cross-couplings can be implemented for the structures excited by a rotating machinery, when the primary concern is predicting the vibration response and determining the dominant paths for condition monitoring and design optimization.

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Our journal uses **double-blind** review, which means that both the reviewer and author identities are concealed from the reviewers, and vice versa, throughout the review process. So, the uploaded manuscript does not contain the name, address and affiliation of author(s). The manuscript evaluation steps are as follows;

Editor is assigned by the Editor in Chief

The relevant reviewers are assigned by the Editor

As a result of the reviewer's evaluation, the manuscript may be rejected, accepted or a correction for the manuscript may be requested.

If the negative feedback is given by major number of the reviewers the process is terminated and the article is rejected.

If major/minor revisions are required for the manuscript, the author has to do this revision according to the reviewers' comments in "three weeks".

If the revision is accepted by the reviewers, the article is accepted.

The workflow diagram for the evaluation process can be accessed from the web page of the journal.

The accepted articles are published **free-of-charge** as online from the journal website and printed.

DENİZ BİLİMLERİ VE MÜHENDİSLİĞİ DERGİSİ (DBMD) YAYIN KURALLARI

Yazıların Gönderilmesi: Dergiye gönderilen makaleler başka bir yerde yayımlanmamış ya da yayımlanmak üzere gönderilmemiş olmalıdır. Yayımlanması istenilen yazılar aşağıda verilen adresten sisteme yüklenmeli (tercih edilen) veya aşağıdaki adrese bir kopya kağıda basılı olarak, aynı zamanda e-mail adresine de dijital olarak gönderilmelidir.

Sistem Adresi:
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Yazı Türleri: Dergide; orijinal yazılar, derlemeler, teknik notlar, kitap incelemeleri, editöre mektuplar ile konferans ve toplantıların genişletilmiş raporları yayımlanır.

Yazıların Değerlendirilme Süreci: Makalenin Ön Kontrol Süreci:

Makalenin içeriği ve yazım formatı incelenir ve iThenticate programı ile benzerlik taraması yapılır.

Makalenin İngilizce özetinin, Türkçe öz ile uygunluğu ve yazım dili kontrol edilir.

Benzerlik oranı %40'ın üzerinde olan makale reddedilir. Benzerlik oranı %20 ile %40 arasında olan (tek bir kaynakla benzerlik %5'ten fazla olmamalıdır), yazım formatına uymayan ya da İngilizce ve Türkçe özetinde düzeltme gereken makale yazara bildirilir ve "iki hafta" içerisinde makalenin düzeltilmesi istenir. Aksi takdirde makale çekilmiş kabul edilir.

Dergimiz, makale değerlendirme sürecinde **çift-kör** hakemlik sistemini kullanmaktadır. Buna göre değerlendirme sürecinde hakem ve yazarlar birbirlerinin bilgilerini görememektedir. Bu yüzden, yüklenen ön yükleme formatında yazar(lar)ın isim, adres ve bağlı olduğu kuruluş(lar) yer almamaktadır. Makale değerlendirme sürecindeki adımlar aşağıdaki gibidir;

Baş editör tarafından makaleye editör atanır.

Editör makale için hakemleri atar.

Hakem değerlendirmesi sonucunda makale reddedilebilir, kabul edilebilir veya makalenin düzeltilmesi istenebilir.

Hakem görüşlerinin çoğunluğu doğrultusunda makale ret edilmişse süreç sonlandırılır ve makale reddedilir.

Makale için düzeltme istenirse hakem görüşleri doğrultusunda yazarın düzeltmeleri en geç "üç hafta" içerisinde yapması istenir.

Makale kabul alırsa düzenleme aşamasına geçilir.

Değerlendirme sürecine ilişkin iş akış sürecine, dergi web sayfasından erişilebilir.

Kabul edilen makaleler, dergi web sayfasından **ücretsiz** olarak çevrimiçi (on-line) ve basılı şekilde yayınlanmaktadır.

JOURNAL OF NAVAL SCIENCES AND ENGINEERING (JNSE)
WRITING RULES

General: Manuscripts must be prepared in MS Word, single-spaced with justify. Font: Times New Roman, 12 points. Margins: left 4,5 cm- right 3,5 cm, top 5 cm- bottom 7 cm, header 3,25 cm- footer 6 cm, gutter 0. Paper type: A4. Page numbers should be on the middle of bottom of page with -1-, -2-, -3- etc format. Using footnotes is not allowed.

Body of Text: Follow this order when typing manuscripts: Title, Authors, Abstract, Keywords, Title (Turkish), Abstract (Turkish), Keywords (Turkish), Main Text, Appendix (if any), References.

Title: Title should reflect objectives of the paper clearly, be easily understandable and not exceed 15 words.

Abstracts: Each paper should have an abstract with 100-200 words and have a structured form, i.e. standard structure of an article (background, purpose, material and methods used, results, conclusion).

Paper Length: The manuscript should be minimum 2000 words or 5 pages, maximum 7000 words or 25 pages including references.

Keywords: Author must provide some keywords (between 3 and 5) that will be used to classify the paper.

Unit: International System of Unit (Système Internationale d'Unités; SI) (https://www.britannica.com/science/International-System-of-Units) should be used for all scientific and laboratory data.

References: Referring to references should be in the text by using reference numbers in parenthesis (i.e. [2]).

List of References: Publications cited in the text should only be presented in a list of references following the text of the manuscript. References should be listed according to their orders in which they are cited in the manuscript, i.e., [1] cited first, [2] cited next, and so on. An example of a reference list is below.

Examples:

[1] Berndt, T. (2002). "Friendship Quality and Social Development", ***Current Directions in Psychological Science***, vol.82, no.3, pp.114-140. **(Single authored article)**

[2] Rother, M. and Shook, J. (1999). "Learning to See: Value Stream Mapping to Create Value and Eliminate Muda", ***The Lean Enterprise Institute***, vol.22, no.4, pp.3-4**. (Multi-authored article)**

[3] Okamoto, G. (1999). ***Smart Antenna Systems and Wireless LANs,*** Boston: Kluwer Academic Publishers. **(Single Author Books)**

[4] Author, A. (Year). "Title of document", Retrieved from http://wwwwwwwwwwwwwwwwwwww wwwwwwwwwwwwwww (Access Date: 00.00.0000). **(Internet Sources)**

[5] Lastname, F.N. (Year). Title of dissertation (Doctoral dissertation). University Name, Institute Name, City. (Retrieved from Name of database). **(Published Dissertation)**

[6] Bergmann, P. G. (1993). Relativity, ***In The New Encyclopedia Britannica,*** (Vol. 26, pp. 501-508). Chicago, IL: Encyclopedia Britannica**.(Encyclopedia)**

[7] Author, A. A. (Year, Month Day). "Title of article", ***Title of Newspaper***. Retrieved from http://www.someaddress.com/full/url/wwwwwwwwwwwwwwwwwwwwwwwwwwwwwwwwwwwwwwwwww wwwwwwwwwww wwwwwwwwwwwwwww **(Newspaper article)**

[8] Önaçan, M.B.K., Uluağ, M., Önel, T. and Medeni, T.D. (2018). "Selection of Plagiarism Detection Software and Its Integration Into Moodle for Universities: An Example of Open Source Software Use in Developing Countries". Ricardo Queirós (ed.), Emerging Trends, Techniques, and Tools for Massive Open Online Course (MOOC) Management, ***IGI Global***, 250-265, pp. 255. **(Book chapter)**

Abbreviations and Acronyms: Standard abbreviations and acronyms should be used for each related discipline. Acronyms should be identified at the first occurrence in the text. Abbreviations and acronyms may also be attached to main text as an appendix.

Equations and Formulas: Equations and formulas should be numbered consecutively. These numbers must be shown within parentheses being aligned to right. In the text, equations and formulas should be referred with their numbers given in parentheses. Comprehensive formulas, not appropriate to be written in the texts, should be prepared in figures.

Figures and Tables: Figures and tables should be numbered consecutively. In the text referring to figures and tables should be made by typing "Figure 1" or "Table 1" etc. A suitable title should be assigned to each of them.

DENİZ BİLİMLERİ VE MÜHENDİSLİĞİ DERGİSİ (DBMD)
YAZIM KURALLARI

Genel Bilgiler: Yazılar; Microsoft Word'de tek satır aralığı ve iki yana yaslanarak hazırlanmalıdır. Yazı tipi: Times New Roman, 12 punto. Kenar boşlukları: sol 4,5 cm- sağ 3,5 cm- üst 5 cm- alt 7 cm- üst bilgi 3,25 cm- alt bilgi 6 cm, oluk 0. Kağıt ölçüsü: A4. Sayfa numaraları sayfanın alt ortasında -1-, -2-, -3- şeklinde yer almalıdır. Dipnot kullanılmamalıdır.

Yazı Yapısı: Yazı şu sırada hazırlanmalıdır: Başlık, Yazarlar, Özet, Anahtar Kelimeler, Başlık (Türkçe), Özet (Türkçe), Anahtar Kelimeler (Türkçe), Ana Metin, Ek (varsa), Referanslar.

Başlık: Başlık; açık, net, anlaşılır olmalı ve 15 kelimeyi geçmemelidir.

Öz (Abstract): Yazı, 100-200 kelimelik, arka plan, amaç, yöntem, bulgular ve sonuçtan oluşan yapılandırılmış bir özeti içermelidir.

Sayfa Sayısı: Dergiye gönderilecek yazıların boyutu, kaynakça dahil asgari 2000 kelime veya 5 sayfa, azami 7000 kelime veya 25 sayfa arasında olmalıdır.

Anahtar Kelimeler: Yazıyı sınıflandırmaya yarayacak, anahtar görevi yapan 3-5 kelime yer almalıdır.

Birimler: Yazının uluslararası alanlarda da kolay izlenebilir ve anlaşılabilir olması için Uluslararası Birim Sistemine (https://www.britannica.com/science/International-System-of-Units) uygun olarak hazırlanması gerekir.

Referans: Referanslar dipnotlar ile değil metin içinde açılacak parantezlerde yer alan referans numarası ile ([2] gibi) yapılmalıdır.

Referans Listesi: Makalenin ana metninden sonra sadece yazıda gönderme yapılan eserler yer almalıdır. Gönderme yapılan eserler, ana metin içerisinde atıf yapıldıkları sıraya göre listelenmelidir, yani ilk atıf yapılan eser [1], ikinci atıf yapılan eser [2] olmalı ve bu şekilde devam etmelidir. Bir referans listesi örneği aşağıdadır.

Örnekler:

[1] Berndt, T. (2002). "Friendship Quality and Social Development", ***Current Directions in Psychological Science***, vol.82, no.3, pp.114-140. **(Tek yazarlı makale)**

[2] Rother, M. and Shook, J. (1999). "Learning to See: Value Stream Mapping to Create Value and Eliminate Muda", ***The Lean Enterprise Institute***, vol.22, no.4, pp.3-4**. (Çok yazarlı makale);**

[3] Okamoto, G. (1999). ***Smart Antenna Systems and Wireless LANs,*** Boston: Kluwer Academic Publishers. **(Tek yazarlı kitap)**

[4] Author, A. (Year). "Title of document", Retrieved from http://wwwwwwwwwwwwwwwww wwwwwwww wwwwwwwwwww (Access Date: 00.00.0000). **(İnternet kaynakları)**

[5] Lastname, F.N. (Year). Title of dissertation (Doctoral dissertation). University Name, Institute Name, City. (Retrieved from Name of database). **(Yayınlanmış tez)**

[6] Bergmann, P. G. (1993). Relativity, ***In The New Encyclopedia Britannica,*** (Vol. 26, pp. 501-508). Chicago, IL: Encyclopedia Britannica**.(Ansiklopedi)**

[7] Author, A. A. (Year, Month Day). "Title of article", ***Title of Newspaper***. Retrieved from http://www.someaddress.com/full/url/wwwwwwwwwwwwwwwwwwwwwwwwwwwwwwwwwww wwwww wwwwwwwwwwwwwwwwwwwwwwwwwwwww **(Gazete makalesi)**

[8] Önaçan, M.B.K., Uluağ, M., Önel, T. and Medeni, T.D. (2018). "Selection of Plagiarism Detection Software and Its Integration Into Moodle for Universities: An Example of Open Source Software Use in Developing Countries". Ricardo Queirós (ed.), Emerging Trends, Techniques, and Tools for Massive Open Online Course (MOOC) Management, ***IGI Global***, 250-265, pp. 255. **(Kitap bölümü)**

Notasyon ve Kısaltmalar: İlgili bilim alanının standart notasyon ve kısaltmaları kullanılmalı, yeni notasyonlar ise metin içinde ilk geçtiği yerde tanımlanmalıdır. Gerekli durumlarda, notasyon ve kısaltmalar ek olarak konulabilir.

Denklem ve Formüller: Denklem ve formüller ardışık olarak numaralandırılmalı ve bu numaralar sağa dayalı parantez içinde yazılmalıdır. Metin içinde denklem ve formüllere parantez içinde yazılan numaraları ile atıfta bulunulmalıdır. Metin arasında verilmesi uygun olmayan kapsamlı formüller şekil olarak hazırlanmalıdır.

Şekiller ve Tablolar: Şekiller ve tablolar, ardışık olarak numaralandırılmalıdır. Bunlara metin içinde "Şekil 1" veya "Tablo 1" şeklinde atıfta bulunulmalıdır. Her bir şekil ve tablo için uygun bir başlık kullanılmalıdır.

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