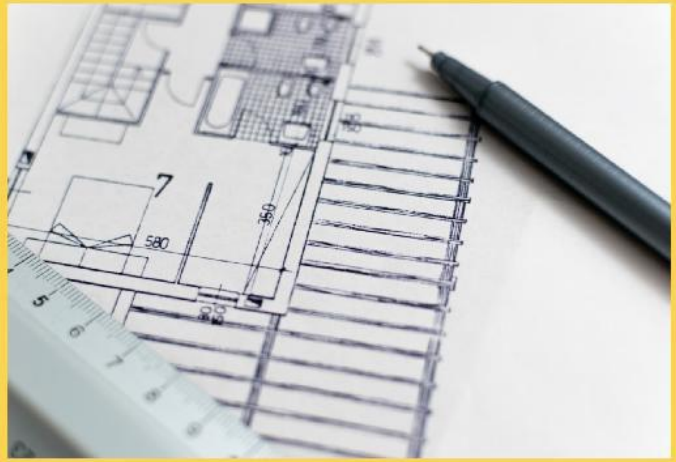
ENGINEERING AND ARCHITECTURE SCIENCES

Theory, Current Research and New Trends/2

Editor
Dr. Emine Yıldız Kuyrukçu



Cetinje 2020

ENGINEERING AND ARCHITECTURI

2020

ISBN: 978-9940-46-054-9

ENGINEERING AND ARCHITECTURE SCIENCES

Theory, Current Research and New Trends/2

Editor
Dr. Emine Yıldız KUYRUKÇU

Editor
Dr. Emine Yıldız KUYRUKÇU

First Edition •© December 2020 /Cetinje-Montenegro

ISBN • 978-9940-46-054-9

web: www.ivpe.me

Tel. +382 41 234 709

e-mail: office@ivpe.me

Cetinje, Montenegro

PREFACE

The development of scientific publications and the service of those publications to the relevant environment extends the framework of science. Today, the value of interdisciplinary work is increasing. With information being spread and aged quickly, cross-disciplinary work is important to innovation and development. The need for a combination of different disciplines and the wide impact of the resulting solution ideas cannot be denied. Recognizing each other's work in different areas of science, recognizing the work of different scientists will help solve problems that have been unresolved to the present day through interdisciplinary work.

I believe that new ideas and different perspectives will be developed in readers with the information presented in this book, which brings together academic studies in engineering and architecture. I think that this book of various fields will be an important resource for academics, researchers, and students.

By supporting the book through its work, I am very thankful to the IVPE Publisher, which brings together all authors and writers who have provided information to be shared, universally integrated, and the development of science into the book.

Editor

Asst. Prof. Dr. Emine YILDIZ KUYRUKÇU

CONTENTS

REFEREES

Assoc. Prof. Dr. Mücahit Sütçü, İzmir Katip Çelebi University

Assoc. Prof. Dr. Rüya Şamlı, İstanbul University -Cerrahpaşa

Assoc. Prof. Dr. Ümit Özer, İstanbul University -Cerrahpaşa

Asst. Prof. Dr. Mehmet Aksoy, Eskisehir Osmangazi University

CHAPTER I

HYDRAULIC TRANSIENTS IN IRRIGATION SYSTEMS: A CASE STUDY

Assist. Prof. Dr. A. Ersin DİNÇER

Abdullah Gül University, Kayseri, Turkey,
e-mail: ersin.dincer@agu.edu.tr
Orcid no: 0000-0002-4662-894X

1.Introduction

Long-distance water supply systems such as pipeline systems are necessary to deliver water from reservoirs to arid regions or to cities. In any modern pipeline system, there are different operation regimes. Any change in the velocity due to the operation regime, causes a change in the pressure. An example of operation regimes may be sudden shutdown or start-up of pumps in the pipeline systems. When there is no change in the flow properties over time, the flow is steady flow. In steady flow, the flow properties may change from point to point, however they remain constant at a point with respect to time. If the properties change with time, then the flow is unsteady flow. In real life, slight changes in velocity and pressure always occur, but if the mean values are the same, then the flow is accepted as steady flow. When the steady condition of a system changes or unsteady flow occurs in a pressurized pipeline system transient flow or in other words water hammer is observed. Water hammer may cause excessive pressures in pipelines and can cause pipe and device damage by high positive or negative pressures (Wan, Zhang, & Chen, 2019). Negative pressures may cause the column separation, the breaking of liquid columns in pipelines and it occurs when the pressure in a pipeline drops below the vapor pressure. Vapor cavity separates the liquid column and the collision of the separated liquid columns causes large pressures which travel along the pipeline and may damage the pipes or hydraulic machinery (Bergant, Simpson, & Tijsseling, 2006).

To understand the travelling of the pressure better, a piping system having a valve shown in Figure 1 is considered. The flow is steady initially. The valve is assumed to be instantaneously closed at time zero (t=0). The behavior of the flow can be seen for different time periods. Note that in the figures, the minor and friction losses are ignored. In the time duration of $0 < t \leq L/a$, the valve is closed and the velocity at the valve is reduced to zero. This causes a pressure rise of $\Delta H = (a/g)V_{\text{o}}$. In this equation, a is

the wave speed, g is the gravitational acceleration and V_o is the initial velocity. At $t = L/a$, the wave reaches the reservoir, the pressure rise of ΔH along the entire pipe is felt. In the conditions during $L/a < t \leq 2L/a$, in the reservoir end, the head is initially equal to H_o. At t=L/α, an inequality in the reservoir end occurs. Although the head at the reservoir end is H_o, the head at the adjacent section is H_o+ΔH. Therefore, a flow from the pipe into the reservoir with a velocity $-V_o$ occurs. Consequently, the velocity is changed from zero to $-V_o$ and this results in a decrease at the head from H_o+ΔH to H_o. At t=2L/α, the entire pipe has the head of H_o and pressure wave reaches the valve. Since the reverse flow cannot be maintained any longer, the velocity will be reduced to zero from $-V_o$ at t=2L/α. This causes a drop in the pressure head by ΔH. Therefore, the new pressure head is H_o-ΔH. At t=3L/a, the flow velocity along the entire pipe is zero and the pressure is H_o-ΔH. After the negative pressure reaches the reservoir end, again unbalanced conditions occur. At that time, the pressure at the reservoir is higher than the one at the pipe. Therefore, the fluid starts to flow back into the pipe and the pressure head becomes H_o. At t=4L/a, the head along the entire pipe section is H_o. As can be seen, the conditions are repeated in every 4L/a time periods. This example is very useful to understand the water hammer concept. The closure of the valve causes a change in the pressure head. Both an increase and a decrease in the head occur along the pipe.

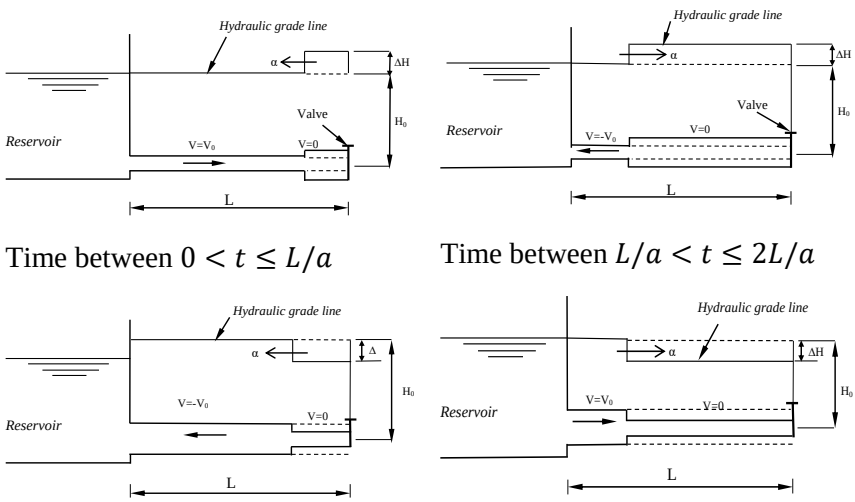


Figure 1. Water hammer phenomena

Although the operation is easy in the steady case; in the transient case, the behavior of the flow is complex and should be understood

correctly. Various numerical methods such as arithmetic method (Joukowsky, 1898), graphical method (Parmakian, 1963), wave-plan method (Wood, Dorsch, & Lightner, 1966) and method of characteristics (MOC) (Chaudhry, 2014) have been proposed to solve the transients in pipes.

In the present study, MOC is used to simulate the transients in the pipes of an irrigation system. A case study located in Turkey is investigated. The irrigation project is first investigated without any protective measures. Then, a hydropneumatic tank and a pressure relief valve are added and the simulations are repeated. The results are investigated in terms of hydraulic grade lines, air entrainment into the pipe and pressures.

2. Numerical model

The continuity and momentum equations of a fluid flow in a pipe can be expressed as:

$$\frac{1}{\rho}\left(\frac{\partial P}{\partial t}+V\frac{\partial P}{\partial x}\right)+a^2\frac{\partial V}{\partial x}=0 \tag{1}$$

$$\frac{1}{\rho}\frac{\partial P}{\partial x}+\frac{\partial V}{\partial t}+V\frac{\partial V}{\partial x}+\frac{4\tau_w}{\rho D}+g\sin\theta=0 \tag{2}$$

where, ρ is the density of the fluid, P is the pressure, V is the velocity, τ_w is the shear stress, D is the diameter of the pipe, g is the gravitational acceleration and a is the pressure wave speed throughout the fluid in pipe and can be calculated as,

$$a=\frac{\sqrt{\frac{K}{\rho}}}{\sqrt{1+\left[\left(\frac{K}{E}\right)\left(\frac{D}{e}\right)\right]C_1}} \tag{3}$$

where K is the bulk modulus of elasticity, E is the Young's modulus of the pipe, D and e are the diameter and thickness of the pipe, respectively. C_1 is a constant that shows the effect of pipe constraint conditions. If a pipe is anchored at its upstream end C_1= 1-μ/2, downstream end, C_1=1-μ^2. If a pipe is anchored throughout its expansion joints C_1=1.

To solve continuity and momentum equations, MOC is used. In this method, these equations are transformed into four differential equations and by integrating them, the numerical solutions are obtained (Bozkuş & Wiggert, 1997).

In these equations, independent variables are "x" and "t", while "P" and "V" are dependent variables. After some simplifications which can be

found in the study of Dinçer (2013), the essential assumption of MOC can be obtained as,

$$\frac{dx}{dt} = \pm a \tag{4}$$

This equation represents two straight lines with slopes of "$+1/a$" and "$-1/a$". These lines are called characteristics lines and shown in Figure 2. The complete forms of compatibility and characteristics equations can be stated as:

$$\frac{1}{\rho}\frac{dP}{dt} + a\frac{dV}{dt} + a\left(\frac{4\tau_w}{\rho D} + g\sin\theta\right) = 0 \qquad \frac{dx}{dt} = +a \tag{5}$$

$$\frac{1}{\rho}\frac{dP}{dt} - a\frac{dV}{dt} - a\left(\frac{4\tau_w}{\rho D} + g\sin\theta\right) = 0 \qquad \frac{dx}{dt} = -a \tag{6}$$

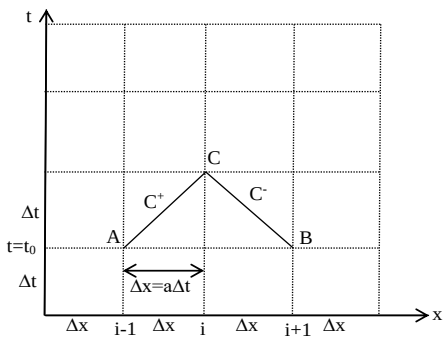


Figure 2. Characteristics lines

The C^+ and C^- lines are used to solve equations (5) and (6). HAMMER software is used to solve MOC equations and simulate the whole pipeline system.

3. Case study

3.1 Information about the case study

The location of the project used in the case study is in the middle black sea region of Turkey. The main aim of the project is to supply water to the irrigation areas of 4 cities.

In the project, the water is pumped to two regulation basins. Therefore, there are two pipelines called as profile 1 and profile 2. The pump stations of these pipelines are in the same building as given in Figure 3. The elevation of the pump station is 796.00 m while the pump station suction pipe axis elevation is 794.18 m.

For profile 1, the maximum and the minimum water levels of regulation basin are 856.60 m and 855.00 m, respectively. The piezometric head at just upstream of the pump is 809.8 m. The pump station has a total flow rate of 768 l/s divided into 3 pumps. Each pump flow rate is 256 l / s.

For profile 2, the maximum and the minimum water levels of regulation basin are 906.30 m and 905.00 m, respectively. The total flow rate of pumps in profile 2 is 510 l/s and there are 3 identical pumps.

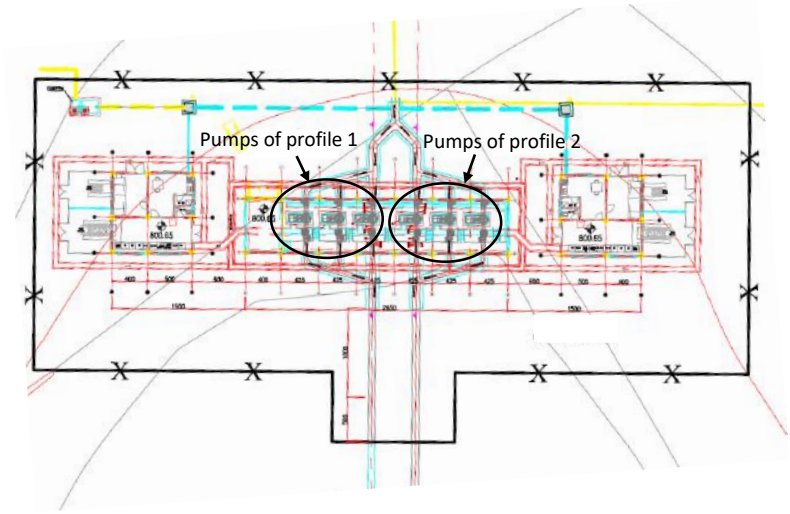


Figure 3. Plan view of the pump station

A simplified plan view of the project taken from the analysis software is given in Figure 4. Profile 1 and profile 2 are shown in the figure. The diameter of the pipes upstream of the pumps is 900 mm with 9 mm thickness. The diameter of the pipes of profiles 1 and 2 are 800 mm with 8 mm thickness and 700 mm with 9 mm thickness, respectively. The pipes are steel. The pipe axis profile is given in Figure 5.

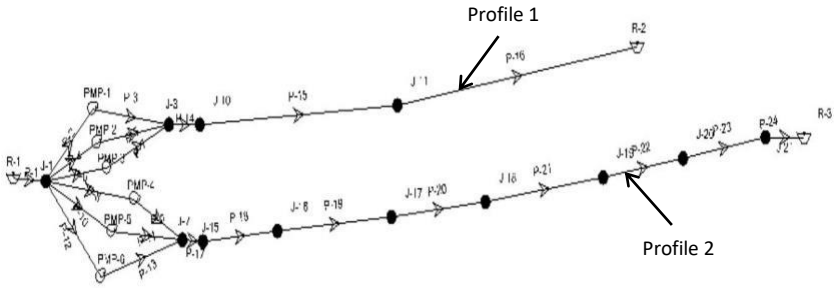


Figure 4. A simplified plan view of the water supply system

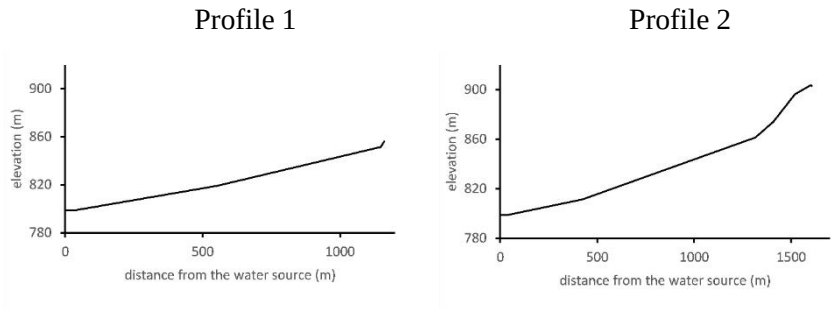


Figure 5. Simplified pipe axis profile

The design head and flow rate of the pumps in Profile 1 are 48.80 m and 256 l/s while they are 100.49 m and 170 l/s in Profile 2. Necessary NPSH values for profiles 1 and 2 are 3.57 m and 3.14 m, respectively. The design efficiency of the pumps for profiles 1 and 2 are 83.6% and 83.2% while the rotational speeds are 1491 rpm and 1490 rpm. Pump curves are given in Figure 6.

Pump curves of Profile 1 Pump curves of Profile 2

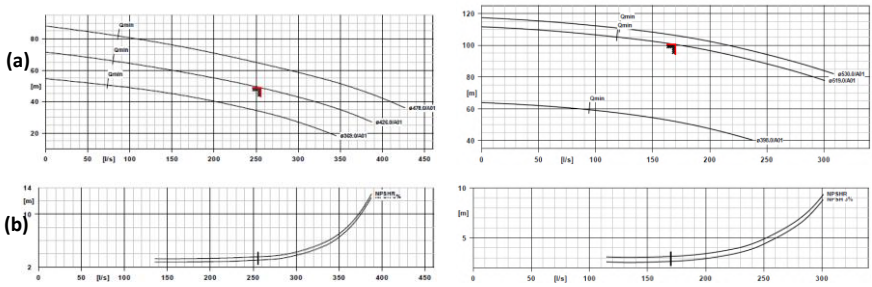


Figure 6. Pump curves (a) head vs discharge (b) NPSH vs discharge

3.2 Results

Although the pressure changes that may occur in profiles 1 and 2 are not expected to affect each other, the system is solved as a whole since the pump stations are gathered in a single building. The most critical case in which all the pumps are suddenly shut down is investigated. The calculations are repeated for the minimum and the maximum water levels in the regulation basins.

In Figure 7, air/vapor volume, the maximum (red line) and minimum (blue line) hydraulic grade lines throughout the pipeline (black line) are given when the water level in the regulation basins is maximum and minimum.

In Profile 1, air is entrained into the pipe. The hydraulic grade line is critically below the pipe axis and pressure drops to the vapor pressure resulting in the air entrainment. When the water level is minimum the air entrainment is nearly 1.5 times the one when the maximum water level in regulation basin is observed.

Maximum and minimum hydraulic grade lines are very close independent of the water level in the regulation basin. Although in profile 2, air entrainment is not observed, hydraulic grade line drops below the pipe axis at the downstream. There is a column separation risk in profile 1 and protective measures should be taken.

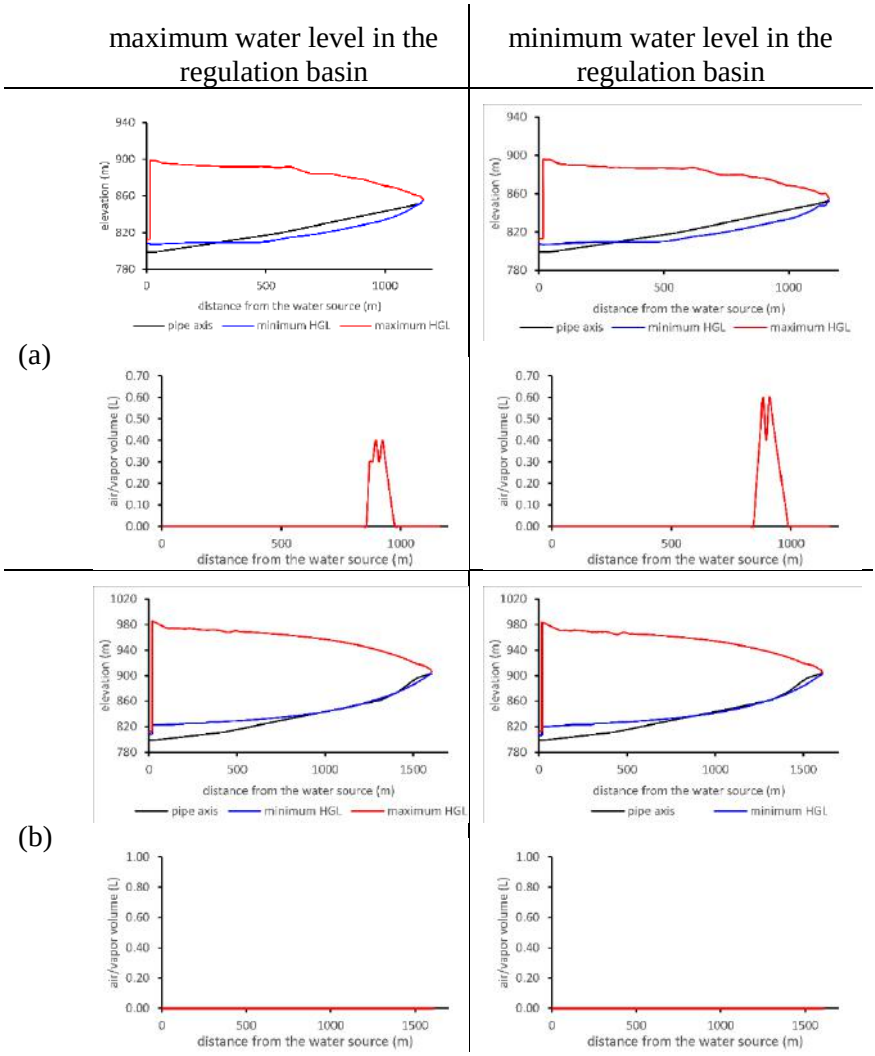


Figure 7. The results without any protective measures for (a) Profile 1 and (b) Profile 2

After a detailed investigation, a hydropneumatic tank is decided to be placed to profile 1, while a pressure relief valve is placed to profile 2. The volume and diameter of the tank are 5000 l and 1.4 m, respectively. The lower and upper elevation of the hydropeumatic tank are 807.39 m and 811.39 m, respectively. The tank is placed 270 m downstream of the pump station of profile 1. The tank is connected to the pipeline with a 200 mm connection pipe. There is a butterfly valve of the same diameter on the connection pipe and a check valve in the direction of the water from the tank to the pipeline. Two pressure valves are placed on the tank and the

water level in the tank is controlled. The pressure relief valve is placed to 1050 m downstream of the pump station of profile 2.

The results when all the pumps are shut down are given in Figure 8. As can be seen in the figure, hydraulic grade line never falls below the pipe axis for both profiles. Air does not enter the pipe and it is safe to conclude that there is no cavitation risk when necessary precautions are taken.

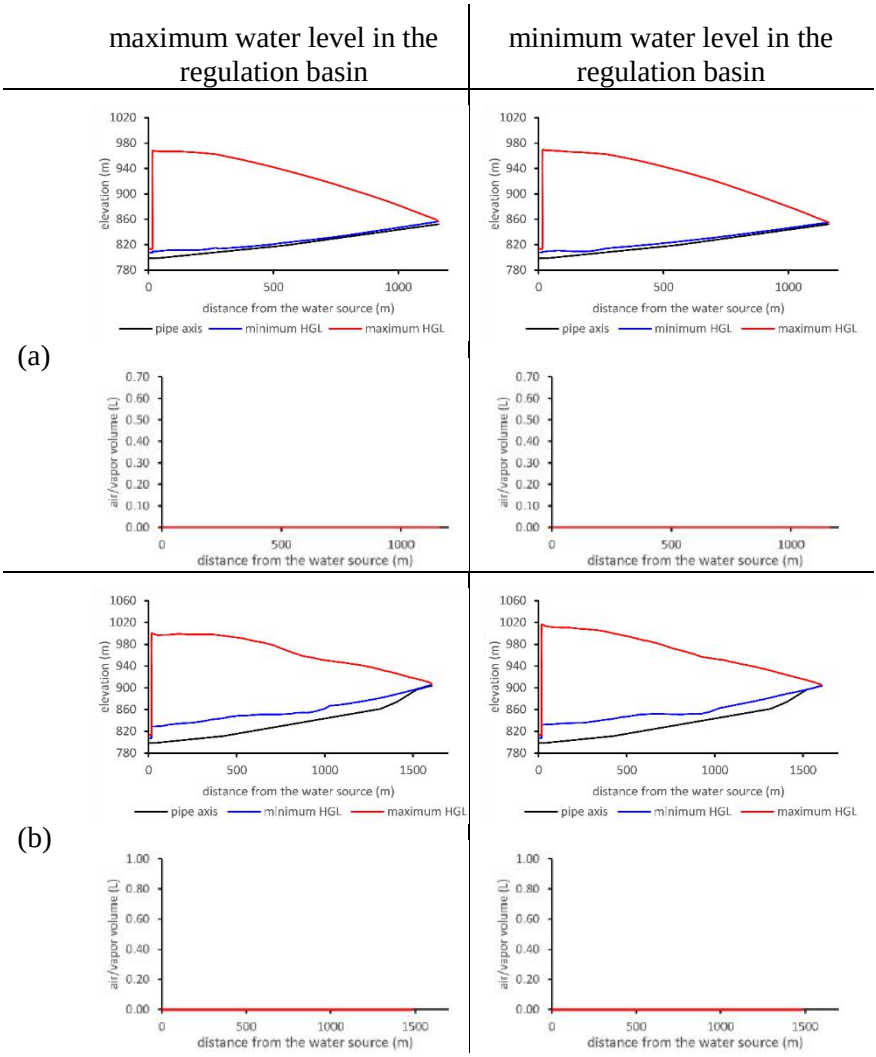


Figure 8. The results with hydropneumatic tanks for (a) Profile 1 and (b) Profile 2

In Figure 9, the change in pressure on the pumps of both profiles is given. Since the upstream conditions are the same, the pressure history in just upstream of both pumps is very close to each other. However, the pipe profile changes in the downstream of the pumps, so pressure history on the pump changes drastically. The maximum pressures on the pumps of profile 2 are higher than the ones of profile 1.

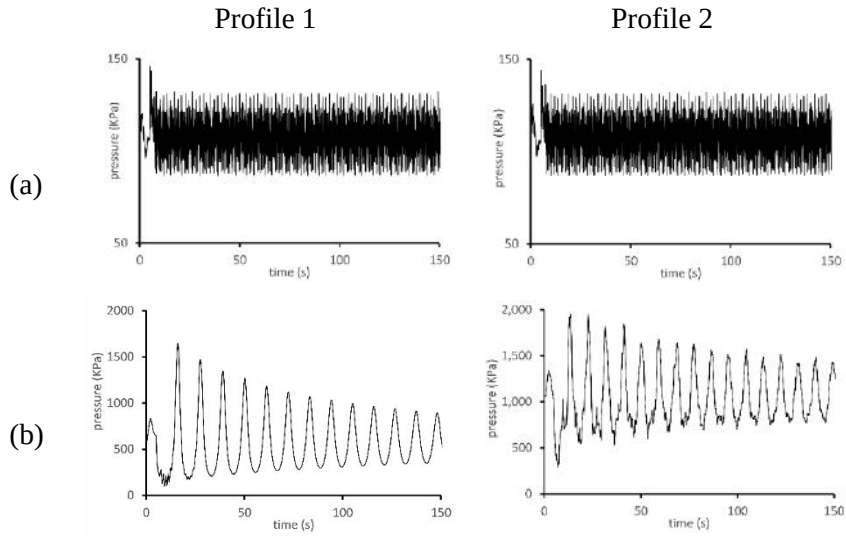


Figure 9. Pressure history in (a) just upstream and (b) just downstream of the pumps

In addition to the pressures on the pumps, the pressure history on hydropneumatic tank is given in Figure 10. The maximum pressure is observed at the beginning of the simulation as expected. Hydropneumatic tank is very effective to control the pressure in the pipes of the irrigation system.

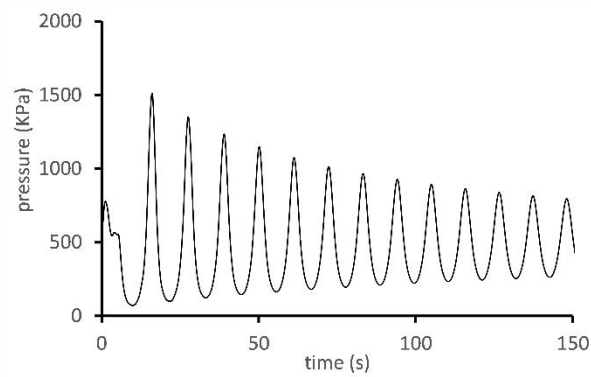


Figure 10. Pressure history on the hydropneumatic tank

The maximum pressures calculated in profiles 1 and 2 are approximately 1600 kPa and 2000 kPa. In order to withstand that pressure, the diameters of the pipes are chosen as 800 mm and 700 mm, while the thicknesses are 8 mm and 9 mm, respectively. St-37 steel pipe is used. The calculations are made using the design criteria in AWWA M11.

4. Conclusions

In this chapter, an irrigation project in which water is pumped to a regulation basin and then transmit it to the irrigation area is investigated in terms of hydraulic transients. The maximum and minimum pressures occurring in the pipes due to rapid shut down of all the pumps are calculated. It is seen that protective measures should be taken since piezometric head drops below the elevation of the pipe axis. After installing a hydropneumatic tank and a pressure relief valve, negative pressures are prevented. The dimensions of the pipe are decided by using the design criteria in AWWA M11.

5. References

Bergant, A., Simpson, A. R., & Tijsseling, A. S. (2006). Water hammer with column separation: A historical review. *Journal of Fluids and Structures*, *22*(2), 135–171. https://doi.org/10.1016/j.jfluidstructs.2005.08.008

Bozkuş, Z., & Wiggert, D. C. (1997). LIQUID SLUG MOTION IN A VOIDED LINE. *Journal of Fluids and Structures*, *11*(8), 947–963. https://doi.org/https://doi.org/10.1006/jfls.1997.0112

Chaudhry, M. H. (2014). *Applied Hydraulic Transients* (3rd ed.). https://doi.org/10.1007/978-1-4614-8538-4

Dinçer, A. E. (2013). *Investigation of waterhammer problems in the penstocks of pumped storage power plants*. Middle East Technical University, Ankara.

Joukowsky, N. (1898). Über den hydraulischen Stoss in Wasserleitungsröhren.(On the hydraulic hammer in water supply pipes). *Mémoires de l'Académie Impériale Des Sciences de St.-Pétersbourg*, *9*(5), 1–71.

Parmakian, J. (1963). *Waterhammer Analysis* (1st ed.). New York: Dover Publications, Inc.

Wan, W., Zhang, B., & Chen, X. (2019). Investigation on Water Hammer Control of Centrifugal Pumps in Water Supply Pipeline Systems. *Energies*. https://doi.org/10.3390/en12010108

Wood, D. J., Dorsch, R., & Lightner, C. (1966). Wave-Plan Analysis of Unsteady Flow in Closed Conduits. *Journal of the Hydraulics Division*, *92*(82), 83–110. https://doi.org/https://doi.org/10.1006/jfls.1997.0112

CHAPTER II

A REVIEW OF RESEARCHES IN UNDERGROUND MINING METHOD SELECTION

Dr. Abdulkadir KARADOGAN

Istanbul University-Cerrahpasa, Istanbul, Turkey, e-mail: akadir@istanbul.edu.tr
Orcid No: 0000-0001-7321-3320

Dr. Meriç Can OZYURT

Istanbul University-Cerrahpasa, Istanbul, Turkey, e-mail:
meric.ozyurt@istanbul.edu.tr
Orcid No: 0000-0002-7545-7756

1. Introduction

Nearly 90 percent of the tools and equipment that make life functional are obtained from natural resources, especially mines. There is a strong relationship between the welfare and development levels of societies and mining activities. Mining constitutes the foundations of the industry, energy, and agriculture sectors, which are accepted as determinants of countries' development and living standards.

Mining is the whole of engineering practices related to exploring, extracting, and processing valuable minerals or other Earth's geological materials. It is an applied science developed to minerals with economic importance to the industry rationally. It includes operations related to exploration, project design, operation, and enrichment of the extracted mine.

The raw mines extracted from the Earth are transformed into metal after the mineral processing process. In the next stage, metals such as copper, lead, zinc, or iron are transformed into steels in metallurgical facilities. These steels are used in factories to produce cars, computers, phones, refrigerators, or a wind turbine. Non-metallic minerals are used to create cement, ceramic, paint, glass. Fossil sources such as coal, petrol, or natural gas are also important sources of energy.

The necessity for natural sources, especially mines, has been growing over the years due to population growth and the ever-expanding industrial areas. Considering these mineral reserves' exhaustibility, it becomes necessary to evaluate mine deposits optimally (Kahriman et al., 1996). This

evaluation process begins with the selection of the appropriate underground mining method.

Underground mining method selection is an important process affecting mine planning. It also affects economic considerations in underground mining, such as cost estimation parameters (especially ore production costs) as a function of settlement and depth. A wrong decision to be made during the underground mining method selection will cause significant economic losses and inefficient production (Bascetin, 1999).

Therefore, selecting the appropriate underground mining method is an essential subject that mine planning engineers and researchers have been working on for many years.

This paper presents the studies on underground mining method selection. The contributions, advantages and drawbacks of these studies were investigated.

It was seen that the first studies on underground mining method selection were based on conventional methods. In the following years, numerical models were developed by digitizing the selection criteria. Considering that these methods are insufficient to solve a complex problem such as underground mining method selection, many researchers have been studied applying expert systems, multi-criteria decision-making methods, and intelligent systems to select the most appropriate mining methods.

2. Selection Criteria and Underground Mining Methods

In this section, underground mining methods and selection criteria useful in method selection are explained.

Ozyurt (2018) made a literature review on the underground mining method selection and presented the selection criteria and appropriate underground mining methods by the direct and indirect use of the most up-to-date information in Nicholas (1981), Demirbilek (1987), Bieniawski (1989), Hartman (1992), Bibb and Hargrove (1993), Brady and Brown (1993), Demirci (1993), Miller et al. 1995), Gertsch and Bullock (1998), Kahriman (2000), Karpuz and Hindistan (2008), Kose and Tatar (2011), Yalcin (2012), CSGB (2013), Simsir et al. (2013), Kuzu (2013), Kose and Kahraman (2014a), Kose and Kahraman (2014b), Simsir (2015), Tatar and Ozfirat (2016).

The result of the literature review was presented in In Table 1 and 2. In these tables, * means that the underground mining method can be applied to all values for the criteria.

Table 1 Selection Criteria and Underground Mining Methods (Part I)

Selection Criteria	Longwall Mining	Diagonal Longwall	Shrinkage Stoping	Cut & Fill Stoping	Top Slicing	Sublevel Stoping	Open Room	Room and Pillar	Sublevel Stoping	Blok Caving	Square Set Stoping
Ore Type	Coal et. all	Coal et. all	Metal	Metal	*	Metal	*	*	Metal	Metal	*
Ore Composition	*	*	Sulfurless	*	Sulfurless	*	Sulfurless	*	*	*	Sulfurless
Ore Shape	Tabular	Tabular	Tabular/ Irregular	Tabular/ Irregular	*	Tabular/ Massive	Tabular/ Massive	Tabular/ Irregular	Tabular/ Massive	Tabular/ Massive	Irregular
Ore Thickness (m)	≤ 10	≤ 10	≤ 10	≤ 30	30 - 100	> 10	≤ 50	≤ 10	> 10	> 30	≤ 30
Ore Plunge (º)	≤ 36	> 36	> 55	> 55	≤ 55	> 55	*	≤ 36	> 55	> 55	*
Depth (m)	*	*	*	*	*	*	*	*	*	*	*
Grade	*	*	High	High	Intermediate	Intermediate	Intermediate	Intermediate	Low/ Intermediate	Low	*
Grade Distribution	Uniform	Uniform	*	Gradational/ Erratic		*	Gradational/ Uniform	Gradational/ Uniform	*	*	Erratic
Separation (O & R)	Significant	Significant	*	*	*	*	Significant	Significant	*	Significant	*
Ore - RMR	≤ 60	≤ 60	> 40	> 60	≤ 40	≤ 80	> 60	> 40	> 40	≤ 40	≤ 40
Ore - RSS	≤ 10	≤ 10	> 10	> 10	≤ 10	*	>10	> 10	> 10	≤ 5	≤ 10
Hanging Wall RMR	≤ 60	≤ 60	> 40	*	> 40	≤ 60	> 60	> 40	> 40	≤ 60	≤ 40
Hanging Wall RSS	≤ 10	≤ 10	> 10	*	*	≤ 15	> 10	> 10	> 10	≤ 10	≤ 10
Footwall RMR	> 40	> 40	> 40	*	> 60	> 20	> 60	> 40	> 60	≤ 60	≤ 40
Footwall RSS	> 10	> 10	> 5	> 5	≤ 10	> 5	*	*	> 10	≤ 10	≤ 10

(Source: Ozyurt, 2018)

Table 2 Selection Criteria and Underground Mining Methods (Part II)

Selection Criteria	Longwall Mining	Diagonal Longwall	Shrinkage Stoping	Cut & Fill Stoping	Top Slicing	Sublevel Stoping	Open Room	Room and Pillar	Sublevel Stoping	Blok Caving	Square Set Stoping
Overburden	*	*	*	*	*	*	*	*	*	*	*
Underground Water	*	*	*	*	*	None	*	*	*	None	*
Subsidence Effect	High	High	Low	Low	Low	High	Intermediate	Low	Low	High	Low
Explosive Dust	*	*	*	*	Risky	Risky	*	*	*	Risky	Risky
Explosive Gas	*	*	*	*	Risky	Risky	*	*	*	Risky	Risky
Oxidation	*	*	Risky	*	Risky	*	Risky	*	*	*	Risky
Economic Value	*	*	Low	*	High	*	Low	Low	*	High	High
Production Rate	Intermediate	Intermediate	Low	Low	Low	Intermediate	Intermediate	Intermediate	Intermediate	Maximum	Low
Dilution in Ore	20%	25%	30%	10%	10%	20%	5%	5%	20%	25%	0%
Loss in Ore	20%	35%	30%	10%	2%	35%	50%	45%	25%	40%	0%
Production Cost	40%	65%	50%	60%	70%	55%	25%	30%	30%	20%	80%
Cost of Capital	High	High	Low	Intermediate	Low	High	Intermediate	Intermediate	Intermediate	Intermediate	Low
Strata Control	*	*	Shrinkage	Stowing	Stowing	Caving	Open Room	Pillar	Pillar	Caving	Timbering
Ventilation Planning	Basic	Intermediate	Intermediate	Intermediate	Complex	Intermediate	Complex	Complex	Intermediate	Basic	Complex
Mechanization	Max	Intermediate	Low	Intermediate	Low	Intermediate	Intermediate	Intermediate	Intermediate	Low	Low
Risk-Based Safety	Intermediate	Intermediate	Risky	Intermediate	Intermediate	Risky	Risky	Risky	Risky	Risky	Safety
Efficiency	High	Intermediate	Low	Intermediate	Low	Intermediate	High	High	High	High	Low
Flexibility	None	None	Intermediate	None	None	Intermediate	High	Intermediate	Intermediate	None	High
Controlling	Easy	Kolay	Intermediate	Intermediate	Intermediate	Intermediate	Complex	Complex	Intermediate	Easy	Complex
Selectivity	None	None	None	None	None	Intermediate	High	High	Intermediate	None	High

(Source: Ozyurt, 2018)

3. Conventional Methods on Mining Method Selection

Early studies on underground mining method selection were based only on experts' discussions, the descriptions and measurements obtained from the experiences. Therefore, the proposed approaches are similar and have a few differences. Most of these approaches were designed to select the most appropriate underground mining method in mine deposits, where many underground mining methods can be applied (Karadogan, 2001).

Boshkov and Wright (1973) carried out the first scientific study on underground mining method selection. This approach recognizes that it will always be possible to minimize open-pit and underground mining methods. Applicable underground mining methods were identified by using ore thickness, depth, and strength of ore and country-rock.

Morrison (1976) divides the underground mining methods into three groups: methods with rigid pillars, methods to control caving, and caving methods. This approach can determine the appropriate underground mining method by accepting ore thickness, roof supporting type, and rock stresses as criteria.

Laubscher (1981) developed a model that provides suggestions for the determination of collapsibility. This model was originally developed for the block-caving method and offered solutions based on RQD, joint spacing, and numbers of joints. In 1990, Laubscher modified the model by considering the hydraulic diameter, and the collapsibility became applicable for many rock units in large areas.

Hartman (1987) presented a flow chart for the underground mining method selection process. The flow chart uses ground conditions and geometric properties of mine deposits to determine the most applicable underground mining method.

As stated above, in the early studies on underground mining method selection, the selection criteria and production methods were clustered separately. For this reason, many specific situations remained unanswered. The search for solutions to unanswered specific situations has led to the development of numerical methods.

For the first time, Nicholas (1981) suggested a numerical approach for underground mining method selection . The Nicholas methodology accepts applicability as the basic principle and follows a numerical approach to rate different underground mining methods based on the rankings of specific input parameters such as ore geometry, grade distribution, and ore/rock characteristics. A numerical rating for each underground mining method is arrived at by summing these rankings. The higher the rating, the more suitable the underground mining method. Later, Miller et al. (1995) studied the Nicholas Approach's modification and developed the University of

British Columbia (UBC) approach. According to the research and technological developments, this modification involved adding new input parameters and weighting of various categories. The UBC approach continues to form the basis of many studies today.

Since many years have passed since the UBC method was developed, it does not adequately satisfy today's conditions, and the most significant drawback is that it provided solutions without considering the constraining factors that adversely affect mining operations. Thus, the proposed methods should be updated by experts. Starting from this point of view, Ozyurt (2018) studied the UBC approach's modification by reweighting various categories and adding new input parameters (especially the constraining factors such as fire risk, underground water, subsidence effect, etc.) and new underground mining methods. As a result, the UBC method was modified to provide answers to many specific situations without a secondary assessment.

Bitarafan and Atai (2004) stated that one of the Nicholas Approach's problems and similar approaches are that all selection criteria have the same relevance and do not consider each criterion's weighting factors. However, the importance of each criterion varies according to researchers and experts. This drawback has been overcome by using soft computing technologies such as expert systems and multi-criteria decision-making techniques.

4. Soft Computing Technologies on Mining Method Selection

Firstly Bandophadhyay and Venkatasubramanian (1988) and then Camm and Smith (1992) studied the implementation of an expert system that emulates a human expert's decision-making ability in the underground mining method selection process. In these studies, selection criteria were weighted and if-then based rules defined by using expert opinions.

Gershon et al. (1995) presented that by using Multi-Attribute Utility Theory, which provides a convenient way of handling preference and attitudes in decision-making, expert systems could make choices regarding the user's priorities. Later, Basu (1999) improved the system of Gershon et al. (1995). Both Tatiya (1998) and Clayton et al. (2002) developed similar expert systems. However, the developed expert systems could not give interactive decisions to increase the selection efficiency and not embed the intuition and judgment simulating the experts (Guray et al., 2003). From this point of view, Guray et al. (2003) developed a dynamic system to make underground mining method selection. The system tries to learn the experiences of the experts. After these learning processes, the knowledge base includes these experiences, making the system more efficient and intuitive. The study had two significant contributions; first of all, the experts' databases dynamically evolved based on a neuro-fuzzy training

algorithm, and the second contribution was related to the system's interactive tutoring ability.

However, all of these approaches mentioned above can not answer the problem in fuzzy environments such as underground mining method selection process where uncertain or insufficient data can be encountered within the criteria set. Therefore, in the early 2000s, it was proposed to apply new methods in the underground mining method selection process: Multi-Criteria Decision Making Methods.

5. Multi Criteria Decision Making Methods on Mining Method Selection

First time in the literature, Karadogan (2001) used the fuzzy set theory to evaluate uncertainties variables in the underground mining method selection process by benefiting from expert views through a questionnaire to determine the alternative methods and criteria weights. Yager Theory was used to have optimal results and obtain weighting degree comparing criteria both among them and alternatives. Thus, the advantages of each underground mining method were obtained. In the following years, many researchers have studied on the implementation of the different decision-making methods to underground mining method selection process:

- Fuzzy Multiple-Attribute Decision-Making (FMADM) was applied by Kesimal and Bascetin (2002), Bitarafan and Ataei (2004), Namin Set al. (2004), Miranda and Almedia (2005), Uysal and Demirci (2006), Karadogan et al. (2008), Yavuz and Alpay (2008), and Namin et al. (2011).
- Analytic Hierarchy Process (AHP) was applied by Alpay and Yavuz (2007), Ataei et al. (2008), Yavuz and Alpay (2008), Yavuz and Iphar (2008), Musingwini and Minnitt (2008), Jamshidi et al. (2009), Alpay and Yavuz (2009), Namin Set al. (2009), Bogdanovic et al. (2012), Gupta and Kumar (2012) Ataei et al. (2013), Gélvez and Aldana (2014), Yavuz (2015), Jianhong et al. (2015), and Baloyi and Meyer (2020).
- Technique for Order Preference by Similarity to Ideal Solutions (TOPSIS) was applied by Yavuz and Alpay (2008), Alpay and Yavuz (2009), Uysal and Demirci (2006), Alpay and Yavuz (2007), Musingwini and Minnitt (2008), Ataei et al. (2008), and Namin Set al. (2009).
- TOPSIS was applied by Namin Set al. (2008), Mikaeil et al. (2009) and Baloyi and Meyer (2020).
- Fuzzy AHP was applied by Mikaeil et al. (2009), Naghadehi et al. (2009), Azadeh et al. (2010), Karimnia and Bagloo (2015), Yavuz (2015), and Balusa and Gorai (2019).

- Preference Ranking Organization Method for Enrichment Evaluation (PROMETHEE) was applied by Bogdanovic et al. (2012), Gupta and Kumar (2012), and Baloyi and Meyer (2020).
- Monte Carlo Analytic Hierarchy Process (MAHP) was applied by Mohammed et al. (2013).
- VIKOR was applied by Jianhong et al. (2015), and Baloyi and Meyer (2020).
- Grey Relational Analysis (GRA) wa applied by Deghani et al. (2017), and Baloyi and Meyer (2020).
- Interactive Multi-Criteria Decision Making (TODIM) was applied by Deghani et al. (2017), and Baloyi and Meyer (2020).
- Operational Competitiveness Rating (OCRA) was applied by Baloyi and Meyer (2020).
- Complex Proportional Assessment Of Alternatives with Grey Relations (COPRAS) was applied by Baloyi and Meyer (2020).
- Simple Additive Weighting (SAW), Additive Ratio Assessment (ARAS), ELECTRE and CP was applied by Baloyi and Meyer (2020).

According to Yavuz (2015), MADM, AHP, and TOPSIS are very easily understandable and applicable methods, while the other methods are more complex. However, there are two drawbacks of AHP: firstly, expert opinions should be express as exact values (Wang and Chen, 2007), and the second one is the improper handling of intrinsic vagueness in the pairwise comparison process and the judgment scale biases (Kahraman et al., 2003; Jang and Topal, 2014). These drawbacks were overcome by applying Fuzzy AHP, where a fuzzy algorithm decided each criterion's weights, and underground mining methods were ranked by AHP (Naghadehi et al., 2009). The fact that the Fuzzy AHP is a reliable tool in the underground mining method selection was supported by Balusa and Gorai (2019) study, where the sensitivity in deciding for the selection of the underground mining method of the Fuzzy AHP was analyzed.

Baloyi and Meyer (2020) presented that PROMETHEE, TOPSIS, and TODIM stood out as methods for underground mining method selection for a coal deposit, where VIKOR and GRA were not suitable methods for underground mining method selection.

Bitarafan and Atei (2004) presented a new method to assign weights to selection criteria based on Yager Theory and Hipel's Method. The study's significant contribution was using exponential scalars to represent the weight of the criteria, which could dramatically increase the value of the criteria that have similar conditions to the target deposit. Otherwise, the value would be significantly reduced. Azadeh et al. (2010) modified Nicholas techinque by the use of AHP and the control of inconsistency

ratio of judgements and resolved the problems such as obtaining equal weights for each selection criterion.

Namin et al. (2011) developed a model named Fuzzy Mining Method Selection with Interrelation Criteria (FFMSIC). FMMSIC models each criterion's weights by combining the fuzzy analytic network process and fuzzy entropy and discusses using these hybrid techniques to determine the overall weights.

Ataei et al. (2013) used a Monte Carlo simulation to determine the confidence level of each alternative's score calculated by AHP concerning the variance of experts' opinions.

Despite these studies, which benefited from expert opinions and obtained successful results to select the most appreciate underground mining method for a mine deposit, the multi-criteria decision-making methods' success depends on the experts' knowledge and experience. Whereas, there is a possibility that experts may make mistakes. In this possibility, the evaluation of the criteria and the alternatives will be erroneous, and therefore underground mining methods that are inefficient or technically not applicable will be decided. This wrong decision to be made will cause great economic losses and inefficient production.

Since the existing techniques were generally based on determining the underground mining method for a specific mine deposit, they only consider the input parameters that were important in the relevant mine deposit (Table 3). For this reason, they are far from being an applicable model for general and needs to be modified to be applied in different mine deposits. Another drawback of the existing techniques for selecting optimal underground mining methods requires the presence or prediction of all relevant criteria; therefore, in situations where one or more criteria are unknown, the techniques fail to offer a solution. Moreover, most of the existing techniques are static. They will be limited over time because new findings from technological developments and scientific/sectoral studies change many selection criteria and the related underground mining methods, and thus, the techniques offer obsolete solutions that cannot satisfy today's requirements

Table 3 A respectitive part of the studies on mining method selection and criteria considered

Selection Criteria	Boshkov (1973)	Morrison et al. (1973)	Laubsher (1981)	Nicholas (1981)	Hartman (1987)	Miller et al. (1995)	Kahriman et al. (1996)	Karadoğan (2001)	Bitarafan and Ataei (2004)	Azadeh et al. (2010)	Mohammad et al. (2013)	Ozyurt and Karadogan (2020)
Ore Shape	+	+	+	+	+	+	+	+	+	+	+	+
Ore Thickness	+	+	-	+	+	+	+	+	+	+	+	+
Ore Plunge	+	-	-	+	+	+	+	+	+	+	+	+
Depth	-	-	-	+	+	+	+	+	+	+	+	+
Grade	-	-	-	-	-	-	+	-	-	-	-	+
Grade Distribution	-	-	-	+	-	+	+	+	+	+	+	+
Separation (O & R)	-	-	-	-	-	-	+	+	-	-	-	+
Ore	-	-	-	-	-	-	-	+	-	-	-	+
Discontinuties	-	-	+	+	-	+	-	+	+	+	+	+
UCS	+	-	-	+	+	+	+	+	+	+	+	+
RQD	-	-	+	+	-	+	+	-	+	+	+	+
RMR	-	-	-	-	-	+	+	-	-	-	-	+
RSS	-	-	-	-	-	+	-	-	-	-	-	+
Overburden	-	-	-	-	-	+	-	-	-	-	-	+
Underground Water	-	-	-	-	-	-	+	+	-	-	-	+
Subsidence Effect	-	-	-	-	-	-	+	+	-	-	-	+
Explosive Dust	-	-	-	-	-	-	-	+	-	-	-	+
Explosive Gas	-	-	-	-	-	-	-	-	-	-	-	+
Air Condition	-	-	-	-	-	-	-	-	-	-	-	+
Oxidation	-	-	-	-	-	-	-	-	-	-	-	+
Economic Value	-	-	-	-	-	-	-	-	-	+	-	+
Production Rate	-	-	-	-	-	-	+	+	-	-	-	+
Dilution in Ore	-	-	-	-	-	-	+	-	-	-	-	+
Loss in Ore	-	-	-	-	-	-	+	-	-	-	-	+
Production Cost	-	-	-	-	-	-	+	+	-	-	-	+
Cost of Capital	-	-	-	-	-	-	+	+	+	+	+	+
Strata Control	-	+	-	-	-	-	-	+	-	-	-	+
Ventilation Planning	-	-	-	-	-	-	-	-	-	-	-	+
Mechanization	-	-	-	-	-	-	+	-	-	-	+	+
Risk-Based Safety	-	-	-	-	-	-	+	-	-	-	-	+
Efficiency	-	-	-	-	-	-	+	-	-	-	-	+
Flexibility	-	-	-	-	-	-	+	-	-	-	-	+
Controlling	-	-	-	-	-	-	+	-	-	-	-	+
Selectivity	-	-	-	-	-	-	+	+	-	-	-	+

6. Intelligent Systems on Mining Method Selection

Ozyurt (2018) stated that Artificial Neural Networks (ANNs), which are computer programs that can provide solutions for similar or different cases (regardless of the lack of information) by learning from cause and effect relationships in sample cases, could overcome these abovementioned problems. Yiming et al. (1995) and Lv and Zhang (2015) were also applied ANNs to select the most appropriate mining method for a mine deposit.

Ozyurt and Karadogan (2020) developed six different ANN models that can evaluate an underground mine deposit's geometry, rock mass properties, environmental factors, and air conditions to determine underground mining methods and applications that satisfy an underground's safety conditions. Among the underground mining methods determined by ANNs, the optimal underground mining method was determined by the ultimatum games, in which a compromise between safety and economic conditions was simulated. By using a combination of developed ANN models and ultimatum games, a new model based on artificial neural networks and game theory for the selection of an underground mining method was developed. This model can make predictions in the presence of a lack of information by following technological developments and new findings obtained in scientific/sectoral studies if learning is continuous. Moreover, the model can evaluate all selection criteria and provide literature-based solutions.

7. Conclusion

It was seen that early studies on underground mining method selection were based only on the discussions made by experts, the descriptions and measurements obtained from the experiences. Therefore, the proposed approaches are similar and have a few differences. In these studies, the selection criteria and production methods were clustered separately. For this reason, many specific situations remained unanswered.

In the search for solutions to unanswered specific situations, Nicholas (1981) suggested for the first time a numerical approach for underground mining method selection. Later, Miller et al. (1995) and Ozyurt (2018) modified the Nicholas Approach. The main drawback of these numerical approaches is that all selection criteria have the same relevance and do not consider each criterion's weighting factors. To overcome this drawback, Azadeh et al. (2010) modified the Nicholas Technique by using AHP and the control of inconsistency ratio of judgments and resolved the problems such as obtaining equal weights for each selection criterion.

In 2001, Karadogan used the fuzzy set theory to evaluate uncertainties variables in the underground mining method selection process by

benefiting from expert views through a questionnaire to determine the alternative methods and criteria weights and achieved a critical turn in the literature. Many researchers have later used expert systems and multi-criteria decision-making methods to determine the most appreciate underground mining method for a mine deposit. However, these studies benefited from expert opinions, and success depends on the experts' knowledge and experience. Another drawback is that many of these studies are static models and become inadequate in the face of new events as time goes on. Therefore, Ozyurt and Karadogan (2020) developed a new model based on artificial neural networks and game theory for the selection of underground mining method, which makes predictions in the presence of lack of information by following technological developments and new findings obtained in scientific/sectoral studies if learning is continuous.

Underground mining method selection is an important factor affecting mine planning. For this reason, it has been the center of attention of researchers for nearly 50 years, and by this means, new findings are obtained, and new approaches are presented continuously. Therefore, developing dynamic models that can keep their knowledge up-to-date and follow technological developments will greatly contribute to the underground mining method selection process

References

ALPAY S, YAVUZ M (2007). *A Decision Support System for Underground Mining Method Selection*. New Trends In Applied Artificial Intelligence. Pp. 334–343.

ALPAY S, YAVUZ M (2009). *Underground Mining Method Selection by Decision Making tools*. Tunn. Undergr. Sp. Technol. 24. Pp. 173–184.

ATAEI M, JAMSHIDI M, SERESHKI F, JALALI S (2008). *Mining Method Selection By AHP Approach.* Journal of the Southern African Institute of Mining and Metallurgy, 10 (2008) 741-749.

ATAEI M, SHAHSAVANY H, MIKAEIL R (2013). *Monte Carlo Analytic Hierarchy Process (MAHP) Approach to Selection of Optimum Mining Method*. International Journal of Mining Science and Technology, 23: 573-578.

AZADEH A, OSANLOO M, ATAEI M (2010). *A New Approach to Mining Method Selection Based on Modifying the Nicholas Technique*, Applied Soft Computing 10.

BANDOPADHYAY S, VENKATASUBRAMANIAN P, (1988). *Rule-Based Expert System for Mining Method Selection*, CIM Bulletin, 81: 84-88.

BASCETİN A (1999). *Optimal Equipment Selection in Open-Pit Mines*, PHd Thesis, Istanbul University Enstitute for Sciences.

BIBB CT, HARGROVE KM (1993) *Coal Mining: Method Selection, Mining Engineering Handbook*. V:2, P.1854-1866.

BIENIAWSKI ZT (1989) *Rock Mass Classification*, ISBN 0-471-60172-1

BITARAFAN MR, ATAEI M (2004). *Mining Method Selection By Multiple Criteria Decision Making Tools*. The Journal of the South African Instutre of Mining and Metallurgy.

BOSHKOV SH, WRIGHT FD (1973) *Basic and Parametric Criteria in the Selection, Design and Development of Underground Mining Systems.* SME mining engineering handbook, New York.

BOGDANOVIC D, NIKOLIC D, ILIC I (2012). *Mining Method Selection by Integrated AHP and PROMETHEE Method.* Anais da Academia Brasileira de Ciências 84(1): 219-233.

BOLASI BC, GORAI AM (2019). *Sensitivity Analysis of Fuzzy-Analytic Hierarchical Process (FAHP) Decision Making Model in Selection of Underground Metal Mining Method.* Journal o fSustainable Mining 18, 8-17.

BRADY BHG, BROWN ET (1993) *Mining Methods And Methods Selection, Rock Mechanics For Underground Mining*. Second Edition, U.K.

CAMM TW, SMITH ML (1992). *An Object-Oriented Expert System for Underground Mining Method Selection and Project Evaluation*. 23rd APCOM Proceedings, Denver. USA. Pp. 909-916.

CLAYTON C, PAKALNIS R, MEECH J (2002). *A Knowledge-Based System for Selecting a Mining Method*. IPPM Conference, Canada.

CSGB (2013). *Republic of Turkey, Ministry of Labor and Social Security, Law No. 6331 on Occupational Health and Safety*, Ankara.

DEHGHANI H, SIAMI A, HAGHI P (2017). *A New Model for Mining Method Selection Based on Grey and TODIM Methods*. Journal of Mining & Environment. Vol 8. No 1. 2017.

DEMIRBILEK S (1987). *A Review of General Principles of Underground Mine Design in Reference to Thick Coal Seams*, Scientific Mining Journal, vol. 26, no 4, pp. 23-30.

DEMIRCI U (1993). *Die Optimalen abbauver-fahren bestimmende merkmale*. Master Thesis, Istanbul Technical University, Istanbul.

GÉLVEZ JIR, ALDANA AC (2014) M*ining Method Selection Metodology by Multiple Criteria Decision Analysis - Case Study in Colombian Coal Mining*. International Symposium of the Analytic Hierarchy Process 2014. Washington D.C. U.S.A.

GERSHON ME, BANDOPADHYAY S, PANCHANADAM V (1995). *Mining Method Selection: A Decision Support System Integrating Multi-Attribute Utility Theory and Expert Systems*. Proceedings 24th APCOM Meeting. Montreal. Quebec. Canada. Pp. 11–18.

GERTSCH RE, BULLOCK RL (1998). *Techniques in Underground Mining: Selections from Underground Mining Methods Handbook*. Society for mining, metallurgy, and exploration, Inc., Littleton, CO, USA.

GUPTA S, KUMAR U (2012). *An Analytical Hierarchy Process (AHP)-Guided Decision Model for Underground Mining Method Selection*. Int. J. Min. Reclam. Environ. 26. Pp. 324– 336.

GURAY C, CELEBI N, ATALAY V, GUNHAN A (2003). *Ore-Age: A Hybrid System For Assisting And Teaching Mining Method Selection*. Expert Systems With Applications. Volume 24. Issue 3. 261-271.

HARTMAN HI (1987) *Introductory Mining Engineering*. John Wiley & Sons, New York, Pp. 1-6.

HARTMAN HI (1992). *SME Mining Engineering Handbook, 2nd Edition, Volume 2*. Society Of Mining Metallurgy And Exploration Inc., Littleton, Co, Usa.

JANG H, TOPAL E (2014). *A Review of Soft Compuing Technology Applications in Several Mining Problems*. Applied Soft Computing. Doi: 10.1016/J.Asoc.2014.05.019.

JAMSHIDI M, ATAEI M, SERESHKI F, JALALI SME (2009). *The Application of AHP Approach to Selection of Optimum Underground Mining Method, Case Study: Jajarm Bauxite Mine (Iran).* Arch. Min. Sci. 54. 103-117.

JIANHONG C, ZOU Z, REN C (2015). *Research on Optimization of Mining Method Based on the AHP-VIKOR Method.* Gold Science and Technology. 2015: 13.

KAHRAMAN C, RUAN D, DOĞAN I (2003). *Fuzzy Group Decision-Making for Facility Location Selection*. information Sciences 157, 135-153.

KAHRİMAN A, CEYLANOĞLU A, DEMİRCİ A (1996) *Kayseri Pinarbaşi-Pulpinar Krom Cevheri İçin En Uygun Yeraltı Üretim Yöntemi Seçimi, TMMOB Scientific Mining Journal*. Vol 35, No 4, pp. 27-41.

KAHRIMAN A (2000). *Selection of Optimum Underground Mining Method for Kayseri Pınarbaşı-Pulpınar Chromite Ore*. Middle East Technical University, Turkey.

KARADOGAN A (2001) *Selection Of Optimum Underground Mining Method For The Çiftalan Lignite Basin*. Master Thesis, Istanbul Universitesi, Enstitute for Sciences.

KARADOGAN A, KAHRIMAN A, OZER U (2008). *Application of Fuzzy Set Theory in the Selection of Underground Mining Method*. J. S. Afr. inst. Min. Metall. 108. Pp. 73–79.

KARIMNIA H, BAGLOO H (2015). *Optimum Mining Method Selection Using Fuzzy Analytical Hierarchy Process-Qapiliq Salt Mine,* Iran. international Journal of Mining Science and Technology 25. 225-230.

KARPUZ C, HINDISTAN MA (2008). *Rock Mechanics – Princibles, Applications*. TMMOB Chamber of Mining Engineers, Ankara.

KESIMAL A, BASCETIN A (2002). *Application of Fuzzy Multiple Attribute Decision Making in Mining Operations*. Mineral Resour. Eng 11. Pp. 59–72.

KOSE H, KAHRAMAN B (2014)a. *Rock mechanics.* Publications of Dokuz Eylul University Faculty of Engineering, No: 223, Izmir, Turkey.

KOSE H, KAHRAMAN B (2014)b. *Economics of Mining Operations*. Publications of Dokuz Eylul University Faculty Of Engineering, No: 177, Izmir, Turkey.

KOSE H, TATAR C (2011). *Underground Mining Methods*. Publications of Dokuz Eylul University Faculty of Engineering No:014, Izmir, Turkey.

KUZU C (2013). *Underground Mining Methods*, http://web.itu.edu.tr/~kuzu/pro/MetodSecimi.pdf [Date: 06.05.2016].

LAUBSCHER DH (1981). *Selection of Mass Underground Mining Methods*. Society for mining metallurgy, New York. Pp. 23–38. Isbn 978-0-89520-287-1

LAUBSCHER DH (1990). *A Geomechanics Classification System for Rating of Rock Mass in Mine Design*. Journal of the South African

Institute Of Mining And Metallurgy, 90 (10): 257–273. Issn 0038-223x

LV W, ZHANG Z (2015). *Establishment and Application of Thin Coal Seam Mining Method Prediction Model Based on Improved Neural Network*. International Journal of Ecological Economics and Statistics. 36:1-11.

MIKAEIL R, NAGHADEHI MZ, ATAEI M, KHALOKAKAIE R (2009). *A Decision Support System Using Fuzzy Analytical Hierarchy Process (FAHP) and TOPSIS Approaches for Selection of the Optimum Underground Mining Method*. Arch. Min. Sci. 54. Pp. 349–368.

MILLER L, PAKALNIS R, POULIN R (1995). *UBC Mining Method Selection*. Mine planning and equipment selection, ISBN 90 510 569 0.

MIRANDA C, ALMEIDA C (2005). *Mining Methods Selection Based on Multi Criteria Models*. Application of Computes and Operation Research in the Mineral industry. London.

MORRISON RGK (1976). *A Philosophy of Ground Control*, McGill University, Montreal, Canada.

MUSINGWINI C, MINNITT RCA (2008). *Ranking the Efficiency of Selected Platinum Mining Methods Using the Analytic Hierarchy Process (AHP)*. Third international Platinum Conference 'Platinum in Transformation'. Sun City. South Africa.

MUTAGWABA WK, Terezopoulos NG (1994). *Knowledge-Based System for Mine Method Selection.* Institution of Mining and Metallurgy. Section A. Mining industry. 103: 27-32.

NAGHADEHI ZM. MIKAEIL R, ATAEI M (2009). *The Application of Fuzzy Analytic Hierarchy Process (FAHP) Approach to Selection of Optimum Underground Mining Method for Jajarm Bauxite Mine, Iran.* Expert Systems With Applications. 36: 8218-8226.

NAMIN SF, SHAHRIAR K, NASAB KS (2003). *Fuzzy Decision Making for Mining Method Selection in Third Anomaly Gol-E-Gohar Deposit*. 18th international Mining Congress and Exhibition of Turkey. I MCET.

NAMIN SF, SHAHRIAR K, NASAB KS (2004). *Method Selection of MEHDI ABAD Lead-Zinc Mine and Related Problems*. 5th ISMST Conferences. China.

NAMIN FS, SHAHRIAR K, BASCETIN A, GHODSYPOUR SH (2009). *Practical Applications from Decision-Making Techniques for*

Selection of Suitable Mining Method in Iran. Gospod. Surowcami Min. 25. Pp. 57–77.

NAMIN SF, SHAHRIAR K, ATAEE-POUR M, DEHGHANI H (2008). *A New Model for Mining Method Selection of Mineral Deposit Based on Fuzzy Decision Making*. the Journal of the Southern African institute of Mining and Metallurgy. 108: 385-395.

NAMIN SF, SHAHRIAR K, BASCETIN A, GHODSYPOUR S (2011). *FMMSIC: a hybrid fuzzy based decision support system for MMS (in order to estimate interrelationships between criteria)*. Journal of the Operational Research Society 63, 218-231.

NICHOLAS DE (1981). *Method Selection – A Numerical Approac*h. *SME*, New York.

OZYURT MC (2018). *The Investigation of Using Artificial Neural Networks and Game Theory on Underground Mining Method Selection.* PHD Thesis, Institute of Sciences, Istanbul University, 2018.

OZYURT MC, KARADOGAN A (2020). *A New Model Based on Artificial Neural Networks and Game Theory for the Selection of Underground Mining Method.* Journal of Mining Science Volume 56, Pages 66–78.

SIMSIR F, TATAR C, OZFIRAT MK (2013). *Transporting in Mines*, Publications of Dokuz Eylul University Faculty of Engineering, No:296, Izmir, Turkey.

SIMSIR F (2015). *Underground Mining Methods*. Publications of Dokuz Eylul University Faculty of Engineering, No:337., Izmir, Turkey.

TATAR MK, OZFIRAT MK (2016). *Underground Mining Machinery and Mechanization*, Publications of Dokuz Eylul University Faculty of Engineering, Izmir, Turkey.

TATİYA RR (1998). *Computer Assisted Economic Analysis To Selected A Stopping Method*. CIM bulletin, 91: 82-86.

UYSAL O, DEMIRCI A (2006). S*hortwall Stoping Versus Sub-Level Longwall Caving-Retreat in ELI Coal Fields*. J. S. Afr. I. Min. Metall. 106. Pp. 425–432.

WANG TC, CHEN YH (2007). *Applying Consistent Fuzzy Preference Relations to Partnership Selection*. Omega. 35. 384-388

YALCIN E (2012). *Underground Ventilation*. Publications of Dokuz Eylul University Faculty of Engineering, No:336, Izmir, Turkey.

YAVUZ M, IPHAR G (2008). *Once the Optimum Support Design Selection by Using AHP Method for the Main Haulage Road in WLC Tuncbilek Colliery*. Tunnelling and Underground Space Technology. 23: 111-119.

YAVUZ M, ALPAY S (2008). U*nderground Mining Technique Selection by Multicriterion Optimization Methods*. J. Min. Sci. 44. Pp. 391–401.

YAVUZ M (2015). *The Application of the Analytic Hierarchy Process (Ahp) and Yager's Method in Underground Mining Method Selection Problem*. in*ternational Journal of Mining. Reclamation and Environment*. 29(6)**.** 453-475 (2015).

YIMING W, GUAGNXU T, XIAOHUA C (1995). *A Study on the Neural Network Based Expert Systems For Mining Method Selection*. Journal of Comput. Appll. Softw. 5 009.

CHAPTER III

DISTRIBUTED REPRESENTATIONS OF SENTENCES AND MACHINE LEARNING APPROACH FOR ARABIC SENTIMENT ANALYSIS

Dr. Anwar ALNAWAS

Nasiriyah Technical Institute, Southern Technical University, Iraq;
anwar.alnawas@stu.edu.iq
Orcid No: 0000-0001-9181-9377

Assoc. Prof. Dr. Nursal ARICI

Department of Computer Engineering, Faculty of Technology, Gazi University, 06500 Ankara, Turkey; nursal@gazi.edu.tr
Orcid No: 0000-0002-4505-1341

Prof. Dr. Mehmet Hakkı SUÇIN

Department of Foreign Languages Education, Faculty of Education, Gazi University, Ankara, Turkey; mhsucin@gazi.edu.tr
Orcid No: 0000-0003-4433-7468

1. Introduction

The growth of social media over the past few years has resulted in an increase in user-generated content. These social media networks allow users to express their opinions and post what they wish to express (Sohail, Siddiqui, and Ali, 2018). Thoughts and feelings are things that users post on social media. The data that carry these feelings are of great importance to many entities, such as companies and governments (Akyol and Alatas, 2020; Dilawar et al., 2018; Vinodhini and Chandrasekaran, 2017). Mining through such data is of considerable interest (Kim, Kang, and Jeong, 2018). Mining tasks face many challenges, such as data size, unstructured data and difficulty of natural languages (Al-Smadi, Al-Ayyoub, Jararweh, and Qawasmeh, 2018). Sentiment analysis (SA) techniques are related to mining the opinions contained in the text and classify them into positive and negative classes, or more (Asghar, Khan, Khan, and Kundi, 2018; Song, Kim, Lee, Kim, and Youn, 2017).

Many approaches and techniques have been used in the field of SA. The main aim of these approaches and techniques is to enhance SA tasks . In recent years, many studies of English SA have been conducted. For the

Arabic language, there are fewer studies carried out for SA (Al-Ayyoub, Khamaiseh, Jararweh, and Al-Kabi, 2019; Alnawas and Arıcı, 2018). Arabic is the fifth language among the most spoken languages worldwide (UNESCO, 2012) and fourth in use on the Internet (IWS, 2017). Arabic SA is considered a complex task. Owing to the characteristics of the Arabic language; it has a complex morphology, dialects and short vowels and orthography (Al-Sallab et al., 2017). For example, one letter can be written in different forms, such as ت/t/ can be written as (ة or ه or ـة). Thus, people can make simple mistakes.

In the SA task, the text should be structured in proper forms. The problem with using multiple forms (such as bag-of-words and N-grams) is that the importance of the sequence of words is lost through the sentence, ignoring syntactic structures and lexicon (Maas et al., 2011). However, SA is not applicable because it separates the syntax connectedness, disables the order of words and sometimes the semantic information is ignored (Dahou, Xiong, Zhou, Haddoud, and Duan, 2016).

The distribution representation of words was suggested by (Maas et al., 2011), to overcome the limitations of multiple forms and deal with complex languages, such as Arabic. Distributed representations determine continuously distributed representations of the vector from texts by an unsupervised learning method. The length of the texts is variable; it could be a word, a sentence, a paragraph or a full document (Alnawas and Arıcı, 2019).

Previous studies, such as (Al-Azani and El-Alfy, 2017; Al-Sallab et al., 2017; Alayba, Palade, England, and Iqbal, 2018; Altowayan and Tao, 2016; Dahou et al., 2016; Salama, Youssef and Fahmy, 2018), used the word2vec technique to process the tasks of Arabic sentiment analysis. Many words have more than one meaning according to the sentence context. The word2vec technique represents the word as the same vector. For example, the word “left” in the following sentences “I left my phone on the desk” and “the house is on the left side” represents one vector. Word2vec cannot capture the difference between the meanings of the same word used in different contexts.

To avoid the limitations of word2vec, the doc2vec technique was proposed by (Le and Mikolov, 2014). It uses neural network learning techniques to represent words as vectors. This technique represents each word as a vector rather than a single value. As a result, the word vectors in the same perspective will be associated. In other words, the doc2vec model is used to convert sentences into sentence vectors. The doc2vec technique was suggested in two architectures: the distributed bag-of-words (PV-

DBOW) and the distributed memory model of paragraph vectors (PV-DM).

In this study, we propose the process of Arabic SA using doc2vec and machine learning approaches. We use five different Arabic corpora. The Arabic corpora are presented as vectors based on PV-DBOW and PV-DM architectures. Then, four machine learning methods are trained using these vectors. We compared the results of two architectures (PV-DBOW and PV-DM), and we also compared our results with other studies that used the same datasets.

The rest of the paper is organized as follows. In Section 2, related studies are explained. In Section 3, the doc2vec model and their architectures are described. Section 4 describes the proposed process of Arabic SA. Section5, describes how our experiments are conducted. In Section 6, the results are investigated and discussed. Finally, Section 7, concludes the paper and remarks on key findings.

2. Related studies

Different perspectives of machine learning approaches are used in many studies to deal with sentiment analysis tasks. Since the choices of data representation is heavily depended on the performance of a machine learning technique, many studies aim to build an effective feature extractor based on the requirement of careful engineering and domain expert (Tang, Qin, and Liu, 2015).

Most of the studies conducted in Arabic sentiment analysis were based on training machine learning classifiers using different models to extract features. For example, n-grams model achieved the best performances using bi-grams with Support Vector Machines Naive Bayes classifier (Aly and Atiya, 2013; Rushdi-Saleh, Martín-Valdivia, Ureña-López and Perea-Ortega, 2011). Syntactic and stylistic features also achieved high performances when applied to web forum contents(Abbasi, Chen and Salem, 2008).

The study of (Boudad, Faizi, Thami and Chiheb, 2017) reviewed the major studies that had been conducted on sentiment analysis in Arabic. A thorough investigation of the available literature revealed that the works were mainly concentrated on dealing with specific sentiment analysis tasks. The researchers used three different approaches, namely supervised, unsupervised and hybrid methods to tackle a variety of sentiment analysis tasks.

Distributed word representations contribute to improved performance across many natural language processing (NLP) tasks (Naili, Chaibi and

Ghezala, 2017). Distributed word representations can be used in many research areas. The study of (Suleiman, Awajan and Al-Madi, 2017) used the word2vec technique to represent Arabic words as vectors. Moreover, the similarity between words' vectors was used to detect plagiarism. The study of (Salama et al., 2018) used the word2vec model to represent both semantic and morphological annotations of Arabic words. The word2vec model was used in Arabic ontology learning tasks in the study of (Albukhitan, Helmy and Alnazer, 2017). The study of (Helmy, Vigneshram, Serra and Tasso, 2018) proposed a word2vec -based approach for Arabic key-phrase extraction.

Recently, deep learning approaches appear as effective computational models to represent and discover intricate semantic of texts automatically from data without feature engineering. These approaches have improved the state-of-the-art in many sentiment analysis tasks including feature extracting and representation, sentiment classification of sentences/documents, sentiment extraction and sentiment lexicon learning (Çano and Morisio, 2018).

Unlike English, only few studies used word vector presentation (Al-Azani and El-Alfy, 2017; Al-Sallab et al., 2017) for the Arabic SA task. The English NLP tasks are not suitable for Arabic because of the characteristics of the Arabic language. In the following paragraphs, the studies that used distributed word representations for Arabic SA will be shown.

The authors of (Heikal, Torki and El-Makky, 2018) proposed a hybrid model to predict the sentiment analysis of Arabic tweets. A convolutional neural network (CNN) and long short-term memory (LSTM) models were combined to enhance Arabic sentiment analysis.

The study of (Dahou et al., 2016) used word embedding for Arabic SA. In that study, several architectures were used. The best architecture was CNN as a word representations architecture for Arabic SA. When high dimensionality is used to represent the vectors, it gives a good performance, especially with a large corpus.

In the study of (Altowayan and Tao, 2016), they used the word2vec tool from (Mikolov, Yih and Zweig, 2013) to represent the word as a vector. The aim of their study was to detect subjectivity and sentiment by training several binary classifiers. Their approach achieved an enhancement in accuracy compared with other approaches in the literature.

The study of (Al-Azani and El-Alfy, 2017) experimented word embedding with highly imbalanced Arabic tweet datasets. They compared more than one SA classifiers. The authors of (Al-Sallab et al., 2017)

proposed a recursive deep learning model for opinion mining in Arabic (AROMA) to handle the morphological complexity of the Arabic language and the lack of Arabic opinion resources.

The authors of (Alayba et al., 2018) studied the benefit of constructing a word2vec model from a large Arabic corpus to get similar words. Different machine learning methods were applied and CNN was used to expand the vocabularies.

In the study of (Dahou, Elaziz, Zhou and Xiong, 2019), differential evolution (DE) algorithm and CNN were combined to build an effective Arabic sentiment classification model. Since building a powerful CNN for Arabic sentiment classification can be highly complicated and time-consuming, the DE algorithm was used to automatically search for the optimal configuration including CNN architecture and network parameters. The performance of the proposed approach was evaluated on five Arabic sentiment datasets. The results of the combined approach showed higher accuracy and the approach is less time consuming than state-of-the-art algorithms.

3. Doc2vec model

Techniques for representation of words as vectors (word2vec) are considered a source of paragraph vector techniquederivation. Thus, we starts by discussing word2vec methods as explained by (Le and Mikolov, 2014; Mikolov, Le and Sutskever, 2013). Figure 1 shows the framework for learning the word vectors. The task is to predict a word among the other words in a context.

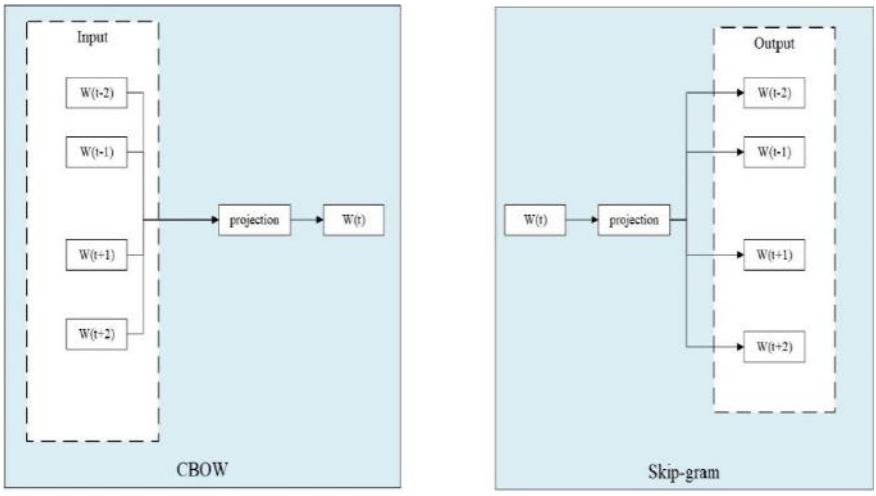


Fig. 1. Learning word vectors framework (Le and Mikolov, 2014)

In this framework, every word is mapped to a unique vector and these vectors are represented by a column in a matrix W. Based on the location of the words in the vocabulary table, the columns of the W matrix are indexed. The main task of this framework is to predict the next probable word in a word set. To achieve this goal, the sum of the vectors is used as a unique feature.

Assume that we have a sequence of training words w_1, w_2, w_3, ..., w_T; then the objective of the word2vec model is to maximize the average log probability

$$\frac{1}{T}\sum_{t=k}^{T-K} \log p\,(\,w_t|w_{t-k},\dots,w_{t+k}) \tag{1}$$

The prediction task is typically performed via a multiclass classifier, such as softmax. Thus, we have

$$\mathrm{p}(w_t|w_{t-k},\dots,w_{t+k}) = \frac{e^{y_{wt}}}{\sum_i e^{yi}} \tag{2}$$

where each y_i is a non-normalized log-probability for each output word i, computed as

$$y = b + Uh(w_{t-k},\dots,w_{t+k};W) \tag{3}$$

where U and b are the softmax parameter and h is constructed by concatenation or the average of word vectors extracted from W.

After the training, words with similar meanings are mapped to a similar position in the vector space.

This section may be divided into subheadings. It should provide a concise and precise description of the experimental results, their interpretation as well as the experimental conclusions that can be drawn.

3.1. Paragraph vector: a distributed memory model

This approach accomplishes the tasks with the help of two methods for representations. The first is the representation of each paragraph with a single and distinct vector and the second represents each word with a unique vector. The paragraph vectors are represented as a column in matrix D. Word vectors are represented as a column in matrix W. The vectors of the paragraphs and words are linked together to achieve the task of predicting the subsequent word in the sentence. When this model is compared with the word2vec model, the main change is shown in equation 3, where variable h is calculated based on W and D.

Each paragraph has its own token (id), which can be considered as a distinctive word. During the representation stage, if the paragraph loses part of the text context or the paragraph subject, the id works as a memory to remember these missing parts. Thus, they call this model the distributed memory model of paragraph vectors (PV-DM).

The paragraph vector is involved in all generated contexts of the same paragraph but not across paragraphs. However, the word vectors are shared across all paragraphs. That is, the vector value of "nice" is the same for all paragraphs. This approach is shown in Fig. 2.

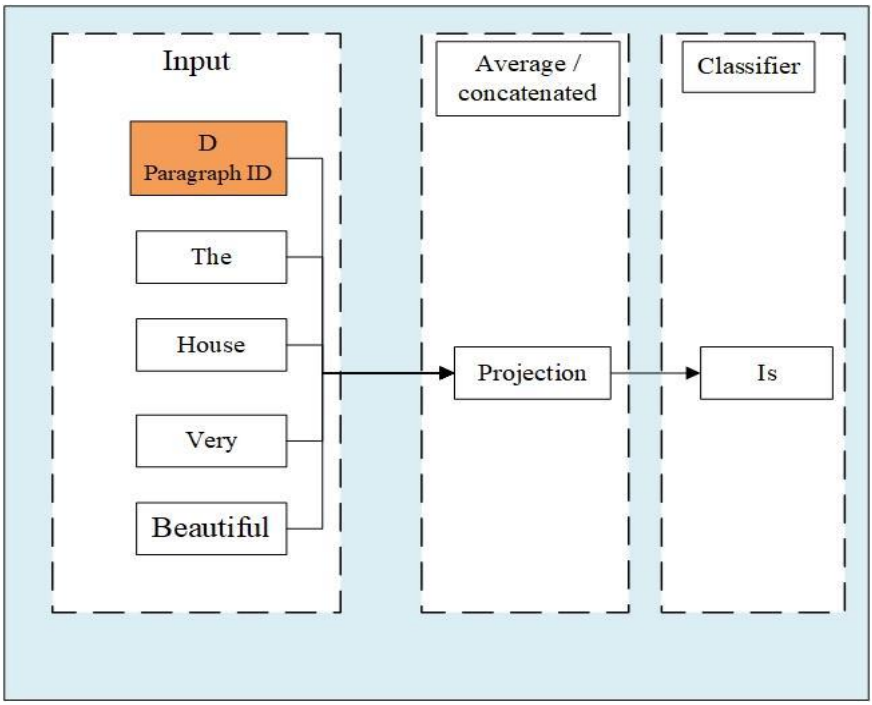


Fig. 2. A framework for learning paragraph vectors PV-DM (Le and Mikolov, 2014)

3.2.Distributed bag-of-words

The PV-DM approach predicts the next word in the word set through the consideration of the paragraph vector and the word vectors. The second approach is not to count the context of the words at the input stage but instead to use the paragraph vector. It works on predicting words through a paragraph vector. The process of training this approach is similar to skip-grams, but the difference is that they use one vector for full text to predict words. The name of this approach is paragraph vector with a distributed bag-of-words version of the paragraph vector (PV-DBOW), Fig. 3. This

model requires storing fewer data and is analogous to the skip-gram approach in the word2vec model (Mikolov, Sutskever, Chen, Corrado and Dean, 2013).

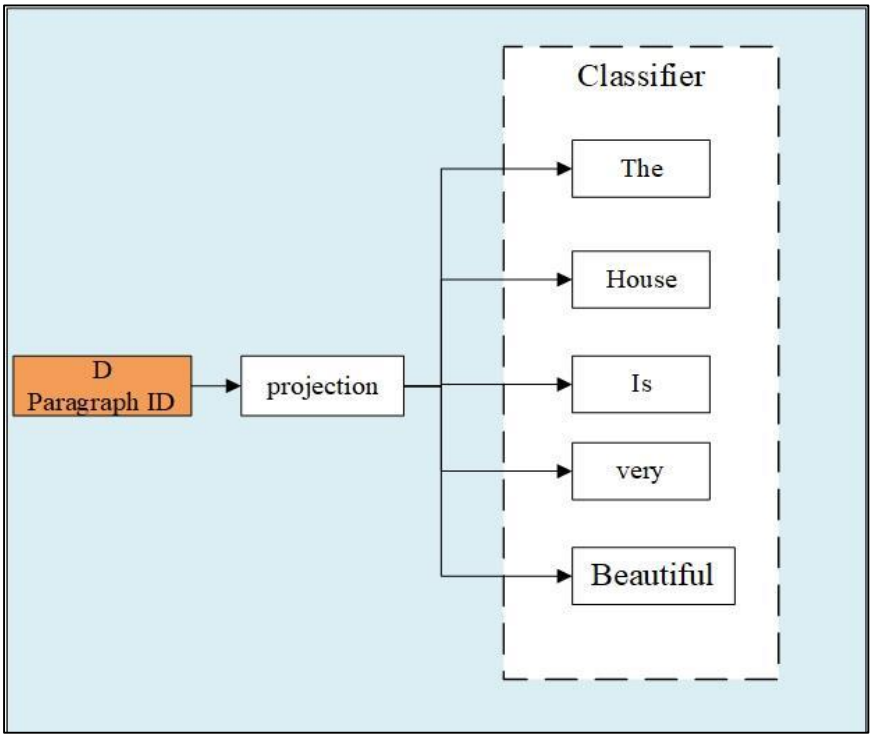


Fig. 3. Distributed bag-of-words version of paragraph vectors (Le and Mikolov, 2014).

4. Sentiment analysis framework

We aim to propose the steps of the process based on doc2vec and machine learning approaches in Arabic SA. The proposed framework is presented in Fig. 4.

The processing steps begin by cleaning and normalizing the datasets. NLP is one of the important techniques used in the field of text mining. NLP works in the following steps: The first step, tokenized text file into smaller pieces. In our work this step was performed in two sub-steps; split document into single lines and split each line to single words. Further processing can be achieved after a text has been suitably tokenized. The second step is to delete non-Arabic words and characters. The third step is to delete numbers as a commonplace step in the field of NLP. The fourth step contentment the processing to delete punctuations marks. In the fifth step, Stop words will be deleted because they are not affected by the

sentiment decision. In the sixth step, the noise (short vowels) and other symbols will be deleted to proceed uniformly. In the seventh step, the normalization of Arabic letters will be performed to unify multi-writing forms of Arabic letters. The last two steps include the aggregation of words to source line and each line to source document.

After cleaning the datasets in pre-processing, each sentence was formatted as [['w_1', 'w_2', 'w_3', …,'w_n'], ['$Label_1$']] in the vector space (García-Pablos, Cuadros and Rigau, 2018), embedding all words and filtering out the unique words to build the vocabulary table.

Next, the datasets are trained with two architectures, PV-DM andPV-DBOW, to represent every word as a vector. Words that have the same contexts are presented as close as possible to one another in the space.

In PV-DM model, every paragraph is mapped to a unique vector, represented by a column in matrix D and every word is also mapped to a unique vector, represented by a column in matrix W. The paragraph vector and word vectors are averaged or concatenated to predict the next word in a context. In the experiments, we use concatenation as the method to combine the vectors. More formally, the only change in this model compared to the word vector framework is in equation 1, where h is constructed from W and D.

PV-DBOW model is slightly different from the PVDM model. This model ignores the context words in the input, but force the model to predict words randomly sampled from the paragraph in the output.

At prediction time, an inference step is needed to be performed to compute the paragraph vector for a new paragraph. This is also obtained by gradient descent. In this step, the parameters for the rest of the model, the word vectors W and the Softmax weights, are fixed. Suppose that there are N number of paragraphs in the corpus, M number of words in the vocabulary and we want to learn paragraph vectors such that each paragraph is mapped to “p” dimensions and each word is mapped to “q” dimensions and each word is mapped to “q” dimensions, then the model has the total of N * p + M * q parameters (excluding the softmax parameters). Even though the number of parameters can be large when N is large, the updates during training are typically sparse and thus efficient.

After being trained, the paragraph vectors can be used as features for the paragraph (e.g., in lieu of or in addition to bag-of-words). We can feed these features directly to conventional machine learning techniques.

For the training and test SA tasks, four classifiers widely used in the SA research area are proposed (Awwad and Alpkocak, 2017; Liu, 2012).

Logistic regression (LR), support vector machine (SVM), k-nearest neighbours (KNN) and random forest (RF) are used. The proposed SA process is evaluated in terms of accuracy (Acc) and F1-score (F1).

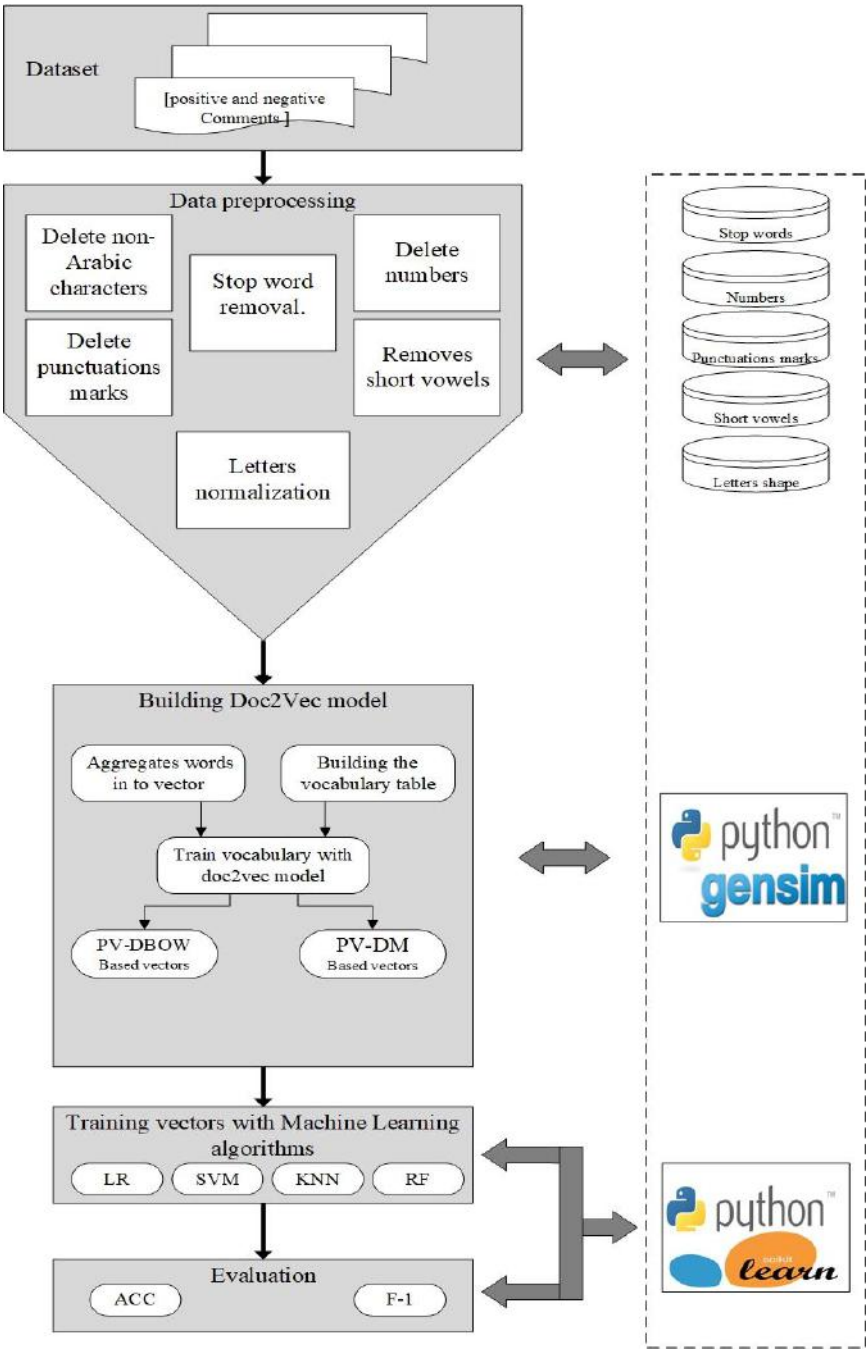


Fig. 4. The process of Arabic sentiment analysis using doc2vec and machine learning approaches

5. Experiments

5.1. Datasets

To fulfil our experiments, the doc2vec model is examined using the five publicly available datasets described in Table 1. The first dataset is of the Attraction (ATT) dataset from the TripAdvisor site (ElSahar and El-Beltagy, 2015), Hotel (HTL) for the hotels domain collected from TripAdvisor (ElSahar and El-Beltagy, 2015), Restaurant (RES) covers restaurant reviews (ElSahar and El-Beltagy, 2015), Movie (MOV) consists of movies reviews (ElSahar and El-Beltagy, 2015) and the fifth dataset is LABR, Large Scale Arabic Book Reviews from (Aly and Atiya, 2013), which consists of over 51,000 book reviews (positive and negative).

Table 1. Dataset collections and sources

Dataset	Word count	Unique Word count	Positive reviews	Negative reviews
ATT (ElSahar & El-Beltagy, 2015)	61075	15041	1939	80
HTL (ElSahar & El-Beltagy, 2015)	894848	80454	10049	2470
RES (ElSahar & El-Beltagy, 2015)	295790	43022	7568	2513
MOV (ElSahar & El-Beltagy, 2015)	154978	36016	399	135
LABR (Aly & Atiya, 2013)	694440	96489	42832	8224

The dataset comes in CSV format with their associated binary sentiment polarity labels, positive and negative. The Twitter and OCA datasets come in two directories. One contains negative comments and the other contains positive comments. The other datasets come in one text file for each one. The text files have multi lines and the structure of lines could be like (comments, sentiment). The sentiment labels are presented as “1” for positive and “0” for negative. Some datasets are presented in labels as “1” for positive and “-1” for negative. We used simple python program to split

lines into sentiment category. Consequently, each dataset gets turned into two files (positive and negative). All positive files are combined together, and negatives files, too. These datasets are referred to as raw datasets. Further preprocessing is applied as suggested in section 5. Table 2 presents examples for the comments.

Table 2 Examples for training datasets.

Dataset	Positive comments	Negative comments
ATT	المجمع راقي وجميع سبل الترفية والماركات موجودة فية.	الجو حار كثيروالاقسام سيئة جداً والمبنى صغيرولا انصح بالذهاب إليه.
	The mall is sophisticated and there is many entertainment and brands.	It is so hot, the sections are very bad, the building is small, and I do not recommend going there.
HTL	الموقع جميل جداً فندق بعيد عن الزحمه وقريب على كل الاماكن السياحيه وسعر معقول.	في الواقع، إنه لا ينبغي أن يكون حتى فندق. إنه متهالك.
	The location is very nice and the hotel is far from crowded and close to tourist destinations and reasonable price.	In fact, it should not even be a hotel. It is worn out.
RES	المنيو وجدته أسعاره في متناول الجميع والطعام جيد جدا.	سيء جداً لا انصح به اطلاقاً، أكل سيء الطعم، طريقه التقديم أسوأ.
	Affordable prices and a very good food.	Very bad, I do not recommend it at all, tasteless food, The service worse.
MOV	موسيقى هانز زيمر ممتازة و مناسبة لأجواء الفيلم.	اخراج سئ وتمثيل مبالغ فيه من أسوأ الافلام الي شفتهم في حياتي.
	Hans Zimmer's music is good and suitable for the film.	Bad directing, bad acting, one of the worst films I have ever seen.
LABR	رواية رائعة بما تحمله الكلمة من معنى . مراد تحسن اسلوبه كثيرا بعد فيرتيجو.	كتاب سي جدا .الاسلوب غير ممتع نهاية مفتوحة والكتاب بوجهة عام كئيب,.
	A wonderful novel, Murat improved his style a lot after Vertigo.	A very bad book. The writingstyle is not interesting and gloomy.

5.2. Pre-processing

Formatting sentences and words were necessary before training word embedding. In datasets that were used, some irregularities were found in the texts, such as punctuation marks, numbers and non-Arabic characters. Therefore, further pre-processing was performed on the datasets. For this

task, Python's Natural Language Toolkit (NLTK), which deals with textsin encoding issues perfectly, was used (Perovšek, Kranjc, Erjavec, Cestnik and Lavrač, 2016).

The pre-processing task consists of the following:

- Deleting non-Arabic characters.
- Deleting numbers.
- Deleting punctuations marks.
- Stop word removal.
- Deleting short vowels and other symbols (*ḥarakāt*)
- Letter normalization, which unifies the orthography of letters.

5.3. Building the doc2vec model

In this study, we use doc2vec to represent Arabic text data. In the doc2vec model, every review in the datasets is learned as an independent sentence. This means that the data begin to be modelled in the vector space by formatting each sentence as [['w_1', 'w_2', 'w_3', …,'w_n'], ['$Label_1$']]. The main aim of word embedding of the model is to learn vector representations of words by mapping semantic information into a geometric word embedding space. In these models, the vector representation "v" of a given word is usually learned through a fixed context window "w". Doc2Vec model maximizes the conditional probability of a word in the context of words given that appear around that word within the context window W. After training, the learned vector representations of "w" can be used to reveal the relation between two words using their corresponding vector representations v_i and w_j and a similarity measure (e.g. cosine similarity):

$$Sim(v_i , v_j) = cosine (v_i , v_j) \quad (4)$$

Dimension represents the vector Size. Negative samples define how many negative examples are randomly sampled from the corpus vocabulary to train the word embedding models. For example, for the context ''the cat sits on the mat'', a negative sample will be a word (e.g. project) randomly sampled from the entire corpus, which is often irrelevant to the current context. Such negative examples help the word embedding model to differentiate the correct word relationships from noise (i.e. negative samples). Therefore, during training, the model maximizes the probabilities to real word relationships and minimizes the probabilities to the noise words.

In each training epoch, the sequence of sentences fed to the model is randomized for a better-trained model. Therefore this step is important to

get better results. The data are trained with 100 epochs. Multi-dimensional vectors are presented using NumPy array. It is an efficient multi-dimensional container of generic data.

We cross-validate the window size, embedding dimensions and negative samples using the validation set and the optimal is 3, 800 and 5. Two concatenation vectors were presented to the classifier, one from PV-DBOW and another from PV-DM. Experiments were conducted on both the implementation of doc2vec by (Le and Mikolov, 2014)modified by (Qiu, 2015) and Python's Gensim. After learning the vector representations for training sentences, we feed them to the classifiers to learn a predictor of the datasets.

5.4. Classifiers

Classifiers that are widely used in the field of sentiment analysis were applied (Abdulla, Ahmed, Shehab and Al-Ayyoub, 2013; Altowayan and Tao, 2016; Aly and Atiya, 2013; Refaee and Rieser, 2014; Zahran et al., 2015). LR, SVM, KNN and RF are used with default parameter settings. For LR, binary logistic regression was used; for SVC, the linear SVC model was used; and for KNN, N=3 was taken, N is the number of nearest neighbors. Essentially boils down to forming a majority vote between the K most similar instances to a given "unseen" observation. Learning library of Scikit-learn machine based on Python (Pedregosa et al., 2011) was used. Scikit-learn library includes the functionality of regression and classification and others. It is designed to interoperate with the numerical and scientific Python libraries such as NumPy and SciPy.The predicted model is evaluated based on Acc and F1. Scikit-learn library was used to generate a classification report. Acc and F1 can be obtained from Scikit - learn library.

6. Results and discussion

To evaluate the doc2vec proposed and machine learning approaches, the proposed method was implemented using five datasets (ATT, HTL, MOV, RES, and LABR) with four machine learning methods (LR, SVM, KNN, and RF). Tables 3 and 4 show the sentiment classification performance of each base classifier on each of the datasets. Table 3 represents the results of different machine learning algorithms and five datasets based on PV-DBOW architecture.

Table 3. Performance comparison of various classifiers and datasets using the PV-DBOW architecture.

Dataset	Measure	LR	SVM	KNN	RF
ATT	Acc	94%	93%	95%	97%
	F1	92%	93%	93%	94%
HTL	Acc	94%	93%	85%	87%
	F1	94%	93%	80%	86%
MOV	Acc	89%	81%	81%	80%
	F1	88%	82%	80%	71%
RES	Acc	86%	86%	79%	77%
	F1	86%	85%	78%	75%
LABR	Acc	83%	82%	70%	69%
	F1	83%	82%	69%	68%

According to Table 3, LR classifier yields the best performance for HTL, MOV, RES, and LABR datasets. While ATT dataset achieved the best result using RF classifier, ATT dataset achieved the best performance in terms of Acc and F1 compared with other datasets. The performance of LR and SVM classifiers was very close on ATT and HTL datasets in terms of Acc and F1. Results achieved using LR and SVM on RES and LABR datasets performed well compared with KNN and RF classifiers. The best performance was 97% of Acc, attained for the RF classifier with the ATT dataset.

Table 4 represents classifier performance on five datasets using PV-DM architecture. The table reviews the best performance results obtained by using four classifiers with the ATT dataset in terms of Acc and F1. The best performance is 95% of Acc, attained for both the RF and LR classifiers.

Table 4. Performance comparison of various classifiers and datasets using the PV-DM architecture

Dataset	Measure	LR	SVM	KNN	RF
ATT	Acc	95%	93%	95%	95%
	F1	94%	93%	94%	93%
HTL	Acc	93%	93%	88%	88%
	F1	92%	92%	87%	87%
MOV	Acc	85%	80%	74%	89%
	F1	85%	80%	75%	87%
RES	Acc	85%	85%	75%	76%
	F1	85%	85%	75%	74%
LABR	Acc	81%	81%	64%	67%
	F1	81%	81%	63%	63%

Table 4 shows HTL, RES, and LABR datasets that yielded the best classification results using LR and SVM classifiers in terms of Acc and F1. While MOV dataset yielded the best results with RF classifier in terms of Acc and F1, ATT dataset achieved the best results for both LR and RF classifiers in term of Acc, but F1 using LR was a little larger when RF classifier was used. The performance of LR and SVM shows the best performance with HTL dataset in terms of Acc and F1.

With the application of both architectures, PV-DM and PV-DBOW, there was a little difference in the performances of classifiers that was noticed. The significant difference was smaller between the two presentations. Figures 5 and 6 show the compression between classifiers' performance on datasets in terms of Acc and F1 using PV- DM and PV-DBOW.

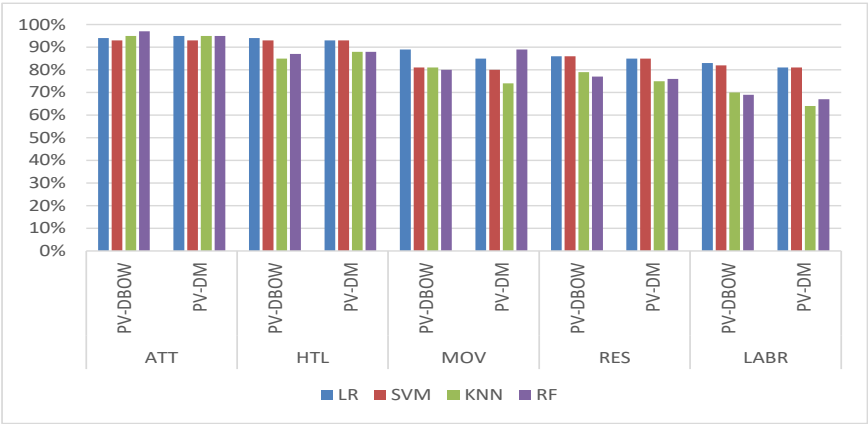


Fig. 5. Performances comparison in term of Accuracy

Figure 5. represents accuracies of classifiers. The performance of classifiers is clearly noted on five datasets that yielded the highest accuracies when PV-DBOW architecture was applied. Comparing PV-DBOW and PV-DM architectures, LR classifier achieved the highest accuracies on HTL, MOV, and LABR using PV-DBOW architecture. SVM, KNN, and RF classifiers obtained the highest accuracies on MOV, RES, and LABR using PV-DBOW architecture. ATT dataset achieved the highest accuracies using RF classifier based on PV-DBOW architecture. Out of the two architectures and four classifiers, it is clear that the lower accuracies were obtained on LABR dataset. LABR reviews were written in MSA and dialectal Arabic. Doc2vec algorithm represents words based on semantic information. The training corpus that is used in this study has

dialectal more than MSA. It is thought that many words in LABR wear represented among the wrong class. For this reason, the accurse of LABR dataset were poor compared with other datasets.

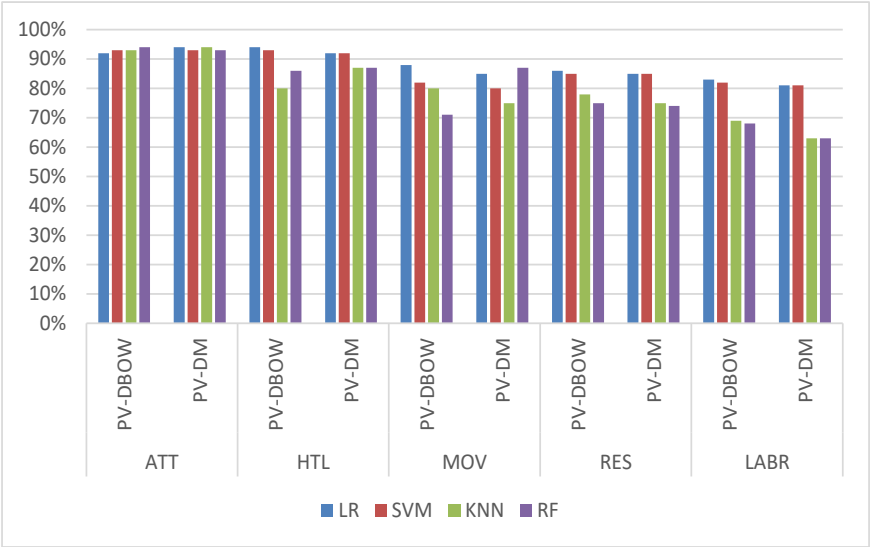


Fig. 6. Performances comparison in term of F1 score

Figure 6. illustrates F1 scores of classifiers. Classifiers achieved the highest F1 score on datasets using PV-DBOW architecture, except that KNN classifier yielded the highest F1 on ATT and HTL datasets using PV-DM architecture. The highest F1 is achieved with ATT dataset using RF classifier and PV-DBOW architecture, but using PV-DM architecture ATT achieved the highest F1 with LR and KNN classifiers. For all classifiers on datasets, the difference in F1 scores between PV-DBOW and PV-DM were negligible.

Table 5 presents the comparison between our doc2vec model against other studies that used the same datasets. In study of Rabab'ah, Al-Ayyoub, Jararweh and Al-Kabi (2016), datasets were used to evaluate SentiStrength sentiment analysis tool. Hassan, Bakr and Ziedan (2018) used datasets to show the effectiveness of the proposed framework. Dahou et al. (2016) apply a binary sentiment classification on datasets using CNN classifier. ElSahar and El-Beltagy (2015) presented an average accuracy of datasets. Moreover, they compared the results with LABR dataset. Altowayan and Tao (2016), Al Shboul, Al-Ayyoub and Jararweh (2015) and El Ariss and

Alnemer (2017) run the experiments on the LABR dataset. The best results were highlighted in bold for each dataset.

Table 5: Comparison of our doc2vec models with existing models on the same datasets.

Classifier	Features	Measure	ATT	HTL	MOV	RES	LABR
LR (our study)	PV-DBOW	Acc	94%	**94%**	**89%**	**86%**	83%
		F1	**92%**	**94%**	**88%**	86%	83%
SentiStrength (Rabab'ah et al., 2016)	-	Acc	71%	77.1 %	44.6 %	67.6 %	56.3%
		F1	82.6 %	84.7 %	46.4 %	77.5 %	68.8%
A novel Framework (Hassan et al., 2018)	POS	Acc	89%	73%	70%	85%	-
		F1	91%	84%	81%	**91%**	-
CNN (Dahou et al., 2016)	CBOW	Acc	**96.2 %**	91.7 %	83.2 %	78.5 %	89.6%
		F1	-	-	-	-	-
Multi classifiers (ElSahar &El-Beltagy, 2015)	Count	Acc	-	87	83	81	81%
		F1	-	-	-	-	-
NuSVC (Altowayan & Tao, 2016)	CBOW	Acc	-	-	-	-	81.69 %
		F1	-	-	-	-	81.27 %
MNB (Al Shboul et al., 2015)	CRF	Acc	-	-	-	-	47%
		F1	-	-	-	-	40%
SVM (El Ariss & Alnemer, 2017)	Tfidf + bigram	Acc	-	-	-	-	**90%**
		F1	-	-	-	-	**94%**

- Not mentioned

Doc2vec model shows that HTL and MOV and RES datasets increased the accuracy when compared with (Dahou et al., 2016). ATT dataset achieved the best result using (Dahou et al., 2016), but Table 2 shows that

RF classifier achieved a 97 % of accuracy for ATT dataset. Results of the study show the highest accurses an F1 scores on datasets compering with (Rabab'ah et al., 2016) and (Hassan et al., 2018) except F1 score for RES dataset.

On the other hand, the accuracy and F1 score of the doc2vec model for LABR dataset is lower than that of listed in (El Ariss and Alnemer, 2017) and (Dahou et al., 2016). The reason is the existence of short sentences (less than 5 words) could have a severe impact on the accuracy of the model because, in our study window size is chosen equal to 3 and required at least 7 words in a sentence.

In general, the doc2vec model provides a remarkable performance improvement over other approaches. The existence of sarcastic and dialectal Arabic really could have a severe impact on model accuracy. Also the semantic content in a review is very important since it determines the correct representation of vectors.

7. Conclusion

In this paper, the process of Arabic sentiment analysis using doc2vec and machine learning approaches was introduced. Continuous vector representations of words were computed using PV-DM and PV-DBOW architectures. Furthermore, these vectors were used to train four popular machine learning methods (LR, SVM, KNN and RF). Experiments were conducted with the proposed process using five Arabic datasets. The results of proposed approach for Arabic sentiment analysis show that initializing word vectors using a distributed representations of sentences yield a remarkable performance. RF classifier achieved the best performance in terms of Acc equals to 97% for ATT dataset. To extend this study further, the authors plan to investigate the effect of hyper-parameters for the doc2vec model in a detailed way.

References

Abbasi, A., Chen, H. and Salem, A. (2008). Sentiment analysis in multiple languages: Feature selection for opinion classification in web forums. *ACM Transactions on Information Systems (TOIS), 26*(3), 12.

Abdulla, N. A., Ahmed, N. A., Shehab, M. A. and Al-Ayyoub, M. (2013). *Arabic sentiment analysis: Lexicon-based and corpus-based.* Paper presented at the IEEE Jordan Conference on Applied Electrical Engineering and Computing Technologies (AEECT), Amman, Jordan.

Akyol, S. and Alatas, B. (2020). Sentiment classification within online social media using whale optimization algorithm and social impact theory based optimization. *Physica A: Statistical Mechanics and its Applications*, *540*, 123094.

Al-Ayyoub, M., Khamaiseh, A. A., Jararweh, Y. and Al-Kabi, M. N. (2019). A comprehensive survey of arabic sentiment analysis. *Information Processing and Management*, *56*(2), 320-342.

Al-Azani, S. and El-Alfy, E.-S. M. (2017). *Using word embedding and ensemble learning for highly imbalanced data sentiment analysis in short arabic text.* Paper presented at the Proceedings of The 8th International Conference on Ambient Systems, Networks and Technologies, ANT Madeira, Portugal.

Al-Sallab, A., Baly, R., Hajj, H., Shaban, K. B., El-Hajj, W. and Badaro, G. (2017). Aroma: A recursive deep learning model for opinion mining in arabic as a low resource language. *ACM Transactions on Asian and Low-Resource Language Information Processing (TALLIP)*, *16*(4), 25. doi: 10.1145/3086575

Al-Smadi, M., Al-Ayyoub, M., Jararweh, Y. and Qawasmeh, O. (2018). Enhancing Aspect-Based Sentiment Analysis of Arabic Hotels' reviews using morphological, syntactic and semantic features. *Information Processing and Management*.

Al Shboul, B., Al-Ayyoub, M. and Jararweh, Y. (2015). *Multi-way sentiment classification of arabic reviews.* Paper presented at the 6th International Conference on Information and Communication Systems (ICICS), Amman, Jordan.

Alayba, A. M., Palade, V., England, M. and Iqbal, R. (2018). *Improving Sentiment Analysis in Arabic Using Word Representation.* Paper presented at the Proceedings of the 2nd International Workshop on Arabic and Derived Script Analysis and Recognition (ASAR), London, UK.

Albukhitan, S., Helmy, T. and Alnazer, A. (2017). *Arabic ontology learning using deep learning.* Paper presented at the Proceedings of the International Conference on Web Intelligence.

Alnawas, A. and Arıcı, N. (2019). Sentiment Analysis of Iraqi Arabic Dialect on Facebook Based on Distributed Representations of Documents. *ACM Transactions on Asian and Low-Resource Language Information Processing (TALLIP)*, *18*(3), 20. doi: https://doi.org/10.1145/3278605

Alnawas, A. and Arıcı, N. (2018). The Corpus Based Approach to Sentiment Analysis in Modern Standard Arabic and Arabic Dialects: A Literature Review. *Journal of Polytechnic, 21*(2), 461-470. doi: 10.2339/politeknik.403975

Altowayan, A. A. and Tao, L. (2016). *Word embeddings for Arabic sentiment analysis.* Paper presented at the Proceedings of IEEE International Conference on Big Data, Washington, DC, USA.

Aly, M. and Atiya, A. (2013). *LABR: Large Scale Arabic Book Reviews.* Paper presented at the Proceedings of the 51st Annual Meeting of the Association for Computational Linguistics Sofia, Bulgaria.

Asghar, M. Z., Khan, A., Khan, F. and Kundi, F. M. (2018). RIFT: A Rule Induction Framework for Twitter Sentiment Analysis. *Arabian Journal for Science and Engineering, 43*(2), 857-877.

Awwad, H. and Alpkocak, A. (2017). *Using Hybrid-Stemming Approach to Enhance Lexicon-Based Sentiment Analysis in Arabic.* Paper presented at the 2017 International Conference on New Trends in Computing Sciences (ICTCS), Amman, Jordan.

Boudad, N., Faizi, R., Thami, R. O. H. and Chiheb, R. (2017). Sentiment analysis in Arabic: A review of the literature. *Ain Shams Engineering Journal, 9*(4). doi: http://dx.doi.org/10.1016/j.asej.2017.04.007

Çano, E. and Morisio, M. (2018, April 20–22, 2018). *A deep learning architecture for sentiment analysis.* Paper presented at the the International Conference on Geoinformatics and Data Analysis (ICGDA 2018), Prague, Czech Republic.

Dahou, A., Elaziz, M. A., Zhou, J. and Xiong, S. (2019). Arabic Sentiment Classification Using Convolutional Neural Network and Differential Evolution Algorithm. *Computational Intelligence and Neuroscience, 2019*. doi: https://doi.org/10.1155/2019/2537689

Dahou, A., Xiong, S., Zhou, J., Haddoud, M. H. and Duan, P. (2016, 2016). *Word embeddings and convolutional neural network for arabic sentiment classification.* Paper presented at the Proceedings of the 26th International Conference on Computational Linguistics: Technical Papers, Osaka,Japan.

Dilawar, N., Majeed, H., Beg, M., Ejaz, N., Muhammad, K., Mehmood, I. and Nam, Y. (2018). Understanding citizen issues through reviews: A step towards data informed planning in smart cities. *Applied Sciences, 8*(9), 1589. doi: https://doi.org/10.3390/app8091589

El Ariss, O. and Alnemer, L. M. (2017). *Morphology based Arabic sentiment analysis of book reviews.* Paper presented at the International Conference on Computational Linguistics and Intelligent Text Processing.

ElSahar, H. and El-Beltagy, S. R. (2015). *Building large arabic multi-domain resources for sentiment analysis.* Paper presented at the Proceedings of 16th International Conference on Intelligent Text Processing and Computational Linguistics, Cairo, Egypt.

García-Pablos, A., Cuadros, M. and Rigau, G. (2018). W2VLDA: almost unsupervised system for aspect based sentiment analysis. *Expert systems with Applications, 91*, 127-137. doi: doi.org/10.1016/j.eswa.2017.08.049

Hassan, H. G., Bakr, H. M. A. and Ziedan, B. E. (2018). A Framework for Arabic Concept-Level Sentiment Analysis using SenticNet. *International Journal of Electrical and Computer Engineering, 8*(5), 4015. doi: 10.11591/ijece.v8i5.pp4015-4022

Heikal, M., Torki, M. and El-Makky, N. (2018, November 17-19 2018). *Sentiment Analysis of Arabic Tweets using Deep Learning.* Paper presented at the Proceedings of the 4th International Conference on Arabic Computational Linguistics (ACLing 2018), Dubai, United Arab Emirates.

Helmy, M., Vigneshram, R., Serra, G. and Tasso, C. (2018). Applying Deep Learning for Arabic Keyphrase Extraction. *Procedia Computer Science, 142*, 254-261.

IWS. (2017). INTERNET WORLD USERS BY LANGUAGE. Retrieved July, 2018, from https://www.internetworldstats.com/stats7.htm

Kim, Y., Kang, M. and Jeong, S. R. (2018). Text Mining and Sentiment Analysis for Predicting Box Office Success. *KSII Transactions on Internet and Information Systems, 12*(8). doi: http://doi.org/10.3837/tiis.2018.08.030

Le, Q. and Mikolov, T. (2014). *Distributed representations of sentences and documents.* Paper presented at the Proceedings of International Conference on Machine Learning, Beijing, China.

Liu, B. (2012). *Sentiment analysis and opinion mining* (Vol. 5): Morgan and Claypool Publishers.

Maas, A. L., Daly, R. E., Pham, P. T., Huang, D., Ng, A. Y. and Potts, C. (2011, June 19 - 24). *Learning word vectors for sentiment analysis.* Paper presented at the Proceedings of the 49th annual meeting of the

association for computational linguistics: Human language technologies-volume 1.

Mikolov, T., Le, Q. V. and Sutskever, I. (2013). Exploiting similarities among languages for machine translation. *arXiv preprint arXiv:1309.4168*.

Mikolov, T., Sutskever, I., Chen, K., Corrado, G. S. and Dean, J. (2013). *Distributed representations of words and phrases and their compositionality.* Paper presented at the Proceedings of Advances in Neural Information Processing Systems 26, Nivada.USA.

Mikolov, T., Yih, W.-t. and Zweig, G. (2013). *Linguistic regularities in continuous space word representations.* Paper presented at the Proceedings of the 2013 Conference of the North American Chapter of the Association for Computational Linguistics: Human Language Technologies, Atlanta, Georgia.

Naili, M., Chaibi, A. H. and Ghezala, H. H. B. (2017). Comparative study of word embedding methods in topic segmentation. *Procedia Computer Science, 112*, 340-349.

Pedregosa, F., Varoquaux, G., Gramfort, A., Michel, V., Thirion, B., Grisel, O., . . . Dubourg, V. (2011). Scikit-learn: Machine learning in Python. *Journal of machine learning research, 12*(Oct), 2825-2830.

Perovšek, M., Kranjc, J., Erjavec, T., Cestnik, B. and Lavrač, N. (2016). TextFlows: A visual programming platform for text mining and natural language processing. *Science of Computer Programming, 121*, 128-152.

Qiu, L. (2015). Sentiment Analysis using Doc2Vec in gensim. Retrieved December, 2017, from https://github.com/linanqiu/word2vec-sentiments

Rabab'ah, A. M., Al-Ayyoub, M., Jararweh, Y. and Al-Kabi, M. N. (2016). *Evaluating sentistrength for arabic sentiment analysis.* Paper presented at the 2016 7th International Conference on Computer Science and Information Technology (CSIT),, Amman-Jordan.

Refaee, E. and Rieser, V. (2014). *An Arabic Twitter Corpus for Subjectivity and Sentiment Analysis.* Paper presented at the LREC, Reykjavik, Iceland.

Rushdi-Saleh, M., Martín-Valdivia, M. T., Ureña-López, L. A. and Perea-Ortega, J. M. (2011). OCA: Opinion corpus for Arabic. *Journal of*

the Association for Information Science and Technology, 62(10), 2045-2054.

Salama, R. A., Youssef, A. and Fahmy, A. (2018). Morphological Word Embedding for Arabic. *Procedia Computer Science, 142*, 83-93.

Sohail, S. S., Siddiqui, J. and Ali, R. (2018). Feature-Based Opinion Mining Approach (FOMA) for Improved Book Recommendation. *Arabian Journal for Science and Engineering*, 1-20.

Song, J., Kim, K. T., Lee, B., Kim, S. and Youn, H. Y. (2017). A novel classification approach based on Naïve Bayes for Twitter sentiment analysis. *KSII Transactions on Internet and Information Systems, 11*(6). doi: https://doi.org/10.3837/tiis.2017.06.011

Suleiman, D., Awajan, A. and Al-Madi, N. (2017). *Deep Learning Based Technique for Plagiarism Detection in Arabic Texts.* Paper presented at the Proceedings of the New Trends in Computing Sciences (ICTCS), 2017 International Conference on.

Tang, D., Qin, B. and Liu, T. (2015). Deep learning for sentiment analysis: successful approaches and future challenges. *Wiley Interdisciplinary Reviews: Data Mining and Knowledge Discovery, 5*(6), 292-303.

UNESCO. (2012). Unesco World Arabic Language Day. Retrieved 23 March 2017, from http://www.unesco.org/new/en/unesco/events/prizes-and-celebrations/celebrations/international-days/world-arabic-language-day

Vinodhini, G. and Chandrasekaran, R. (2017). A sampling based sentiment mining approach for e-commerce applications. *Information Processing and Management, 53*(1), 223-236.

Zahran, M. A., Magooda, A., Mahgoub, A. Y., Raafat, H., Rashwan, M. and Atyia, A. (2015). *Word representations in vector space and their applications for arabic.* Paper presented at the Proceedings of the International Conference on Intelligent Text Processing and Computational Linguistics, Cairo, Egypt.

CHAPTER IV

CHARACTERIZATION OF GEOPOLYMERS WITH DIFFERENT ANALYSIS TECHNIQUES

Assoc. Prof. Dr. Ceyda BİLGİÇ

Eskişehir Osmangazi University, Eskişehir, Turkey
e-mail: cbilgic@ogu.edu.tr,
Orcid No: 0000-0002-9572-3863

Asst. Prof. Dr. Şafak BİLGİÇ

Eskişehir Osmangazi University, Eskişehir, Turkey
e-mail: safakb@ogu.edu.tr,
Orcid No: 0000-0002-9336-7762

1. Introduction

Climate change due to global warming is a vital threat to the whole world. Greenhouse gases such as carbon dioxide emitted through human activities lead to global warming. CO_2 has the greatest impact on global warming among greenhouse gases which is responsible for about 65 % of global warming (Vijaya Rangan, 2010:68; Mccaffrey, 2002:15). The CO_2 level in the air has risen from 315 ppm to 365 ppm between 1960 and 2000. Two billion tonnes of CO_2 per year are emitted in cement production. It is estimated that 3.5 billion tonnes of CO_2 will be produced annually by the cement industry in ten years (Shi, et al., 2011:750). The production of portland cement contributes to 5-7 % of global CO_2 emissions (Turner and Collins, 2013:125; Huntzinger and Eatmon, 2009:668; Meyer, 2009:601). Therefore, it is fair to mention that the cement manufacturing process increases environmentally unfriendly greenhouse gas emissions (Joseph and Mathew, 2012:1188; Malhotra, 2002:22, Mccaffrey, 2002:15).

An innovative technology studies have started to focus on ‘geopolymers’ that are inorganic polymers that arise as potential future alternatives to cement-based materials. Geopolymer was first contrived by Prof. Joseph Davidovits in the 1970s. It was first used as a fire-resistant to protect cruise ships from fire, in the protection of wooden structures, and different implementations. Geopolymers have also been shown to display good mechanical and thermal properties, low shrinkage, and longer design lives compared to some cementitious materials. Geopolymers, if used as an alternative to Portland cement, CO_2 emission

produced by geopolymer technology is estimated to be 80 % less than Portland cement. Therefore, it is thought that geopolymer technology is going to be vital in the near future for the green construction industry (White and Provis, 2009; Duxson et al., 2007:1590; Provis and van Deventer, 2009).

The geopolymerization process is based on an exothermic heterogeneous chemical reaction between a solid aluminosilicate raw material and an alkali metal silicate solution under atmospheric conditions and at temperatures up to 100 °C. Generally, geopolymerization involves a series of operations, such as dissolution, redirecting, and solidification, as shown in figure 1. Various aluminosilicate sources can be used as raw materials for geopolymer synthesis including kaolinite, fly ash, and blast furnace slag (Mohd Salahuddin et al., 2015:4273). The atomic structure and corresponding mechanical performance of the geopolymers depend strongly on the raw material employed in geopolymerization as well as the synthesis and aging conditions (Duxson, et al., 2006:2917).

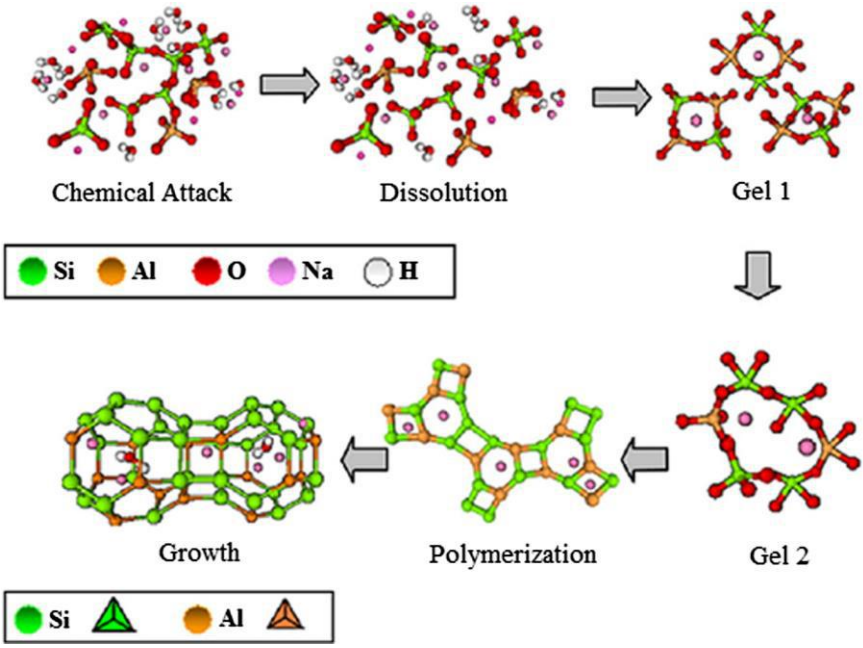


Fig. 1 Graphic model of alkalinization of geopolymers (Duxson et al., 2007:2917).

Understanding the structure of geopolymers is critical for designing geopolymers with desired properties. The relationships established between the structure and physical properties will be important for controlling product properties. X-Ray Diffraction (XRD), Fourier Transform Infrared spectroscopy (FTIR), Scanning Electron Microscopy (SEM), and Brunauer-Emmett-Teller (BET) method. XRD measurements are performed to investigate the amorphous or crystalline phase of the synthesized geopolymers. FTIR spectroscopy is utilized to understand the vibrational fingerprints of geopolymers, SEM images are performed on synthesized geopolymers to resolve their surface microstructures, and BET using for the determination of specific surface area and pore size distribution analysis.

2.1. X-Ray Diffraction (XRD)

X-Ray Diffraction is the elastic scattering of X-Rays by atoms in a periodic lattice. It is a non-destructive method and used to have information about chemical compositions, particle size distributions, and crystallographic structure of materials. XRD plays a crucial role in the characterization of geopolymers by providing information on the crystalline phases and amorphous character of the samples.

Geopolymers are completely amorphous according to X-Ray diffraction (XRD). Typically, they possess a diffuse halo peak at about 27-30° 2θ (Davidovits, 1991:1633; Lecomte et al., 2003:2571; Lizcano et al., 2012:2607; Zhang et al., 2005:23). The broad diffuse hump is corresponding to the amorphous aluminosilicates which form the primary binder phase in the geopolymer matrix and contribute to the strength of geopolymers. The angle of this diffuse halo is dependent on the Si/Al ratio. Increasing Si/Al ratio lowers the degree of the hump (Lizcano et al., 2012:2607). Moreover, reaction products with halo diffuse between 2θ value of 18° and 25° were observed for metakaolin geopolymers by Wang et al. (Wang et al., 2005:1). After alkalinization, the quartz phase has been found to be largely unreactive. However, the impurities present in kaolin (due to incomplete calcination) reduce in intensity (Yao et al., 2009:49). The growth of crystalline phases, particularly zeolites, could commonly be seen in the XRD pattern of geopolymers in conjunction with the amorphous phase of geopolymers (Davidovits, 2008:145; Zibouche et al., 2009:453). The chemical composition of geopolymer is similar to zeolitic materials. Sometimes, geopolymers are regarded as a zeolitic precursor. The difference between geopolymers and zeolites is that geopolymer is amorphous whereas zeolite is crystalline in nature (Lecomte et al., 2003:2571; Khale and Chaudhary, 2007:729). Crystallization does not only depend on curing temperature but also influenced by the type of

alkali reactant used and curing time. Zeolites crystallization is promoted by high water content, high curing temperature as well as extended curing period (Provis et al., 2005:3075; Duxson et al., 2007:8).

It is known that zeolites are highly porous and have poor mechanical properties. It was believed that there is always a limitation of the amount of crystalline phase that can be tolerated by the matrix. Several researchers (Kolousek et al., 2007:9267; Palomo et al., 1999:997) discovered that zeolite crystallites reinforce the geopolymer matrix and improve strength, but it will cause a substantial reduction in longterm strength. A similar strength development trend has been concluded for fly ash geopolymers (Criado et al., 2007:671).

The study of geopolymers using X-Ray diffraction is difficult because of the fact, a large part of the structure is amorphous content between 20º and 40º 2θ. The degree of disorder in geopolymers can be inferred by the way it diffracts X-Ray to form a diffraction pattern. In a non-crystalline state, diffraction of X-Ray results in a broad diffuse halo rather than sharp diffraction peaks (Davidovits, 1991:1633; Rees et al., 2007:9076). Peaks were of quartz, mullite, and hematite of the crystalline component of the fly ash. The broad peak in region 20-30º 2θ arises from the glassy phase of fly ash and peaks in the region 6-10º and 16º 2θ arise from the alumino-silicate gel. A considerable amount of zeolites were found in cement-fly ash system blend, activated by the highly alkaline multi-compound activator, around pH 14 and cured at 70 ºC (Bakharev et al., 2005:1244).

Crystalline phases in the XRD pattern of kaolinite disappear with thermal treatment revealing a loss of crystallinity and order in the system; metakaolin is largely amorphous showing a broad pattern between 20 and 30º and it is centered approximately at about 27.5º with minor quartz content (Arellano-Aguilar et al., 2014:642). Main crystalline phases exist in raw red mud are hematite Fe_2O_3), quartz (SiO_2), goethite (FeO(OH)), and some other minor components sodalite ($Na_8(Al_6Si_6O_{24})Cl_2$) and cancrinite ($Na_6Ca_2Al_6Si_6O_{24}(CO_3)_2$) (Kumar and Kumar, 2013:865). XRD pattern of fly ash shows a broad and disordered characteristic lying between 20-40º. Fly ash contains mullite ($Al_6Si_2O_{13}$) and quartz (SiO_2) crystals in general (Zhang et al., 2014:194).

The microstructure of the alkali-activated fly ash changes with the chemical composition (Rowles et al. 2007:663). After geopolymerization, all the main characteristic peaks of Al-Si minerals remained but decreased slightly. This suggested that the Al-Si mineral did not dissolve totally into the gel phase. However, there were no new peaks, which means that no new major crystalline phases were formed (Xu and van

Deventer, 2000:247). The baseline broadened between 20° and 40° 2θ was an indicative of an increased amorphicity (Van Jaarsveld et al., 2002:63). Palomo et al. (2014) studied a series of fly ash samples activated under different experimental conditions and concluded that geopolymers are a family of materials with the same basic chemical composition but potentially different microstructures (Palomo et al., 2014:1). The structural properties of geopolymers depend strongly on many factors including raw material selection, synthesis conditions, thermal treatment temperatures, and durations following synthesis, etc. The phase's composition and pore structure were characterized by XRD and SEM.

2.2. Scanning Electron Microscope (SEM)

Scanning Electron Microscope (SEM) is used to obtain information about the external morphology, chemical composition, and also crystalline structure of the raw material and also synthesized geopolymers. Scanning Electron Microscopy (SEM) can be using to study the morphology of raw materials and synthesized raw materials based geopolymers. Micromorphologies of the raw materials provide insights for understanding the effect of different raw materials based geopolymers. In addition, unreacted phases present in the geopolymer structure can be identified from the analysis of SEM images. This fast and non-destructive technique gives information about surface properties, particle size, and also particle distribution (Yunsheng et al., 2010:271).

The microstructural analysis allows monitoring of geopolymer development over time. The strength of geopolymers is closely related to the density and porosity of the structure. In general, low porosity, high density, and fine-grained microstructure contribute to high strength geopolymers.

The SEM images obtained by Wang et al. (2005) show that metakaolin geopolymers are not compact and maintained their layered structure after geopolymerization reaction (Wang et al., 2005:1). It agrees and proves the statement by Davidovits (2008) that the reaction occurs at the surface of geopolymers (Davidovits et al., 2008:145).

Microstructure development of metakaolin geopolymers over time observed the precipitation of sponge-like geopolymer globular units on the surface of loosely-paced metakaolin particles, densification, and continuous formation of dense geopolymer matrix inside and outside voids. SEM images imply that the homogeneous and dense microstructure of metakaolin based geopolymer leaves its place to a structure which has microcracks and even unreacted metakaolin particles

for the highest red mud containing sample (Zhang et al., 2005:23; Sun et al., 2004:935).

At the early stage of mixing, Zhang et al. (2005) noticed that the K/Al and Si/Al molar ratios were high as a result of the release of Si from liquid sodium silicate (Zhang et al., 2005:23). The dissolution of Al at this stage is low. As time passed, these molar ratios lowered as more dissolved Al enter the system. However, decreased Si/Al and Si/Na ratios deteriorated the strength of geopolymers, as accordance to Song et al. (2015) (Song et al., 2015:305).

According to Rowles et al. (2007), the presence of residual particles in bulk geopolymer structure becomes the stress concentration point that causes cracks and fractures (Rowles et al. 2007:663). Besides, the nominal composition of geopolymer might be altered by the residual particles and thus prevent the complete development of the geopolymer network.

Differ from metakaolin geopolymers; fly ash geopolymers reveal heterogeneous elements with lots of unreacted fly ash particles in the hollow cavities left by the partially dissolved fly ash particles. Unreacted particles act as filler and strengthen the composite. In fly ash geopolymers, smooth and connecting geopolymer matrix was observed instead of a globular unit of geopolymer matrix in metakaolin geopolymers.

SEM images of fly ash samples show the presence of spherical particles with smooth outer surfaces called cenospheres. After geopolymerization reaction, partially reacted cenospheres and gel formation are observed according to SEM results. The gel formation is related to the dissolution of aluminate and silicate phases in geopolymer structure (Kumar and Kumar, 2011:533; Nyale et al., 2013:722).

As can be seen from the SEM image of the geopolymers, crystalline structure increases with the Si/Al molar ratio. Scanning electron microscopy (SEM) indicated that the microstructures of geopolymers evolved into a more homogeneous but highly crystalline structure as the molar Si/Al ratio is raised to a value of 10. The SEM images of sepiolite-based geopolymers with Si/Mg ratios between 2 and 4 involved microcracks possibly due to higher water content.

2.3. Fourier Transform Infrared Spectroscopy (FTIR)

FTIR spectroscopy is an analytical technique used for both qualitative and quantitative measurements of mainly organic and inorganic materials. FTIR is used to identify the different chemical bonds in a molecule from

the absorption of infrared radiation at various wavelengths. Asides from aiding in the characterization of functional groups of geopolymers, FTIR spectroscopy can also use to provide information on the transition of vibrations due to small structural changes. Clay-based geopolymers show the main absorption band around 990 cm^{-1}, corresponding to the asymmetric stretching of Si–O and Al–O bonds (Alonso and Palomo, 2001:25; Rovnanik, 2010:1176). This band becomes more concentrated (more aluminosilicates matrix) as the polycondensation reaction proceeds. In addition, it shifted to a higher wavenumber as a consequence of higher curing temperature. This is owing to molecular structural changes induced by the substitution of aluminum for silicon (Kani and Allahverdi, 2009:3088). The band shift from lower to higher wavenumbers indicates the transform of Gel 1 to Gel 2 proposed by Duxson et al. (2007), aforementioned. This was in agreement with Criado et al. (2007) in the case of fly ash geopolymers (Figure 2) (Duxson et al. 2007:2917; Criado et al., 2007:180).

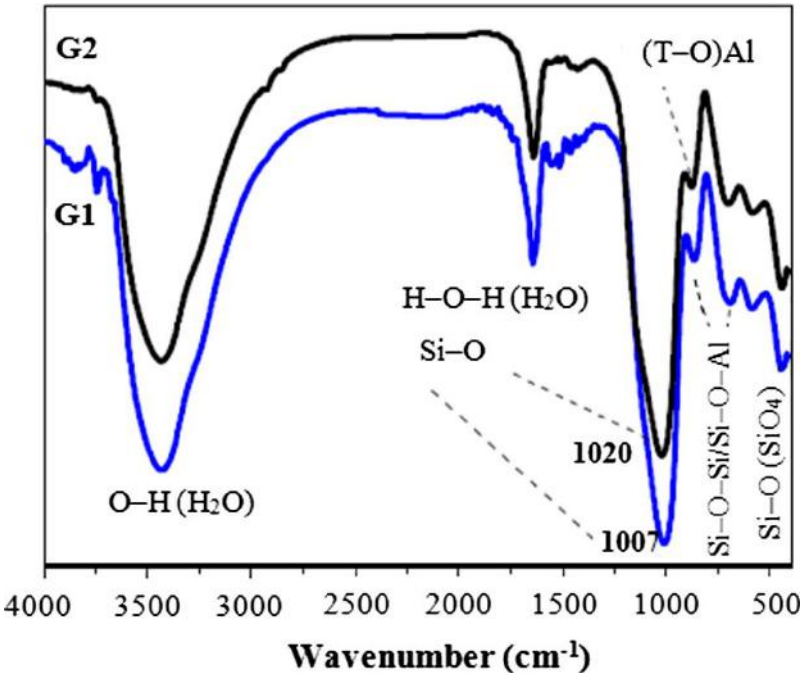


Fig. 2 FTIR spectra of Gel 1 (G1) and Gel 2 (G2) (Criado et al., 2007:180)

FTIR spectra of geopolymers is generally characterized by a

broadband in 900-1300 cm^{-1} region that is characteristic of disordered geopolymer structure. Bands observed in this region are related to asymmetric stretching vibrations of Si–O–T (T=Al, Si) (Ye et al., 2014:1652; Arıöz et al., 2012:1115). Shifting of this band to lower wavenumbers is a clear indication of the dissolution of the raw materials in an alkaline activator and the evolution of a new amorphous aluminosilicate phase during geopolymerization process. In a metakaolin and red mud-based geopolymer study, it has been revealed that the peak obtained in the metakaolin at 1087 cm^{-1} regarding asymmetric stretching vibrations of Si–O–T has shifted to 1000 cm^{-1} in its' geopolymer form.

On the other hand, no such shift is detected in the red mud which points out that red mud has a small solubility in alkaline solutions whereas metakaolin is highly dissolved in caustic solutions (Dimas et al., 2009:211). Similar results are obtained in another study where FTIR spectroscopy is performed on fly ash-based geopolymers. FTIR band detected at 1085 cm^{-1} in fly ash has shifted to lower frequencies (986 cm^{-1}) with alkaline activation (Arıöz et al., 2012:1115). Bands detected in the region between 550-750 cm^{-1} are assigned to symmetric stretching vibrations of Si–O–Si and Al–O–Si. An enhancement in the intensity of the bands in this region points out an enhancement in chain length and formation of aluminosilicate gel. High-frequency bands observed in the region between 1300-1600 cm^{-1} are assigned to stretching vibrations of O–C–O bonds and show the presence of carbonate materials (Ye et al., 2014:1652; Dimas et al., 2009:211; Mustafa Al Bakri et al., 2011:289). In a recent study, red mud is used together with fly ash as a raw material for geopolymer production, and a peak is detected at 458 cm^{-1} (Kumar and Kumar, 2013:865), this peak is associated with vibrations of Fe–O bonds (Muñiz-Villarreal et al., 2011:995) because of the iron present in red mud. Band detected at frequencies higher than 1600 cm^{-1} is due to stretching (–OH) and bending (H–O–H) vibrations of interlayer adsorbed H_2O molecules (Nath and Kumar, 2013:924; Mustafa Al Bakri et al., 2011:289). In a recent research employing fly ash and bottom fly ash in geopolymer production, FTIR spectra of raw materials and products are used to quantitively express the degree of geopolymerization. This calculation is made in terms of height ratios and area ratios of the Si–O–Si stretching peaks that exist in the FTIR spectra of geopolymers to their regarding ashes' peak. It is found in this study that the ratios of peak heights and areas to their corresponding ashes are much higher and this situation points out the high degree of geopolymerization in the system (Ferone et al., 2013:1920).

2.4. BET Measurements

The surface area and pore structure analysis of samples were characterized by the BET method. In catalytic applications and heavy metal adsorption, the performance of photocatalysts and adsorbents often progress with certain structural properties (e.g. pore volume and surface area). Geopolymers are well-known materials which often consist of high pore volume and large surface area. These have been found to substantially contribute to heavy metal adsorption. Synthesis methods play a significant role in fine-tuning these properties. For instance, Tang et al. (2015) reported a metakaolin based geopolymer with a BET surface area of 53.95 m^2/g and porosity of about 60.30 % (Tang et al., 2015:1244). The high surface area and porosity are derived through the use of suspension and solidification method, where foaming agent SLS (i.e. K12 sodium lauryl sulphate) is used to increase the mesoporous nature of the geopolymer. This geopolymer shows high adsorption capacity for Pb^{2+}, $Cu^{2+,}$ and Ca^{2+} with removal capacity of 45.6, 35.5, and 24.0 mg/g respectively. Spherically shaped geopolymer/alginate hybrid with high BET surface area (16.2 m^2/g), pore size (11.5 nm), and pore volume of 0.05 mL/g is also reported by Ge et al. (2017) via one-pot impregnation method. In fact, this specific surface area (i.e. 16.2 m^2/g) is about 1.7 times higher than of pure metakaolin-based geopolymer (i.e. with BET surface area of ~9.6 m^2/g) (Ge et al., 2017:126). The use of sodium alginate to coat the metakaolin based geopolymer in a $CaCl_2$ aqueous solution is known to be an efficient method to create a mesoporous surface and abundant inner pores which contribute immensely to the high adsorption capacity towards Cu(II) (Ge et al., 2017:126). Similarly, Lee et al. (2016) have recently shown that the post-hydrothermal treatment method can be used to obtain fly-ash-based geopolymer with high surface area and pore volume of 114.16 m^2/g and 0.2677 cm^3/g respectively (Lee et al., 2016:22). These obviously give advantages such as high adsorption capacity relevant for the removal of Cs^+ from aqueous solution (Lee et al., 2017:288). Hence synthesis methods continue to be relevant for improving the surface area and pore volume of the geopolymers for water remediation and related applications.

3. Conclusions

Geopolymeric materials can offer valuable solutions to environmental remediation challenges. These solutions are likely to be low on infrastructure maintenance, and of relevance to the scalability needs of current industrial wastewater treatment plants. The possibility of (i) synthesizing from accessible and rather abundantly available raw

materials and (ii) fabrication using room temperature approaches with low or zero greenhouse gases emission have made geopolymer a material relevant for cleaner production and for green technologies. This also offers windows of 'green technology' opportunities in allied industries – including construction, surface engineering, and healthcare. Advanced uses of this material for catalysis applications and energy production will particularly benefit industries that focus on waste treatment and water remediation.

This study will offer insights into the various techniques to use the characterization of geopolymers. The properties of geopolymers are also affected by various parameters such as alkali concentration, mixing ratios and proportions, curing regimes, water content, and incorporation of additives/fillers. The combination of various mixing and processing parameters determines the optimum performance of the geopolymer produced. Among all, main parameters (alkali concentration, mixing ratios and mixture proportions, and curing regimes) are believed to have a crucial influence on geopolymers. Due to their excellent properties, geopolymers have been successfully applied in various fields and new applications are yet to be discovered in the future.

Acknowledgments

This study is part of a project (2018-2233) supported by the Research Fund of Eskişehir Osmangazi University.

References

Alonso S., Palomo A. (2001) "Calorimetric study of alkaline activation of calcium hydroxide-metakaolin solid mixtures", *Cement and Concrete Research*, 31(1), 25-30.

Arellano-Aguilar R., Burciaga-Díaz, O., Gorokhovsky, A., Escalante-García, J.I., (2014) "Geopolymer Mortars Based on a Low Grade Metakaolin: Effects of the Chemical Composition, Temperature and Aggregate: Binder Ratio", *Construction and Building Materials*, 50, 642-648.

Arıöz, E., Arıöz, Ö., Koçkar, Ö.M. (2012) "Leaching of F-type Fly Ash Based Geopolymers'', 20th International Congress of Chemical and Process Engineering CHISA, *Procedia Engineering*, 42, 1114-1120.

Bakharev T (2005) "Geopolymeric materials prepared using Class F fly ash and elevated temperature curing" *Cement and Concrete Research*, 35(6), 1224-1232.

Criado M, Fernández-Jiménez A., de la Torre A.G., Aranda M.A.G., Palomo A. (2007) An XRD study of the effect of the SiO_2/Na_2O ratio on the alkali activation of fly ash, *Cement and Concrete Research*, 37(5), 671-679.

Criado M., Fernández-Jiménez, A., Palomo A. (2007) Alkali activation of fly ash: effect of the SiO_2/Na_2O ratio. Part 1: FTIR study, *Microporous and Mesoporous Materials*, 106 (1-3), 180-191.

Davidovits, J. (1991) "Geopolymers: Inorganic Polymeric New Materials", *Journal of Thermal Analysis and Calorimetry*, 37(8), 1633-1656.

Davidovits, J. (2008) " Geopolymer Chemistry and Applications", 2nd edition., Ch. 8, Geopolymer Institute, Saint-Quentin, France, 145-192 pp.

Dimas, D. D., Giannopoulou, I.P., Panias, D. (2009) "Utilization of Alumina Red Mud for Synthesis of Inorganic Polymeric Materials", *Mineral processing and extractive metallurgy review: An International Journal*, 30 (3), 211-239.

Duxson P, Mallicoat, S.W., Lukey, G.C., Kriven W.M., van Deventer J. S. J. (2007), The effect of alkali and Si/Al ratio on the development of mechanical properties of metakaolin-based geopolymers, *Colloids and Surfaces A: Physicochemical and Engineering Aspects*, 292(1), 8-20.

Duxson P., Provis J.L., Lukey G.C., van Deventer J. S. J. (2007) "The Role of Inorganic Polymer Technology in the Development of 'Green Concrete'", *Cement and Concrete Research*, 37(12), 1590-1597.

Duxson, P., Fernández-Jiménez, A., Provis, J.L., Lukey, G.C., Palomo, A., van Deventer, J. S. J. (2007) "Geopolymer Technology: the Current State of the Art", *Journal of Materials Science*, 42(9), 2917-2933.

Ferone, C., Colangelo, F., Roviello, G., Asprone, D., Menna, C., Balsamo, A., Prota, A., Cioffi, R., Manfredi, G. (2013) "Application-Oriented Chemical Optimization of a Metakaolin Based Geopolymer", *Materials*, *6*(5), 1920-1939.

Ge, Y., Cui, X., Liao, C., Li, Z. (2017) "Facile fabrication of green geopolymer/alginate hybrid spheres for efficient removal of Cu (II) in water: batch and column studies", *Chemical Engineering Journal*, 311, 126-134.

Huntzinger, D. N., Eatmon, T.D. (2009) “A life-cycle Assessment of Cement Manufacturing: Comparing Traditional Process with Alternative Technologies”, *Journal of Cleaner Production,* 17(7), 668-675.

Joseph, B., Mathew, G. (2012) “Influence of Aggregate Content on the Behavior of Fly Ash Based Geopolymer Concrete”, *Scientia Iranica,* 19(5), 1188-1194.

Kani E.N., Allahverdi A. (2009) “Effects of curing time and temperature on strength development of inorganic polymeric binder based on natural pozzolan”, *Journal of Materials Science,* 44, 3088-3097.

Khale D., Chaudhary R. (2007) “Mechanism of geopolymerization and factors influencing its development: a review”, *Journal of Materials Science,* 42, 729-746.

Koloušek D., Brus J., Urbanova M., Andertova J., Hulinsky V., Vorel J. (2007) “Preparation, structure and hydrothermal stability of alternative (sodium silicate-free) geopolymers”, *Journal of Materials Science,* 42(22), 9267-275.

Kumar, S., Kumar, R. (2011) “Mechanical activation of fly ash: Effect on reaction, structure and properties of resulting geopolymer”. *Ceramics International*, *37*(2), 533-541.

Kumar, A., Kumar S. (2013) “Development of Paving Blocks from Synergistic Use of Red Mud and Fly Ash Using Geopolymerization”, *Construction and Building Materials,* 38, 865-871.

Lecomte I., Liegeois M., Rulmont A., Cloots R. (2003) “Synthesis and characterization of new inorganic polymeric composites based on kaolin or white clay and on ground-granulated blast furnace slag”, *Journal of Materials Science,* 18(11), 2571-2579.

Lee N.K., Khalid, H.R., Lee, H.K. (2016) “Synthesis of mesoporous geopolymers containing zeolite phases by a hydrothermal treatment”, *Microporous Mesoporous Materials,* 229, 22-30.

Lee, N.K., Khalid, H.R., Lee, H.K. (2017) “Adsorption characteristics of cesium onto mesoporous geopolymers containing nano-crystalline zeolites”, *Microporous Mesoporous Materials,* 242, 238-244.

Lizcano M., Kim H.S., Basu S., Radovic M. (2012) Mechanical properties of sodium and potassium activated metakaolin-based geopolymers. , *Journal of Materials Science,* 47, 2607-2616.

Malhotra, V. M. (2002) ‘‘Introduction: Sustainable Development and Concrete Technology’’, *American Concrete Institute*, 24(7), 22 p.

Mccaffrey, R. (2002) ‘‘Climate change and the cement industry’’, *Global Cement and Lime Magazine (Environmental Special Issue)*, 15-19.

Meyer, C. (2009) “The Greening of the Concrete Industry’’, *Cement and Concrete Composites*, 31(8), 601-605.

Mohd Salahuddin, M. B., Norkhairunnisa, M., Mustapha, F. (2015) ‘‘A Review on Thermophysical Evaluation of Alkali-Activated Geopolymers’’, *Ceramics International*, 41(3), 4273-4281.

Mustafa Al Bakri, A.M., Kamarudin H., BinHussain M., Khairul Nizar I., Zarin Y., Rafiza A.R. (2011) “The Effect of Curing Temperature on Physical and Chemical Properties of Geopolymers’’, *Physics Procedia*, 22, 289-290.

Muñiz-Villarreal, M. S., Manzano-Ramírez, A., Sampieri-Bulbarela, S., Ramón Gasca-Tirado J., Reyes-Araiza, J.L., Rubio-Ávalos, J.C., Pérez-Bueno, J.J., Apatiga, L.M., Zaldivar-Cadena A.,Amigó-Borrás V. (2011) “The Effect of Temperature on the Geopolymerization Process of a Metakaolin-Based Geopolymer’’, *Materials Letters*, 65(6), 995-998.

Nath S. K., Kumar, S. (2013) “Influence of Iron Making Slags on Strength and Microstructure of Fly Ash Geopolymer”, *Construction and Building Materials*, 38, 924-930.

Nyale, S. M., Babajide, O. O., Birch, G. D., Böke, N., Petrik, L. F. (2013) “Synthesis and Characterization of Coal Fly Ash-based Foamed Geopolymer”, *Procedia Environmental Sciences*, 18, 722-730.

Palomo A., Blanco-Varela M.T., Granizo M.L., Puertas F., Vazquez T., Grutzeck M.W. (1999) “Chemical stability of cementitious materials based on metakaolin”, *Cement and Concrete Research*, 29, 997-1004.

Palomo, A., Krivenko, P., Garcia-Lodeiro, I., Kavalerova, E., Maltseva, O., Fernández-Jiménez, A. (2014) “A review on alkaline activation: new analytical perspectives” *Materiales de Construccion*, 64 (315), 1-24.

Provis, J. L., van Deventer, J.S.J. (2009) *Geopolymers: Structures, Processing, Properties and Industrial Applications*, Woodhead Publishing Limited, Cambridge, UK, 454 pp.

Provis J.L., Lukey G.C., van Deventer J.S.J. (2005) "Do geopolymers actually contain nanocrystalline zeolites? A reexamination of existing results", *Chemistry Materilas,* 17(12), 3075-3085.

Rees, C.A., Provis, J.L., Lukey, G.C., van Deventer, J.S.J. (2007) "In situ ATR-FTIR study of the early stages of fly ash geopolymer gel formation", *Langmuir,* 23 (17), 9076-9082.

Rovnanik P. (2010) Effect of curing temperature on the development of hard structure of metakaolin-based geopolymer. *Construction and Building Materials,* 24, 1176-1183.

Rowles M.R., Hanna J.V., Pike K.J., Smith M.E., O'Connor B.H. (2007), ^{29}Si, ^{27}Al, ^{1}H and ^{23}Na MAS NMR study of the bonding character in aluminosilicate inorganic polymers. *Applied Magnetic Resonance,* 32, 663-89.

Shi, C., Jiménez, A.F., Palomo, A. (2011) "New Cements for the 21st Century: The pursuit of an Alternative to Portland Cement", *Cement and Concrete Research,* 41(7), 750-763.

Sun W., Zhang W., Lin W., Liu Z.Y. (2004) "In situ monitoring of the hydration process of K-PS geopolymer cement with ESEM", *Cement and Concrete Research,* 34, 935-940.

Song, M., Qian, J., Zhong, L.J., Liang, S. (2015) From a View of Alkali Solution: Alkali Concentration to Determine Hydration Process of Alkali Activating Metakaolin. In: Scrivener K., Favier A., editors. *Calcined clays for sustainable concrete: proceedings of the 1st international conference on calcined clays for sustainable concrete,* 305-313.

van Jaarsveld, J. G. S., van Deventer, J. S. J., Lukey, G.C. (2002) "The Effect of Composition and Temperature on the Properties of Fly Ash- and Kaolinite-Based Geopolymers", *Chemical Engineering Journal,* 89(1-3), 63-73.

Vijaya Rangan B. (2010) "Fly Ash-Based Geopolymer Concrete", *Proceedings of the International Workshop on Geopolymer Cement and Concrete,* Allied Publishers Private Limited, Mumbai, India, 68-106 pp.

Wang H., Li H., Yan F. (2005) "Synthesis and mechanical properties of metakaolinite-based geopolymer" *Colloids and Surfaces A: Physicochemical and Engineering Aspects,* 268 (1-3), 1-6.

White, C. E, Provis, J.L., Proffen, T., Daniel P.R., van Deventer, J.S.J. (2009) ‘‘Solving the Structure of Metakaolin’’, *Nature Materials*, 1-7.

Tang, Q., Ge, Y.Y., Wang, K.T., He, Y., Cui, X.M. (2015) “Preparation and characterization of porous metakaolin-based inorganic polymer spheres as an adsorbent”, *Materials and Design*, 88, 1244-1249.

Turner L.K., Collins F.G., (2013) “Carbon dioxide equivalent (CO_2-e) emissions: a comparison between geopolymer and OPC cement concrete”, *Construction and Building Materials*, 43(6), 125-130.

Yao X., Zhang Z., Zhu H., Chen Y. (2009) “Geopolymerization process of alkali-metakaolinite characterized by isothermal calorimetry” *Thermochimica Acta*, 493, 49-54.

Xu, H., van Deventer, J.S.J. (2000) “The geopolymerization of alumino-silicate minerals”, *International Journal of Mineral Processing*, 59 (3), 247-266.

Ye N., Yang, J., Ke, X., Zhu, J., Li, Y., Xiang, C., Wang, H., Li L., Xiao B. (2014) “Synthesis and Characterization of Geopolymer from Bayer Red Mud with Thermal Pretreatment”, *Journal of American Ceramic Society*, 97(5), 1652-1660.

Yunsheng, Z., Wei, S., Zongjin, L. (2010) “Composition design and microstructural characterization of calcined kaolin-based geopolymer cement”, Applied *Clay Science*, 47 (3-4), 271-275.

Zhang Z., Wang, H., Zhu, Y., Reid, A., Provisc J.L., Bullen, F. (2014) “Using Fly Ash to Partially Substitute Metakaolin in Geopolymer Synthesis”, *Applied Clay Science*, (88-89), 194-201.

Zhang Y.S., Sun W., Li Z.J. (2005) “Hydration process of potassium polysialate (K-PSDS) geopolymer cement”, *Advances in Cement Research*, 17(1), 23-28.

Zibouche, F., Kerdjoudj, H., d’Espinose de Lacaillerie, J.B., Van Damme, H.L., (2009) “Geopolymers from Algerian metakaolin. Influence of secondary minerals”, *Applied Clay Science*, 43(3-4), 453-458.

CHAPTER V

THE BENDING BEHAVIOR OF MARINE SANDWICH COMPOSITES MANUFACTURED BY VACUUM-ASSISTED RESIN TRANSFER METHOD

Dr. Fatih BALIKOĞLU

Balıkesir University, Balıkesir, Turkey
e-mail: fatih.balikoglu@balikesir.edu.tr,
Orcid ID: 0000-0003-3836-5569

Dr. Tayfur Kerem DEMİRCİOĞLU

Balıkesir University, Balıkesir, Turkey
e-mail: tkerem@balikesir.edu.tr,
Orcid ID: 0000-0002-0518-0739

Asst. Prof. Dr. Ege Anıl DİLER

Ege University, Izmir, Turkey
e-mail: ege.anil.diler@ege.edu.tr,
Orcid ID: 0000-0002-1667-5737

Asst. Prof. Dr. Akın ATAŞ

The University of Manchester, Manchester, UK
e-mail: akin.atas@manchester.ac.uk,
Orcid ID: 0000-0002-2185-465X

1. Introduction

Marine structures are exposed to harsh operating conditions including the combined effects of humidity, temperature and different mechanical forces throughout their service life (Davies & Rajapakse, 2014; Rubino, Nisticò, Tucci, & Carlone, 2020). Traditional materials such as wood, steel and aluminum have been used for many years as building materials in watercraft. Since the 1950s, fiber reinforced polymers have started to replace conventional materials in the marine industry. Although fiber reinforced polymers were initially limited to rescue lifeboats, canoes, lifeguards, over time it has been used in large-scale structures such as ship hulls and superstructures, submarines, and offshore structures. This has been caused by the development of high performance resin and fiber materials, and advances in production methods and design stages (Pemberton, Summerscales, & Graham-Jones, 2018).

The production rate, cost, size, shape, and strength are critical parameters in choosing the appropriate manufacturing method in boat construction. The most used composite production for large structures such as boat hulls and decks has been open molding methods. The first glass fiber reinforced boats had a reinforced monocoque design to maintain reasonable panel dimensions. These structures were produced by using the isotropic mats and orthophthalic polyester resin by hand lay-up or spraying methods. The hand lay-up has been the dominant manufacturing method in small and medium-sized boats since the 1960s. In the 1970s, sandwich constructions were used in marine applications. In the 1990's, the maritime industry was introduced to vacuum bagging and resin infusion methods (Associates, 1999; Neşer, 2017).

The Seemann composite resin infusion method (SCRIMP) method, which was patented by Bill Seeman in 1990, is a closed mold composite manufacturing technique that is applied in different industrial branches all over the world, especially in the USA (Seemann III, 1990). This method has been described with various different abbreviations: SCRIMP VARTM, VARIM, RFIM, VIMP, VAIM, VARI, VIM, RIFT, RFI etc. acronyms are used (Marsh, 2010; Summerscales & Searle, 2005). The most common names are resin infusion under flexible tooling (RIFT), Seemann composite resin infusion molding process (SCRIMP), and vacuum assisted resin infusion method (VARTM). The VARTM method used in the marine applications is a closed mold resin infusion method that offers similarities to resin transfer molding (RTM). The main difference is that the fully enclosed, two-piece rigid molds used in RTM are replaced by a one-piece rigid mold sealed with a vacuum bag. Comparing VARTM and vacuum bagging, reinforcements and core structure are dry placed inside the mold in VARTM. In other words, it does not include wet lay-up process. Vacuum application is used both to compress the layers and to allow the resin to move through the dry fibers. Thus, it is possible to manufacture the composite product whose manufacturing preparations are completed without human touch. In the VARTM method, unlike the materials used in vacuum bagging manufacturing, a "flow mesh" layer used to facilitate flow and reduce filling time is placed on top of the peel-ply fabric. Mold components in the VARTM method can be listed as: mold, spiral tubing, T-fittings, inlet and outlet tubing, sealant and vacuum nylon (see in Fig.1). As seen in Figure 2, this method consists of four (4) parts: vacuum pump, resin trap, mold, and resin tank. The system is simply defined; in the closed mold system, it includes the infusion process that allows the resin to move from the feeding line to the vacuum line. The resin inlet tubing can be arranged in the mold to provide central, linear and peripheral feeding. Different arrangement of vacuum and resin lines affects production times

(see in Fig. 3). The choice of resin and reinforcing materials is critical in the VARTM process. Generally, resins with low viscosity properties that can more easily penetrate the reinforcement fabrics are preferred. Resins classified as infusion type are used in the market. However, higher viscosity resins can also be used in VARTM, but requires more careful planning, and it becomes imperative to install numerous and short resin suction lines. Reinforcement selection is an important step for all composite structures, but there are additional considerations when using the VARTM method to produce sandwich composites. Infusion technique can be applied to all fabrics, but different materials and textile styles can seriously affect resin flow rates. In particular, because there is less intersection of warp and weft in woven fabrics, resin progression occurs more easily. Knitted fabrics and mat reinforcements also contain large amounts of voids for resin absorption. Stitched non-crimps fabrics are reinforcements with the lowest resin absorption rate. It should also be noted in the design that most fabrics experience a reduction in thickness of up to 30% under vacuum pressure. As with resins and reinforcements, the selection of core materials is also important (Calabrese, Di Bella, & Fiore, 2016). Core materials suitable for VARTM must be closed-cell structure. Most of the honeycomb materials are not suitable for infusion methods due to their open cells. Holes, grooves and cuts are machined in the polymer foam materials to increase the resin permeability and provide sufficient flow and absorption. These modifications allow the production of sandwich composites without the use of flow mesh. Foam producers (DIAB, Airex, Baltek companies, etc.) supply products with modifications to facilitate resin transfer during infusion at the request of their customers (Reuterloev, 2003; Reuterlöv, 2002).

Today, a significant number of boat builders have adopted resin infusion production techniques to improve product quality, speed up the production process, and comply with health and safety regulations. All indicators show that this trend will gain momentum and open-mold techniques will be abandoned. This situation was observed during the visits made to the sector within the scope of this research. It has been observed that the VARTM technique is preferred in shipyards where sandwich-built yachts are manufactured.

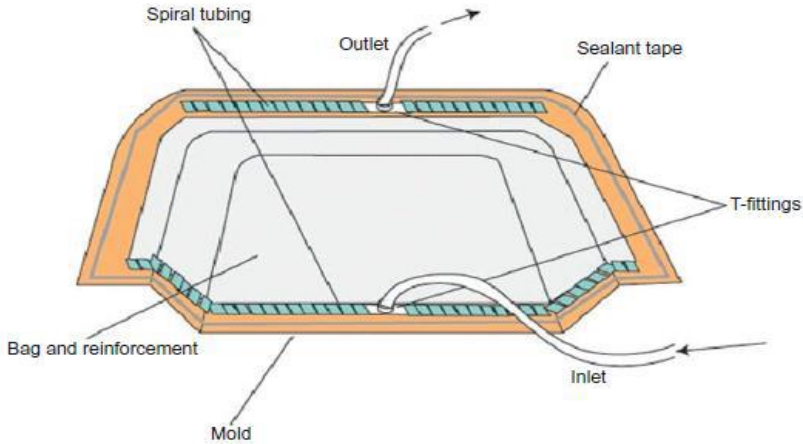


Fig. 1 Mold and bag system in VARTM method (Graham-Jones & Summerscales, 2015).

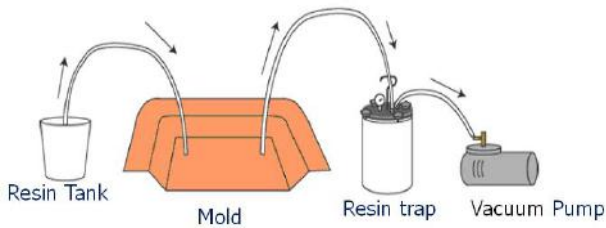


Fig. 2 Elements of VARTM system (Graham-Jones & Summerscales, 2015).

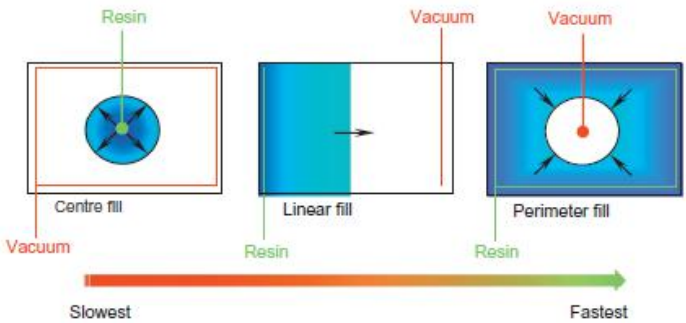


Fig. 3 Arrangements resin and vacuum lines and estimated fill times (Pemberton et al., 2018).

2. Production of marine sandwich composites by VARTM method

In Figure 4, the elements of production of a sandwich composite panel with VARTM technique is given schematically and the production steps are explained in detail afterwards.

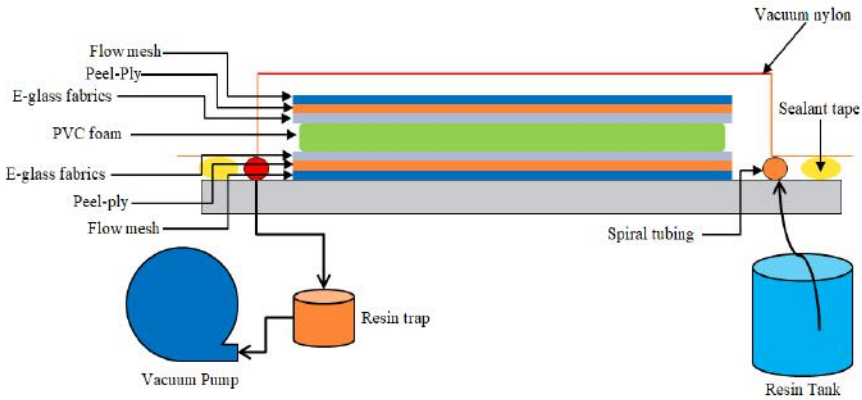


Fig. 4 Elements of sandwich composite panel production with VARTM.

Sandwich composite production with VARTM method consists of the following steps:

- By measuring the mold, fabric layers should be cut and numbered on a table beforehand,
- Cleaning the mold and apply a release agent,
- Dry fabrics and core materials are placed in the mold in accordance with the lamination plan (see in Fig.5a),
- Spiral tubing are cut for resin and vacuum lines in the mold, T-fittings are attached to the spiral tubing to connect inlet and outlet lines, double-sided sealing paste is applied to surround the mold (see in Fig.5b),
- The vacuum bag is cut by taking into account part thickness and mold depth in order to apply sufficient pressure on the mold. After the vacuum bag is cut, it is pasted around the mold with sealing paste (see in Fig. 5c),
- Polyethylene hoses are cut for inlet and outlet lines and they are connected to spiral tubing by means of T-fittings. The vacuum hose is connected to the resin trap container, while the resin suction hose is kept closed. The leakage in the vacuum bag is checked by comparing the resin trap container and the manometers on the vacuum pump (see in Fig. 5c),
- The amount of resin is calculated according to the lamination plan. The amount of resin that will remain in the hoses should be taken into

account. The hardener and accelerators are added to the resin and mixed,

- The resin line is opened and after the entire composite structure is wetted, the sandwich structure is allowed to cure. The curing can be made in an open atmosphere or by the firing method (considering the resin curing cycle) (see in Fig. 5d).

The advantages of the VARTM method can be list as follows:

- Provides high fiber/resin ratio, and light, stronger and stiffer structures are provided (Lazarus, 1996; Shah & Chaudhary, 2020),
- Provides low void content (less than 1%), and the risk of the initiation of damage is reduced (Kedari, Farah, & Hsiao, 2011),
- It prevents the formation of resin-rich or dry areas and provides homogeneous resin distribution (Yalcinkaya, Sozer, & Altan, 2019),
- Provides low styrene steam emission (Hoge & Leach, 2016),
- Does not involve wet-lay-up processes, resulting in low waste and material savings (Bhatt, Gohil, & Chaudhary, 2018),
- No time limit caused by resin gelation like other methods, and the reinforcements are placed in the mold dry (Calabrese et al., 2016),
- Reduces manufacturing defects; for example, no high exothermic temperatures caused by the resin-rich regions and distortion of the produced parts (Pemberton et al., 2018),
- Resin infusion provides reproducible laminate properties. Process variables such as vacuum pressure and resin viscosity can be measured and adjusted (Hsiao & Heider, 2012; Pemberton et al., 2018).

Although the VARTM method provides many advantages over open molding methods, the following points should be noted (Calabrese et al., 2016; Pemberton et al., 2018; Summerscales & Searle, 2005):

- Staff must be trained in the infusion process; must have knowledge of infusion consumables and installations, ability to read and apply lamination plans,
- The number of production parameters is greater than the open molding methods. In general, variables such as workshop temperature and humidity values, areal weights of fabrics, resin, hardener and accelerator mixing ratios and mold temperature should be controlled. During the infusion process, additional parameters such as resin viscosity and vacuum pressure levels need to be monitored,
- The VARTM method is more costly than open molding methods in terms of investment and production costs. Vacuum pump, resin trap, vacuum bag, sealant tape, spiral hoses etc. many consumables are needed,

- Open mold method involves low risk. In the VARTM method, after the resin is transferred to the mold, it is impossible to return. For example, the decrease in the vacuum level due to power failure or the impregnation of the non-ready resin to the layers causes the production to be terminated,
- Care should be taken against air leaks that may occur in the mold and vacuum bag,
- The VARTM method can be used for parts of any size, but is not preferred for small parts with complex shapes, whereas the technique is more suitable for large parts produced in a short time such as boat hulls;
- The trial-and-error approach is a costly method to apply to locate the resin and vacuum lines. Therefore, simulations of the infusion process are performed with commercial finite element analysis programs such as PAM-RTM, LIMS, PolyWorx and myRTM.

During the visit to GCG Yacht Manufacturing Company (Gaziemir/Izmir), the production steps of the sandwich composite panel produced using the VARTM production technique are given in Fig.6.

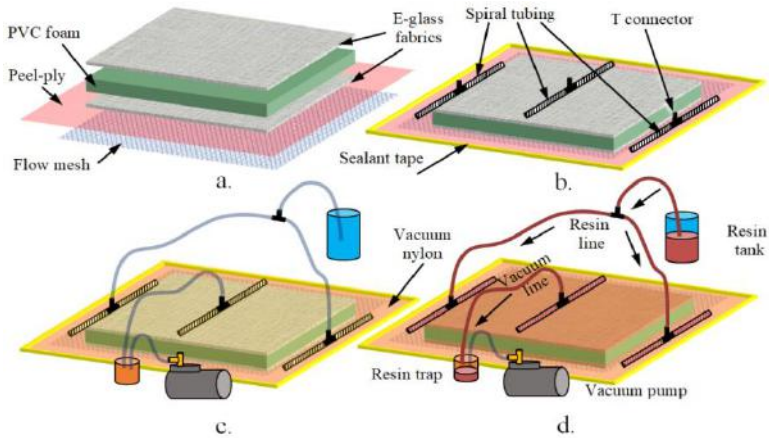


Fig. 5 Steps of manufacturing of sandwich composite panel using VARTM method, a) Placement of reinforcements and core materials, peel-ply and flow mesh on the mold, b) Installation of spiral tubing and T-fittings in the mold c) Sealing the vacuum bag and installation of resin and vacuum lines, and d) Opening the inlet and impregnating the sandwich plate with resin.

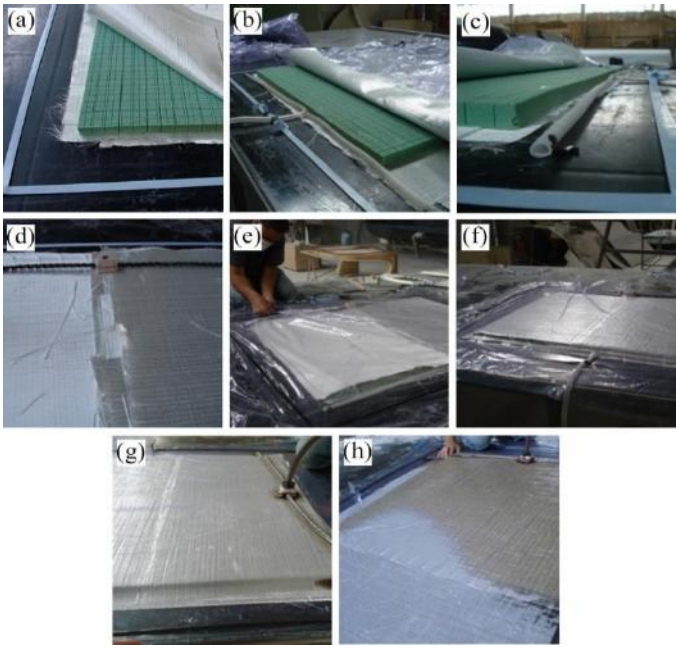


Fig. 6 VARTM production steps of sandwich composite material (GCG Yat İmalat Sanayi A.Ş, Sarnıç, İzmir), a) Placement of fabrics and foam materials in the mold b) Placing spiral hoses, c, d) Installing resin and vacuum lines, e) and f) Sealing of vacuum nylon, g) and h) Opening the resin line and resin impregnation.

3. Four-point bending test results of marine sandwich beams

3.1. Test and materials

Four point bending (4PB) tests of sandwich composite beams were carried out in accordance with ASTM C393/C393M-11 standard (ASTM, 2016). 4PB tests were performed on a Zwick Roell 250 kN universal testing machine with a test speed of 6 mm / min (Figure 7). Support distance (span) for four (4) point bending tests was determined as 300 mm (Figure 8 a). All specimens were tested up to failure to determine the failure load and failure mechanisms.

Fig. 7 Zwick Roell 250 kN universal testing machine and four point bending (4PB) test setup.

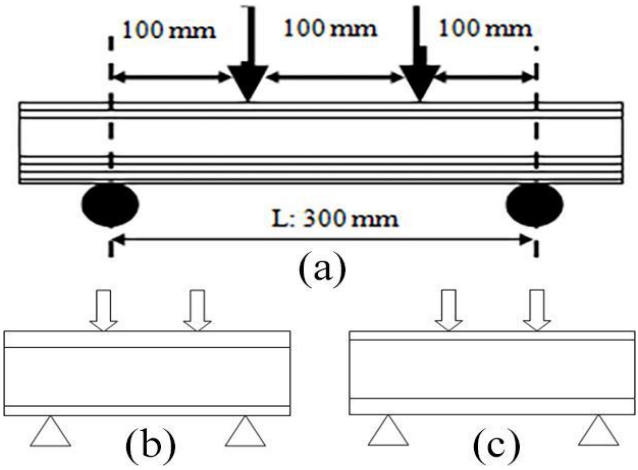


Fig. 8 Schematic diagram of 4PB testing, a) Four-point flexural testing, b) Flexural-up test, c) Flexural-down test.

Five samples of 450 mm x 75 mm in size were prepared from the panels of the hull floor (two pieces, 450 mm x 450 mm) and freeboard (two pieces, 450 mm x 450 mm). The bending tests were carried out by applying the loading on the inner (thin) side and outer (thick) side of the sandwich beams. The flexural-up and flexural-down test typologies of the sandwich beams are shown in Figure 8 b, c. Lamination plans for sandwich beams are given in Table 1. The hull floor is the lowest part of the boat hull and the freeboard is the part of the above water part of the hull. 30 mm thick DIAB Divinycell® H 130 and Divinycell® H80 PVC foams were used as the core material of the sandwich beams. The top and bottom face sheets were made of 2 layers of E-glass [0/90] non-crimp biaxial stitched fabrics

with a 944 g/m^2 and 710 g/m^2 areal weights. E-glass mats with a 300 g/m^2 and 450 g/m^2 areal weights were also used for the upper face sheets (in thicker face sheet of sandwich panels). Sandwich panels were manufactured using VARTM method with bisphenol-A epoxy vinyl ester resin.

Table 1 Plans of hull floor and freeboard laminations.

Plan of hull floor lamination	**Plan of freeboard lamination**
Mat300	Mat300
Mat300	Mat450
LT944	LT710
LT944	LT710
H130×30mm PVC foam	H80×30mm PVC foam
LT944	LT944
LT 944	LT 944

3.2. Load displacement behavior of marine sandwich beams

The load-displacement graphs and failure modes of the sandwich specimens were reported in this section. Due to the unsymmetrical nature of the face sheets, flexural up and flexural down loading were conducted in the asymmetrical sandwich beams. Different failure loads and modes were observed depending on the loading conditions for the freeboard and hull floor sandwich beams. The load-bearing capabilities of beams with peel-stopper and core junction under bending load were also compared with reference beams with rigid foam.

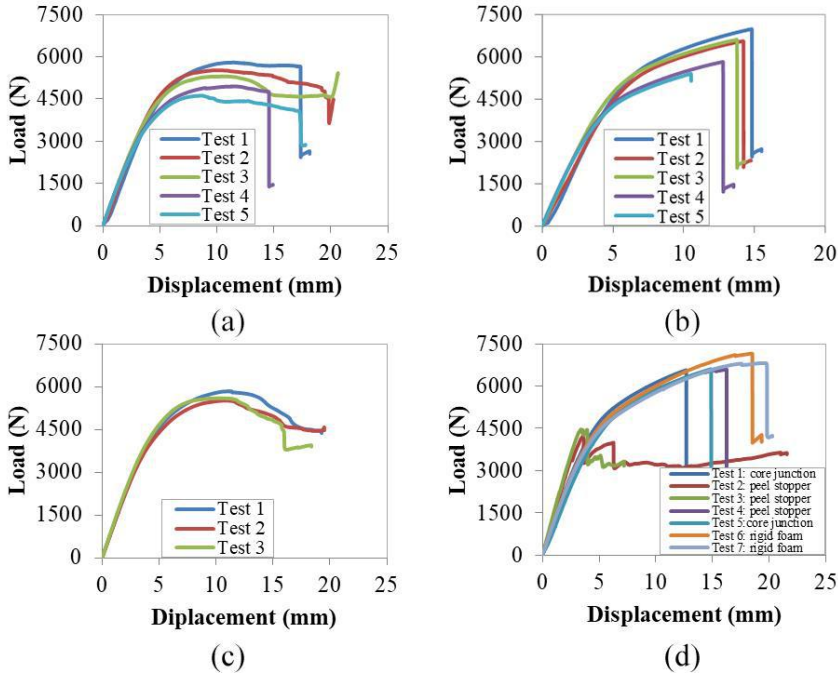


Fig. 9 Load-displacement graphs of the sandwich beams, a) Flexural down results of the freeboard beams, b) Flexural-up results of the freeboard beams, c) Flexural-down results of the hull floor beams, and d) Flexural-up results of the hull floor beams.

Under the flexural-down load, the freeboard sandwich beams were damaged in the form of upper fiber breakage under compression load (see in Fig. 10) while under the flexural-up test, freeboard beams suffered from the core shear failure. The shear crack occurred between loading pins and supports as seen in Fig. 11. As seen in Fig. 9 a, b, for flexural-up tests, it was observed that the freeboard beams were damaged at less displacement values and higher loads. The freeboard beams was damaged at an average load values of 5265 N under flexural-down loading and 6271 N in the case of the flexural-up loading. Failure loads increased by 19% in flexural-up loading for freeboard sandwich beams.

Under flexural-down tests, the hull floor sandwich beams were damaged due to upper fiber breakage under compression load. The fiber breakage occurred under the loading pins (see in Fig. 12).

Fig. 10 Failure modes of freeboard sandwich beams under flexural-down loading.

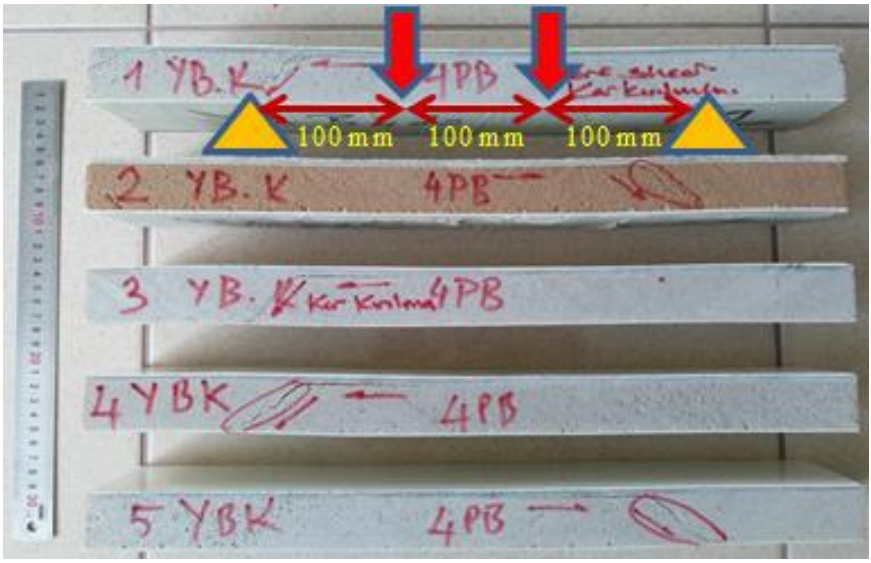


Fig. 11 Failure modes of freeboard sandwich beams under flexural-up loading.

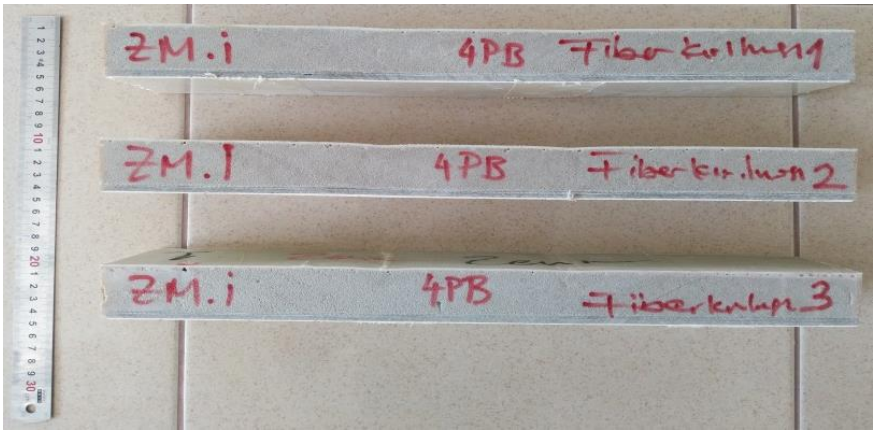


Fig. 12 Failure modes of hull floor sandwich beams under flexural-down loading.

Core shear failure was observed in hull floor sandwich beams under flexural-up tests. Core junction (specimens 1, 5) and peel-stopper (specimens 2, 3, 4) applications have been applied on the hull floor sandwich beams compared to rigid foamed specimens (specimens 6, 7) (see in Fig. 13). A decrease in load carrying capacity was observed in samples containing peel stopper and core junction (see in Fig.9 d). The application of the peel-stopper was effective to stop crack propagation between the core-face sheet interfaces (Jakobsen, Bozhevolnaya, & Thomsen, 2007; Jakobsen, Thomsen, Andreasen, & Bozhevolnaya, 2009) (Fig. 14). The core junction inserted in the middle part of the beam has stopped the crack propagation between the upper face sheet and foam core material (Fig. 15). The hull floor beams were failed at an average load values of 5651 N under-flexural-down loading and 6992 N in the case of flexural-up loading. In the flexural-up loading for hull floor sandwich beams with rigid foam, failure loads increased by 23.7% compared to those of flexural-down loadings (see in Fig. 9c, d). The test results indicated that the core junction and peel-stopper applications had a positive effect in stopping the crack propagation, but a negative effect on the load carrying ability of the beams.

Fig. 13 Failure modes of hull floor sandwich beams under flexural-up loading, (specimens 1, 5: core junction, specimens 2,3,4: peel-stopper, specimen 6,7: rigid foam).

Fig. 14 Peel-stopper effect on core shear propagation in the hull floor sandwich beams under flexural-up loading.

Fig. 15 Core shear fracture in the hull floor sandwich beams with core junction under flexural-up loading.

4. Conclusions

The following results were obtained:

- Sandwich beams exhibited different failure modes under four-point bending loads depending on the flexural-down and up loading conditions.
- Failure loads were found to be higher in flexural-up tests than flexural-down tests.
- Failure modes were observed in the form of core shear under the flexural-up loads and upper fiber breakage due to the compression under flexural-down loads for both freeboard and hull floor sandwich beams.
- In the case of flexural-up loading for hull floor sandwich beams with core junction and peel-stopper, 5.7% and 26.1% decrease in the failure load was observed, respectively.
- Core junctions including grid-scored foam in the middle of hull floor beams prevented the crack propagation between the upper face sheet and the foam core.
- The peel stopper stopped the progress of the crack between face sheet and foam core and hindered it from spreading to the whole sandwich beam.
- In terms of the repair process, it may be desirable that the lamination plan applied on the interior of the boat hull structure is damaged due to face sheet compression failure. The repair of core shear damage in the boat hull can be more complex and costly.

References

Associates, E. G. (1999). Marine composites: Eric Greene Associates.

ASTM. (2016). ASTM C393 / C393M-16, Standard Test Method for Core Shear Properties of Sandwich Constructions by Beam Flexure West Conshohocken, PA: ASTM International.

Bhatt, A. T., Gohil, P. P., & Chaudhary, V. (2018). Primary Manufacturing Processes for Fiber Reinforced Composites: History, Development & Future Research Trends. Paper presented at the IOP Conference Series: Materials Science and Engineering.

Calabrese, L., Di Bella, G., & Fiore, V. (2016). Manufacture of marine composite sandwich structures Marine Applications of Advanced Fibre-Reinforced Composites (pp. 57-78): Elsevier.

Davies, P., & Rajapakse, Y. D. (2014). Durability of composites in a marine environment (Vol. 208): Springer.

Graham-Jones, J., & Summerscales, J. (2015). Marine applications of advanced fibre-reinforced composites: Woodhead Publishing.

Hoge, J., & Leach, C. (2016). Epoxy resin infused boat hulls. Reinforced Plastics, 60(4), 221-223.

Hsiao, K.-T., & Heider, D. (2012). Vacuum assisted resin transfer molding (VARTM) in polymer matrix composites Manufacturing techniques for polymer matrix composites (PMCs) (pp. 310-347): Elsevier.

Jakobsen, J., Bozhevolnaya, E., & Thomsen, O. T. (2007). New peel stopper concept for sandwich structures. Composites Science and Technology, 67(15-16), 3378-3385.

Jakobsen, J., Thomsen, O. T., Andreasen, J. H., & Bozhevolnaya, E. (2009). Crack deflection analyses of different peel stopper designs for sandwich structures. Composites Science and Technology, 69(6), 870-875.

Kedari, V. R., Farah, B. I., & Hsiao, K.-T. (2011). Effects of vacuum pressure, inlet pressure, and mold temperature on the void content, volume fraction of polyester/e-glass fiber composites manufactured with VARTM process. Journal of Composite Materials, 45(26), 2727-2742.

Lazarus, P. (1996). Resin infusion of marine composites. Paper presented at the 41st Int. SAMPE Symp.

Marsh, G. (2010). Marine composites—drawbacks and successes. Reinforced Plastics, 54(4), 18-22.

Neşer, G. (2017). Polymer based composites in marine use: history and future trends. Procedia Engineering, 194, 19-24.

Pemberton, R., Summerscales, J., & Graham-Jones, J. (2018). Marine Composites: Design and Performance: Woodhead Publishing.

Reuterloev, S. (2003). Grooved Core Materials Aid Resin Infusion-Influence on Mechanical Properties. SAMPE journal, 39(6), 57-64.

Reuterlöv, S. (2002). Cost effective infusion of sandwich composites for marine applications. Reinforced Plastics, 46(12), 30-34.

Rubino, F., Nisticò, A., Tucci, F., & Carlone, P. (2020). Marine application of fiber reinforced composites: a review. Journal of Marine Science and Engineering, 8(1), 26.

Seemann III, W. H. (1990). Plastic transfer molding techniques for the production of fiber reinforced plastic structures: Google Patents.

Shah, M., & Chaudhary, V. (2020). Flow modeling and simulation study of vacuum assisted resin transfer molding (VARTM) process: A review. Paper presented at the IOP Conference Series: Materials Science and Engineering.

Summerscales, J., & Searle, T. (2005). Low-pressure (vacuum infusion) techniques for moulding large composite structures. Proceedings of the Institution of Mechanical Engineers, Part L: Journal of Materials: Design and Applications, 219(1), 45-58.

Yalcinkaya, M. A., Sozer, E. M., & Altan, M. C. (2019). Dynamic pressure control in VARTM: Rapid fabrication of laminates with high fiber volume fraction and improved dimensional uniformity. Polymer Composites, 40(6), 2482-2494.

CHAPTER VI

KNOWLEDGE MANAGEMENT AND INTERNET OF THINGS: EVOLUTIONS IN BUSINESS PROCESSES

Assoc. Prof. Dr. Hüseyin FIDAN

Burdur Mehmet Akif Ersoy University Faculty of Engineering and Architecture,
Department of Industrial Engineering, Burdur/Turkey,
e-mail: hfidan@mehmetakif.edu.tr,
Orcid ID: 0000-0002-7482-8922

Asst. Prof. Dr. Mehmet Erkan YÜKSEL

Burdur Mehmet Akif Ersoy University Faculty of Engineering and Architecture,
Department of Computer Engineering, Burdur/Turkey,
e-mail: erkanyuksel@mehmetakif.edu.tr,
Orcid ID: 0000-0001-8976-9964

1. Introduction

Technological developments have created milestones that affect social and economic life and lead to important changes. Discovery of printing press, invention of steam machines and development of Information and Communication Technologies (ICT) are regarded as the cornerstones of these changes. These developments have also brought great transformations in business and caused to be described as *"revolution"*. The plow in the agricultural revolution, the steam boiler in the industrial revolution and computers in the ICT revolution were the technological developments that played an important role in their own periods. These developments have led to changes in structure of business activities both production and service industries (Fidan, 2013; Fidan, 2014). Nowadays, a new revolution called Industry 4.0 has been mentioned, which bases on systems that operate automatically by communicating machines with each other.

Knowledge Management (KM) that companies have focused on sensitively for the last two decades has become an important issue in terms of the corporate operations of companies. The concept of KM, which argues that the success of the company depends on the stock of information it has and that organizational implicit knowledge must be revealed to achieve success, is generally defined as a system that includes data production, data transmission and data analysis (Tiwana, 2000). Data production includes the acquisition of data from company processes and data transmission includes the sharing of data between production units.

Data analysis, which includes methods such as statics, data mining, machine learning and artificial intelligence, aims to reveal hidden information for supporting firm decisions. For example, as a result of the analysis of time, quality, cost, so on of a machine tool process, information about the effectiveness of these operations can be obtained in data analysis. Today, planning the production processes that are intertwined with technology, preparing technological infrastructure and implementing the applications for the future technologies has become the main issues of the companies. It is possible to form industrial processes according to technology by using appropriate technology management and effective data analysis.

Internet of Things (IoT), which provides a different perspective on technology management issues, has been widely heard in the industry for last decade. The concept based on the principle of data communication between machine-machine, machine-human and human-human is one of the basic components of Industry 4.0. IoT systems have a structure that can perform not only data transmission but also data generation and decision support processes. For this reason, it is defined as a system having relational structure that includes humans and machines as well as devices (Patel and Patel, 2016). According to this definition, it can be said that IoT systems generally contain three basic components: decision support system, data generation and data transmission. Sensors, Radio Frequency Identification (RFID) and readers are involved in data production, while wireless communication techniques are involved in data transmission. Data analyzing techniques such as statistics, data mining and machine learning are used in decision support applications.

Industry 4.0 is defined as a set of systems aiming the communication and manages of machines based on data production, transmission, storage and analysis (Lasi et al., 2014). According to this definition, it is clear that data processing issues in KM are crucial subjects for Industry 4.0. In this context, it must be stated that the main objectives of Industry 4.0 are data production, data transmission and data analysis. This study focuses on the basic components of IoT systems, the usage of IoT systems in business process, advantages and potential problems of IoT systems in company processes in context of KM.

2. Knowledge Management

The concept of knowledge, which is defined as justified and rationalized facts, is accepted as a power that increases of individual and organizational value (Fidan, 2014). Knowledge, which is seen as an entity whose importance never decreases, is obtained by processing information that is defined as the organized and systematic form of data (Tiwana,

2000). In other words, information is obtained by systematically organizing the data acquired as a result of observations about current situations, while knowledge is obtained by processing the information. The knowledge obtained can be used as data for another knowledge production. Considering this cyclical transformation to access information, it would not be wrong to state that the most important and fundamental component of this dynamic process is data. In this context, it would be an appropriate approach to argue that information quality is directly related to data quality.

KM is one of the main research fields of organizations. The concept was formed by a project of McKinsey determining that the main problem in organizations is the sharing of industrial information produced. McKinsey implemented the project in 1987 to identify those information sharing problems in organization. As a result of the project, it was revealed that employees have high extensive knowledge in organizations, but this knowledge potential could not be turned into an advantage by companies and could not be used for higher quality service (Perepu, 2007). Regarding the solution of knowledge sharing problem, it has been suggested to save all company projects in a database, to create a core information stock with 2000 documents and a list containing keywords. In the light of these suggestions, it can be said that McKinsey approaches on KM are focused on collecting data and sharing knowledge. After the McKinsey project, studies on KM have dealt with the subject in a similar framework and the definition of KM has been realized on the basis of McKinsey's approaches. In this context, KM is defined as the process of obtaining, distributing and using knowledge in organizations effectively (Davenport and Prusak, 1998; Tiwana, 2000). This definition, which is the most accepted in the literature developed by Davenport and Prusak, also draws a road map for KM processes.

Firms recognizing the importance of KM aim to reveal their intellectual knowledge potentials by providing efficiency in their human capital management (Andreeva and Kianto, 2012). The knowledge potential increases the production of new knowledge and thus the innovation capacity of the firm (Alavi and Leidner, 2001). Furthermore, increasing of the organizational know-how will lead to decrease in level of uncertainty and risk faced by companies (Madsen and Desai, 2010). In this context, companies lead to produce new knowledge in company processes by adding the new information to their information stock (Vasudeva and Anand, 2012). In this way, they can realize more effective strategic plans.

KM strategies of companies are closely related with technological processes. KM, which is a dynamic subject, is an area that requires companies to follow technology-appropriate processes. For this reason, it

can be stated that KM is a concept developing through information and communication technologies. Especially by the developments of internet technologies, it has been discussed more intensively in the academic areas since the 2000s. Academic researches generally focus on human, technology, management and organizational issues (Inkinen, 2016). While human-oriented studies focus on human resources management and leadership (Liao, 2011), technology-oriented studies are on performance analysis of new technologies (Kim and Hancer, 2010).

Data processing is one of the most fundamental tools of KM processes. For this reason, technologies related to data processing have crucial importance in KM efficiency. Data production, data acquiring and data transmission must be faultless, perfect and punctual in order to reveal implicit knowledge. In this context, IoT technologies that increase efficiency in data processing offer companies significant opportunities. For this reason, IoT technologies attract the KM researchers as well as companies.

3. Industry 4.0 and Knowledge Management

Industry 4.0 described as automation of devices that communicate each other for process controls, is accepted as a new industrial revolution (Lasi et al., 2014). This revolution, which has the potential to affect all company processes and therefore lead to requiring to be revised of firm activities, includes data communications for human-human, human-machine and machine-machine (Cooper and James, 2009; Bi, Xu, and Wang, 2014). For this reason, the changes by Industry 4.0 also affect the KM processes, and some researchers emphasize these changes as KM 4.0 (Dominici et al., 2016).

The positive effects of information and communication technologies on business models are agreed by all researchers (Zoroja, 2015). In this context, Industry 4.0 is considered as an important technology that offers significant opportunities for new business models. The IoT technologies are considered as the most important part of Industry 4.0 systems (Kagermann, 2014). According to Kagermann, IoT technology is a crucial component of production and service processes in Industry 4.0. For the purpose of smart factory, IoT systems provide the opportunity to monitor the working conditions of the machines, energy consumptions, process times and other parameters to control production process. According to another view, IoT is a network system based on data communication including all company activities such as Enterprise Resource Planning (ERP), Supply Chain Management (SCM), Customer Relationships Management (CRM), Operation Management (OP) (Gamarra, Guerrero, and Montero, 2016).

3.1. IoT and System Architecture

IoT is a technology built on obtaining real-time data in the production process and sharing it with other end units such as employees, devices, and machines (Bi, Xu, and Wang, 2014). Gubbi et al. (2013) stated that IoT systems consist of four components: Radio Frequency Identification (RFID), wireless sensor network (Wireless Sensor Networks - WSN) data storage-analysis and application layer. According to another approach, the IoT system consists of five components: RFID, WSN, Middleware, Cloud computing and IoT application software (Lee and Lee, 2015). Patel and Patel (2016), realizing a more general categorization, stated that IoT systems consist of four components: sensor layer, network layer, management service layer and application layer. When the literature on system architecture of IoT is evaluated incontext of KM, it will be a suitable approach to examine the system by having 3 general layers: data generation, data transmission and data storage-analysis. The IoT system structure within the scope of KM is given in Figure 1.

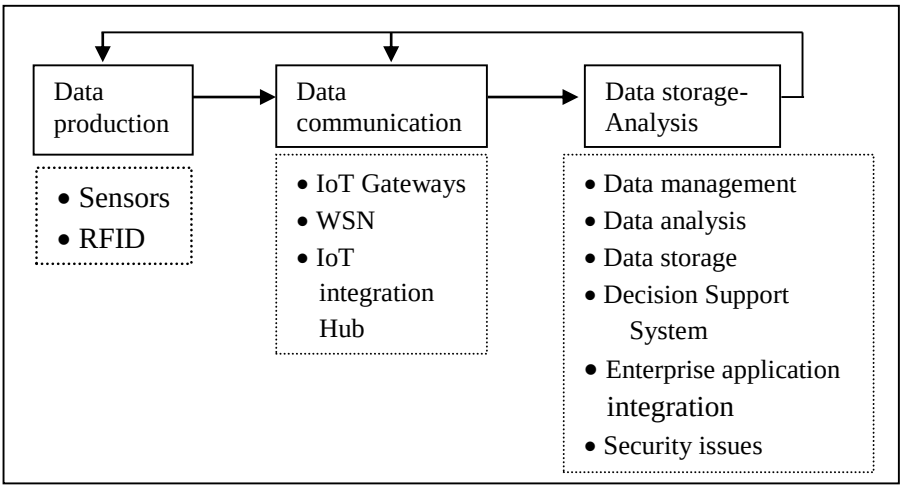


Figure 1: IoT system architecture

Figure 1 shows the general structure of the IoT system based on KM. The data obtained from the objects connected to the internet are transmitted to the IoT gateway and Integration Hub in the data communication layer. The IoT Integration Hub, which assumes the device connectivity and managements, performs the synchronization of the connected nodes in the network. In this way, it brings together the data obtained from data production layer and makes the data available in company processes. As seen in Figure 1, data storage, data analysis, data security, data management and data sharing operations are performed in the data storage-

analysis layer. This layer also realizes the integrations of company decision support systems with applications such as ERP, CRM, SCM used by the company.

3.1.1. Data Production Layer

Data production layer is a part on which IoT systems establish relationships with the outside world. In other words, the environmental data of the system is collected in data production layer by using sensors, RFID, objects, machines, so on. In particular, RFIDs are one of the main devices of IoT systems for object-based data acquisition.

RFID tag is a data capturing device includes object identification information and automatically sends the information it contains to the reader via wireless communication (Yüksel and Yüksel, 2011). An RFID system has two basic components, RFID tags and RFID readers. A RFID tag consists of a microchip that holds the object identification information in Digital and Analog blocks and an antenna used for communication. A demodulator and a modulator are used for modulating data. A passive RFID tag architecture is shown in Figure 2.

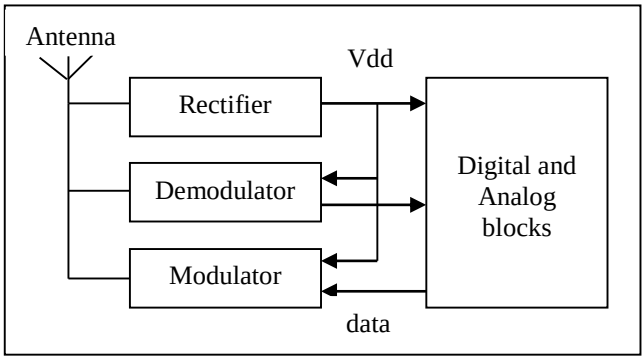


Figure 2: Architecture of passive RFID tag (Yüksel and Yüksel, 2011)

RFID reader is a transmitter-receiver device working with radio frequency. The RFID reader includes a microcontroller to analyze the tag information it reads, a communication module and an I/O module for external device connections. A basic RFID reader scheme is given in Figure 3.

An RFID system that includes tags and readers has a very simple operating principle. The RFID reader radio frequency signal triggers the RFID tags in the system through its antennas and the triggered RFID tag becomes active. The activated RFID tag sends the object data stored in its memory. Thus, the RFID reader obtains object identification information.

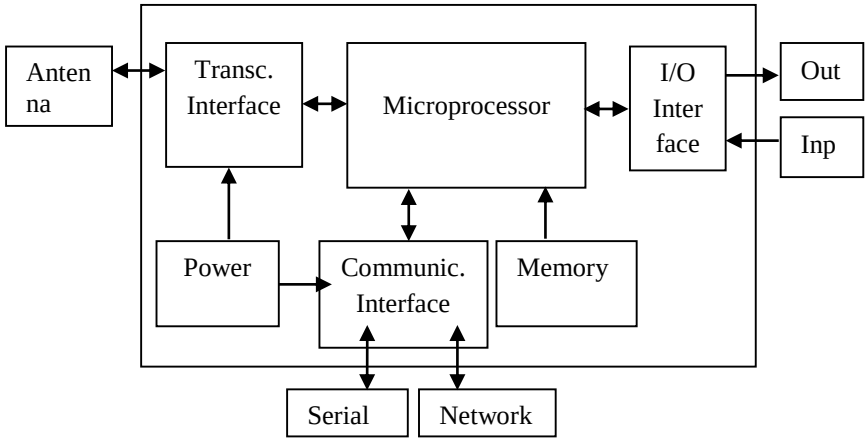


Figure 3: Architecture of RFID reader (Yüksel and Yüksel, 2011)

3.1.2. Data Comminication

Ensuring an efficient flow of information between business units in organizations is one of the main objectives of KM (Hendricks, 1999; Tiwana, 2000). Especially, delivering information to the right target at the right time is directly related to process efficiency. Technological developments play a critical role in the establishment of KM system (Omotayo, 2015). In this context, IoT systems based on the idea of the communication of objects have brought different approaches to KM.

Wireless networks are used for object communications in IoT systems. Wireless data transmission systems developed to collect the environment and status data obtained from sensors at the terminal units called Node at a central point are defined as WSN (Kabara and Calle, 2012). WSN is used to establish communication between IoT units by using certain communication protocols. The communication protocol is selected by considering features such as energy consumption, data quantity, environmental conditions, network topology and communication distance. Some of the communication protocols and properties used in IoT systems are given in Table 1.

Table 1: WSN protocols and some features

Protocol	Standart	Frequency	Topology	Power	Range	Data Rate
6LoWPAN	IEEE 802.15.4	868Mhz (EU) 915Mhz (USA) 2.4Ghz (Global)	Star Mesh	(1-2 years lifetime on batteries) Low power consumption	Short Range 10-100 m	250 kbps
Zigbee	IEEE 802.15. 4	2.4 GHz	Star Mesh Cluster Network	30 mA Low power	Short Range 10-100 m	250 kbps
BlueTooth	IEEE 802.15.1	2.4 GHz	Star Bus	30 mA Low power	Short Range 15-30 m	1 Mbps
NFC	ISO/IEC 14443 A&B,JIS X-6319- 4	125Khz 13.56Mhz 860Mhz	P2P	50 mA low power	Short Range 0-10cm 0-1m 10cm-1m	106, 212 or 424 kbps
Cellular	GPP GSMA, GSM/GPRS/EDGE (2G), UMTS/HSPA (3G), LTE (4G)	Common Cellular bands	NA	High power consumption	Several km	NA
Z-Wave	Z-Wave	868 MHz - 908 MHz	Mesh	2.5 mA Low power consumption	30m(indoor) 100m(outdoor)	40kbps

Al-Sarawi et al., 2017

3.1.3. Data Storage-Analysis

According to a research report conducted by Gartner, it is estimated that the number of objects that will be connected to the internet in the world in 2020 will exceed 20 billion (Egham, 2017). Considering such high amount of data production, it would not be wrong to say that the most critical component of IoT systems will be data storage and data analysis in the future. The results achieved by storing and analyzing data will enable decisions that will guide the operation of the IoT system. The amount of data that will be produced in an IoT system is proportional to the size of the system and the life span of the system. The data storage strategy should be planned considering the data production capacity of each device in the IoT system. For this reason, choosing the appropriate databases to be used in the data recording process according to the IoT application will provide an advantage in terms of cost and effectiveness.

Distributed databases are used for data storage process in case IoT application contains distant geographic areas. In distributed systems, data is saved not only in the local database, but also in different locations. Cloud computing, which is defined as the systems that store data and run applications on different computers, provides effective solutions especially in big data analysis that express different types of data. In huge and distributed IoT applications, it would be appropriate to use large data-based cloud databases to save different types of data such as images, videos and text.

Large amounts of data will be obtained with the enormous data generation capacity of IoT systems. Traditional statistical methods will not be sufficient to analyze such a large amount of data. For this reason, companies that plan their IoT systems strategy need to create strategies related to large data analysis, machine learning and artificial intelligence at the same time. Failure in the analysis process will become the biggest obstacle to the success of IoT systems. Another important issue is the integration of the information obtained after the analysis process within the company. Integration of the knowledge obtained by analysis with enterprise applications will increase the efficiency of IoT systems.

4. Advantages of IoT Systems Based on Knowledge Management

Developing operational processes according to technologies has vital importance for companies. For this reason, the use of IoT systems within the scope of KM, which provides important advantages to companies, enables the processes more effective.

4.1. Data Acquisition

Collecting and recording data on company processes systematically is an important issue for KM success. The most common errors are human-oriented faults and occur during data collection and data recording phase (Bock et al., 2005). The fact that classical data collection and recording processes are performed manually means that error possibilities are high. Since company decisions are shaped by data obtained from the situation and process operations, the accurate and complete data is directly related to the accuracy of the company decisions. For this reason, the data production process, which has data collection and recording stages, is one of the important processes in KM. In this context, sensor and RFID technologies used in the IoT system mean that human-induced problems in data production are eliminated.

Data collection, data storage and data transmission processes are carried out via RFID, ensuring that data transactions are error-free, easy, secure and fast. In this respect, RFID technology is one of the main tools in data generation for IoT system. RFID, which offer a contactless and wireless technology for auto identification of objects, bring many advantages to companies for business processes such as production, storage and logistics. RFID systems, which allow the possibility of minimizing the possibility of missing information about products and processes and the development of instant stock and product tracking systems, increase management efficiency and contribute positively to the profitability of the company (Robert, 2006; Shepard, 2005). RFIDs, which have a very wide application area, are systems that can be used in all processes of production and service sectors, especially retail, logistics, health and tourism.

Data collection from company processes is not instantaneous. In other words, company processes should be continuously monitored within the planned time frame and the data in these processes should be recorded continuously. A separate unit and worker should be employed in companies for data recording. The workforce to be employed for data collection has a cost to the firm. Considering that the company's fields of activity do not consist of only a few processes, it is clear that the said cost will increase. However, the fact that there is no need for any workforce for data collection and recording in IoT systems means that companies get rid of this cost. On the other hand, it is another matter that the efficiency of data collection workers in classical KM applications is inversely proportional to the working time. The performance of the employee performing the data collection process in the first hours of work will decrease as the working time increases due to attention deficit and

concentration problems (Hunter and Thatcher, 2007). This will decrease the quality of data observed.

4.2 Data Sharing

The main problem for KM project of McKinsey is the low level of information sharing within the company and reducing effectiveness of the company. According to McKinsey, the regulation of the information flow means the use of the implicit information stock of the company. In parallel with today's developing technology, there have been variations in company objectives within the scope of KM, but there has been no change in the starting point. In other words, the main issue of KM process is the effective use of information sharing within the company. IoT system is a technology that can realize in-house information flow and data sharing in real time. According to Patrizio (2018), the main purpose of companies in transitioning to IoT systems is to enable real-time data sharing. The realization of data sharing between company units such as supply chain, production, marketing, and human resources is as important as data sharing among employees. For example, the fact that marketing, warehouse management and production units can instantly see the amount of product owned will contribute to the decision-making process of the level of demand.

The general tendency of the companies is that they do not share information with their customers and their competitors in the sector. In market economy, asymmetric information is dominant. Valuable information that companies have is considered as one of the important advantage factors of the firm in terms of competition. For this reason, it is not possible for traditional companies to have a tendency to share information within the sector. However, IoT applications create new organizational loyalties as they can work in relation to systems used by companies or organizations within and outside the industry. For example, e-invoice systems, which are still being implemented, require the sector-related institutions, especially the company and the Ministry of Finance, to share data in an integrated manner. It is an inevitable result for companies in the competitive environment to share data with IoT technologies that have the potential to change the traditional view in terms of information sharing. Although the idea of sharing data with a competitor is not attractive to companies in terms of competition conditions, a study reveals that 22% of companies using IoT systems have data exchange agreements with competitors (Jernigan, Ransbotham and Kiron, 2016). According to another study with the participation of 9 countries, 400 employees and 250 managers, 75% of the managers stated that they can share IoT data if they will contribute to the companies (Aig, 2017). In the report prepared by the

European Commission on data sharing in business environments, IoT technology is shown as one of the goals determined within the framework of data sharing. In addition, it is emphasized in the same report that a successful data sharing policy depends on some factors such as trust, good understanding of data demand, cooperation, ease of use and legal regulations (Arnaut et al., 2018).

4.3 Decision Efficiency

It is generally accepted in the literature that the success of data analysis is directly related to data quality and data quantity. Using as much data as possible in the analysis means achieving healthy results and therefore making correct decisions. In high-volume data analysis, methods such as data mining, machine learning and artificial intelligence are used in large amounts of data analysis, since traditional analysis methods will yield limited results and will be insufficient. With the use of these analyses, data relationships and hidden information that traditional statistical approaches cannot determine can be obtained. However, processing large amounts of data will bring about the problem of recording media as well as a costly process. For example, a huge recording environment is needed for a system to be used in the field of medicine regarding patient data across the country. In addition, using a central recording system for this recording medium will reduce the efficiency. In order to increase data processing efficiency, it would be appropriate to use different systems such as distributed database systems instead of central ones.

Even in the first studies of McKinsey on KM, it was mentioned that there should be a database containing the core information stock of the company. Storage of data and its ability to be used when necessary is considered among the fundamental issues in KM, as it is important for analysis. Designing databases, storing data and performing analyzes in systems where large amounts of data are produced is a technical and vital issue that requires expertise in KM.

It is a wrong approach to make database designs to be used in data recording and analysis processes in KM based on data entries. Considering that the data will be used within the company's strategic plan, the efficiency of the system, data capacity and processing speed are issues to be taken into consideration. IoT data does not have a specific structure. It has various data types and timestamp. In this respect, the use of relational and cloud databases, especially in large-scale IoT systems, will increase the performance of the KM system.

5. Contributions of IoT Based Systems to Business Processes

Intention of companies providing high quality products to customers aim to increase their market power by planning their production costs to minimum. The basic condition for gaining market power is to have higher competitive advantage compared to other companies. For this purpose, companies aim to develop new methods and strategies in parallel with technological developments in their production processes. At this point, the basic question is that "Can IoT systems bring competitive advantages to business?"

Technology, one of the main determinants of competition, is accepted as a force that can lead to structural changes in sectors (Porter, 1985). IoT systems, which have attracted the attention of large groups in the last decade, are seen as an exciting technological development that provides an advantage to companies (Jernigan, Ransbotham, and Kiron, 2016). Companies have already begun to explore how to apply IoT technologies with the goal of improving business processes. Organizations that realize the advantages of IoT systems have begun to prepare themselves for IoT technologies. The following subsections introduce possible contributions of IoT systems to some business processes.

5.1 Automation

The provision of inter-object communication reveals different approaches in automation systems used in the production and service sectors. With the start of the analysis, decision and implementation processes to be made entirely by IoT systems, the concept of automation is carried to a completely different dimension. Data collection process, analysis, decision-making and routing of systems designed with IoT technology will create a dynamic system structure in automation. System applications such as a machine that predicts malfunction, a production line that detects low production quality, a system that predicts employee productivity from social media sharing, and production line balancing according to demand and stock status will contribute to production processes.

5.2 Tracking/Monitoring in Real-Time

Effective use of production factors is an important issue in all scientific area, especially engineering and economics. Realization of optimum production at the point of efficient use of resources is among the basic principles for efficiency. In this context, it is very important to monitor the production factors from the beginning to the end of the production process. However, due to some deficiencies such as factor insufficiencies and lack of technology, establishing and maintaining monitoring systems is costly for companies and becomes impossible. Due to the data collection and

communication possibilities of IoT systems, it is possible to easily implement real-time and automatic monitoring systems. Although IoT-based monitoring systems, which have very low operating costs, have been used in the logistics sector for the last 10 years, interestingly, they have not become widespread in other sectors. Especially with RFID integration, it is clear that real-time monitoring systems will make great contributions in both production and service sectors (Werner and Schill, 2009). Real-time stock control systems, monitoring workers, tracking car system can be given as examples.

5.3 Decreasing the Human Factor

The most basic element in successful analysis is the collecting of sufficient and qualified data. There is a high probability of errors, especially in data collected manually. It is inevitable that data quality will be low, especially during the collection of large amounts of data, since data is obtained and saved from production processes manually. For this reason, it is necessary to organize and extract data before analysis. This situation, which means interference with the collected data, negatively affects the analysis results when it is not done carefully. Realizing the data collection process with IoT systems means that human-related errors are also prevented in this process. Thanks to technologies such as sensors and RFID, the error rates in the data obtained will decrease and accordingly, the data analysis quality will increase. In this way, healthier analysis will be achieved. Especially in quality control processes performed by different people, errors that may occur due to personal evaluations will be minimized, and the efficiency of the quality control process will increase.

5.4 Productivity and Efficiency in Processes

The concept of productivity, which has been examined in a wide range, is evaluated according to different parameters according to sectors, business area and companies. For this reason, there is no standardized tool for measurements (Sauermann, 2016). Productivity, which is defined as the ratio of output to inputs in terms of quantity or money, can be considered separately depending on two factors as labor and capital, or it can be evaluated by considering all factors of production together (Fisher, 1990). However, the main view is that the increase of labor, capital, and method or process efficiency is considered to be the increase of the productivity of the firm or sector (Reynolds, 1998). In this respect, measuring worker or machine productivity is among the important issues for companies. In the analysis related to efficiency and effectiveness monitoring, IoT systems will enable the determination of the low-productivity employee or the machine in a healthy way, as they will ensure the monitoring of the whole process, complete collection of data and clear analysis. These contributions

can be seen significantly in the logistics sector. RFID supported cargo tracking systems minimize error rates in all processes and allow real-time tracking systems. In this way, companies in the sector, which prevent the workforce occupation caused by unnecessary calls, will increase customer satisfaction.

5.5 Data Security and Data Sharing Issues

Although it is a new technology, there are some security issues related to data source objects and wireless networks used in the IoT system. Particularly, security problems such as reading data from objects, colonizing and modifying cause security vulnerabilities in IoT systems. Cryptographic techniques such as Elliptic Curve or mutual authentication algorithms are used to overcome the security problems related to object data (Koralalage and Cheng, 2008). Thanks to these algorithms, undesired persons or devices are prevented from reading data. Similarly, by using the same algorithms, it is ensured that the data can be safely transmitted to the target terminal. Thus, data sharing becomes more secure.

5.6 Cost Reduction

An IoT system contributes to the efficient operation of the production system by obtaining data from all objects in the production unit. In this way, it enables improvements to be made that will cause reductions in production costs. In addition, it enables the prediction of possible errors in the production system and malfunctions that may arise from machines. Thus, situations where production may be interrupted are prevented. Besides, RFID tags used in the data collection process of IoT systems prevent data errors that may be encountered during data collection.

5.7 Increasing Cooperation

An IoT system that analyzes the health status of a mine worker based on health data such as heartbeat, body temperature, breathing frequency. It decides whether to continue working according to the health status and location information of the worker. This decision is communicated to the administrator or/and the closest employee who can help the worker. Thus, the decrease in working performance is prevented and the health safety of the employee is ensured.

5.8 New Strategies in Processes

A production process is collections of relational decisions, processes, events and activities. IoT is a technology that provides the opportunity to increase the control and examination of these relational processes. It brings new possibilities for design, control and improvement of production

processes. In this context, IoT systems will make significant contributions to the development of new methods and strategies for business processes.

6. Conclusion

IoT technologies, which enable the establishment of decision-making mechanisms based on data by taking the decision processes of the company out of experience and habits, provide important opportunities in internal and external business processes. It is obvious that IoT systems will make significant contributions in data collection and analysis, healthy decision mechanisms, increasing company process efficiencies, decreasing costs and minimizing risks. In addition, thanks to the data sharing opportunities offered by IoT systems, customer relations, competition and relations with other companies in the sector will be moved to a different dimension. In this context, the increase in firm value in the upcoming periods will be related to the inclusion of IoT-based systems in business processes as well as brand and product value.

The use of IoT devices in business processes will lead to the emergence of large amounts of data. Collecting, organizing, storing and analyzing data related to company activities will have critical value in IoT-based systems. Integration of IoT systems with applications such as CRM, ERP and SCM will increase the efficiency of these applications by eliminating human-based errors in the data collection process. In this context, data analytics, data security and data analysis, which are the sub-topics of information management, will be among the issues that will gain importance for companies in the early stages, and big data and data sharing.

References

Aig. (2017). The Data Sharing Economy: Quantifying Tradeoffs that Power New Business Models, https://www.aig.com/content/dam/aig/america-canada/us/documents/brochure/the-data-sharing-economy-report.pdf (10.05.02019).

Alavi, M., and Leidner, D. E. (2001). Knowledge Management and Knowledge Management Systems: Conceptual Foundations and Research Issues. *MIS Quarterly*, 25(1), 107-136.

Al-Sarawi, S., Anbar, M., Alieyan, K., and Alzubaidi, M. (2017). Internet of Things (IoT) Communication Protocols: Review. In Proceedings of the 2017 8th International Conference on Information Technology (ICIT), Singapore, 27–29 December 2017, 685–690.

Andreeva, T., and Kianto, A. (2012). Does Knowledge Management Really Matter? Linking KM Practices, Competitiveness and

Economic Performance. *Journal of Knowledge Management*, 16(4), 617-636.

Arnaut, C., Pont, M., Scaria, E., Berghmans, A., and Leconte, S. (2018). Study on Data Sharing between Companies in Europe. European Commission Final Report. https://publications.europa.eu/en/publication-detail/-/publication/8b8776ff-4834-11e8-be1d-01aa75ed71a1/language-en (10.05.2019).

Bi Z., Xu L.D., and Wang C. (2014). Internet of Things for Enterprise Systems of Modern Manufacturing. *IEEE Transactions on Industrial Informatics*, 10(2), 1537-1546.

Bock, G. W., Zmud, R. W., Kim, Y., and Lee, J. N. (2005). Behavioral Intention Formation in Knowledge Sharing: Examining the Roles of Extrinsic Motivators, Social-Psychological Forces, and Organizational Climate. *MIS Quarterly*, 29(1), 87-111.

Cooper, J., and James, A. (2009). Challenges for Database Management in the Internet of Things. *IETE Technical Review*, 26, 320-329. doi:10.4103/0256-4602.55275

Davenport, T. H., and Prusak, L. (1998). *Working Knowledge*. Harvard Business School Press, Boston, USA.

Dominici, G., Roblek, V., Abbate, T., and Tani, M. (2016). Click and Drive: Consumer Attitude to Product Development towards Future Transformations of Driving Experience. *Business Process Management Journal*, 22, 420-434. doi:10.1108/BPMJ-05-2015-0076

Egham, U. K. (2017). Gartner Says 8.4 Billion Connected "Things" Will Be in Use in 2017, Up 31 Percent From 2016. Gartner, https://www.gartner.com/en/newsroom/press-releases/2017-02-07-gartner-says-8-billion-connected-things-will-be-in-use-in-2017-up-31-percent-from-2016

Fisher, T. (1990). Business Productivity Measurement Using Standard Cost Accounting Information. *International Journal of Operations & Production Management*, 10(8), 61-69. https://doi.org/10.1108/01443579010142243

Gamarra, C., Guerrero, J. M., and Montero, E. (2016). A Knowledge Discovery in Databases Approach for Industrial Microgrid Planning. *Renewable & Sustainable Energy Reviews*, 60, 615-630. doi:10.1016/j.rser.2016.01.091View Full Reference List).

Gubbi, J., Buyya, R., Marusic, S., and Palaniswami, M. (2013). Internet of Things (IoT): A Vision Architectural Elements and Future Directions. *Future Generation Computer System*, 29(7), 1645-1660.

Hunter, L. W. and Thatcher, S. M. B. (2007). Feeling the Heat: Effects of Stress, Commitment and Job Experience on Job Performance. *Academy of Management Journal*, 50(4), 953-968.

Jernigan, S., Ransbotham, S., and Kiron, D. (2016). Data Sharing and Analytics Drive Success with IoT, *MIT Sloan Management Rev.*, http://sloanreview.mit.edu/projects/data -sharing-and-analytics-drive-success -with-internet-of-things

Kabara, J., and Calle, M. (2012). MAC Protocols Used by Wireless Sensor Networks and a GeneralMethod of Performance Evaluation. *Hindawi Publishing Corporation International Journal of Distributed Sensor Networks*, Article ID 834784, doi:10.1155/2012/834784

Kagermann, H. (2014). Chancen von Industrie 4.0 nutzen (Seizing opportunities of Industry 4.0). In Bauernhansl T., Hompel M., Vogel-Heuser B. (Eds.), *Industrie 4.0 in Produktion, Automatisierung und Logistik. Anwendung, Technologien und Migration (Industry 4.0 in production, automation and logistics. Application, technologies and migration)*, 603-614, Springer: Wiesbaden, Germany.

Kim, Y. J., and Hancer, M. (2010). The Effect of Knowledge Management Resource Inputs on Organizational Effectiveness in the Restaurant Industry. *Journal of Hospitality and Tourism Technology*, 1(2), 174-189.

Koralalage, S., and Cheng, J. (2008). A Comparative Study of RFID Solutions for Security and Privacy: POP vs. Previous Solutions, International Conference on Information Security and Assurance, https://doi.org/10.1109/ISA.2008.89

Lasi, H., Fettke, P., Kemper, H. G., Feld, T., and Hoffmann, M. (2014). Industry 4.0. *Business & Information Systems Engineering*, 6(4), 239–242.

Lee, I., and Lee, K. (2015). The IoT: Applications, Investments, and Challenges for Enterprises. *Business Horizons*, 58, 431-440. doi:10.1016/j.bushor.2015.03.008

Lee, J., Bagheri, B., and Kao, H. A. (2015). A Cyber-Physical Systems Architecture for Industry 4.0-based Manufacturing Systems. *Manufacturing Letters*, 3, 18-23.

Liao, Y.S. (2011). The Effect of Human Resource Management Control Systems on the Relationship between Knowledge Management Strategy and Firm Performance. *International Journal of Manpower*, 32(5/6), 494-511.

Madsen, P. M., and Desai, V. (2010). Failing to Learn? The Effects of Failure and Success on Organizational Learning in the Global Orbital Launch Vehicle Industry. *Academy of Management Journal*, 53(3), 451-476.

Omotayo, F. O. (2015). Knowledge Management as an Important Tool in Organisational Management: A Review of Literature. *Library Philosophy and Practice (e-journal)*, 1238. http://digitalcommons.unl.edu/libphilprac/1238

Patel, K., and Patel, S. (2016). Internet of things-IoT: Definition, characteristics, architecture, enabling technologies, Application & Future Challenges. *International Journal of Engineering Science and Computing*, 69(5), 6122-6131.

Patrizio, A. (2018). Data Sharing is the Main Driver for IoT Projects. Network World, https://www.networkworld.com/article/3326536/data-sharing-the-main-driver-for-iot-projects.html (09.05.2019).

Perepu, I. (2007). McKinsey's Konowledge Management Practices. ICMR Center of Management Research. https://astro.temple.edu/~wurban/Case Studies/McKinsey Knowledge Management.pdf

Porter, M. E. (1985). Technology and Competitive Advantage. *Journal of Business Strategy*, 5(3), 60–78.

Reynolds, D. (1998). Productivity Analysis: In the onsite Food-service Segment. *Cornell Hotel and Restaurant Administration Quarterly*, 39(3), 22-31.

Roberts, C. M. (2006). Radio Frequency Identification (RFID). C*omputers & Security*, 25, 18–26.

Sauermann, J. (2016). Performance Measures and Worker Productivity. *IZA World of Labor*, 260, doi: 10.15185/izawol.260

Shepard, S. (2005). *RFID: Radio Frequency Identification*. McGraw-Hill Companies, NY, USA.

Vasudeva, G., and Anand, J. (2012). Unpacking Absorptive Capacity: A Study of Knowledge Utilization from Alliance Portfolios. *Academy of Management Journal*, 54(3), 611-623.

Werner, K., and Schill, A. (2009). Automatic Monitoring of Logistics Processes Using Distributed RFID based Event Data. *International Workshop on RFID Technology (IWRT*), Milan, Italy, 101-108.

Yüksel, M. E., and Yüksel, A. S. (2011). RFID Technology in Business Systems and Supply Chain Management. Journal of Economic and Social Studies, 1(1), 53-71.

Zoroja, J. (2015). Fostering Competitiveness in European Countries with ICT: GCI Agenda. *International Journal of Engineering Business Management*, 7(18), doi:10.5772/60122

CHAPTER VII

MODIFYING THE UNIVERSITY OF BRITISH COLUMBIA APPROACH

Dr. Meric Can OZYURT

Istanbul University-Cerrahpasa, Istanbul, Turkey, e-mail: meric.ozyurt@istanbul.edu.tr
Orcid No: 0000-0002-7545-7756

Dr. Abdulkadir KARADOGAN

Istanbul University-Cerrahpasa, Istanbul, Turkey, e-mail: akadir@istanbul.edu.tr
Orcid No: 0000-0001-7321-3320

1. Introduction

It is very important to determine the most suitable mining method in efficiency and profitability, given that mine reserves are generally considered finite depletable resources. An incorrect decision regarding mining methods can adversely affect mining operations and result in substantial financial losses.

Therefore, many researchers have studied how to optimised the selection of mining methods, including Peele and Church, 1941; Boshkov and Wright, 1973; Morrison, 1976; Nicholas, 1981; Laubscher, 1981; Karabeyoğlu, 1986; Demirbilek, 1987; Hartman, 1987; Marano and Everitt, 1987; Bandopadhyay and Venkatasubramanian, 1988; Agoshkov, Borisov and Boyarsky, 1988; Hamrin, 1988; Hartman, 1992; Camm and Smith, 1992; Bibb and Hargrove, 1993; Brady and Brown, 1993; Demirci, 1993; Nicholas, 1993; Mutagwaba and Terezopoulos, 1994; Gershon, Bandopatdhyay and Panchanadam, 1995; Miller et al., 1995; Tatiya, 1998; Gertsch and Bullock, 1998; Basu, 1999; Kahriman, 2000; Karadogan, Kahriman and Bascetin, 2001; Kesimal and Bascetin, 2002; Clayton, Pakalnis and Meech, 2002; Samimi Namin, Shahriar and Kariminasab, 2003; Yiming, Ying and Weixuan, 2003; Guray et al., 2003; Samimi Namin, Shahriar and Kariminasab, 2004; Bitarafan and Ataei, 2004; Yiming, Ying and Weixuan, 2004; Miranda and Almedia, 2005; Bascetin, 2005; Alpay and Yavuz, 2007; Yavuz, Iphar and Once, 2008; Ataei et al., 2008; Samimi Namin et al., 2008; Karadoğan, Kahriman and Ozer, 2008;

Jamshidi et al., 2009; Zare Naghadehi, Mikaeil and Ataei, 2009; Samimi Namin et al., 2010; Bogdanovic, Nikolic and Ilic, 2012; Azadeh, Osanloo and Ataei, 2010; Ataei, Shahsavany and Mikaeil, 2013; Gélvez, Aldana and Sepulveda, 2014; Karimnia and Bagloo, 2015; Yavuz, 2015; Lv and Zhang, 2015; Chen and Tu, 2015; Jianhong, Zou and Ren, 2015; and Dehghani, Saimi and Haghi, 2017.

For the first time, Nicholas (1981) suggested a numerical approach for underground mining method selection . The Nicholas methodology accepts applicability as the basic principle and follows a numerical approach to rate different underground mining methods based on the rankings of specific input parameters such as ore geometry, grade distribution, and ore/rock characteristics. A numerical rating for each underground mining method is arrived at by summing these rankings. The higher the rating, the more suitable the underground mining method.

In the following years, new findings obtained from technological developments and scientific/sectoral studies have resulted in significant changes to many selection criteria and related mining methods, thus, causing conclusions presented by Nicholas (1981) to be outdated. Later, Miller et al. (1995) studied the Nicholas Approach's modification in accordance with the level of knowledge and technology at that time (Edumine, 2018); and and developed the University of British Columbia (UBC) approach. This modification involved adding new input parameters and weighting of various categories.

The UBC approach continues to form the basis of many studies today (Miller et al., 1995; Alpay and Yavuz, 2007; Samimi Namin et al., 2008; Azadeh, Osanloo and Ataei, 2010; Karimnia and Bagloo, 2015; Yavuz, 2015; Dehghani, Saimi and Haghi, 2017; Ozyurt, 2018).

2. University Of British Columbia (UBC) Approach

Miller et al. (1995) developed the UBC approach, whereby the selection criteria are evaluated numerically with different ratings according to applicable mining methods (Table 1-3). The highest rating is given to the most suitable mining method from a technical perspective. In this approach, the selection criteria are classified as either eliminated (-49), very unlikely (-10), unlikely (0), probable (1-2), preferred (3-4), and very preferred (5-6).

Table 1 UBC Approach (Part I)

Mining Method	Ore Shape			Ore Thickness (m)				
	Massive	Tabular	Irregular	< 3	3-10	10-30	30-100	>100
Block Caving	4	2	0	-49	-49	0	3	4
Sublevel Stoping	3	4	1	1	1	3	4	3
Sublevel Caving	3	4	1	-49	-49	0	4	4
Longwall Mining	-49	4	-49	3	3	0	-49	-49
Room and Pillar	0	4	2	3	3	1	-49	-49
Shrinkage Stoping	0	4	2	4	4	0	-49	-49
Cut & Fill Stoping	1	4	4	3	4	4	1	0
Top Slicing	1	2	0	1	1	0	2	1
Square Set Stoping	0	1	4	4	3	2	0	0

(Source: Miller et al., 1995)

Table 2 UBC Approach (Part II)

Mining Method		Rock Substance Strength (RSS)				Rock Mass Rating (RMR)				
		≤5	5-10	10-15	>15	≤20	20-40	40- 60	60-80	>80
Coal/Ore	Block Caving	4	2	1	0	4	3	2	0	-49
	Sublevel Stop.	0	2	4	4	1	3	4	4	4
	Sublevel Caving	2	3	3	2	3	4	3	1	0
	Longwall Mining	6	5	2	1	6	6	4	2	2
	Room and Pillar	0	0	3	6	-49	0	3	5	6
	Shrinkage Stoping	0	1	3	4	0	1	3	3	3
	Cut & Fill Stoping	0	1	3	3	0	1	2	3	3
	Top Slicing	3	2	1	0	3	2	1	1	0
	Square Set Stoping	4	3	1	0	4	4	1	0	0
Hanging Wall	Block Caving	4	3	2	0	3	3	3	2	2
	Sublevel Stoping	0	1	2	5	-49	0	3	4	4
	Sublevel Caving	4	3	2	1	4	4	3	2	2
	Longwall Mining	6	5	2	2	6	5	4	3	3
	Room and Pillar	0	0	2	6	-49	0	3	5	6
	Shrinkage Stoping	0	1	2	4	0	0	2	4	4
	Cut & Fill Stoping	3	5	3	2	3	5	4	3	3
	Top Slicing	3	2	2	2	0	0	2	3	3
	Square Set Stoping	4	2	1	0	4	4	1	0	0
Footwall	Block Caving	4	3	2	1	3	3	3	2	2
	Sublevel Stoping	0	1	3	3	0	0	2	3	3
	Sublevel Caving	1	2	2	2	1	2	3	3	3
	Longwall Mining	-	-	-	-	-	-	-	-	-
	Room and Pillar	-	-	-	-	-	-	-	-	-
	Shrinkage Stoping	0	2	3	3	0	0	2	3	3
	Cut & Fill Stoping	1	1	3	2	3	3	3	2	2
	Top Slicing	2	2	1	1	0	0	1	2	2
	Square Set Stoping	3	2	0	0	3	1	0	0	0

(Source: Miller et al., 1995)

Table 3 UBC Approach (Part III)

Mining Method	Ore Plunge(^{0})			Grade Distribution			Depth (m)		
	<20	20-55	>55	Uniform	Gradational	Erratic	<100	100-600	>600
Block Caving	3	2	4	3	2	2	2	3	3
Sublevel Stoping	2	1	4	4	4	3	3	4	2
Sublevel Caving	1	1	4	3	2	2	3	2	2
Longwall Mining	4	0	-49	4	1	0	2	2	3
Room and Pillar	4	0	-49	4	2	0	3	3	2
Shrinkage Stop.	-49	0	4	3	2	2	3	3	2
Cut & Fill Stop.	1	3	4	2	3	4	2	3	4
Top Slicing	4	2	0	2	1	1	2	1	1
Square Set Stop.	2	3	2	0	1	3	1	1	2

(Source: Miller et al., 1995)

The UBC approach offers solutions by ignoring specific criteria that play a constraining role in underground mining operations. The most significant drawback of the UBC approach is that it provides solutions without considering the constraining factors that adversely affect mining operation, and thus, the proposed methods should be updated by experts.

3. Selection Criteria and Underground Mining Methods

In this section, underground mining methods and selection criteria useful in method selection are explained. Ozyurt (2018) made a literature review on the underground mining method selection and presented the selection criteria and appropriate underground mining methods by the direct and indirect use of the most up-to-date information in Nicholas (1981), Demirbilek (1987), Bieniawski (1989), Hartman (1992), Bibb and Hargrove (1993), Brady and Brown (1993), Demirci (1993), Miller et al. 1995), Gertsch and Bullock (1998), Kahriman (2000), Karpuz and Hindistan (2008), Kose and Tatar (2011), Yalcin (2012), CSGB (2013), Simsir et al. (2013), Kuzu (2013), Kose and Kahraman (2014a), Kose and Kahraman (2014b), Simsir (2015), Tatar and Ozfirat (2016) and Ozyurt (2018).

The result of the literature review was presented in In Table 1 and 2. In these tables, * means that the underground mining method can be applied to all values for the criteria.

Table 4 Selection Criteria and Underground Mining Methods (Part I)

Selection Criteria	Longwall Mining	Diagonal Longwall	Shrinkage Stoping	Cut & Fill Stoping	Top Slicing	Sublevel Stoping	Open Room	Room and Pillar	Sublevel Stoping	Blok Caving	Square Set Stoping
Ore Type	Coal et. all	Coal et. all	Metal	Metal	*	Metal	*	*	Metal	Metal	*
Ore Composition	*	*	Sulfurless	*	Sulfurless	*	Sulfurless	*	*	*	Sulfurless
Ore Shape	Tabular	Tabular	Tabular/ Irregular	Tabular/ Irregular	*	Tabular/ Massive	Tabular/ Massive	Tabular/ Irregular	Tabular/ Massive	Tabular/ Massive	Irregular
Ore Thickness (m)	≤ 10	≤ 10	≤ 10	≤ 30	30 - 100	> 10	≤ 50	≤ 10	> 10	> 30	≤ 30
Ore Plunge (°)	≤ 36	> 36	> 55	> 55	≤ 55	> 55	*	≤ 36	> 55	> 55	*
Depth (m)	*	*	*	*	*	*	*	*	*	*	*
Grade	*	*	High	High	Intermediate	Intermediate	Intermediate	Intermediate	Low/ Intermediate	Low	*
Grade Distribution	Uniform	Uniform	*	Gradational/ Erratic		*	Gradational/ Uniform	Gradational/ Uniform	*	*	Erratic
Separation (O & R)	Significant	Significant	*	*	*	*	Significant	Significant	*	Significant	*
Ore - RMR	≤ 60	≤ 60	> 40	> 60	≤ 40	≤ 80	> 60	> 40	> 40	≤ 40	≤ 40
Ore - RSS	≤ 10	≤ 10	> 10	> 10	≤ 10	*	>10	> 10	> 10	≤ 5	≤ 10
Hanging Wall RMR	≤ 60	≤ 60	> 40	*	> 40	≤ 60	> 60	> 40	> 40	≤ 60	≤ 40
Hanging Wall RSS	≤ 10	≤ 10	> 10	*	*	≤ 15	> 10	> 10	> 10	≤ 10	≤ 10
Footwall RMR	> 40	> 40	> 40	*	> 60	> 20	> 60	> 40	> 60	≤ 60	≤ 40
Footwall RSS	> 10	> 10	> 5	> 5	≤ 10	> 5	*	*	> 10	≤ 10	≤ 10

Table 5 Selection Criteria and Underground Mining Methods (Part II)

Selection Criteria	Longwall Mining	Diagonal Longwall	Shrinkage Stoping	Cut & Fill Stoping	Top Slicing	Sublevel Stoping	Open Room	Room and Pillar	Sublevel Stoping	Blok Caving	Square Set Stoping
Overburden	*	*	*	*	*	*	*	*	*	*	*
Underground Water	*	*	*	*	*	None	*	*	*	None	*
Subsidence Effect	High	High	Low	Low	Low	High	Intermediate	Low	Low	High	Low
Explosive Dust	*	*	*	*	Risky	Risky	*	*	*	Risky	Risky
Explosive Gas	*	*	*	*	Risky	Risky	*	*	*	Risky	Risky
Oxidation	*	*	Risky	*	Risky	*	Risky	*	*	*	Risky
Economic Value	*	*	Low	*	High	*	Low	Low	*	High	High
Production Rate	Intermediate	Intermediate	Low	Low	Low	Intermediate	Intermediate	Intermediate	Intermediate	Maximum	Low
Dilution in Ore	20%	25%	30%	10%	10%	20%	5%	5%	20%	25%	0%
Loss in Ore	20%	35%	30%	10%	2%	35%	50%	45%	25%	40%	0%
Production Cost	40%	65%	50%	60%	70%	55%	25%	30%	30%	20%	80%
Cost of Capital	High	High	Low	Intermediate	Low	High	Intermediate	Intermediate	Intermediate	Intermediate	Low
Strata Control	*	*	Shrinkage	Stowing	Stowing	Caving	Open Room	Pillar	Pillar	Caving	Timbering
Ventilation Planning	Basic	Intermediate	Intermediate	Intermediate	Complex	Intermediate	Complex	Complex	Intermediate	Basic	Complex
Mechanization	Max	Intermediate	Low	Intermediate	Low	Intermediate	Intermediate	Intermediate	Intermediate	Low	Low
Risk-Based Safety	Intermediate	Intermediate	Risky	Intermediate	Intermediate	Risky	Risky	Risky	Risky	Risky	Safety
Efficiency	High	Intermediate	Low	Intermediate	Low	Intermediate	High	High	High	High	Low
Flexibility	None	None	Intermediate	None	None	Intermediate	High	Intermediate	Intermediate	None	High
Controlling	Easy	Kolay	Intermediate	Intermediate	Intermediate	Intermediate	Complex	Complex	Intermediate	Easy	Complex
Selectivity	None	None	None	None	None	Intermediate	High	High	Intermediate	None	High

4. Modifying the UBC Approach

In this section, the UBC Approach was modificated based on Table 4. The changes made were explained below.

The UBC approach uses the classification system presented in Table 1 for ore thickness. However, Kahriman (2000) suggested using sublevel caving and sloping methods for a 6 m thick deposit. Simsir (2015) suggested that longwall and diagonal longwall mining methods can be applied efficiently for deposits with a thickness of 5 m, whereas the room and pillar method works better for ores with a thickness of 6 m or more Hartman (1992) states that room heights could reach up to 50 m using the open-room method. It is reasonable to assert that ore thickness should be classified in different value ranges for each different mining method, given these previous studies' conclusions.

In the UBC approach, deposits with a plunge of 20° to 55° are intermediate (Nicholas, 1981). Given that gravity's effects begin at 37º (Simsir et al. 2013), which falls with the intermediate range, deposits with an intermediate plunge should be evaluated in two separate groups, those a plunge range from 18°-36º and the others in a range from 37°-55º. Thus, longwall mining and room and pillar methods should be listed among the applicable methods for deposits with an 18°-36º plunge.

In the UBC approach, the footwall's rock mass properties are neglected for longwall mining and room and pillar methods: In longwall mining, a weak hanging wall with a strong footwall is an important advantage (Hartman, 1992; Demirci, 1993; Kose and Tatar, 2011; Simsir, 2015). Therefore, for longwall mining, the rock mass properties of the footwall were scored in the exact opposite way of the hanging wall to account for this important distinction, whereas, for the room and pillar method, the footwall was scored the same way as the ore since it is an advantage that all rock units are strong (Hartman, 1992; Demirci, 1993; Kose and Tatar, 2011; Simsir, 2015).

The diagonal longwall, which was a variation to longwall mining and developed to be applied in deposits with plunges greater than 37º (Kose and Tatar, 2001; Simsir, 2015), was included in the new model. For diagonal longwall, ore plunge was scored as eliminated (-49) for deposits with a 0°-36º plunge, preferred (4) for a 37°-55º plunge, and unlikely (0) for a 55°-90º plunge. All other criteria were scored in the same way as the longwall mining.

The open-room method was also included. In this method preferred in deposits with very strong rock units, it is possible to open larger rooms than the rooms open in the room and pillar method (Kose and Tatar, 2011). Moreover, it can also be applied to massive or irregular-shaped deposits (Simsir, 2015). Therefore, for the open room method, rock mass properties were scored as eliminated (-49) for weak and very weak, unlikely (0) forAlso, massive deposits were scored as preferred (3), deposits with 18°-36º plunge were scored as preferred (3), deposits with 37°- 55º plunge were scored as probable (2), and steep deposits were scored as probable (1).

The most significant drawback of the UBC approach is that it provides solutions by ignoring ore type and the constraining factors such as subsidence effect, oxidation, explosive dust and gas, and underground water. For this reason, the results of the UBC method need to be re-evaluated by experts. To eliminate the necessity for re-evaluation process, the constraining factors were included in the modified approach as selection criteria.

The modified UBC approach is summarised in Tables 6-8 and the changes are highlighted in red.

Table 6 The Modified UBC Approach (Part I)

Selection Criteria		Block Caving	Sublevel Stoping	Sublevel Caving	Longwall Mining	Diagonal Longwall	Room & Pillar	Shrinkage Stoping	Cut & Fill Stoing	Top Slicing	Square Set Stoping	Open Room
Ore Shape	Massive	4	3	3	-49	-49	0	0	1	1	0	3
	Tabular	2	4	4	4	4	4	4	4	2	1	4
	Irregular	0	1	1	-49	-49	2	2	6	0	4	2
Ore Thickness (m)		(< 3) -49	(< 6) -10	(< 6) -49	(< 5) 4	(< 5) 4	(< 6) 4	(< 3) 4	(< 3) 3	(< 3) 1	(< 3) 4	(< 6) 0
		(3-10) -49	(6-10) 1	(6-10) 1	(5-10) 3	(5-10) 3	(6-10) 3	(3-10) 4	(3-10) 4	(3-10) 1	(3-10) 3	(6-10) 2
		(10-30) 0	(10-30) 3	(10-30) 2	(10-30) 0	(10-30) 0	(10-30) 1	(10-30) 0	(10-30) 4	(10-30) 0	(10-30) 2	(10-50) 4
		(30-100) 3	(30-100) 4	(30-100) 4	(30-100) -49	(30-100) -49	(30-100) -49	(30-100) -49	(30-100) 1	(30-100) 2	(30-100) 0	(50-100) 0
		(>100) 4	(>100) 3	(>100) 4	(>100) -49	(>100) -49	(>100) -49	(>100) -49	(>100) 0	(>100) 1	(>100) 0	(>100) -49
Ore Plunge	< 18º	3	2	1	4	-49	4	-49	1	4	2	4
	18-37º	2	1	1	3	-49	2	0	3	2	3	3
	37-55º	2	1	1	-10	4	0	0	3	2	3	2
	> 55º	4	4	4	-49	0	-49	4	4	0	2	1
Grade Distribution	Uniform	3	4	3	4	4	4	3	2	2	0	4
	Gradational	2	4	3	1	1	2	2	3	1	1	2
	Erratic	2	3	2	0	0	0	2	4	1	3	0
Depth (m)	< 100	2	3	3	2	2	4	3	2	2	1	4
	100-600	3	4	2	2	2	3	3	3	1	1	3
	> 600	3	2	2	3	3	2	2	4	1	2	2

Table 7 The Modified UBC Approach (Part II)

Selection Criteria			Block Caving	Sublevel Stoping	Sublevel Caving	Longwall Mining	Diagonal Longwall	Room & Pillar	Shrinkage Stoping	Cut & Fill Stoping	Top Slicing	Square Set Stoping	Open Room
RMR	Ore	≤20	4	1	3	6	6	-49	0	0	3	4	-49
		21-40	3	3	4	6	6	0	1	1	2	4	-49
		41-60	2	4	3	4	4	2	3	2	1	1	0
		61-80	0	4	3	2	2	5	3	3	1	0	3
		>80	-49	4	0	2	2	6	3	3	0	0	4
	Hanging Wall	≤20	3	-49	4	6	6	-49	0	3	0	4	-49
		21-40	3	0	4	5	5	0	0	5	0	4	-49
		41-60	3	3	3	4	4	2	2	4	2	1	0
		61-80	2	4	0	2	2	5	4	3	3	0	3
		>80	2	4	-10	1	1	6	4	3	3	0	4
	Footwall	≤20	3	0	1	1	1	-49	0	3	0	3	-49
		21-40	3	0	2	2	2	0	0	3	0	1	-49
		41-60	3	2	3	3	3	2	2	3	1	0	0
		61-80	2	3	4	5	5	5	3	2	2	0	3
		>80	2	3	4	6	6	6	3	2	2	0	4
RSS	Ore	≤5	4	0	2	6	6	0	0	0	3	4	0
		5-10	2	2	3	5	5	0	1	1	2	3	0
		10-15	1	4	3	2	2	3	3	3	1	1	2
		>15	0	4	2	1	1	6	4	3	0	0	4
	Hanging Wall	≤5	4	0	4	6	6	0	0	3	3	4	0
		5-10	3	1	3	5	5	0	1	5	2	2	0
		10-15	2	2	2	2	2	2	3	4	2	1	1
		>15	0	5	0	2	2	6	4	2	2	0	4
	Footwall	≤5	4	0	1	2	2	0	0	1	2	3	0
		5-10	3	1	2	2	2	0	2	3	2	2	0
		10-15	2	3	2	5	5	2	3	3	1	0	1
		>15	1	3	2	6	6	6	3	2	1	0	4

Table 8 The Modified UBC Approach (Part III)

Selection Criteria		Block Caving	Sublevel Stoping	Sublevel Caving	Longwall Mining	Diagonal Longwall	Room & Pillar	Shrinkage Stoping	Cut & Fill Stoping	Top Slicing	Square Set Stoping	Open Room
Subsidence Effect	Exist	-49	0	-49	-49	-49	0	0	0	0	0	-10
	None	0	0	0	0	0	0	0	0	0	0	0
Oxidation	Exist	0	0	0	0	0	0	-49	0	0	0	-49
	None	0	0	0	0	0	0	0	0	0	0	0
Explosive Dust or Gas	Exist	-49	0	-49	0	0	0	0	0	-49	-49	0
	None	0	0	0	0	0	0	0	0	0	0	0
Underground Water	Exist	-49	0	-49	0	0	0	0	0	0	0	0
	None	0	0	0	0	0	0	0	0	0	0	0
High Value	Low Grade	2	1	1	1	1	0	0	0	1	2	0
	Intermediate Grade	1	1	1	1	1	0	0	0	1	2	0
	High Grade	0	1	1	1	1	0	0	1	2	2	0
Low Value	Low Grade	0	1	1	1	1	1	0	0	0	2	1
	Intermediate Grade	0	1	1	1	1	2	1	0	0	2	2
	High Grade	0	1	1	1	1	1	2	1	1	2	1
Ore Type	Coal et al..	-49	-49	-49	0	0	0	-49	-49	0	0	0
	Metal	0	0	0	-49	-49	0	0	0	0	0	0

5. Implementation of the Modified UBC Approach on Underground Mine Deposits

In this section, the practice of using the UBC approach on 12 underground deposits, of which 10 were scientific study and 2 were from the industry were detailed. The technical characteristics of testing samples were shown in Table 9.

Table 9 Technical Characteristics of Testing Samples

Source No	Ore	Shape	Thickness (m)	Plunge (°)	Depth (m)	Grade
1	Iron	Irregular	1,5	80	80	Intermediate
2	Metal	Tabular	5	65	400	Intermediate
3	Metal	Massive	40	40	300	High
4	Coal	Tabular	2,3	5	55	High
5	Metal	Massive	50	68	200	Intermediate
6	Metal	Tabular	15	57	380	Intermediate
7	Chrome	Tabular	6	60	100	Intermediate
8	Iron	Massive	55	22	395	Intermediate
9	Coal	Tabular	1,5	16	600	Intermediate
10	Bauxite	Tabular	1	70	100	Intermediate
11	Iron	Massive	35	70	63	High
12	Copper	Massive	20	60	500	High
Source No	**Grade Distibution**	**Subsidence Effect**	**Underground Water (ltm)**	**HW RMR**	**HW RSS**	**FW RMR**
1	Uniform	None	None	Medium	Strong	Medium
2	Erratic	None	None	Strong	Strong	Strong
3	Uniform	None	None	Weak	Medium	Weak
4	Uniform	Exist	10-20	Medium	Weak	Medium
5	Gradational	None	None	Medium	Strong	Medium
6	Erratic	None	None	Weak	Weak	Weak
7	Uniform	None	None	Strong	Weak	Strong
8	Gradational	None	None	Weak	Weak	Weak
9	Uniform	None	None	Weak	Weak	Weak
10	Gradational	None	None	Medium	Very Weak	Strong
11	Gradational	None	1060	Weak	Strong	Weak
12	Gradational	Exist	40	Weak	Very Weak	Medium
Source No	**FW RSS**	**Ore RMR**	**Ore RSS**	**FW RSS**	**Risk of Oxidation**	**Risk of Dust or Gas Explosion**
1	Strong	Weak	Medium	Strong	Risky	Safe
2	Strong	Strong	Strong	Strong	Safe	Safe
3	Medium	Weak	Medium	Medium	Safe	Safe
4	Weak	Medium	Weak	Weak	Risky	Safe
5	Strong	Medium	Strong	Strong	Safe	Safe
6	Weak	Medium	Medium	Weak	Safe	Safe
7	Very Weak	Medium	Weak	Very Weak	Safe	Safe
8	Medium	Weak	Weak	Medium	Risky	Safe
9	Very Weak	Weak	Very Weak	Very Weak	Risky	Safe
10	Very Weak	Medium	Very Weak	Very Weak	Safe	Safe
11	Strong	Medium	Strong	Strong	Risky	Safe
12	Very Weak	Medium	Very Weak	Very Weak	Risky	Safe

In Table 9-11, Alpay & Yavuz (2009) was coded as 1, Guray et al. (2003) was coded as 2, Azadeh et al. (2010) was coded as 3, Karadogan (2001) was coded as 4, Kose & Tatar (2011) was coded as 5, Miller et al. (1995) was coded as 6, Kahriman et al. (1996) was coded as 7, Bitarafan & Ataei (2004) was coded as 8, Gélvéez et al. (2015) was coded as 9, Samimi Namin et al. (2009) was coded as 10, Anon (2018,a) was coded as 11 and Anon (2018,b) was coded as 12.

The UBC method and the modified UBC method was used to determine the most suitable mining methods for the samples whose properties are given in Table 6 and 7. According to the UBC method, the results are given in Table 8, and the results according to the modified UBC method are given in Table 9. The mining methods whose scores are highlighted in bold and italics are applicable for the relevant mine deposits, and the red color indicates the most suitable method.

The significant differences between the results (Table 8 & 9) are as follows:

The UBC method proposed the Cut & Fill Stoping, which is not applied in coal mining, as a solution alternative for Karadoğan (2001) ve Gelvez et al. (2015). However, according to the literature, the modified UBC method eliminated the Cut & Fill Stoping (Hartman, 1992).

The UBC approach presented the Top Slicing, which increases the fire risk, as a solution alternative for mine deposits with oxidation and dust/gas explosion risk mentioned in Alpay and Yavuz (2009), Karadoğan (2001), Gelvez et al. (2015), and Bitrafan and Ataei (2004). The modified model evaluated these risks and eliminated the Top Slicing.

Since the results obtained by using the UBC method are based only on the mine deposit's technical characteristics without evaluating the existence of surface structures, the methods with high subsidence effect are proposed in risky areas (Karadogan, 2001; Anon, 2018(b). The modified model evaluated these risks and eliminated the methods with a high subsidence effect.

The UBC presented the Block-Caving and Sublevel Caving as a feasible method, causing negative consequences such as flooding by ignoring the underground water presented in Anon (2018, a) and Anon (2018,b). The modified method, on the other hand, evaluated underground water as well as many constraining factors

Table 10 Results of the UBC Method

Source No	Longwall Mining	Shrinkage Stoping	Cut & Fill Stoping	Top Slicing	Sublevel Caving	Room & Pillar	Sublevel Stoping	Block-Caving	Square Set Stoping
1	-79	***30***	***33***	***13***	-23	-25	***32***	-30	***18***
2	-28	***39***	***32***	***15***	-25	-7	***40***	-32	***9***
3	-81	-34	***31***	***13***	29	-41	***27***	***28***	***16***
4	***31***	-25	***31***	***20***	-22	***24***	***26***	-22	***21***
5	-133	-22	***27***	***12***	***29***	-72	***40***	***25***	***6***
6	-23	***23***	***38***	***11***	***30***	-31	***29***	***27***	***18***
7	-23	***29***	***32***	***18***	-21	-25	***29***	-22	***20***
8	-74	-38	***29***	***14***	***30***	-44	***25***	***32***	***17***
9	***35***	-34	***30***	***18***	-24	***15***	***18***	-17	***28***
10	-19	***25***	***28***	***19***	-20	-25	***26***	-18	***23***
11	-132	-26	***28***	***10***	***30***	-78	***34***	***24***	***10***
12	-74	***14***	***28***	***13***	***28***	-37	***24***	***35***	***22***

Table 11. Results of the Modified UBC Method

Source No	Longwall Mining	Diagonal Longwall	Shrinkage Stoping	Cut & Fill Stoping	Top Slicing	Sublevel Caving	Open Room	Room & Pillar	Sublevel Stoping	Block-Caving	Square Set Stoping
1	-117	-68	-19	***33***	-34	-23	-81	-20	***22***	-27	-29
2	-65	-16	***39***	***32***	***17***	-26	***32***	-1	***30***	-31	11
3	-171	-118	-34	***32***	***15***	***30***	-132	-39	***30***	***30***	***18***
4	-11	-64	-121	-17	-27	-119	-46	***23***	-33	-120	-26
5	-172	-123	-22	***27***	***14***	***29***	***24***	-69	***41***	***26***	***8***
6	-67	-18	***23***	***38***	***13***	***33***	-81	-32	***30***	***28***	***20***
7	-65	-16	***29***	***32***	***20***	***29***	***15***	-25	***30***	-21	***22***
8	-112	-164	-87	***29***	-33	***31***	-185	-40	***26***	***35***	-30
9	***41***	-12	-131	-19	-29	-72	-184	***17***	-41	-64	-19
10	-59	-10	***25***	***28***	***21***	-18	***14***	-26	***16***	-17	***25***
11	-172	-123	-75	***29***	-37	-19	-121	-72	***35***	-25	-37
12	-166	-117	-35	***29***	-34	-67	-96	-39	***25***	-63	-25

In light of the findings mentioned above, it can be said that the UBC approach offers a solution by ignoring the constraining factors. Therefore, these solutions need to be re-evaluated by experts. On the other hand, the modified UBC approach offers a solution considering the constraining factors such as underground water, fire risk, subsidence effect, and ore type. Therefore, there is no need for a secondary assessment.

6. Conclusions

The UBC approach, which cannot satisfy today's conditions to the fullest extent and obtains solutions by ignoring the many factors that affect underground mining method selection, was modified.

A review of the available literature was conducted on underground mining methods, selection criteria, and method selection in this context. As a result of this review, the direct and indirect use of the most up-to-date information, selection criteria, and appropriate mining methods were determined and given in Table 4 and 5, which are comprehensive literature reviews prepared within the scope of this study.

The UBC approach is modified, as shown in Table 5 and 6, and the classification of selection criteria and the ratings for mining methods have been revised. Additionally, several constraining criteria for ore type, grade, the economic value of the ore, and mining practices were also incorporated into the approach. Therefore, while the UBC approach's solutions warrant a re-evaluation by experts, the modified UBC approach's solutions need only be evaluated from economic aspects, but there is no need for a technical re-evaluation.

References

AGOSHKOV, M., BORİSOV, S. and BOYARSKY, V., 1988. Classification of Ore Deposit Mining Systems. Mining of Ores and Non-Metalic Minerals, Union of Soviet Socialist Republics, pp. 59-62.

ALPAY, S. and YAVUZ, M., 2007. A decision support system for underground mining method selection, *International Conference on Industrial, Engineering and Other Applications of Applied Intelligent Systems: New Trends in Applied Artificial Intelligence*, Hiroshi G. Okuno, Moonis Ali (eds), June 26-29, Kyoto, Japan, pp. 334–343.

ANON, 2018(a). *Mining operations project of an underground iron mine in Turkey*.

ANON, 2018(b). *Mining operations project of an underground copper mine in Turkey*.

ATAEI, M., SERESHKI, F., JAMSHIDI, M., AND JALALI, S.M.E. 2008. Mining method selection by AHP approach, *The Journal of the Southern African Institute of Mining and Metallurgy*, vol.108, pp.741-749.

ATAEI, M., SHAHSAVANY, H., AND MIKAEIL, R. 2013. Monte Carlo Analytic Hierarchy Process (MAHP) approach to selection of

optimum mining method, *International Journal of Mining Science and Technology*, vol.23, pp. 573-578.

AZADEH, A., OSANLOO, M., and ATAEI, M. 2010. A new approach to mining method selection based on modifying the Nicholas technique, Applied Soft Computing, 10, (2010), pp. 1040-1061.

BANDOPADHYAY, S., AND VENKATASUBRAMANIAN, P. 1988. Rule-based Expert System for Mining Method Selection, *CIM Bulletin*, vol.81, pp. 84-88.

BASCETIN, A. 2005. A Decision Support System Using Analytical Hierarchy Process (AHP) For the Optimal Environmental Reclamation of an Open-pit Mine, *Environmental Geology*, vol.52, pp. 663-672.

BASU. A.J. 1999. Mining Method Selection Expert System with Prototype with Australian Case Studies, *International Symposium on Mine Planning And Equipment Selection*, Ukraine, pp. 73-78.

BIENIAWSKI, Z. T. 1989, Engineering Rock Mass Classification Systems, New York; Wiley-Interscience, ISBN 0-471-60172-1

BIBB, C.T., and HARGROVE, K.M. 1993, Coal mining: method selection, Mining Engineering Handbook, vol.2, pp.1854-1866.

BITARAFAN, M.R., and ATAEI, M. 2004. Mining method selection by multiple criteria decision making tool. *The Journal of the South African Institute of Mining and Metallurgy*, vol.104, no.9. pp. 493-498.

BOGDANOVIC, D., NIKOLIC, D. and ILIC, I. 2012. Mining method selection by integrated AHP and PROMETHEE method. *Anais da Academia Brasileira de Ciências*, vol.84, no.1. pp. 219-233.

BOSHKOV, S., and WRIGHT, F. 1973. Basic and Parametric Criteria in the Selection. Design and Development of Underground Mining System, SME Mining Engineering Handbook, vol. 1, New York.

BRADY, B. H. G., and BROWN, E. T. 1993, Mining Methods and Methods Selection, Rock Mechanics for Underground Mining, Second Edition, U.K.

CAMM, T.W., and SMITH, M.L. 1992. An object-oriented expert system for underground mining method selection and project evaluation, *23rd APCOM Proceedings*, Denver, USA, pp. 909-916.

CHEN, W., and TU, S. 2015. Selection of an appropriate mechanized mining technical process for thin coal seam mining, Mathematical Problems in Engineering, vol. 2015, no.7. pp.1-10.

CLAYTON, C., PAKALNIS, R., and MEECH, J. 2002. A Knowledge-based System for Selecting a Mining Method, *IPPM conference*, Canada.

CSGB, 2013, Republic of Turkey, Ministry of Labor and Social Security, Law No. 6331 on Occupational Health and Safety, Ankara.

DEHGHANI, H., SIAMI, A., and HAGHI, P. 2017. A new model for mining method selection based on grey and TODIM methods, *Journal of Mining and Environment*, vol 8, no 1. pp. 49-60.

DEMIRBILEK, S. 1987. A review of general principles of underground mine design in reference to thick coal seams, *Scientific Mining Journal*, vol. 26, no 4, pp. 23-30.

DEMIRCI, U. 1993. Die Optimalen abbauver-fahren bestimmende merkmale, Master Thesis, Istanbul Technical University, Istanbul.

EDUMINE, 2018, Edumine website, underground mining method selection tool.

GERSHON, M.E., BANDOPADHYAY, S. and PANCHANADAM, V. 1995. Mining method selection: a decision support system integrating multi-attribute utility theory and expert systems, *Proceedings 24th APCOM Meeting*, Montreal, Quebec, Canada, pp. 11–18.

GERTSCH, R.E., and BULLOCK, R.L., 1998. Techniques in Underground Mining: Selections from Underground Mining Methods Handbook, Society for mining, metallurgy, and exploration, Inc., Littleton, CO, USA.

GÉLVEZ, J.I.R., ALDANA, F.A.C., and SEPÚLVEDA, G.F. 2014. Mining Method Selection Methodology by Multiple Criteria Decision Analysis- Case Study in Colombian Coal Mining, *International Symposium of the Analytic Hierarchy Process*, Washington D.C., USA.

GURAY, C., CELEBI, N., ATALAY, V., and PASAMEHMETOGLU, A.G. 2003. Ore-age: a hybrid system for assisting and teaching mining method selection. *Expert Systems with Applications*, vol. 24, pp. 261-271.

HAMRIN, H. 1988. Choosing Underground Mining Method Techniques in Underground Mining. Mining Engineering Handbook, USA, 1988, pp. 45-85.

HARTMAN, H.L. 1987. Introduction Mining Engineering, Willy, New York, USA.

HARTMAN, H.I., 1992. SME Mining Engineering Handbook, 2nd Edition, vol. 2, Society of Mining Metallurgy and Exploration Inc., Littleton, Co, USA.

JAMSHIDI, M., ATAEI, M., SERESHKI, F., and JALALI, S.M.E. 2009. The Application of AHP Approach to Selection of Optimum Underground Mining Method, Case Study: Jajarm Bauxite Mine (Iran), *Arch. Min. Sci*, vol.54, pp. 103-117.

JIANHONG, C., ZOU, Z., and REN, C. 2015. Research on Optimization of Mining Method based on the AHP-VIKOR Method, *Gold Science and Technology*, 2015- 03.

KAHRIMAN, A. 2000. Selection of Optimum Underground Mining Method for Kayseri Pinarbasi- Pulpinar Chrome Ore. Middle East Technical University, Turkey.

KARABEYOGLU, A. 1986. Critical analysis of underground mining method selection with respect to Kure-Asikoy copper orebody. Master's Thesis. Middle East Technical University, 1986.

KARADOGAN, A., BASCETIN, A., and KAHRIMAN, A. 2001. A New Approach in Selection of Underground Mining Method. *International Scientific Conference SGEM*. Bulgaria.

KARADOGAN, A., KAHRIMAN, A. and OZER, U. 2008. Application of fuzzy set theory in the selection of underground mining method, *Journal of the Southern African Institute of Mining & Metallurgy*, vol.108, no.2, pp. 73-79.

KARIMNIA, H. and BAGLOO, H. 2015. Optimum mining method selection using fuzzy analytical hierarchy process-Qapiliq salt mine, Iran, *International Journal of Mining Science and Technology*, vol.25, pp. 225-230.

KARPUZ, C., and HINDISTAN, M.A., 2008. Rock Mechanics – Princibles, Applications, TMMOB Chamber of Mining Engineers, Ankara.

KESIMAL, A., and BASCETIN, A. 2002. Application of Fuzzy Multiple Attribute Decision Making in Mining Operations, *Mineral Resources Engineering*, vol.11, pp.59-72.

KOSE, H., and KAHRAMAN, B. 2014a. Rock mechanics, Publications of Dokuz Eylul University Faculty of Engineering, No: 223, Izmir, Turkey.

KOSE, H., and KAHRAMAN, B. 2014b. Economics of Mining Operations, Publications of Dokuz Eylul University Faculty Of Engineering, No: 177, Izmir, Turkey.

KOSE, H., and TATAR, C. 2011. Underground Mining Methods, Publications of Dokuz Eylul University Faculty of Engineering No:014, Izmir, Turkey.

KUZU, C. 2013. Underground mining methods, http://web.itu.edu.tr/~kuzu/pro/MetodSecimi.pdf [Date: 06.05.2016].

LAUBSCHER, D.H. 1981. Selection of Mass Underground Mining Methods, In: D. Stewart, ed. Design and Operation of Caving and Sublevel Stoping Mines, New York: SME-AIME, 23-38.

LV, W. and ZHANG, Z. 2015. Establishment and Application of Thin Coal Seam Mining Method Prediction Model Based on Improved Neural Network, *International Journal of Ecological Economics and Statistics*, vol.36, pp. 1-11.

MARANO, G. and EVERITT, A. 1987. Selection of Mining Method and Equipment for block 58. Shabanie Mine, Zimbabwe, *African Mining Conference*, Harare, pp. 229-238.

MILLER, L., PAKALNIS, R. and POULIN, R. 1995. UBC Mining Method Selection. *International symposium on mine planning and equipment selection*, Singhal (ed.), Balkema, Rotterdam, pp.163-168.

MIRANDA, C. and ALMEIDA, C. 2005. Mining Methods Selection Based on Multi criteria Models, Application of Computes and operation research in the mineral industry, London.

MORRISON, R.G.K. 1976. A Philosophy of Ground Control, McGill University, Montreal, Canada, 1976.

MUTAGWABA, W.K. and TEREZOPOULOS, N.G. 1994. Knowledge-based System for Mine Method Selection, *Institution of Mining and Metallurgy, Section A,. Mining industry*, vol.103, pp. 27-32.

MUTLU, E.N. 2017. Slope Stability Report of the lignite deposit in Edirne, Turkey.

NICHOLAS, D. E. 1981. Method Selection-A Numerical Approach, Design and Operation of Caving and Sublevel Stoping Mines, pp. 39-51.

NICHOLAS, D.E. 1993. Selection Procedure. Mining Engineering Handbook. H.L Hartman (ed), SME, New York, 1993, pp. 2090-2105.

OZYURT, M.C., 2018, The Investigation of Using Artificial Neural Networks and Game Theory on Underground Mining Method

Selection, Ph.d Thesis, Institute of Sciences, Istanbul University, 2018.

PEELE, R., and CHURCH, J. 1941. Mining Engineering Handbook Vol. 1, John Wiley & Sons. Inc., 1941.

SAMIMI NAMIN, F., SHAHRIAR, K. and KARIMINASAB, S. 2003. Fuzzy Decision Making for Mining Method Selection in Third Anomaly Gol-E-Gohar Deposit, *18th International mining congress and exhibition of Turkey*, .

SAMIMI NAMIN, F., SHAHRIAR, K., ATAEE-POUR, M., and DEHGHANI, H. 2008. A new model for mining method selection of mineral deposit based on fuzzy decision making, *The Journal of the Southern African Institute of Mining and Metallurgy*, vol.108, pp. 385-395.

SAMIMI NAMIN, F., SHAHRIAR, K., BASCETIN, A., and GHODSY POOR, S. 2010. Practical applications from decision-making techniques for selection of suitable mining method in Iran, *Gospodarku Surowcami Mineralnymi*, pp. 57-77.

SAMIMI NAMIN, F., SHAHRIAR, K., and KARIMINASAB, S. 2004. Method selection of MEHDI ABAD Lead-Zinc Mine and Related Problems, *5th ISMST Conferences*, China.

SIMSIR, F. 2015. Underground mining methods, Publications of Dokuz Eylul University Faculty of Engineering, No:337., Izmir, Turkey.

SIMSIR, F., TATAR, C., and OZFIRAT, M.K. 2013. Transporting in Mines, Publications of Dokuz Eylul University Faculty of Engineering, No:296, Izmir, Turkey.

TATAR ,M.K., and OZFIRAT, M.K., 2016, Underground Mining Machinery and Mechanization, Publications of Dokuz Eylul University Faculty of Engineering, Izmir, Turkey.

TATIYA, R.R. 1998. Computer Assisted Economic Analysis to Selected a Stopping Method, *CIM Bulletin*, vol.91, pp. 82-86.

YALCIN, E. 2012. Underground Ventilation, Publications of Dokuz Eylul University Faculty of Engineering, No:336, Izmir, Turkey.

YAVUZ, M., IPHAR, M., and ONCE, G. 2008. The optimum support design selection by using AHP method for the main haulage road in WLC Tuncbilek colliery, *Tunnelling and Underground Space Technology*, vol.23, pp. 111-119.

YAVUZ, M. 2015. The application of the analytic hierarchy process (AHP) and Yager's method in underground mining method selection

problem, *International Journal of Mining, Reclamation and Environment*, vol.29, pp.453-475.

YILMAZ, Y., ÇAKIR, F., and MUTLU, Y. 2016. Mining Operations Project of the lignite deposit in Edirne, Turkey.

YIMING, W., YING, F. and WEIXUAN, X. 2003. An Integrated Methodology for Decision Making of Mining Method Selection, Manufacturing Technology and Management, China.

YIMING, W., YING, F., and WEIXUAN, X. 2004. Multiple objective integrated methodology of Global Optimum Decision-Making on Mineral Exploitation, *Computer & Industrial Engineering*, vol.46, pp. 363-372.

ZARE NAGHADEHI, M., MIKAEIL, R. and ATAEI, M. 2009. The application of fuzzy analytic hierarchy process (FAHP) approach to selection of optimum underground mining method for Jajarm Bauxite Mine, Iran. *Expert Systems with Applications*, vol.36, pp. 8218-8226.

CHAPTER VIII

BIG DATA SECURITY

Assoc. Prof. Dr. Murat DENER

Gazi University, Ankara, Turkey, e- mail: muratdener@gazi.edu.tr
Orcid No: 0000-0001-5746-6141

1. Introduction

As technology and electronic media develop and spread, the size of the data increases. According to the researches, all the data obtained in the past years are much less than the data obtained in the last year. However, this difference will increase exponentially from year to year. Now, with the developing internet world, we can easily access websites from our personal computers, smart phones, televisions, and other smart devices. One billion people log into Facebook in a minute on the Internet. 42 million messages are sent from Whastapp. 188 million emails are sent. 4.5 million videos are watched from Youtube. 3.8 million searches are made from Google. 1 million dollars worth of online shopping is made. 400 thousand applications are downloaded from Google Play and Apple stores. 500 thousand tweets are sent from the tweeter. This much and more transactions take place within 1 minute. As can be seen as a result of the increase in social network platforms, the increase of smart devices, the increase in sensor nodes, and other video and media sources, data is growing at an increasing rate.

The management, storage, processing and security of so much data have emerged as issues to be considered. At the same time, it is necessary to be able to extract information from this much data and to produce value. As is known, when we search for something on Google, not everyone gets the same result. The same advertisement is not shown to everyone. Results are obtained according to the person's previous records and interests. In this way, a new field of science has emerged in the management of so much data. This is called Big Data.

In this study, Big Data Security is examined. In the second chapter, big data is explained. In the third part, big data security and in the fourth part current studies on big data security are presented. All of the current studies

have been obtained from the web of science database. In the last part, the results are given.

2. Big Data

Big data describes how organizations use confidential information and surprise correlations with statistics and data mining techniques by integrating different digital data sets.

With the big data science, exploration can be made on the combined resources. All kinds of data can be stored and managed. Flowing data is managed, structural and non-structural data can be analyzed. Integration of data sources can be achieved.

Research shows that companies using big data have earned more, have been more effective in market studies, have decreased advertising expenditures and have been more successful in using social media. In addition, big data can be very useful in improving health services, predicting natural and human resources disasters, and preventing crimes.

Many techniques and technologies are needed to perform Big Data analytical operations. Hadoop, Spark, MapR, Cloudera, Microsoft Azure, BigTable, MongoDB, MapReduce, Hive, Flume, Kafka, Weka, R, KNIME can be given as examples of big data techniques and technologies.

Big data refers to large data that contains different types of data from different sources. With big data science, access to information on multidimensional data is provided. There are 5 components in big data formation. Components called 5V because of their English equivalent are as follows: Variety, Velocity, Volume, Verification, Value. Variety refers to the variety of data collected. Velocity refers to the speed at which data is produced. Volume refers to the size of the data produced. Verification refers to tracking data at the correct security level. Value corresponds to the value of the data.

Banking, Communication, Media and Entertainment Sectors, Healthcare, Education, Industry, Government Services, Insurance, Retail and Trade, Transportation, Energy Sector can be considered as the application areas of big data.

It is extremely important to collect, store, process, analyze, secure and generate information about big data. Data storage and analysis processes, information discovery and computational complexity, data scalability and

visualization, data security operations can be given as examples of the difficulties encountered in big data science.

3. Big Data Security

Let's assume that we have a smart city as an example of obtaining Big Data. This city is equipped with smart systems. It contains many systems ranging from smart intersection systems, smart lamp systems, weather monitoring systems, smart waste collection systems, agricultural land monitoring systems, and natural disaster monitoring systems. The data obtained from all systems are collected in one place, processed, managed and finalized. This is where we encounter big data. Managing so many systems from a single center enlarges the network and diversifies different types of devices. The security of big data is important here. Real-time security monitoring systems, intrusion detection and prevention systems are becoming necessary.

The main things to be done regarding big data security are as follows: The environment where big data is stored should be secured both physically and in software. Data should not be accessed by unauthorized persons. Therefore, data access control and authentication methods should be applied. Confidentiality can be ensured with encryption algorithms. With secure data management, the security of stationary data and the transmission of flowing data through secure lines should be ensured. Along with data privacy, data integrity must also be ensured to ensure that data cannot be altered on the road by unauthorized persons.

4. Current Studies

In this section, current studies on big data security are presented.

The economic aspect of big data security has been examined in the study [1].

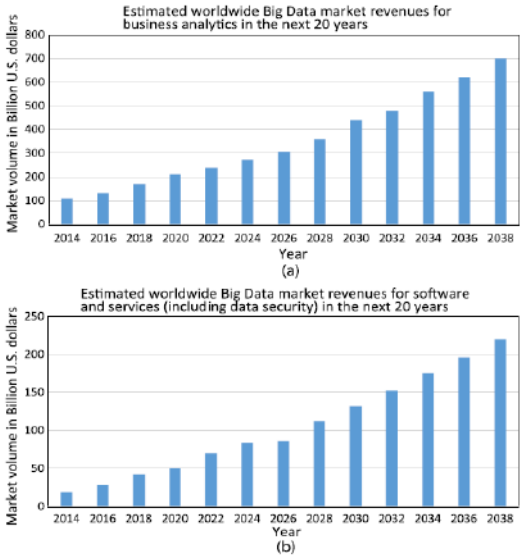


Figure 1. Estimated worldwide big data market revenues (a) for business analytics in the next 20 years; (b) for software and services (including data security) in the next 20 years [1]

As the authors shared in their study (Figure 1), an increasing amount of economy is required for big data security.

Hadoop is a cost effective, scalable and open source solution for storing and processing big data. Hadoop basically consists of two main parts: HDFS (Hadoop Distributed File System) and MapReduce. HDFS is Hadoop's distributed file system and creates a distributed data storage infrastructure. Hadoop MapReduce provides the necessary programming model for distributed data processing. Hadoop architecture allows for data to be partitioned and large data sets to be processed in parallel. The details of these processes are executed in the background, independent of the developers. In the study [2], a plugin for the Hadoop Map Reduce framework named G-Hadoop has been developed. MapReduce tasks can be run in multiple clusters with the developed plugin.

A new group key transfer protocol has been developed [3]. The main security goals for their group key transfer protocol are key freshness, key confidentiality and key authentication. Key freshness refers to the freshness of the key and it means that it has not been used before. Key confidentiality refers to the privacy of the key. Key authentication refers to the accessibility of group members only.

Social platforms with too many people are increasing day by day. There are many private information, pictures, videos, personal security settings of the people on the relevant platforms. Here, when people's accounts are stolen, all private information of the person can be accessed, and serious problems may arise by replacing it. In the study [4], a data protection scheme has been proposed for big data produced on social platforms.

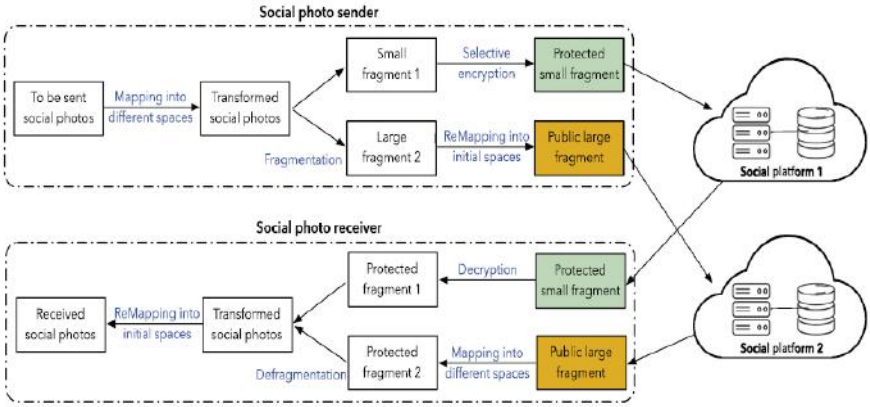


Figure 2. Conceptual architecture of the proposed social photo protection [4]

As understood from the architecture given in Figure 2, Encryption and fragmentation aims to protect personal photos on social media.

A secure big data stream processing architecture has been proposed [5]. Symmetric encryption algorithm is used in the proposed architecture.

Attribute-based encryption developed for big data security is recommended [6]. The study focused on access control.

Big data techniques have been used in the management of food safety due to waste and loss [7]. At the security point, the focus is on Availability, Access and Utilisation.

A framework for the use of big data is suggested in security policies that protect personal data and pay attention to fundamental rights [8].

The effect of the cyber security law published by China in 2016 on China's big data and smart city technologies was examined. In the study [9], different results have emerged, such as laws and technologies slowing down or preventing. Within this scope, the scope of the laws published should be adjusted very well, while keeping the security strict, the

development of technology and the opportunity to develop research should be considered.

The effects of big data technologies and related laws in Russia on the personal rights of Russian citizens are examined [10]. This study is also an important study for countries to question themselves.

The study examined the effect of big data on privacy, security and consumer welfare [11]. The results of eliminating the privacy concerns of the consumer and the protection of the consumer security by law have emerged.

In the study [12], the security, privacy and efficiency of sustainable cloud computing for big data and IoT were examined.

The study [13] describes the development of big data systems based on the information security system developed by the authors themselves.

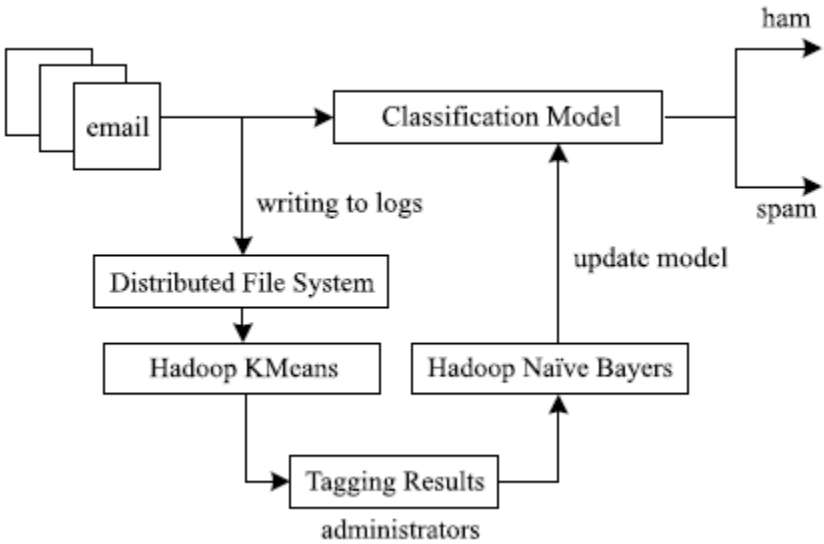


Figure 3. Hadoop-based system [13]

They can detect spam emails with the system they developed. The flow of the system they developed is given in Figure 3.

A visual tool has been developed for big data security using the KDD99 data set [14].

Big data log records have been analyzed for security [15].

Network security situation estimation system has been developed using big data and artificial neural networks [16].

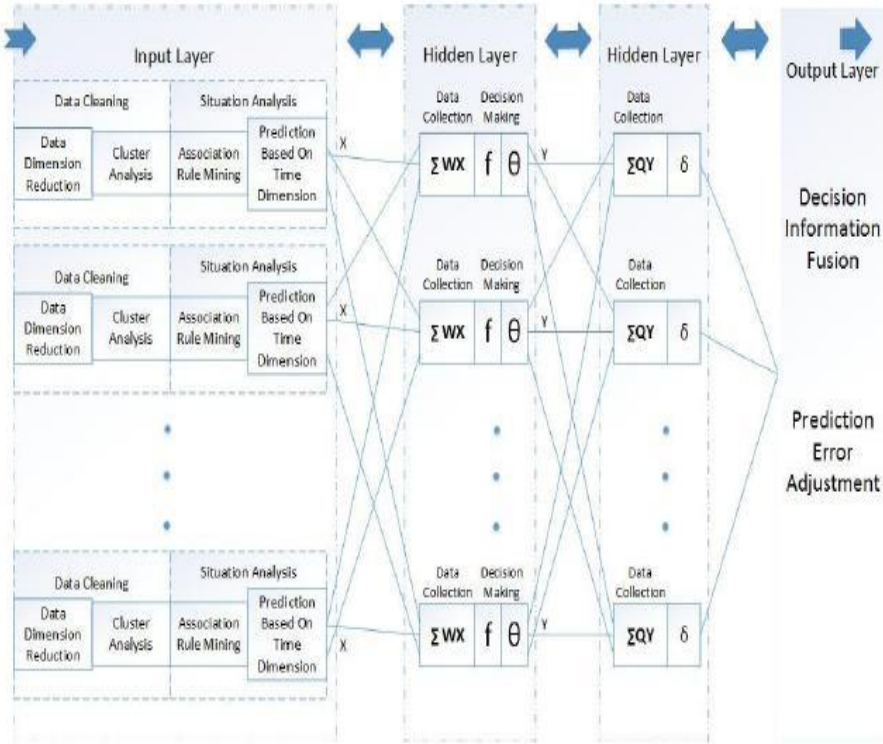


Figure 4. Network Security Situation Prediction System [16]

The display of the developed system is given in Figure 4.

A group key-based security model has been developed for big data systems [17].

The effect of Big Data analytics and data security applications on service supply chain performance has been examined [18].

They examined the risks and challenges of data security that support the socio-economic value and intellectual capital of Big Data [19].

A data-centric architectural model has been proposed for big data security in cloud computing [20]. They stated the following as reasons for security concern in cloud computing: data security, data transmission, virtual machine security, network security, data privacy, data integrity,

data location, data availability, data segregation, compliances and patch management. They used multi-layer authentication.

Big data security algorithms have been studied [21]. Security solutions for system security, personal data security and secure data management have been presented.

Real-time security verification model is proposed for data flowing in big data [22].

They examine community classifiers for big data security [23].

In the study [24], privacy and data mining issues are investigated for big data security.

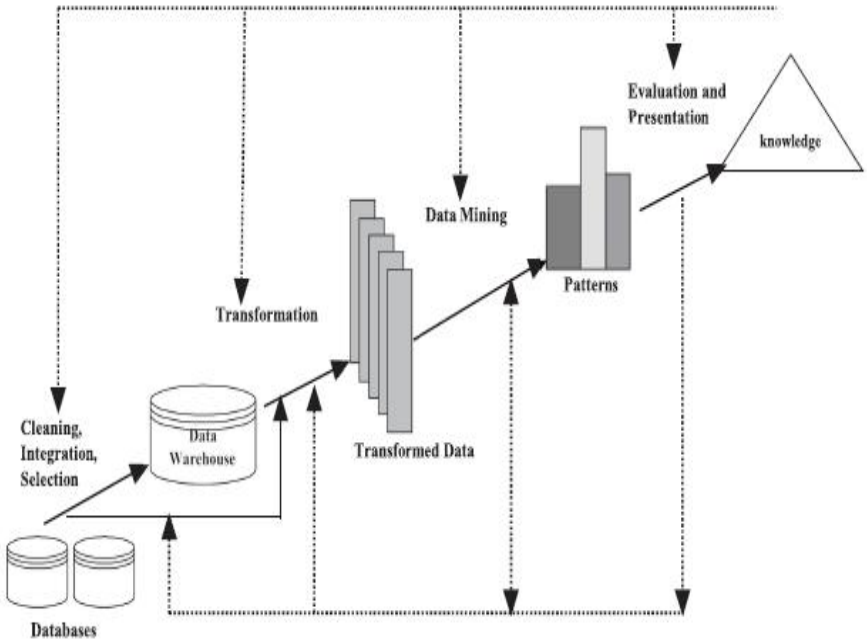


Figure 5. Knowledge discovery from data process [24]

Security solutions have been investigated for each process in Figure 5.

Intrusion detection system has been developed to improve the security of big data [25].

A comprehensive research has been conducted on Big Data security and privacy [26]. Challenges of big data according to the authors are: Data

preparation, Efficient distributed storage and search, Effective online data analysis, Effective machine learning techniques for big data mining, Efficient handling of big data streams, Semantic lifting techniques, Programming models, Social analytics, Security and privacy.

Problems and solutions related to information security in the age of big data are presented [27].

Problems and opportunities on big data analytics and security in the energy field have been explored [28]. The problems are: Scalable and Interoperable Computing Infrastructure, Real-Time Intelligence, Knowledge Represantation and Processing, Security & Privacy.

They developed a big data analysis based security situational awareness model for smart grids [29].

A security analysis based on big data has been performed to protect virtualized infrastructures in cloud computing [30].

An effective classification approach for big data security based on GMPLS / MPLS networks has been proposed [31]. Considerations are as follows: Analysis, Treatment and conversion, Searching, Storage, Visualization, Security and sharing.

A security model for protecting the confidentiality of medical big data has been developed in a healthcare cloud [32].

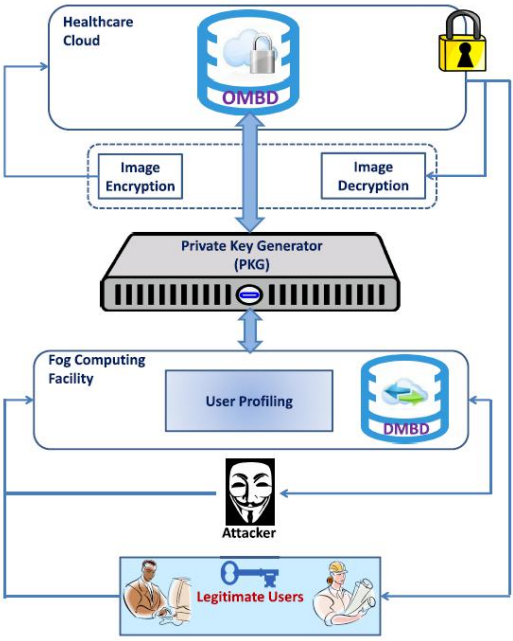


Figure 6.. Proposed system architecture [32]

The architecture of the proposed system is given in Figure 6.

Big data security threats in IoT based smart grid communications were examined [33].

A framework has been proposed for mobile internet of things security based on big data processing and machine learning [34].

Big data security storage research based on compressed perception was conducted [35].

Cloud systems an integrated methodology for big data classification and security has been proposed to improve data mobility [36].

Security and privacy requirements in the processes of collecting, using and managing big data are examined [37].

Edge computing based security framework for big data analytics in VANETs has been proposed [38].

A data sharing protocol has been proposed to minimize security and privacy risks of cloud storage in the big data age [39].

Confidentiality security risk analysis method for medical big data in urban computing has been proposed [40].

Online distributed IoT security monitoring with multidimensional big data flow has been proposed [41].

Security and privacy frameworks for access control big data systems have been reviewed [42].

A big data security mechanism based entirely on homomorphic encryption has been proposed [43].

Network security analysis is presented using big data technology and advanced neural networks [44].

Patient privacy and security concerns regarding big data in medicine have been examined [45].

The big data analytics framework governing security and privacy in healthcare data has been proposed [46].

Main topics in big data security are presented [47]. First of all, big data security challanges are as follows: Infrastructure security, Data management, Data privacy, Integrity and reactive security. Subsequently, the main topics for each are presented. Infrastructure security: security for hadoop, communication security, architecture security, availability, authentication. Data management: security at collection or storage, policies-laws or government, sharing algorithms. Data privacy: cryptography, confidentiality, privacy-preserving queries, access control, anonymization, privacy and social networks, differential privacy. Integrity and reactive security: integrity, attack detection, recovery.

Raw computing and asymmetric security framework has been proposed for big data file sharing [48].

For big data storage, security enhanced identity based collective provided data retention scheme has been proposed [49].

An effective security measure has been proposed for the nuclear power plant using the big data analysis approach [50].

Confidentiality and security have been investigated in the big data paradigm [51]. It has been emphasized that the following topics are related to big data: data mining, data analytics, data cloud computing, data

literature reviews, machine learning, social media, electronic data processing, algorithms, databases, MapReduce, research methods, human behavior, privacy & security.

Big data security access control algorithm has been proposed in wireless sensor networks [52].

Analytical techniques for decision making on information security in big data violations were examined [53].

A solution has been proposed for the confidentiality and security of multimedia information processing in the industrial big data and internet of things [54].

Security of big data in fog enabled IoT applications including block chain has been examined [55]. Privacy and security threats in IoT applications include: forgery, tampering, spamming, sybil, jamming, eavesdropping, DOS, collusion, man-in-the-middle, impersonation, identity privacy, data privacy, usage privacy, location privacy, wormhole, blackhole, greyhole, selective forwarding, local repair, route cache poisoning, sybil, sinkhole, hello flood, neighbor, version number, modification, fabrication, byzantine, location spoofing.

5. Conclusions

Current studies on big data security were investigated in this study. When current studies are examined, it is seen that there are studies on issues such as the economic aspects of big data security, countries' view of big data, new security models, new data flow architectures, the status of big data in smart systems, big data and cloud computing, wireless sensor networks, internet of things connected studies, analyzing big data using artificial intelligence. making new data security algorithms, confidentiality of big data in different networks and ensuring security. As the amount of data will increase exponentially in the coming years, big data science will continue to develop and new techniques and technologies will emerge according to the need.

References

1. Tao, H., Bhuiyan, M.Z.A., Rahman, M.A., Wang, G.J., Wang, T., Ahmed, M.M., Li, J. (2019). Economic perspective analysis of protecting big data security and privacy, *Future Generation*

Computer Systems-The International Journal of Escience, *98*, 660-671.

2. Zhao, J.Q., Wang, L.Z., Tao, J., Chen, J.J., Sun, W.Y., Ranjan, R., Kolodziej, J., Streit, A., Georgakopoulos, D. (2014). A security framework in G-Hadoop for big data computing across distributed Cloud data centres, *Journal of Computer and System Sciences*, *80*(5), 994-1007.
3. Hsu, C.F., Zeng, B., Zhang, M.Y. (2014). A novel group key transfer for big data security, *Applied Mathematics and Computation*, *249*, 436-443.
4. Chen, X. (2020). Security-preserving social data sharing methods in modern social big knowledge systems, *Information Sciences*, *515*, 404-416.
5. Puthal, D., Nepal, S., Ranjan, R., Chen, J.J. (2017). A dynamic prime number based efficient security mechanism for big sensing data streams, *Journal of Computer and System Sciences*, *83*(1), 22-42.
6. Wang, Z.W., Cao, C., Yang, N.H., Chang, V. (2017). ABE with improved auxiliary input for big data security, *Journal of Computer and System Sciences*, *89*, 41-50.
7. Irani, Z., Sharif, A.M., Lee, H.B., Aktas, E., Topaloglu, Z., van't Wout, T., Huda, S. (2017). Managing food security through food waste and loss: Small data to big data, *Computers & Operations Research*, *98*, 367-383.
8. Broeders, D., Schrijvers, E., van der Sloot, B., van Brakel, R., de Hoog, J., Bailin, E.H. (2017). Big Data and security policies: Towards a framework for regulating the phases of analytics and use of Big Data, *Computer Law & Security Review*, *33*(3), 309-323.
9. Parasol, M. (2018). The impact of China's 2016 Cyber Security Law on foreign technology firms, and on China's big data and Smart City dreams, *Computer Law & Security Review*, *34*(1), 67-98.
10. Zharova, A.K., Elin, V.M. (2017). The use of Big Data: A Russian perspective of personal data security, *Computer Law & Security Review*, *33*(4), 482-501.
11. Kshetri, N. (2014). Big data's impact on privacy, security and consumer welfare, *Telecommunications Policy*, *38*(11), 1134-1145.

12. Stergiou, C., Psannis, K.E., Gupta, B.B., Ishibashi, Y. (2018). Security, privacy & efficiency of sustainable Cloud Computing for Big Data & IoT, *Sustainable Computing-Informatics & Systems*, *19*, 174-184.

13. Chen, G., Wu, S., Wang, Y. (2015). The Evolvement of Big Data Systems: From the Perspective of an Information Security Application, *Big Data Research*, *2*(2), 65-73.

14. Ruan, Z.C., Miao, Y.T., Pan, L., Patterson, N., Zhang, J. (2017). Visualization of big data security: a case study on the KDD99 cup data set, *Digital Communications and Networks*, *3*(4), 250-259.

15. Jeon, K.S., Park, S.J., Chun, S.H., Kim, J.B. (2016). A Study on the Big Data Log Analysis for Security, *International Journal of Security and Its Applications*, *10*(1), 13-20.

16. Zhu, B.W., Chen, Y.H., Cai, Y.Q., Tian, H., Wang, T. (2017). Network Security Situation Prediction System Based on Neural Network and Big Data, *International Journal of Security and Its Applications*, *11*(1), 93-108.

17. Kim, H. (2016). A Group Key based Security Model for Big Data System, *International Journal of Security and Its Applications*, *10*(8), 121-130.

18. Fernando, Y., Chidambaram, R.R.M., Wahyuni-TD, I.S. (2018). The impact of Big Data analytics and data security practices on service supply chain performance, *Benchmarking: An International Journal*, *25*(9), 4009-4034.

19. La Torre, M., Dumay, J., Rea, M.A. (2018). Breaching intellectual capital: critical reflections on Big Data security, *Meditari Accountancy Research*, *26*(3), 463-482.

20. Ramasamy, S., Gnanamurthy, R.K. (2020). Cluster Based Multi Layer User Authentication Data Center Storage Architecture for Big Data Security in Cloud Computing, *Journal of Internet Technology*, *21*(1), 159-171.

21. Prasanna, K.L., Reddy, M.T., Prakash, S.S. (2018). A Survey on Big Data Security Algorithms, *Helix*, *8*(2), 3290-3293.

22. Puthal, D., Nepal, S., Ranjan, R., Chen, J.J. (2017). DLSeF: A Dynamic Key-Length-Based Efficient Real-Time Security Verification Model for Big Data Stream, *ACM Transactions on Embedded Computing Systems*, *16*(2), DOI: 10.1145/2937755.

23. Abawajy, J.H., Kelarev, A., Chowdhury, M. (2014). Large Iterative Multitier Ensemble Classifiers for Security of Big Data, *IEEE Transactions on Emerging Topics in Computing*, *2*(3), 352-363.

24. Xu, L., Jiang, C.X., Wang, J., Yuan, J., Ren, Y. (2014). Information Security in Big Data: Privacy and Data Mining, *IEEE Access*, *2*, 1149-1176.

25. Tan, Z.Y., Nagar, U.T., He, X.J., Nanda, P., Liu, R.P., Wang, S., Hu, J.K. (2014). Enhancing Big Data Security with Collaborative Intrusion Detection, *IEEE Cloud Computing*, *1*(3), 27-33.

26. Bardi, M., Zhou, X.W., Li, S., Lin, F.H. (2014). Big Data security and privacy: A review, *China Communications*, *11*(2), 135-145.

27. Yang, M.K., Zhou, X.G., Zeng, J.Q., Xu, J.J. (2016). Challenges and Solutions of Information Security Issues in the Age of Big Data, *China Communications*, *13*(3), 193-202.

28. Hu, J.K., Vasilakos, A.V. (2016). Energy Big Data Analytics and Security: Challenges and Opportunities, *IEEE Transactions on Smart Grid*, *7*(5), 2423-2436.

29. Wu, J., Ota, K., Dong, M.X., Li, J.H., Wang, H.K. (2018). Big Data Analysis-Based Security Situational Awareness for Smart Grid, *IEEE Transactions on Big Data*, *4*(3), 408-417.

30. Win, T.Y., Tianfield, H., Mair, Q. (2018). Big Data Based Security Analytics for Protecting Virtualized Infrastructures in Cloud Computing, *IEEE Transactions on Big Data*, *4*(1), 11-25.

31. Alouneh, S., Al-Hawari, F., Hababeh, I., Ghinea, G. (2018). An Effective Classification Approach for Big Data Security Based on GMPLS/MPLS Networks, *Security and Communication Networks*, DOI: 10.1155/2018/8028960.

32. Al Hamid, H.A., Rahman, S.M.M., Hossain, M.S., Almogren, A., Alamri, A. (2017). A Security Model for Preserving the Privacy of Medical Big Data in a Healthcare Cloud Usinga Fog Computing Facility With Pairing-Based Cryptography, *IEEE Access*, *5*, 22313-22328.

33. Chin, W.L., Li, W., Chen, H.H. (2017). Energy Big Data Security Threats in IoT-Based Smart Grid Communications, *IEEE Communications Magazine*, *55*(10), 70-75.

34. Kotenko, I., Saenko, I., Branitskiy, A. (2018). Framework for Mobile Internet of Things Security Monitoring Based on Big Data Processing and Machine Learning, *IEEE Access*, *6*, 72714-72723.

35. Lv, D.L., Zhu, S.B., Liu, R. (2019). Research on Big Data Security Storage Based on Compressed Sensing, *IEEE Access*, *7*, 3810-3825.

36. Hababeh, I., Gharaibeh, A., Nofal, S., Khalil, I. (2019). An Integrated Methodology for Big Data Classifiation and Security for Improving Cloud Systems Data Mobility, *IEEE Access*, *7*, 9153-9163.

37. Sollins, K.R. (2019). IoT Big Data Security and Privacy Versus Innovation, *IEEE Internet of Things Journal*, *6*(2), 1628-1635.

38. Garg, S., Singh, A., Kaur, K., Aujla, G.S., Batra, S., Kumar, N., Obaidat, M.S. (2019). Edge Computing-Based Security Framework for Big Data Analytics in VANETs, *IEEE Network*, *33*(2), 72-81.

39. Han, S., Han, K., Zhang, S.Y. (2019). A Data Sharing Protocol to Minimize Security and Privacy Risks of Cloud Storage in Big Data Era, *IEEE Access*, *7*, 60290-60298.

40. Jiang, R., Shi, M.Y., Zhou, W. (2019). A Privacy Security Risk Analysis Method for Medical Big Data in Urban Computing, *IEEE Access*, *7*, 143841-143854.

41. Li, F.Y., Xie, R., Wang, Z.Y., Guo, L.L., Ye, J., Ma, P., Song, W.Z. (2020). Online Distributed IoT Security Monitoring With Multidimensional Streaming Big Data, *IEEE Internet of Things Journal*, *7*(5), 4387-4394.

42. Centonze, P. (2019). Security and Privacy Frameworks for Access Control Big Data Systems, *Cmc-Computers Materials & Continua*, *59*(2), 361-374.

43. Krishna, A.V.N. (2018). A big-data security mechanism based on fully homomorphic encryption using cubic spline curve public key cryptography, *Journal of Information & Optimization Sciences*, *39*(6), 1387-1399.

44. Bao, K., Ding, Y.R. (2020). Network security analysis using big data technology and improved neural network, *Journal of Ambient Intelligence and Humanized Computing*, DOI: 10.1007/s12652-020-02080-1.

45. Blobel, B., Lopez, D.M., Gonzalez, C. (2016). Patient privacy and security concerns on big data for personalized medicine, *Health and Technology*, *6*(1), 75-81.

46. Chauhan, R., Kaur, H., Chang, V. (2020). An Optimized Integrated Framework of Big Data Analytics Managing Security and Privacy in Healthcare Data, *Wireless Personal Communications*, DOI: 10.1007/s11277-020-07040-8.

47. Moreno, J., Serrano, M.A., Fernandez-Medina, E. (2016). Main Issues in Big Data Security, *Future Internet*, *8*(3), DOI: 10.3390/fi8030044.

48. Suwansrikham, P., Kun, S., Hayat, S., Jackson, J. (2020). Dew Computing and Asymmetric Security Framework for Big Data File Sharing, *Information*, *11*(6), DOI: 10.3390/info11060303.

49. Zhao, J.N., Xu, C.X., Chen, K.F. (2018). A Security-Enhanced Identity-Based Batch Provable Data Possession Scheme for Big Data Storage, *KSII Transactions on Internet and Information Systems*, *12*(9), 4576-4598.

50. Lee, S., Huh, J.H. (2019). An effective security measures for nuclear power plant using big data analysis approach, *Journal of Supercomputing*, *75*(8), 4267-4294.

51. Sun, Z.H., Strang, K.D., Pambel, F. (2020). Privacy and security in the big data paradigm, *Journal of Computer Information Systems*, *60*(2), 146-155.

52. Peng, J.H., Zhou, H., Meng, Q.J., Yang, J.L. (2020). Big data security access control algorithm based on memory index acceleration in WSNs, *Eurasip Journal on Wireless Communications and Networking*, *2020*(1), DOI: 10.1186/s13638-020-01725-1.

53. Albeshri, A., Thayananthan, V. (2018). Analytical Techniques for Decision Making on Information Security for Big Data Breaches, *International Journal of Information Technology & Decision Making*, *17*(2), 527-545.

54. Yang, X., Hou, Y.M., Ma, J.P., He, H. (2019). CDSP: A Solution for Privacy and Security of Multimedia Information Processing in Industrial Big Data and Internet of Things, *Sensors*, *19*(3), DOI: 10.3390/s19030556.

55. Tariq, N., Asim, M., Al-Obeidat, F., Zubair Farooqi, M., Baker, T., Hammoudeh, M., Ghafir, I. (2019). The Security of Big Data in Fog-Enabled IoT Applications Including Blockchain: A Survey, *Sensors*, *19*(8), DOI: 10.3390/s19081788.

CHAPTER IX

STATISTICAL ANALYSIS OF MAN OVER BOARD (MOB) INCIDENTS

Phd Student Orhan GÖNEL

İstanbul Technical University, İstanbul, Türkiye e-mail: gonelo@itu.edu.tr
Orcid No: 0000-0002-1298-6175

Dr. İsmail ÇIÇEK

İstanbul Technical University, İstanbul, Türkiye e-mail: ism@drcicek.com
Orcid No: 0000-0003-4850-1747

1. Introduction

Below subsections provides an overview for the MOB studies in the literature with relations to statistical analysis to the current study.

1.1 Maritime Accidents and Casualties

Over the period between 2011 and 2018 in EU Countries, 25614 ships which are involved in marine casualties and incidents, had resulted in 23073 casualties & incidents, 7694 injuries, 693 fatalities and 230 lost ships (EMSA, 2019) (See Figure 1). From these reports, the average casualties & incidents per year is found as 2884.

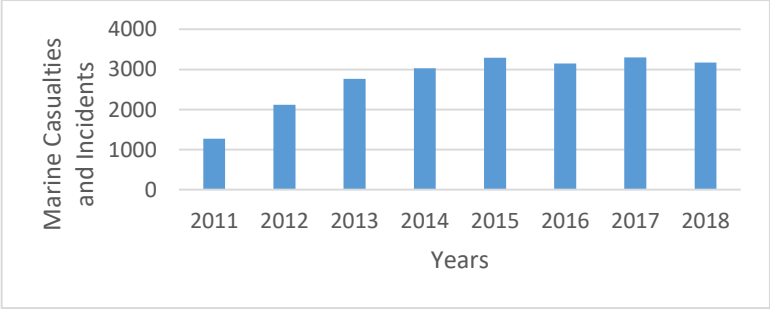


Fig. 1. Occurrence of Maritime Events and Accidents Between 2011 and 2018 (EMSA, 2015, 2016, 2017, 2018, 2019) in EU Waters.

There are various causes of maritime incidents, these are, such as human factor, engineering mistakes, weather conditions, and material mishaps (Baker, C. C., McCafferty, D. B., 2005). For this reason, personnel

working on-board ships are posed to high-level risks (Oldenburg, M., Baur, X., Schlaich, C., 2010). A research study reported by Roberts et.al. (2014) that the seafarers had 21 times more accident involvement rate than the personnel did in general workforce in England between 2003 and 2012. A study focuses on occupational accidents between different nationalities of seafarers reports that the accident rate for all identified accidents, resulting in personal injuries, aboard cargo ships were 84 accidents per 1000 years aboard' (Hansen, L. H., Laursen L. H., 2008). The data was acquired from four different sources including data from 994 incidents. Along with the general accident statistics, accidents resulting with deaths are also investigated.1426, 875, and 1508 deaths were reported globally in years 2011, 2012, and 2013, respectively (Huang, P., F.; Du, Z., X.; Cheng, C., F.; Chen, J., H.; 2016). Even the number of recorded accidents is unknown and the real number of deaths may probably be much higher than reported data. Another study focuses on statistical analysis of ship accident reports occurred between 1990 to 2012 and the fatalities per shipyear is found as 0,0109 in this study (Papanikolaou, A., Eliopoulou, E., Ventikos, N. P., 2015). This data is provided from 10841 accidents and 6569 fatalities from a total of 602998 shipyears. All these numbers indicate there is much higher fatality rates among seafarers than in other occupations.

1.2 Man Overboard (MOB) Event Statistics

A recent report has indicated that 24 percent of maritime accidents resulted with deaths are the result of MOB events in US coasts (Boat US, 2012). The authors could not find direct statistics for fatality rate for the MOB events globally; however, a study indicates a general assumption of that approximately 1000 people falls overboard annually (Selmy, A. S., 2016). These numbers are of importance; however, they do not include detail statistics of the event processes but the fatality rates.

1.3 Academic Studies and Technologies

Most of the academic studies related to MOB events are related to detection systems for man falling overboard and similar equipment related studies. Selmy explains the need of MOB detecting and tracking system for lowering the casualty rates (Selmy, A. S., 2016). Ferguson and Tidball also suggest that MOB signaling technology can save lives and they discuss qualities and characteristics of an ideal alerting system. (Ferguson C. D., Tidball K. G., 1999). Huang and others designed a man overboard and rescue terminal in order to improve the efficiency of search and rescue (Huang, P., F.; Du, Z., X.; Cheng, C., F.; Chen, J., H.; 2016). Li and others designed an automatic- identification-system-based MOB device (Li, Y., Chung, K., Xie, S., 2018). The system designed by Sheu and others provide real time alarming and dynamic global positioning system (GPS) tracking

(Sheu, B. H., Yang, T. C., Yang, T. M., Huang, C. I., Chen, W. P., 2020). Such studies show the interest for introducing innovative technologies for use in recue or systems applied for immediate or early detection of a person falling overboard.

1.4 Purpose of This Study

In order to better understand MOB events, this study focuses on statistically examining MOB events and drive out statistical results. This study not only examines basics of MOB events such as reason of fall, rescue time and similar but also surrounding circumstances, work conditions, meteorological conditions, SAR operation and some other issues in order to fully understand and explain MOB events.

2. Methodology

It might firstly be perceived that a man overboard (MOB) incident happens at a short period of time. This paper, however, considers MOB event as a process that develops and may continue long even after the casualty is rescued. In order to analyze MOB incidents, circumstances that makes the event occur, actions during the fall, immediate response and continuing actions, and the resulting events and their consequences must be studied for having an adequate understanding of the event's processes.

The methodology used in this study is presented in the following two subsections:

- MOB Event Investigation (MEI) Report Format: This part of the study was completed by the authors and already published (Gonel, O., Cicek, I., 2019). This subsection summarizes the format for using in this article (Section 2.1).

- Data Acquisition and Analysis Methodology: The methodology of this study (Section 2.2).

2.1 MOB Event Investigation (MEI) Report Format

International conventions, such as Safety of Life at Sea (IMO, 2019), Maritime Pollution Act (IMO, 2019) and Load Line Convention (Contracting Governments, 1966), introduce liability and responsibility of casualty investigations which are assumed by the flag states. Therefore, flag states must prepare accident or incident reports and share findings as mandated by these international agreements. The United Nations convention (United Nations, 1982) clearly states that flag states are required to carry out an inquiry for the ships sailing under their flag in open seas (Gonel, O., Cicek, I., 2019).

There are many differences between the reports that were published by different countries. In addition to information differences, content differences, page number differences, the sections/information that the reports should include are clearly specified, but some reports even lack these parts. For these reasons, the authors' previous study (Gonel and Cicek, 2019) provided a standardization methodology for formatting a MOB event report with 113 parameters, for the following benefits:

- Obtaining Statistical Data
- Providing Useful Data for Obtaining Lessons Learned
- Better Understanding the Root Cause
- Correlation between Relevant Parameters in a Report
- Automating the Lessons Learned Process
- Readiness for BIG DATA with Structure and Format

Each of the 113 parameters were explained in detail in the aforementioned paper. Refer to this paper for the detail description of the associated parameters as well as the details of the methodology. In summary, the 113 parameters were grouped in the following 11 categories used in this article (Gonel, O., Cicek, I., 2019).

The form prepared in the earlier paper was called the MOB Event Investigation (MEI) Form. This study, employs the MEI Form for capturing 100 MOB events with all details which are populated and analyzed parametrically.

2.2 Data Acquisition and Analysis Methodology

The methodology used is depicted in Figure 2. Each step of the employed methodology is shortly described in the following subsections.

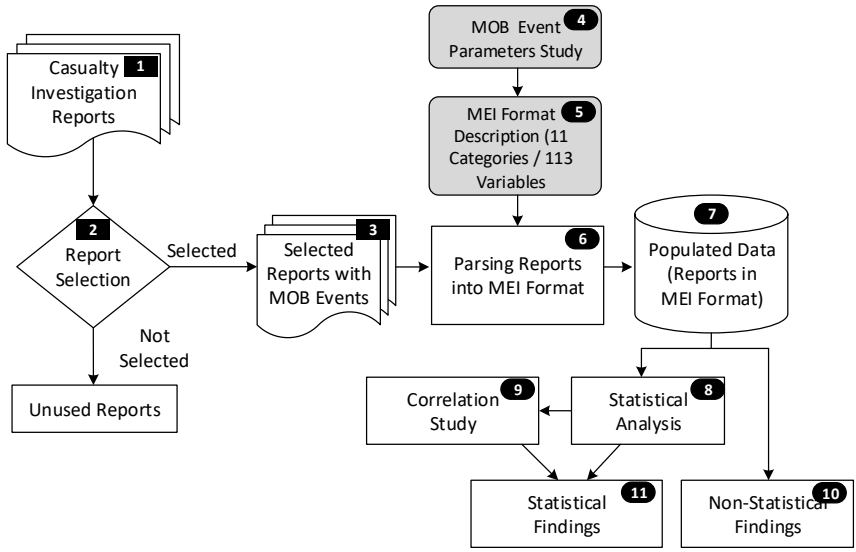


Fig. 2. Methodology

2.2.1 Step 1: Report Acquisition

The agencies that publicly published the accident investigation reports are identified, and the accident investigation reports related to MOB events are obtained from these sources as listed in Appendix I.

2.2.2 Step 2: Report Selection Process

IMO Maritime Safety Committee Regulation (IMO MSC.255(84), 2008) requires the following summary of information is included in a marine safety investigation report, written and submitted as result of a marine safety investigation:

- a summary outlining the basic facts
- the identity of the flag State, owners, operators, the company as identified in the safety management certificate, and the classification society (subject to any national laws concerning privacy)
- where relevant details of the dimensions and engines of any ship involved
- a narrative detailing the circumstances of the marine casualty or marine incident
- analysis and comment on the causal factors including any mechanical, human and organizational factors
- investigation's findings

- recommendations where appropriate

Although this is required by the IMO for all signing counterparts, in practice, most reports do not include these sections or all information. As can be seen in Table 1, some reports do not include some sections and there are some inconsistencies between reports.

Table 1 Review Results of Several Accident Investigation Reports According to Requirements of Resolution MSC.255(84).

Report Number	1	2	3	4	5	6	7
Summary	√	-	-	√	√	√	√
Identities	√	√	√	√	√	√	√
Details	√	√	-	√	-	√	√
Narrative	√	√	√	√	√	√	√
Casual Factors	√	√	√	√	√	√	√
Discussions	√	√	-	√	√	√	√
Recommendations	-	√	-	√	√	√	√
Total Pages	8	8	4	17	35	33	11
Total Pages Without Cover Page	8	4	4	14	31	31	11
Total Number of Words (estimate)	3806	1738	1317	2433	12305	10468	4221
Percent Field Complete (estimate)	85,70%	85,70%	42%	100%	85,70%	100%	100%

Because the report categories and information content are not found to be consistent between the reports, authors generated information criteria as explained in Table 2 for discarding or retaining a report for analysis.

Table 2 Report Selection Criteria

Criteria Name	Information Must be Found
Report Information	o Name of the reporting agency
Ship Information	o Ship's Name
	o Ship's Flag
Other Ship Information	Three of the following items:
	o Ship Age
	o Tonnage
	o Length
	o Vessel Type
	o Number of personnel
Survival Status of the casualty	Report must indicate the survival status of the casualty with one of the following: death/not death/missing and assumed death.
Event Information	o Event date
	o Location
	o Navigation Status
Text (Narrative, Summary, Recommendations, and Other Details):	Because, there is no consistency between reports, **four pages or 1200 words limit criteria** was set as for retaining the reports for including in the analysis.

The reports obtained are listed in Appendix I. Reports containing insufficient information are discarded and not used in this study.

2.2.3 Step 3: Data Selection

All forms in the database, which currently are about over 200, are reviewed and 100 forms containing the most data are selected for review in this study. The data retrieved from reports is shown in Appendix I and national agencies, where the reports are obtained from, are listed in Appendix II.

2.2.4 Step 4: MOB Event Parameter Study

All factors affecting the occurrence and outcome of the fall into the sea have been identified. This list is included in the information needed to determine the root cause of the event.

2.2.5 Step 5: MEI Form

While reviewing the reports, MEI Form is used for as baseline for parsing and formatting the data.

2.2.6 Step 6: Data Parsing

The accident investigation reports published in different formats by different sources were passed through the data parsing process using the MEI form.

2.2.7 Step 7: Data Population

Each of the 100 reports has been analyzed with a 113-item MEI form and recorded in the processed database. When all of the selected forms have been passed through this stage, sufficient data has been generated to make inferences from the processed database.

2.2.8 Step 8: Statistical Analysis

The results in the processed database are first examined and their effects on the MOB events are statistically analyzed.

2.2.9 Step 9: Correlation Study

After the examination of the results for each data category, a cross-interaction (correlation) of the data with each other was also examined.

2.2.10 Step 10: Non-Statistical Findings

There were some findings noted during the report retrieval and formatting process, which are not based on the statistical results.

2.2.11 Step 11: Statistical Findings

The findings, based on the statistical analysis, in this study are grouped and reported in Section 3.

3. Statistical Analysis

Statistical results are provided for each category with details provided in the associated figures, tables, or subsections. Refer to the authors' previous study (Gonel, O and Cicek, I, 2019) for the detail descriptions of each of the categories and parameters. 113 parameters in this study is presented for all 100 reports in the following sections and subsections.

3.1 Vessel Information

Average numbers associated with the 100 vessels are identified as the following: The average vessel length, gross tonnage, age and number of crews are found as 123.4 meters (Section 3.1.6), 20820.4 (Section 3.1.5), 19 (Section 3.1.4) and 15 (Section 3.1.8), respectively.

Out of 100 accidents reports, the majority of the vessels are UK flagged (Figure 3), bulk carrier type (Section 3.1.2) and has a proper classification issued by a classification society (Section 3.1.7).

3.1.1 Ship Flag

The reports acquired are classified based on the ship flags and shown in App 1.

3.1.2 Vessel Type

Vessels types in the utilized reports are shown in Table 3. More than half of the accidents occurred on cargo ships.

Table 3. Vessel Type

Ship Type	Cargo Ship	Fishing Vessel	Other	Other Commercial	Passenger Ship	Research Vessel	Sports & Pleasure
Number	53	21	1	5	17	2	1
Percentage	53%	21%	1%	5%	17%	2%	1%

3.1.3 Vessel Sub Category

Sub categories of vessels are shown in Table 4.

Table 4. Vessel Sub Category

Vessel Sub Category	No	%	Vessel Sub Category	No	%	Vessel Sub Category	No	&
Anchor Handling Tug Supply	1	1	Passenger and General Cargo	1	1	Passenger Ro-Ro Ferry	2	2
Bulk carrier	18	18	Landing craft	1	1	Sail Training Vessel	1	1
Car carrier	1	1	Passenger Ferry	2	2	Survey Ship	1	1
Cargo Ship	4	4	River cruise vessel	1	1	Tanker	12	12
Commercial Fishing	21	21	Passenger ship	8	8	Tug	4	4
Container	11	11	General Cargo	7	7	Yacht	1	1
Cruise Ship	2	2	Reefer Carrier	1	1	Total	100	100

3.1.4 Vessel Age

The average age of the vessels, cited in the reports used in this study, was found as 18.9 years. The oldest ship was 93 years old. 26 of the ships were between 0 and 4 years old. Vessels age groups are presented in Table 5.

Table 5. Vessel Age

Age Group	0-4	5-7	8-10	11-15	16-20	21-25	26-30	31+
Number	26	8	6	12	12	7	9	20
Percentage	26%	8%	6%	12%	12%	7%	9%	20%

3.1.5 Vessel Tonnage

Gross tonnage of the vessels varies from 3.86 to 159397. The highest percentage of the ships is in 25001-100000 GRT group. Average gross tonnage is 19879.2.

3.1.6 Vessel Length

The length of the vessels varies from 8.2 meters to 365.79 meters. The highest percentage of the ships are in 151-200 meter length group. The average length is 121.0.

3.1.7 Vessel Classification

65% of the ships were classed by different classification societies. 35% of the ships were either not classed or classification information was not shared in investigation reports.

3.1.8 Number of Personnel

Number of crew varies from 2 to 105 in average of 15.3 crew per ship. Number of crew information was available in 90 reports and was not available in 10 reports.

3.2 Navigation Conditions

Average numbers associated with the 100 vessels are identified as the following: The average vessel speed, distance to nearest land, and ships' draft are 9.3 knots (Section 3.2.5), 58.4 nautical miles (Section 3.2.3) and 6.4 meters (Section 3.2.4), respectively.

Out of 100 accidents reports, the majority of the vessels are underway (Section 3.2.1) and the ships' commands are under the captain (Section 3.2.2).

3.2.1 Navigation Status

62 of 100 vessels were underway while the 38 of them were not.

40 of the ships that are underway were navigating, 4 of them were maneuvering and the remaining 18 were engaged in 'other' activities such as commercial fishing or surveying. For ships that are not underway; 13 of the MOB events were occurred when the ships were in anchorage and 19 of the ships were at port.

3.2.2 Ship's Command

In 23 cases, for reasons such as being at port, there was no one in the command of ship. In 21 cases, it was not clearly stated that who was in command or there was no information given.

In 38 of the 56 cases, captain was in command of the ship with a percentage of 67.9%. Officer was in command in 16 of the cases with a percentage of 28.6%. Pilot was in command in one case and there was no one in command in one case with both having a percentage of 1.8%.

3.2.3 Distance to Nearest Land

There was no distance to nearest land information in 47 of the cases. 19 of the ships were at port. Distance to nearest land varied from 0 nautical miles to 500 nautical miles making an average of 58.4 nautical miles.

3.2.4 Draft of the Ship

Draft information was available only in 19 of the reports. The lowest draft was 1.2 meters and the highest draft was 12.2 with the average draft of 6.4 meters.

3.2.5 Speed of the Ship

The ship speed is not applicable for the ships on anchor or at port. For the 40 ships that were navigating, 8 of the reports did not have state the speed information. Speed of the ships varied from 1 knot to 26 knots making an average of 9.3 knots.

3.3 Casualty Status/Information

Average numbers associated with the 100 vessels are identified as the following: The average casualty overall work experience onboard ships, the duration of onboard work, and the average age of the casualties when the incident happens are; 8 years, 8.6 months (Section 3.3.3) and 40.3 years old (Section 3.3.2) respectively.

Out of 100 accidents reports, the majority of the subject 100 accidents reports; casualty that falls overboard is a deck rating (Table 6). and is not under influence of alcohol or drugs (Section 3.3.4).

3.3.1 Rank

“Deck ratings” was the highest rank among the casualties (see Table 6). This information clearly indicates that deck rating is more vulnerable to falling overboard than personnel in other ranks.

Table 6. Rank of Casualties

Casualty	Captain	Deck Officer	Engine Officer	Deck Rating	Engine Rating	Other Crew	Passenger	Port Crew	Other
Number	1	11	10	60	2	2	10	2	2

3.3.2 Age

Age of the casualty was stated in 60 reports. Age of the casualties varies from 3 to 63 with an average of 40.3. Notice that there was a 3-year-old casualty is a commuter passenger in a small passenger ferry.

3.3.3 Work Experience of the Casualty

The overall work experience of the casualties was not applicable for 14 cases because the casualty was not part of the ship crew. In 51 cases, this information was absent. For other cases, the overall work experience varies from 0 to 40 years with an average of 8 years.

Work duration of the casualty on the ship was not applicable for 14 cases because the casualty is not part of the ship crew. In 29 cases, there was no information given. The work duration of the casualties varies from 0 to 96 months with an average of 8.6 months.

3.3.4 Alcohol / Drug Influence

On 64 cases, there was no information stating if casualty was under the influence of alcohol or drugs. The casualties were under the influence in 12 cases and not under the influence in 24 cases.

3.4 Meteorological Conditions

The average air temperature, water temperature, and water depth are found as 13.6°C (Section 3.4.3), 12.1°C (Section 3.4.3) and 427.1 meters (Section 3.4.4) respectively.

Out of 100 reports, the majority of the weather conditions indicate a dark weather with no artificial lighting (Section 3.4.5), with no rain (Section 3.4.6), with a wind force of 4 beaufort from SW direction (Section 3.4.2). The average sea scale is 4 and the current direction is SSW (Section 3.4.2) with no adverse weather conditions (Section 3.4.1).

3.4.1 Adverse Weather Conditions

In 6 cases, it is not stated if there were adverse weather conditions at the time of the accident. In 58 cases there were no adverse weather conditions but in 36 cases there were adverse weather conditions.

3.4.2 Wind and Sea Conditions

The average wind force is 4 beaufort with a prevailing wind direction of SW. Average sea scale is 4 and prevailing current direction is SSW.

3.4.3 Temperature

The average sea temperature is found as 11.9°C. Sea temperature is available in 48 cases and varies from -1°C to 29°C. The average air temperature is found as13.6°C. Air temperature information was available in 46 cases varying between -3°C and 36°C.

3.4.4 Water Depth

Water depth information was available only in 5 of 100 cases. Depth of water at the place where the MOB event took place varied from 6.5 meters to 2000 meters making an average of 427.1 meters.

3.4.5 Lighting Conditions

In 47 cases, it was not stated that if it the environment was dark or not. In 23 cases it was not dark. In 30 cases, it was a dark weather. In 30 cases in which the environment was dark, in 7 cases there is no information about the artificial lighting conditions. In 18 cases there was artificial lighting with a percentage of 62.1%.

3.4.6 Rain

Information about the rainfall, including rain, snow, and drizzle, was available only in 12 cases. In the rest 88 cases, there was no information related to the rainfall.

3.5 Work Type and Conditions

The majority of the casualties are engaged in a work-related activity (Section 3.5.1) at the time of the event. Casualty was not working in accordance with the safety rules; however, but there was condition to work according to the safety rules (Figure 4). Casualty was not wearing a lifejacket (Section 3.5.3) and was not alone (Section 3.5.4) either.

3.5.1 Relevance to Work

In 77 cases, casualty was engaged in a work-related event before the occurrence of the MOB event. In 9 cases, the casualty was a passenger; in 10 cases, the casualty was not engaged in a work-related event, i.e. the casualty was fishing. In 4 cases there were no information whether the events were work related or not.

3.5.2 Working in Accordance with the Safety Rules

In 6 of the cases, working in accordance with the safety rules was not stated. 7 cases showed that the casualty was working according to the safety rules. In 87 cases, the casualty was not working according to the safety rules. As can be seen in Figure 3, in 46 of the 87 cases that casualty

was not working as per safety rules while the workplace conditions were in accordance with the safety rules. In 38 cases, the safety workplace condition measures were not in place.

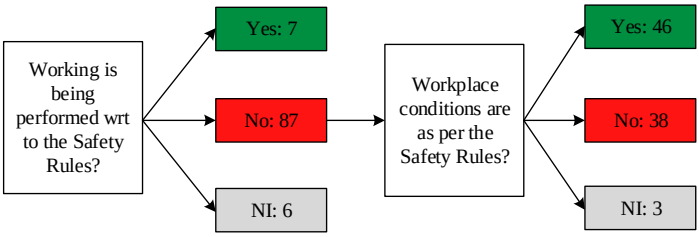


Fig. 3. Result for Working and Workplace Conditions in Accordance with the Safety Rules.

The following information, from Report 05, is provided here as an example for working according to the safety rules:

(W02) "Casualty was not working in accordance with the safety rules. (In addition to Stanislaw's potential impairment through alcohol, the soles of his wellington boots were almost totally bare of tread and his leather gloves had been smoothed through use. Consequently, neither the wellington boots nor the gloves would have provided much grip, particularly on the wet or icy metal surfaces of the guardrails and hand-holds when stepping from the top guardrail to the straddle platform.)"

(W03) "If the casualty wanted, there was no chance to work according to the safety rules. There was no personnel protective equipment available onboard at the time of the accident. (…and important personal protective equipment (PPE) was neither available on board, nor was fit for purpose.)"

3.5.3 Wearing a Lifejacket

In 16 cases either it is not known if the casualty was wearing a lifejacket or there is no information given in the investigation report. In 63 cases, the casualties were not wearing a lifejacket while they were wearing in 21 cases.

3.5.4 Alone

In 3 cases, either it is not known if the casualty was alone or this information is not given in the investigation report. In 44 cases, the casualties were alone while in 53 cases were not alone.

3.6 Managerial/Procedural Conditions

Out of 100 accidents reports, the majority of the managerial/procedural conditions; at the time of the event, did not include an applicable checklist

(Figure 4) but there was an applicable general work procedure (Section 3.6.2) which was not followed properly. Fatigue was not seem to be a contributing factor (Table 7) and man overboard drills were not carried out properly (Section 3.6.4). There was a SAR procedure existed; however, the procedure was not implemented properly (Figure 6).

3.6.1 Applicable Checklist

Figure 2 shows the existence and proper fulfillment of the checklists. There was an applicable checklist in 30 cases. In 19 of the 30 cases, checklist was not filled but filled in 10 of them. 8 of the 10 checklists were not filled properly. Only remaining one checklist is filled properly. In other words, only one report is found with checklist filled properly out of all 100 reports.

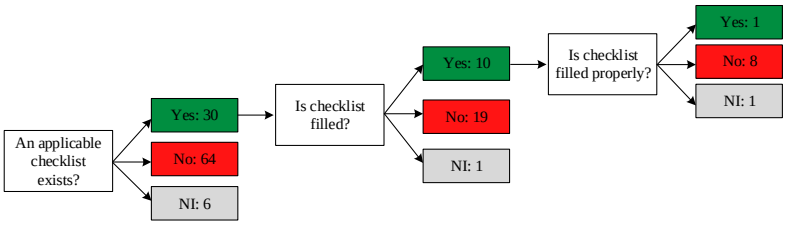


Fig. 4. The Existence and Proper Filling of the Checklists

The following information, related sections from report 57, is provided here as an example:

(P01): 'It is clearly stated in company 'Safety Management System' and 'Operational Procedures' that a work permit is required to be prepared. (Before any work over side is carried out, it is necessary to identify the hazards and then ensure that they are eliminated or effectively controlled. A permit-to-work shall be duly completed and verified prior commencing any work over the side.)'

(P01.1) 'A work permit was issued by chief officer. (A permit to work documented to be valid from 0530H to 1330H on 4 March 2018 for rigging/securing the pilot ladder was authorized24 by the Chief Officer (as a routine task))'.

(P01.2) 'Requirements of the checklist were not fulfilled. Such as;

No personnel protective equipment was used

Officer of the watch was not at the pilot boarding area to supervise

When enquired, the deck cadet was not aware of this permit or its requirements as per SMS'.

3.6.2 Applicable General Work Procedures

In 6 case reports, there is no mention of the existence of an applicable general work procedure. In 33 of the 94 cases, there were no applicable general work procedures available; with a percentage of 35.11%. In 61 of the 94 cases, there were applicable general work procedures; with a percentage of 64.89%.

In 4 of the 61 cases, there was no mention about the existence of the applicable general work procedures that were implemented properly. In 54 of the 57 cases, applicable general work procedures were not implemented properly; with a percentage of 94.74%. In 3 of the 57 cases, applicable general work procedures were implemented properly; with a percentage of 5.26%.

3.6.3 Fatigue Condition

Fatigue condition was considered only for the casualties who are part of the ship crew. There were 13 cases in which fatigue was not applicable, in 44 cases there were no information given for the fatigue condition of the casualty. In 37 of the rest 43 cases, the casualty was not in fatigue condition and in 6 of the 44 cases the casualty was in fatigue condition (Table 7).

Table 7. Fatigue Condition

Fatigue Condition	NA	NI	No	Yes
No	13	44	37	6

3.6.4 Implementation of Man Overboard Drills

In 71 case reports, there is no mention about the implementation of the man overboard drills. MOB drills were implemented in 13 and were not implemented in 16 cases.

3.6.5 SAR Procedures

In 25 cases, the SAR procedures were used and in 8 cases the SAR procedures were not used. In 8 case it is not stated if the existing SAR procedure was applied. In 7 of the cases, the procedure was implemented appropriately whereas in 7 cases, it was not (Figure 5).

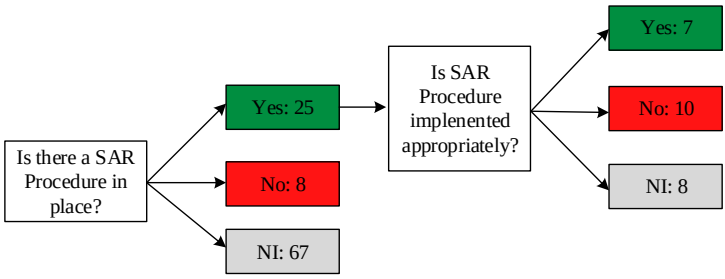


Fig. 5. Existence and implementation status of the SAR procedures.

3.7 Initial Events and Timings

Out of 100 accident reports, the majority of the man overboard accidents happen between 08:00 and 11:59 time interval of the day (Section 3.7.1). Actions leading to man overboard is found as: working overboard (Table 8), casualty falls from port beam (section 3.7.3) and the accident is witnessed momentarily (section 3.7.4).

3.7.1 Time of Day

All cases with an exception of one case provided time information. Results shows that man overboard accidents occur mostly at 08:00-11:59 interval.

3.7.2 Action Causing the Man Overboard Event

Highest actions leading to man overboard is found as: ‘working overboard’, ‘commercial fishing’ and ‘embarkation – disembarkation’ actions. See Table 8.

Table 8. Action Causing the MOB Event

Action Causing the MOB Event	No	Action Causing the MOB Event	No	Action Causing the MOB Event	No
Accidental	7	Drill	2	Waves	11
Bunkering	2	Embarkation - Disembarkation	13	Working overboard	18
Cargo operation	4	Intentional	5	Other	5
Commercial fishing	13	Maneuvering	7	NI	13

3.7.3 Place of Fall

In 18 cases, ship’s section (place) where falling occurs was not entered. For the rest of the 82 cases, the highest occurrence of falling place is port beam with 22 cases followed by starboard beam with 21 cases.

3.7.4 Awareness of the Accident

In 16 cases, the casualty was assumed as lost. In 51 cases, accident was shortly witnessed by another person. In 28 cases, accident was witnessed later meaning casualty was seen on water. The average latency for witnessing the fall is found as 3.3 minutes.

3.8 Response Actions and Times

Table 13 provides information with regards to response actions and their execution times (Table 9). All actions are explained in details in the following sub sections. The casualty falling into water is considered as time is equal to 0 minutes and the response occurrence times, all items, in this section, are provided respectively.

Table 9. Response Actions and Times

Field Code	Field Name	Yes	No/NI	Cases with Timings	Min. Time (Minute)	Max Time (Minute)	Av. Time (Minute)
T01	Notification	65	35	40	0	53	4.1
T02.1	Alarm	41	59	16	1	30	8
T02.2	Announcement	17	83	7	0	50.5	15.2
T02.3	Whistle	3	97	2	3	9.5	6.3
T03	Buoy	48	52	33	1	150	12.4
T04	Maneuvering	57	43	31	1	184	14.2
T05	Captain	85	15	50	0	53	5.2
T06	GPS MOB	11	89	10	1	25	10.2
T07.1	Notification to close by ships	50	50	30	1	47	10.9
T07.2	Notification to SAR stations	71	29	42	1	74	16.7
T07.3	Other notifications	27	63	13	1.5	70	26.5
T08	Rescue boat is ready	27	63	20	0	8	7.5

3.8.1 Event Notification to Bridge

In 65 cases, notification is given to bridge (or cargo control if the ship is in port). The information of the event notification time is given to bridge is provided in 40 cases which varies from 0 to 53 with an average of 4.1 minutes.

3.8.2 Alarm

Ship alarm was used in 41 cases, Timing information is available in 16 cases which varies from 1 to 30 minutes making an average of 8 minutes.

3.8.3 Announcement

Announcement such as public addresser was used only in 17 cases. In the rest 83 cases, announcement was not made, there was no public addresser or announcement was made or not stated in those investigation

reports. Timing information available in 7 cases varies from 0 to 50.5 minutes with an average of 15.2 minutes.

3.8.4 Whistle

Ship whistle/horn was used in 3 cases only. Timing information is available in two cases with 3 and 9.5 minutes and an average of 6.3 minutes.

3.8.5 Lifebuoy

In 48 cases, lifebuoys were thrown to casualties. Timing information is available in 33 cases. Timing varies from 1 to 150 minutes with an average of 12.4 minutes.

3.8.6 Maneuvering

Maneuvering was not applicable in 32 cases for those reasons such as ship is at port or on anchorage. In 57 cases, vessel had to maneuver for the event. In some cases, vessel could not carry out maneuvering even if the vessel in underway. report number 25, even the fall was immediately witnessed, heavy weather conditions are prevented from maneuvering.

3.8.7 Captain Taking Command

In 85 cases captain has taken the command after the accident or was already in command before the accident. In 1 case, casualty is captain therefore it is not considered in the analysis. In other 14 case reports, command information was not stated. Time information is available in 50 cases, varying between 0 and 3 minutes and with an average time of captain taking over command is 5.2 minutes.

The average time for that the captain taking command in the event, from 28 cases, is found as 9.2 minutes.

3.8.8 Acquiring Position

In 43 cases, location for acquiring man overboard was not applicable due to ship being at port or on anchorage. In 11 of the remaining 57 cases, man overboard position was acquired by the MOB button on GPS. Time information is available in 10 cases, varying from 1 to 25 minutes with an average of 10.2 minutes.

3.8.9 Notification to Nearby Ships

In 50 cases, a notification was given to nearby ships. Timing information is available in 30 cases, ranging from 1 to 47 with an average of 10.2 minutes.

3.8.10 Notification Given to SAR Authorities

In 71 cases, a notification was given to SAR authorities. Timing information is available in 42 cases, ranging from 1 to 74 with an average of 16.7 minutes.

3.8.11 Other Notifications

In 27 cases, a notification was given to third parties such as agent or company. Timing information is available in 13 cases, which varies from 1.5 to 70 with an average of 26.5 minutes.

3.8.12 Preparation of Rescue Boat

In 27 cases, rescue boat was prepared for launching. Timing information is available in 20 cases, varying from 0 to 8 with an average of 7.5 minutes.

3.9 SAR Operation (SAR) and Event Timings

Table 10 provides information with regards to the actions required to follow in SAR operations and their execution times. Specific timing information for each action is detailed below the table. The casualty's falling into water is considered as the event start time which is equal to 0 minutes and the response times, all timings, in this section, are considered respectively.

Table 10. SAR Operation and Times

Field Code	Field Name	Yes	No/NI	Cases with Timings	Min. Time (Minute)	Max Time (Minute)	Av. Time (Minute)
R01, R02	Rescue Boat	24	76	18	0	46	10,1
R03, R04	Other Ships	49	51	24	0	500	51,3
R05, R06	SAR Ships	47	53	29	2,5	184	51,1
R07, R08	Air Operation	47	53	29	14	255	87,2
R09, R10	Shore Assistance	22	78	13	3,5	32,5	21,1
R11, R13	Removed from Water	65	35	35	0	3667	214,2
R14, R15	Cancellation of SAR	33	67	19	27,5	5135	986,2
R16, R17	Limited Sighting	24	76	14	1,5	23,5	7,9

3.9.1 Rescue Boat

A rescue boat was used in 24 cases. Timing information is available in 18 cases. Timing of rescue boat in water varies from 0 to 46 minutes with an average of 10.1 minutes.

Small ships may not have a rescue boat. Also ships that berth on the side of the rescue boat may not use a rescue boat.

3.9.2 Other Ships

In 49 cases, it was stated that other ships which are not designated as SAR vessels are participated in the operation. Timing is available in 24 cases, varying from 0 to 500 minutes with an average of 51.3 minutes. In some cases, other ships such as tug boat or pilot boat participated in SAR operation. For these ships which were already alongside timing is taken as 0 minute.

3.9.3 SAR Ships

In 47 cases, it was stated that SAR ships which are specially designated as SAR vessels are participated in operation. Timing is available in 29 cases, varying from 2.5 to 184 minutes with an average of 51.1 minutes. It was observed that the other ship and SAR ship timings are found as about the same.

3.9.4 AIR Operation

In 47 cases, an air vehicle participated in the SAR operation. Timing is available in 29 cases, varying from 14 to 255 minutes with an average of 87.2 minutes.

3.9.5 Shore Assistance

In 22 cases, shore assistance such as shore paramedics, diving team and such assisting personnel participated in the operation. Timing is available in 13 cases, varying from 3.5 to 32.5 minutes with an average of 21.1 minutes. It must be noted that in 62 cases, ships were underway, therefore shore assistance was not applicable.

3.9.6 Removal of the Casualty from Water

In 65 cases, casualty was removed from water either alive or dead. In 35 of those cases timing is available and in 4 cases, casualty removed from water after the SAR operation was cancelled, not as a part of an active SAR operation. Average timing of removal in 35 cases is found as 214.2 minutes. The shortest time is 0 minutes, in which casualty fell overboard to shore and longest time of removal from water is recorded as 3667 minutes.

As can be seen in Table 11, casualty was mostly removed by ship crew followed by other ship crew, SAR crew, air crew or shore crew. It is important to note that it is more likely to be rescued by other ships rather than by SAR ships.

Table 11. Method of Casualty Removed from Water

Casualty Removed By	Number of Casualties	Casualty Removed By	Number of Casualties
Ship Crew	22	Shore Crew	3
Himself	1	Air Crew	5
SAR Crew	13	NI	6
Other Ship Crew	15	Total	65

3.9.7 Cancellation of the SAR Operations

As stated earlier (see Section 3.9.6), casualty was removed from water during SAR operations in 61 cases. In 33 of those cases, the SAR operation was cancelled. Timing is available in 19 cases. Timing of cancellation of SAR operation varies between 27.5 and 5135 minutes with an average of 986.2 minutes.

Most common reason of the cancellations SAR operation is that the casualty was not found. In 17 cases, SAR was canceled because casualty was not found. SAR was terminated. In 11 cases, SAR was cancelled or ship was removed from SAR but SAR was continued by the MRCC authorities. Other reasons are; adverse weather, company directive, darkness and for passengers. All mentioned other reasons are stated once.

3.9.8 Sighting of the Casualty in Water

In 24 cases, the casualty was sighted during a limited period meaning the casualty was not on sight for a short period. Time information is available in 14 cases. The shortest period that casualty was lost from sight is recorded as 1.5 minutes and the longest period recorded is 23.5 minutes, with an average “not on sight” time is 7.9 minutes. In 21 cases, uninterrupted sighting of the casualty in water was maintained.

3.10 Health Status of the Casualty

Table 12 gives information about the casualty’s health status including the timings. All actions are explained in details in the sub sections below the table. The casualty’s falling into water is considered as the time being equal to 0 minutes and the response times for all items are provided respectively.

Table 12. Health Status of the Casualty

Field Code	Field Name	Yes	No/NI	Cases with Timings	Min. Time (Minute)	Max Time (Minute)	Av. Time (Minute)
H01, H03	Death	88	12	19	9	5947	480,7
H05, H05.1	First Aid	41	59	25	6	87,5	33,8
H06, H06,1	Medical Facility	35	65	16	30	257	90

3.10.1 Fatality Status

In 88 cases, the casualty deceased as a result of man overboard accident. Timing of death was available in 19 cases, which varies from 9 to 5947 minutes with an average of 480.7 minutes.

In 54 cases, death of the casualty was witnessed. In other 34 cases, the casualty was assumed dead and missing. As seen in Figure 6, 31 of the 54 deaths happened after casualty was rescued and 18 of the 54 deaths had happened before the rescue, meaning casualty was already death when rescued.

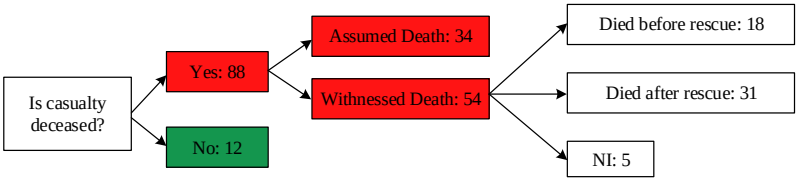


Fig. 6. Casualty's Death Type in the MOB SAR Operations.

Also, reason for the death was available in 42 cases (Table 18). Most common reason of death is identified as drowning (26 cases) followed by a trauma (9 cases), cardiac arrest (4 cases) and hypothermia (3 cases).

3.10.2 First Aid

In 41 cases, the first aid is given to the casualty. Timing of the first aid starting from man overboard time is available in 25 cases. The minimum time is identified as 6 minutes and the maximum time is 87.5 minutes, with an average of 33.8 minutes.

Timing of first aid starting from rescue time is also available in 25 cases. The minimum time recorded is one-minute, maximum time recorded is 58 minutes, with an average of 13.4 minutes.

3.10.3 First Aid at a Medical Facility

In 35 cases, the first aid was given to casualty at a shore based medical facility. Timing of first aid starting from man overboard time is available in 16 cases. The minimum time recorded is 30 minutes and the maximum time recorded is 257 minutes with an average of 90 minutes.

4. Conclusions

100 MOB accident investigation reports are examined using 114 parameters resulting in MOB event profile created for each of these incidents. Findings were considered and discussed in four categories; namely, ship and casualty information, environmental conditions, work and procedural conditions, and event occurrence and SAR operations.

Also, several additional findings were directly identified from the reports are presented. The findings are discussed in detail in Chapter II

References

Baker, C. C., McCafferty, D. B., 2005. Accident Database Review of Human Element Concerns: What do the Results Mean for Classıfıcatıon? ABS Technical Papers.

BoatUS, 2012. Boat Owners Association of the United States. October/November 2012

EMSA, 2015. Annual Overview of Marine Casualties and Incidents 2015. European Maritime Safety Agency.

EMSA, 2016. Annual Overview of Marine Casualties and Incidents 2016. European Maritime Safety Agency.

EMSA, 2017. Annual Overview of Marine Casualties and Incidents 2017. European Maritime Safety Agency.

EMSA, 2018. Annual Overview of Marine Casualties and Incidents 2018. European Maritime Safety Agency.

EMSA, 2019. Annual Overview of Marine Casualties and Incidents 2019. European Maritime Safety Agency.

Ferguson, C. D., Tidball, K. G., 1999. Man-overboard Signaling Technology Can Save Lives. United States Naval Institute. Proceedings; Annapolis 125 (4), 88-89.

Gonel, O., Cicek, I., 2019. Maritime Investigation Reports Involving Man-Over-Board (MOB) Casualties: A Methodology for Evaluation Process. Ordu University Turkish Journal of Maritime and Marine Sciences 5 (2), 141-170

Hansen, L. H., Laursen, L. H., 2008. Major Differences in Rates of Occupational Accidents Between Different Nationalities of Seafarers. International Maritime Health 59 (1-4), 7-18.

Huang, P. F., Du, Z. X., Cheng, C. F.; Chen, J. H., 2016. The Design and Development of Man Overboard Alarm and Rescue Terminal. Journal of Discrete Mathematical Sciences and Cryptography 19 (3), 649-661.

Li, Y., Chung, K., Xie, S., 2018. An Improved Design of Automatic-Identification-System-based Man Overboard Device: A Multidisciplinary Product. IEEE Access 6, 25220-25229.

Oldenburg, M., Baur, X., Schlaich, C., 2010. Occupational Risks and Challenges of Seafaring. Journal of Occupational Health 52 (5), 249-256.

Papanikolaou, A., Eliopoulou, E., Ventikos, N. P., 2015. Statistical Analysis of Ship Accidents that Occurred in the Period 1990—2012 and Assessment of Safety Level of Ship Types. Conference: Maritime Technology and Engineering, Lisbon.

Roberts, S. E., Kotłowski, A., Jaremin, B., 2014. Fatal Accidents and Injuries Among Merchant Seafarers Worldwide. Occupational Medicine 201 (4), 259-266.

Selmy, A. S., 2016. The Need of Man Overboard (MOB) Detecting and Tracking System Descriptive Analyses. Conference: The 9th China International Rescue & Salvage Conference, China.

Sheu, B. H., Yang, T. C., Yang, T. M., Huang, C. I., Chen, W. P., 2020. Real-time Alarm, Dynamic GPS Tracking, and Monitoring System for Man Overboard. Sensors and Materials. Sensors and Materials 32 (1), 197-221.

Appendix I List of Reports Used in This Study

Event No	Agency	Ship Name	Ship Flag	Other Ship Inf.	Survival Status	Event Date	Loc.	Nav. Status
1	UK	Dette G	Antigua &	Included	Deceased	16.01.2012	Yes	Yes
2	UK	Ernest Bevi	UK	Included	Deceased	3.08.2011	Yes	Yes
3	UK	Forth Guard	British	Included	Deceased	13.03.2011	Yes	Yes
4	UK	Hurlingham	UK	Included	Deceased	17.08.2012	Yes	Yes
5	UK	Joanna	St Vincent a	Included	Deceased	13.12.2010	Yes	Yes
6	UK	Konningin	UK	Included	Deceased	29.10.2000	Yes	Yes
7	UK	MS Oldenb	UK	Included	Deceased	3.08.2015	Yes	Yes
8	UK	Sea Melody	Barbados	Included	M.A.D	18.12.2013	Yes	Yes
9	UK	Saga Saphir	Malta	Included	Survived	29.03.2012	Yes	Yes
10	UK	Saga Saphir	Malta	Included	Survived	29.03.2012	Yes	Yes
11	UK	Timberland	UK	Included	Deceased	25.11.2012	Yes	Yes
12	UK	Timberland	UK	Included	Deceased	25.11.2012	Yes	Yes
13	UK	Snowdrop	UK	Included	Survived	14.10.2013	Yes	Yes
14	Australian	Cape Splen	Singapore	Included	M.A.D	6.10.2014	Yes	Yes
15	Australian	Geosounde	Norway	Included	M.A.D	25.08.2007	Yes	Yes
16	Australian	Hyundai Da	Liberia	Included	Deceased	10.07.2015	Yes	Yes
17	Australian	MSC Siena	Liberia	Included	M.A.D	17.11.2011	Yes	Yes
18	New Zealan	Formosa Th	Liberia	Included	M.A.D	12.06.2012	Yes	Yes
19	New Zealan	Melilla 201	Korea	Included	M.A.D	19.11.2004	Yes	Yes
20	New Zealan	San Venture	New Zealan	Included	Survived	14.04.2004	Yes	Yes
21	Hong Kong	Alpine Mys	Hong Kong	Included	Deceased	30.10.2015	Yes	Yes
22	Hong Kong	C. Dream	Hong Kong	Included	M.A.D	12.11.2015	Yes	Yes
23	Hong Kong	Strait Challe	Hong Kong	Included	M.A.D	16.09.2010	Yes	Yes
24	German	Cap Egmon	German	Included	M.A.D	28.12.2006	Yes	Yes
25	German	Beluga Stin	German	Included	Survived	27.10.2006	Yes	Yes
26	German	Lena	Belize	Included	Deceased	19.01.2007	Yes	Yes
27	Canada	Northern Sp	Canada	Included	Deceased	13.06.2015	Yes	Yes
28	Canada	Miss Gatine	Canada	Included	Deceased	12.05.2000	Yes	Yes
29	Canada	Louis Jollie	Canada	Included	Survived	6.06.1994	Yes	Yes
30	Canada	Silver Ange	Canada	Included	M.A.D	3.05.2011	Yes	Yes
31	Canada	Diane Louis	Canada	Included	M.A.D	6.06.2014	Yes	Yes
32	Turkish	Aynacıoğlu	Turkish	Included	Survived	4.04.2014	Yes	Yes
33	Canada	Four Ladies	Canada	Included	Deceased	9.03.2015	Yes	Yes
34	Canada	Cock-a-Wit	Canada	Included	Deceased	30.11.2015	Yes	Yes
35	Danish	Nord Garde	Denmark	Included	Deceased	29.10.2016	Yes	Yes
36	Danish	Maersk Lan	Denmark	Included	Survived	13.11.2010	Yes	Yes
37	Norway	Nysand	Norway	Included	Deceased	24.10.2008	Yes	Yes
38	Norway	Tiderose	Norway	Included	Survived	16.10.2012	Yes	Yes
39	Hong Kong	Ming Fen	China	Included	Deceased	31.07.2010	Yes	Yes
40	UK	Apollo	China	Included	Deceased	24.08.2011	Yes	Yes
41	Hong Kong	Medi Salern	China	Included	Deceased	20.03.2012	Yes	Yes
42	Hong Kong	Joyous Soc	China	Included	Deceased	8.08.2013	Yes	Yes
43	Hong Kong	CF Crystal	China	Included	M.A.D	13.12.2014	Yes	Yes
44	UK	Millgarth	UK	Included	Deceased	27.01.2019	Yes	Yes
45	UK	Endurance	UK	Included	Deceased	5.02.2013	Yes	Yes
46	UK	Enterprise	UK	Included	Deceased	6.11.2017	Yes	Yes
47	Australian	Concordia	Bahamas	Included	M.A.D	5.12.1996	Yes	Yes
48	UK	Pauline Ma	UK	Included	Deceased	2.10.2016	Yes	Yes
49	UK	Graig Rotte	UK	Included	Deceased	18.12.2016	Yes	Yes
50	Malta	HS Rossini	Malta	Included	Deceased	19.06.2016	Yes	Yes

Appendix I List of Reports Used in This Study (Continued)

Event No	Agency	Ship Name	Ship Flag	Other Ship Inf.	Survival Status	Event Date	Loc.	Nav. Status
51	Luxembourg	Nabucco	Luxembourg	Included	Deceased	26.06.2017	Yes	Yes
52	Japan	Buccoo Ree	Japan	Included	Deceased	22.04.2016	Yes	Yes
53	Irish	MFV Our Je	Irish	Included	Deceased	16.06.2015	Yes	Yes
54	Singapore	Resilient	Singapore	Included	Deceased	22.12.2016	Yes	Yes
55	Canada	Picton Cast	Cook Islanc	Included	M.A.D	8.12.2006	Yes	Yes
56	Malta	MV CY Thu	Malta	Included	M.A.D	16.03.2015	Yes	Yes
57	Singapore	Ocean Succ	Singapore	Included	Deceased	4.03.2018	Yes	Yes
58	Hong Kong	Great Fluen	China	Included	Deceased	16.02.2017	Yes	Yes
59	UK	Beryl	UK	Included	Deceased	10.02.2015	Yes	Yes
60	Marshall I.	Cape Mayo	Marshall Is	Included	Deceased	31.12.2015	Yes	Yes
61	UK	Hotspur IV	UK	Included	Survived	15.10.1999	Yes	Yes
62	German	Belen	German	Included	Deceased	23.01.2006	Yes	Yes
63	Hong Kong	Easy Devel	China	Included	M.A.D	3.07.2010	Yes	Yes
64	German	FV Pesorsa	German	Included	Survived	8.02.2016	Yes	Yes
65	German	FV Pesorsa	German	Included	M.A.D	8.02.2016	Yes	Yes
66	Danish	Selendia Sw	Denmark	Included	Deceased	23.07.2015	Yes	Yes
67	Panama	M.T High F	Panama	Included	M.A.D	6.01.2008	Yes	Yes
68	Panama	Grus	Panama	Included	Survived	18.10.2006	Yes	Yes
69	French	La Houle	French	Included	M.A.D	1.02.2019	Yes	Yes
70	French	Pedra Blanc	French	Included	Deceased	3.07.2015	Yes	Yes
71	German	Pesorsa Cu	German	Included	Deceased	17.05.2016	Yes	Yes
72	Bahamas	CMA CGM	Bahamas	Included	M.A.D	21.03.2017	Yes	Yes
73	Bahamas	Vision of th	Bahamas	Included	M.A.D	8.12.2017	Yes	Yes
74	Canada	RED FIR N	Canada	Included	M.A.D	8.04.1994	Yes	Yes
75	Canada	MacDonald	Canada	Included	M.A.D	16.08.1997	Yes	Yes
76	Canada	Fish Finder	Canada	Included	M.A.D	6.05.1997	Yes	Yes
77	Hong Kong	Genco Sug	Hong Kong	Included	Deceased	5.03.2015	Yes	Yes
78	Danish	Carisma	Finland	Included	Deceased	26.01.2012	Yes	Yes
79	Danish	Erika	Denmark	Included	Deceased	27.02.2011	Yes	Yes
80	Danish	Helgoland	German	Included	M.A.D	16.11.2008	Yes	Yes
81	Danish	Tannisbugt	Denmark	Included	Deceased	11.01.2006	Yes	Yes
82	Malta	MV Belved	Malta	Included	Deceased	1.11.2014	Yes	Yes
83	Malta	MV Kiran T	Malta	Included	Deceased	13.11.2014	Yes	Yes
84	Malta	MSC Raver	Liberia	Included	Deceased	22.06.2017	Yes	Yes
85	Malta	Polynesia	Malta	Included	Deceased	2.04.2015	Yes	Yes
86	Malta	Seagull	Malta	Included	Deceased	28.04.2016	Yes	Yes
87	Malta	Zeycan An	Malta	Included	M.A.D	20.03.2012	Yes	Yes
88	Malta	Seastar End	Malta	Included	M.A.D	20.05.2018	Yes	Yes
89	Hong Kong	Win Win	Marshall Is	Included	Deceased	24.02.2018	Yes	Yes
90	Liberia	M/T Alexia	Liberia	Included	M.A.D	7.11.2017	Yes	Yes
91	Liberia	Paros Seas	Liberia	Included	M.A.D	28.03.2017	Yes	Yes
92	Liberia	High Prese	Liberia	Included	Deceased	2.12.2017	Yes	Yes
93	Panama	MV Garnet	Panama	Included	M.A.D	21.01.2016	Yes	Yes
94	Japan	Hunan	Singapore	Included	M.A.D	16.05.2016	Yes	Yes
95	Brazil	Lisa	Netherlands	Included	Deceased	29.07.2014	Yes	Yes
96	Lithuania	Plutonas	Lithuania	Included	Deceased	26.04.2015	Yes	Yes
97	Panama	Sea Orchid	Panama	Included	Deceased	11.01.2015	Yes	Yes
98	Panama	Victoria No.	Panama	Included	M.A.D	10.10.2015	Yes	Yes
99	Marshall I.	Cape Duran	Marshall Is	Included	M.A.D	20.09.2014	Yes	Yes
100	Danish	Freya	The Nether	Included	M.A.D	3.09.2014	Yes	Yes

M.A.D.: Missing, assumed lost.

Appendix II List of National Agencies Published the Reports Used in This Study.

Country	Reporting Agency
Australia	Australian Transport Safety Bureau
Bahamas	The Bahamas Maritime Authority
Brazil	Brazilian Navy – Directorate of Ports and Coasts Department of Inquiries and Investigations of Navigation Accidents
Canada	The Transportation Safety Board of Canada
Danish	The Danish Maritime Accident Investigation Board
French	French Marine Accident Investigation Office
German	Federal Bureau of Maritime Casualty Investigation
Hong Kong	The Hong Kong Special Administrative Region Marine Department Marine Accident Investigation Section
Irish	The Marine Casualty Investigation Board
Japan	Japan Transport Safety Board
Liberia	Liberia Maritime Authority
Lithuania	Ministry of Transport And Communications of The Republic of Lithuania Marine Accidents And Incidents Investigation Manager
Luxembourg	Ministry of Mobility and Public Works Department of mobility and transports Administration of Technical Investigations
Malta	Malta Marine Safety Investigation Unit
Marshall Islands	Republic of the Marshall Islands Maritime Administrator
New Zealand	Maritime New Zealand
Norway	Accident Investigation Board Norway
Panama	Panama Maritime Authority Directorate General of Merchant Marine, Marine Accident investigation Department
Singapore	Singapore Ministry of Transport, Transport Safety Investigation Bureau
Turkey	Türkiye Cumhuriyeti Ulaştırma, Denizcilik Ve Haberleşme Bakanlığı Kaza Araştırma ve İnceleme Kurulu
UK	Marine Accident Investigation Branch

CHAPTER X

INVESTIGATION OF MAN OVER BOARD (MOB) INCIDENTS: FINDINGS AND DISCUSSIONS

Dr. İsmail ÇIÇEK

İstanbul Technical University, İstanbul, Türkiye e-mail: ism@drcicek.com
Orcid No: 0000-0003-4850-1747

Phd Student Orhan GÖNEL

İstanbul Technical University, İstanbul, Türkiye e-mail: gonelo@itu.edu.tr
Orcid No: 0000-0002-1298-6175

1. Introduction

Below subsections provides an overview for the MOB studies in the literature with relations to examining/studying statistical analysis to the current study.

This study is an original work, but it is a continuation of the work named ' Statistical Analysis of Man Over Board (MOB) Incidents: Statistical Analysis '.

1.1 Academic Studies and Technologies

There are several academic studies focused on the prevention of person falling overboard a ship or on the rescue maneuvering. Lucas and Lincoln claim Many fatal falls overboard may be prevented by understanding the circumstances involving and targeting interventions at those specific risk factors. However, their study was limited to commercial fishing vessels and it covered the Alaska region only (Lucas, D. L., Lincoln, J. M., 2007). Manitoba in his study, limited to boating fatalities in Canada, provides information related to effects of alcohol consumption of casualty falling overboard. Study states that; ‘alcohol is detected in two-thirds of victims of boating-related drownings who are tested, and many of these have blood alcohol levels well above the legal limit (Chochinov, A., 1998).

A study performed by Kulbiej and Rosik included numerical analysis of three different MOB maneuvers in different conditions (Rosik, J., Kulblej, E., 2018). Karatas and Akgun studied MOB rescue event for casualty with partial drift information (Karatas, M., Akgun, I., 2014).

Among these studies, a detail study for providing the MOB event statistics, is missing.

1.2 Commercial Products

In the US the Cruise Vessel Security and Safety Act was passed in 2010, after much campaigning from the International Cruise Victims Association. Among other safety areas, the act states that all vessels are required to integrate technology to capture images of or to detect passengers who had fallen overboard as soon as the technology is available (URL 1).

The International Organization for Standardization (ISO) in February 2018 announced new guidelines for the implementation of overboard systems, with the aim to propel forward the development of man overboard (MOB) technology for the cruise industry. The specifications were created in collaboration with the Cruise Lines International Association (CLIA), which acted as an expert in the ISO/TC/SC 1 Maritime Safety technical committee was used by ISO while creating the guidelines (URL 1).

There are many products on the market now. For example, while the system developed by MARSS company uses the radar systems (URL 2), the system developed by Puretech Systems can be integrated with drones (URL 3). Also, personnel locator beacons can be used for same purpose. While AISLINK MOB device produced by ACR Electronics Company weighs only 92 grams and has a range of 5miles (URL 4), PLB1 personal locator beacon device produced by OCEANSIGNALS has GPS receivers and delivers this GPS position to rescue center via rescue alert satellite (URL 5).

1.3 Current MOB Event Reporting Process

The MOB events are usually found in general maritime accident reports. There are some national reports providing with limited information and specific to country. For example, Marine Accident Investigation Branch (MAIB) of UK publishes annual reports. MAIB's 2018 public report provides the vessel type, type of fall, and the number of deaths. In December 2017 edition of 'Accident, incident, and mishap notification' reports, published monthly by the 'Maritime New Zealand' Authority, 2 MOB events are reported with 4 pertaining information, which are the number of events and the type, category, length (m) and tonnage (tons) of the vessels where the incident occurred, respectively.

Some national reports only provide with number of deaths with no other information. Some of others provide only few numbers associated with the event. For providing another example, EMSA, a regional agency providing

reports for EU waters, in its latest publication called ‘Annual Overview of Marine Casualties and Incidents 2019’, provided common information about all marine casualties and accidents such as the following:

- Distribution of ships involved by main category.
- Distribution of voyage segments.

EMSA did not present detailed information other than the above items about the man overboard incidents.

However, there are many reports exist in national or international databases, indicating potential analysis for many aspects of MOB event process with more parameters. The biggest issue of providing statistical results for global numbers is discussed by Gonel and Cicek (Gonel, O., Cicek, I., 2019), which are mainly associated with the inconsistencies between reports and that there is no methodology provided for formatting the reports for further analysis. Therefore, the methodology discussed in this paper is important for determining global statistics and resulting information with that all aspects of the event processes are well captured and used for analysis.

1.4 Purpose of This Study

Understanding the effects into a MOB event process, using statistical analysis, would point out improvements in potential areas to help reducing the number of events or reduce the risk for life when the event occurs. This study introduces a methodology to drive detailed level of parameters associated with a MOB event. The study includes the statistical analysis of MOB events using investigation reports, which are retrieved from various international databases.

2. Methodology

Fig. 2 of ‘Statistical Analysis of Man Over Board (MOB) Incidents: Statistical Analysis’ explains how data is acquired. In this study, the results obtained from the previous study mentioned were grouped, tangible results were obtained and presented. Table 1 shows a summary list of the findings. Only the most important findings are presented and discussed in this section. Statistical analyses results have provided important findings. Authors also performed correlation analysis between several variables to obtain further findings.

It must be noted that, these findings are based on randomly chosen accident investigation reports. First, all accident reports of over 180 are randomly chosen and only 100 of them, listed in Appendix I of ‘Statistical

Analysis of Man Over Board (MOB) Incidents: Statistical Analysis', with enough information, are used in this study.

Table 1. Summary Findings in Grouped by Contents

Group Name	Content	Subsection
Ship and Casualty Information	Vessel and casualty information	4.1
General Conditions before the Event	Entry conditions, such as navigational and meteorological conditions.	4.2
Work and Procedural Conditions	Status of the work conditions, existence of procedures and implementation of drills.	4.3
Event Occurrence and SAR Operation	Event parameters, such as timings and actions as well as specifics to the SAR operations.	4.4

3. Findings and Discussions

3.1 Ship and Casualty Information

3.1.1 Vessel Information

The highest occurrence rate according to age category is between 0 to 4 ages occurring in the 26% of the events. The average ship tonnage and length are found as 19879.2 GRT and 121.0 meters respectively.

3.1.2 Rank

60 percent of the casualties are deck ratings and among them the deck bosun has the highest rate of falling. The rate of the deck ratings to the number of the whole ship crew is found as approximately the 20-25 percent. The 60 percent casualty rate being the deck ratings indicates that the deck ratings are more vulnerable to falling overboard.

3.1.3 Work Experience of the Casualty

Average overall work experience of all casualties is found as 8 years. The average work duration of all casualties working onboard ships where accident occurred is found as 8.6 months. There may be a perception for that the crew who is experienced and more familiar with the ship is less vulnerable to falling overboard; however, the results in this study indicate the opposite.

3.1.4 Ship's Command

In 67.9 percent of the events, the captain of the ship was in command at the time of the event occurrence. This indicates that this type of events may occur even in more formal ship operations in which the ship's captain is in command.

In 38 events that the captain was in command, the casualties were removed from water with a ratio of 71.1 percent, regardless to the survival status. However, in 16 events where the officer was in command, this ratio was found as 31.3%. This finding showed a noticeable change for the rate of the removal of the casualty from water depending on who the person in command is.

3.1.5 Time of Day

Majority of the MOB events occurred in the morning hours, especially between 0800 and 1159hrs, where the weather is bright, most of the ship's crew is awake, and fatigue is not a main contributing factor. In addition, the casualties have more probability of receiving help from their coworkers during these hours. The reason may be attributed to the busy shipping operations which are carried out in this period or human error might be of a bigger issue during those hours or both. The reason why the morning hours are the most occurrence of the MOB events might be an area of another study.

3.1.6 Casualty Information

The average age of all casualties is found as 40.3. Sea personnel's average age is also about the same. For example, the average age of master and officers and ratings having a EU seafarer license is 43.4 and 40.1, respectively (EMSA, 2018). Our finding is about the same as the ones reported in a previous study.

In 54.6% of the cases, the casualty was around with one or more persons. The report 63 in its 'Recommendations' section states the following: "In Particular, for newly-joined and/or inexperienced junior officers and ratings: working alone of crew members should be avoided as far as possible and practicable". While it seems to be a good recommendation, the statistics in this study shows that the personnel seem more careful while working alone and personnel should be careful while working both alone or with someone. Additionally, 40.3 average age reflects that the recommendation is not only valid for junior officers and ratings but also for all ship crew.

Correlation analysis between alcohol or drug influence to death shows that 11 casualties are influenced out of 12 deceased and 23 are not influenced out of 24 deceased. The effect of alcohol into the death rate could not be validated in this study (Figure 1).

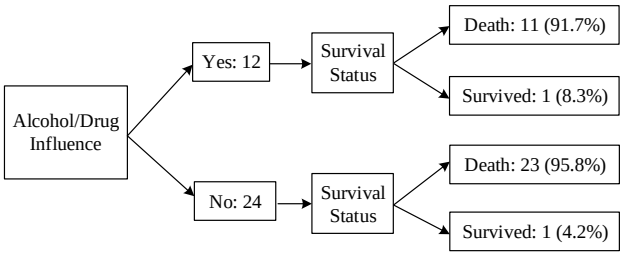


Fig. 1. The Effect of Alcohol on the Survival Status.

3.1.7 Fatality

35.2% of deaths occurred after the victim was taken from the water. This shows that taking the victim alive from the water does not mean the casualty will survive.

'Approximately 17% of immersion deaths occurs just before, during, or immediately following rescue, the term "Circum-rescue collapse" has been given to these deaths' (Tipton. M., 2016). Our current study showed 31 of the 88 deaths (35.2%) occurred after the rescue.

For this reason, MOB procedures must cover / include after rescue medical care.

3.1.8 Wearing a Lifejacket

While 25 percent of the casualties were wearing a lifejacket, other 75 percent of those were not wear at the time of the incident. This shows that the majority of the casualties did not consider themselves under a risk of falling overboard.

3.1.9 Fatigue Condition

Our study shows that the fatigue is not a contributing factor.

3.1.10 Navigation Status

Contrary to the perception among seafarers for that the risk is higher during navigation, 40% of the MOB events occurred when the ship did not navigate. This result indicates that the ship is not sailing pose almost about the same risk as the ship is sailing. Current drills and SAR procedures consider only the incidents occurring meanwhile the ship is navigating. Current procedures may be revisited due to the findings reported in this paper.

The average distance to the nearest land is found as 58.4 nautical miles at the time of the incidents. Drills may include two different scenarios; one

is with the shore assistance is available and another is without the shore assistance.

3.2 Environmental Conditions

3.2.1 Weather Conditions

61.7% of accidents occurred while there were no adverse weather conditions. This indicates that the seafarers must still be very careful whether the weather conditions are normal or adverse. Correlation between parameters; the existence of the adverse weather and the removal of the casualty from water (Figure 2) as well as the survival status (Figure 3), shows that the adverse weather conditions decrease the chance of the casualty's removal from the water (Figure 2) and the survivability (Figure 3).

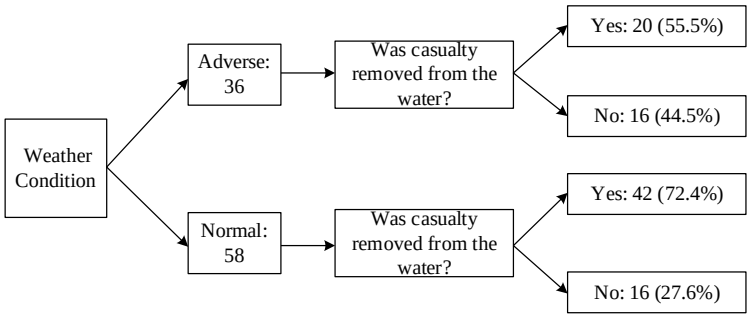


Fig. 2. Effect of Adverse Weather Condition on the removal from water.

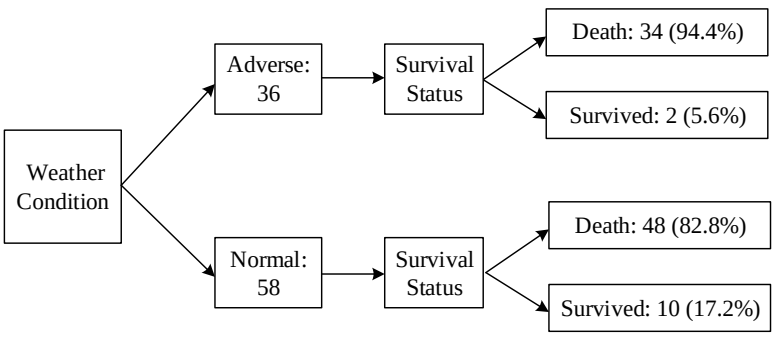


Fig. 3. Effect of Adverse Weather Condition on Survivability.

Averages of sea and water temperatures in all cases are found as 11.9°C. and 13.6°C respectively. In Table 2, average (50% survive) survival times (hours) for lightly clad males, from various authors are given (Tipton. M., 2016). Table 21 shows the distribution of the 88 deaths by the sea temperature. Unfortunately, only 48 of the reports had the sea temperature

information. The comparison of Tables 2 and 3 indicates the decrease in survival time and high potential risk of death in lower seawater temperatures in this study.

Table 2. Average (50% survive) Survival Times (hours) For Lightly Clad Males, in Various Studies.

Water Temp	Molnar	Hayward	Golden	Tikuisis
5°C	1	2.2	1	2.2
10°C	2.2	2.9	2	3.6
15°C	5.5	4.8	6	7.7

Table 3. Death Distribution with the Sea Temperature.

Water Temp	Number of Events	Number of Deaths	Percentage of Deaths
Below 2.5	4	4	100%
2.5 - 7.5°C	10	10	100%
7.5-12.5°C	19	15	78.9%
Above 12.5 °C	15	13	86.7%

Correlation analysis between the event occurrence time in a day and sighting of the casualty is conducted (Figure 4). Figure shows the casualties falling overboard in a daytime have a higher chance to be spotted immediately.

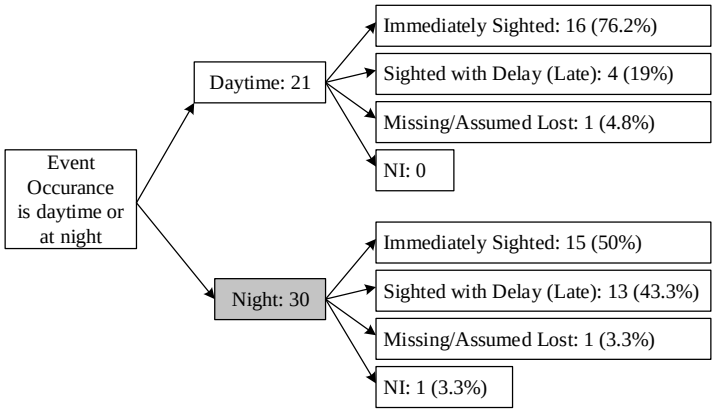


Fig. 4. Correlation between the events occurrence time and sighting of the casualty.

3.3 Work and Procedural Conditions

3.3.1 Relevance to Work

89.6% of the events occur when the casualty is in a work-related activity. Only 10.4% of the events occur when the casualty does not carry out a work-related task, such as fishing and similar recreational activities. Results indicate that risk of falling overboard is much higher in work related activities.

3.3.2 Working in Accordance with the Safety Rules

87 reports indicate that the work was not being carried out in accordance with the safety rules at the time of the event; 46 of which had the workplace conditions were conforming to the safety regulations. However, 38 of 87 reports did not have the work conditions prepared in accordance with the safety rules. Unfortunately, these results indicate that the safety rules are not carried out in most of the events and work conditions are not prepared in accordance with the safety rules. This result in our study show that the practical application of the safety rules is the major root cause of such events.

3.3.3 Applicable Checklist

Out of 100 reports, only in 30 of the events, an applicable checklist was in place and only 10 of them were filled. Unfortunately, only in one event the checklist was found as properly filled. This item also indicates that not filling the checklists with enough care poses major risks for the occurrence of MOB events.

3.3.4 Applicable General Work Procedures

Out of 100, 61 reports indicated that there were applicable work procedures whereas only 4.9 percent of the reports indicated the proper implementation of the applicable procedure, which is considerably low. Not implementing the work procedures properly also poses a major risk for the occurrence of MOB events.

3.3.5 Action Causing the Man Overboard Event

The most occurrence of the events happens while working overboard, especially while setting the ladder. Common issues observed are the absence of a supervision of watchkeeping officer and not wearing a safety belt and harness. Both malpractices are against the existing procedures. These items must be emphasized during the onboard trainings and onboard safety meetings.

3.3.6 Implementation of Man Overboard Drills

This practice was not mentioned in 71 reports. Among others, in 16 reports, the MOB drills were not implemented and only 13 of the reports indicated that the MOB drills were implemented. The scheduled onboard drills are not carried out in more than half of the cases; therefore, this finding raises the question of how the drills could be more encouraged.

Report results were analyzed for correlation of the implementation status of the MOB drills with the casualties' survival status. An important following result is observed: On 14 reports where MOB drills recorded that it was implemented as recommended, the casualty survival rate was found as 71.4% with a death rate of 28.6%. On the other hand, on 16 of the reports indicating the MOB drills were not implemented, the survival rate was 0% with the death rate of 100%. This result obviously demonstrates the direct influence of the MOB drills on the results of the MOB events. Remaining 70 reports did not have indications of the implementation of the drills.

3.4 Event Occurrence and SAR Operations

3.4.1 Response Actions and Times

Initial response times pertaining to event are presented in Section 3.8 of the former study ''Statistical Analysis of Man Over Board (MOB) Incidents: Statistical Analysis'. The response times for SAR operations and timings are included in section 3.9 of the same former study. Also, the response timings for medical response are included in Section 3.10 of the same former study. This study reports the action and response times and durations for all these three types. These results in this study are reported for the first time in literature with details and contain valuable information for use as reference data in future modeling and simulation studies of the MOB events.

Table 9 of the former study 'Statistical Analysis of Man Over Board (MOB) Incidents: Statistical Analysis' indicates whether the response actions are indicated in the reports and provides the associated timing information. In majority of reports, the use of alarms, announcements, ship whistle are not done or not indicated. Authors recommend that the MOB reports should indicate the status of these actions regardless to the need. Similar issues exist in Table 10 of the same former study.

3.4.2 Notification Time to SAR Authorities

There were cases that indicated that the duration between the time of the casualty falling overboard and the time of notification to SAR authorities was as long as over an hour. In some cases, the ship management did not report the accident immediately. Also, examining the

timings in some cases showed that the ship's management reported the event to the coastal authorities after reporting to the company, which is not expected notification order and leads to delays in rescue actions.

3.4.3 Implementation of SAR Procedures

Only in 25 of the events the SAR procedures are surely existed and only in seven of those events, the SAR procedures implemented appropriately. This result may be a good indication of the awareness and application of emergency procedures onboard ships are not implemented satisfactory.

3.4.4 Casualty Transfer to SAR Boats

Correlation of several variables are examined statistically. The average timing of arrival to the event location by air rescue, other ships or SAR ships is found as 87.2, 51.3 and 51.1 minutes respectively. The number of casualties taken from water by a helicopter, by its own ship, SAR ships, other ships in vicinity, or by a shore-crew is found as 5, 22, 13, 15, and 3, respectively. One casualty was saved by own efforts and 6 reports did not provide information. These results indicate that the SAR ships and other ships (ships that are not designated as rescue vessels) arrive on scene sooner than the air rescue and there is more occurrence of saving the casualty by SAR boats or other ships than by a helicopter. In most of the current onboard drill programs, the casualty transfer drills are based on transferring the casualty to helicopters; however, there are no transfer drills found on ship drills for transferring casualty between ships. Also, probably for the same reason, the authors could not identify equipment and procedures specifically for using in transferring the casualty between ships. The authors recommend the inclusion of a casualty transfer between ships in the ship' drill programs. Additionally, the ships might be equipped with ship-to-ship casualty transfer installations. One aspect to this discussion is that the military ships already have the procedure and systems for casualty transfer from ship-to-ship, yet the commercial ships do not.

3.4.5 Sighting of the Casualty

When a casualty could not be sighted, it is assumed that the casualty has fallen overboard, which is called as “awareness to the event” in this paper. Results for the correlation between the awareness to the event and the casualty removed from water is shown in Figure 5 and Table 4, respectively. Figure 6 shows that the death rate is considerably high in late awareness. 2 out of 16 casualties in events with “assumed overboard” cases, are survived. Figure 7 also shows a consistent data; late awareness causes over delay in removal times and the death rates are found higher.

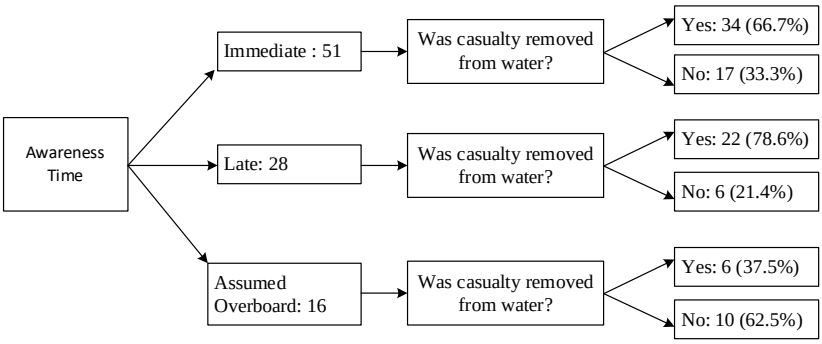


Fig. 5. Awareness to the Occurring Event and the Removal Status from Water.

Table 4 Average removal time depending on the awareness to MOB.

Awareness	Number of Events	Events with Timings	Average Removal Time
Immediate Awareness	51	21	28.4 min
Late Awareness	28	11	608,1 min

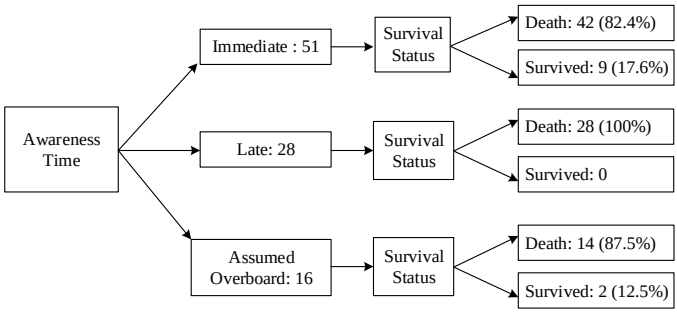


Fig. 6. Awareness to the Occurring Event and Casualty's Survival Status.

Figure 6 shows the casualty's survival status with the status of the sighting of the casualty. The word "limited" in this figure means the casualty could not be sighted at all times. Results show that the survivability rate drastically decreases when the sighting of the casualty could not be done continuously.

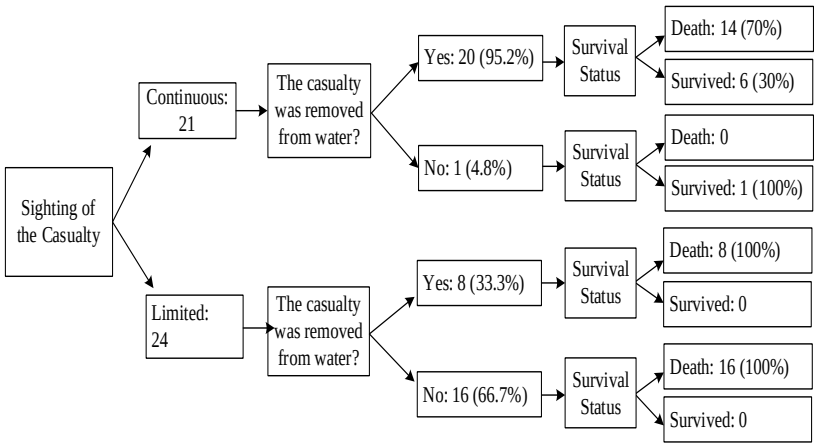


Fig. 7. Status of the Sighting of the Casualty and Casualty's Survival Status.

3.5 Additional Findings Identified from the Investigation Reports

There are other findings captured, which are driven by the authors in their direct review of the reports' manuscripts. Two noticeable ones provided below are as example findings.

o High freeboard of rescue crafts (Event number 2): An unconscious casualty was brought by the side of the work boat of the vessel but could not be recovered due to high freeboard of the work boat. New standards can be set for rescue crafts to allow them to recover unconscious casualty. Extra platforms or portable winch like aids may be developed for recovering casualties from water.

o When the captain of the ship falls overboard (Event number 33): In all training procedures and drills, captain is responsible for the command of the ship. In case the captain falls overboard, there is uncertainty according to the existing guides or procedures, which do not describe how to respond to the situation. A procedural solution might provide an extra drill scenario with that the captain falling overboard can be prepared and carried out onboard.

4. Conclusions

Results are presented such that usable recommendations could be driven for the improvements in MOB operations; by means of human factors, procedures, and equipment. These improvements potentially may reduce the MOB incidents and decrease the number of casualties. The findings in this study are grouped and summarized as follows:

- Human Factor:

o The probability of MOB event occurrence is higher in the morning hours than other times of a day (Section 3.1.5).

o The safety rules are not carried out in most of the events and work conditions are not prepared in accordance with the safety rules (Section 4.3.2).

o Applicable checklists are either not prepared or prepared with inadequate attention (Section 3.3.3).

o Applicable general procedures are not properly implemented (Section 3.3.4).

o Required care is not given while working overboard, especially while setting the ladder. (Section 3.3.5).

o Absence of a supervision of watchkeeping officer and not wearing a safety belt and harness while preparing pilot ladder (Section 3.3.5).

o The scheduled onboard drills are not carried out (Section 3.3.6).

o Proper implementation of existing SAR procedures (Section 3.4.3).

o Falling overboard rate is higher for the crew that are accompanied with other crew than crew who is alone (Section 3.1.6).

o The rate of casualty falling overboard who do not wear lifejackets is higher than those who wear lifejackets. (Section 3.1.8).

o The probability of MOB event occurrence is much higher while carrying out work related duties than while performing recreational activities (Section 3.3.1).

- Procedural:

o Current drill procedures do not consider the ship is not navigating (Section 3.1.10).

o MOB procedures do not cover the after rescue medical care (Section 3.1.7)

o Ship-to-ship casualty transfer procedure does not exist (Section 3.4.4)

o Drill procedures do not include the information when the captain becomes the casualty (Section 3.5).

o Current drills do not consider if there is help from shore is available (Section 3.1.10).

- Equipment Issue:

o There is no designated equipment to remove the casualty from water for the rescue crafts with high freeboard (Section 3.5).

Other important findings in this study are listed as follows:

o MOB accidents occur less frequently in adverse weather conditions (Section 3.2.1).

o The seafarer group that falls overboard most is the deck ratings (Section 3.1.2).

o The rate of falling overboard is higher among the experienced crew than those with less sea time (Section 3.1.3).

o If a MOB casualty is sighted immediately after falling overboard, casualty has a higher survival rate (Section 3.4.5).

o An interesting finding was that when the ship's captain is in command, the rate of falling is considerably higher (Section 3.1.4).

References

Chochinov, A., 1998. Alcohol "on board," man overboard — boating fatalities in Canada. Canadian Medical Association Journal 159 (3), 259-260

EMSA, 2018. Seafarers' Statistics in the EU. Statistical review (201 data STCW-IS). European Maritime Safety Agency.

Gonel, O., Cicek, I., 2019. Maritime Investigation Reports Involving Man-Over-Board (MOB) Casualties: A Methodology for Evaluation Process. Ordu University Turkish Journal of Maritime and Marine Sciences 5 (2), 141-170

Karatas, M., Akgun, I., 2014. Searching for Man Overboard with Partial Drift Information. Conference: The International Workshop on Applied Modeling and Simulation, Istanbul.

Lucas, D. L., Lincoln, J. M., 2007. Fatal Falls Overboard on Commercial Fishing Vessels in Alaska. American Journal of Industrial Medicine 50, (962–968)

Rosik, J., Kulblej, E., 2018. Numerical Analysis of MOB Manoeuvres in Regard to a Body Suffering from Hypothermia. Scientific Journals of the Maritime University of Szczecin. 54 (126), 120–126.

Tipton. M., 2016. Cold Water Immersion. In book: The Science of Beach LifeguardingEdition: 1stChapter: 6Publisher: CRC PressEditors: Mike Tipton, Adam Wooler

URL 1 <https://www.ship-technology.com/features/setting-international-standards-man-overboard-systems/>

URL 2 <https://marss.com/products/mobtronic-cruise> 23.04.2020 20:40

URL 3 <https://www.puretechsystems.com/man-overboard-detection.html> 23.04.2020 20:39

URL 4 <https://www.acrartex.com/products/mob> 23.04.2020 21:09

URL 5 <https://www.westmarine.com/buy/ocean-signal--rescueme-plb1-personal-locator-beacon--17112913?recordNum=4> 23.04.2020 21:14

CHAPTER XI

A SURVEY OF METAHEURISTIC APPROACHES TO SINGLE MACHINE TOTAL WEIGHTED TARDINESS PROBLEM

Dr. Zeynep ADAK

Gebze Technical University, Kocaeli, Turkey
E-mail: zeynepadak@gtu.edu.tr
ORCID no: 0000- 0001-7654- 0773

1. Introduction

Single machine total weighted tardiness (SMTWT) problem is a machine scheduling problem where there is only one machine which can process one job at a time and there are n jobs to be processed on that machine. Each job has its own processing time, p_j, a due date to be ideally completed by, d_j, and an associated weight, w_j. The weight of the job may represent some holding cost or may be related to the importance of the specific job. If C_j is defined as the completion time of job j, then tardiness, T_j, of a job is defined as $T_j = 0$ if the job is completed by its due date ($C_j \leq d_j$), or $T_j = C_j - d_j$ if the job is completed after its due date ($C_j > d_j$). One tries to sequence the jobs in order to minimize the total weighted tardiness of the schedule. SMTWTP is commonly represented as $1||\sum w_j T_j$ which became a standard classification.

Initial efforts to solve SMTWT problem are through Branch and Bound and Dynamic Programming algorithms which provide exact solutions to the problem. The reader may refer to Abdul-razaq et al. (1990) for an extended survey of exact algorithms. The algorithms, though, can be applied only to small problems where there are at most 50 jobs to be processed. Through some recent improvements in branch and bound or dynamic programming algorithms, relatively larger problems are tried to be solved exactly. Tanaka et al. (2009) proposed an improved successive sublimation dynamic programming method that is able to solve SMTWT problems with 300 jobs optimally. In case of even larger problem instances, however, it requires an unreasonable amount of computation time as well as considerable computer storage due to the proved (Lawler

1977) NP-hard nature of the problem. Hence, a well number of heuristic techniques are applied to have faster but satisfactory solutions.

Heuristics are constructive type, improvement type, evolutionary algorithms or in the form of more advanced metaheuristics. Constructive heuristics fix the position of one job in the sequence at each iteration. Potts & Wassenhove (1991) review both simple quick dispatching rules and more sophisticated heuristics. General nature of improvement type heuristics, evolutionary algorithms and the other more advanced heuristics are mentioned briefly later in the paper.

Previously, a number of surveys are published reviewing the research in the field. It has been long since the popular survey by Abdul-razaq et al. (1990), which examines the exact methods. Potts and Wassenhove (1991) survey the simple constructive heuristics and more advanced ones of that time. They miss the heuristics developed in the last decades, especially metaheuristics. A more recent survey of minimizing weighted and unweighted tardiness is by Sen et al. (2003). They review exact algorithms and heuristic approaches. Heuristic algorithms are only presented briefly, and metaheuristics, especially, are mentioned very little. Lastly, Koulamas (2010) reviews theoretical developments and propose extensions to total tardiness problem. To author's knowledge, there are no recent surveys in the field. It would be timely to review the research about metaheuristic approaches to SMTWT problem, since in the last years, a proliferation of metaheuristics to the problem is observed.

Several studies in the literature are not included in the current review although they propose metaheuristics for SMTWT problem. This is due to the contribution of the study being relatively poor, hence ignored here to keep the review more focusing.

Only the literature about $1||\sum w_j T_j$ scheduling problem is reviewed in this survey. Other studies which also consider the job characteristics such as sequence-dependent set-up times, batch scheduling, release dates, preemption, maintenance, deteriorating jobs, etc. or the objective functions such as multiple objectives, square tardiness, earliness tardiness, etc. are out of scope of this paper, hence are not reviewed here.

In section 2, a general brief overview of metaheuristic methods is given. Research papers that use metaheuristic approaches to solve SMTWT problem are presented in Section 3 beginning with initial local search metaheuristics applied to the problem in 1980s. Performance comparisons

of best-performing algorithms are summarized in Section 4. The last section includes conclusive remarks and possible suggestions about future work in the field.

Table 1. Abbreviations

ABC	Artificial bee colony
ACO	Ant colony optimization
DE	Differential evolution
DS	Dynasearch
GA	Genetic algorithm
GPI	Generalized pairwise interchange
GRASP	Greedy randomized adaptive search procedure
hEA	Hybrid evolutionary algorithm
IDS	Iterated dynasearch
ILS	Iterated local search
LS	Local search
luABC	Lunar inspired ABC
MA	Memetic algorithm
ORLIB	OR Library
PR	Path relinking
PSO	Particle swarm optimization
SA	Simulated annealing
SMTWT	Single machine total weighted tardiness
TA	Threshold accepting
TS	Tabu search
VND	Variable neighborhood descent
VNS	Variable neighborhood search

2. Metaheuristics

Definition by Luke (2013) is quoted here to describe what is metaheuristics and when they are used: “Metaheuristics are algorithms used to find answers to problems when you have very little to help you: you don’t know beforehand what the optimal solution looks like, you don’t know how to go about finding it in a principled way, you have very little heuristic information to go on, and brute-force search is out of the question because the space is too large. But if you are given a candidate solution to your problem you can test it and assess how good it is. That is, you know a good one when you see it.”

Metaheuristic methods applied in scheduling field can be represented largely in three classes. One big class contains the local search (LS) based methods such as descent, simulated annealing (SA), threshold accepting (TA), and tabu search (TS) methods. Evolutionary methods like genetic algorithm (GA), ant colony optimization (ACO), particle swarm optimization (PSO), differential evolution (DE) and memetic algorithm (MA) form the second class. The last class contains the other metaheuristics and hybrids of LS and evolutionary algorithms. The reader can refer to Table 1 for the abbreviations used throughout the text.

2.1. Local search algorithms

LS methods are the most important class of algorithms that still produce good quality solutions for scheduling problems. For the other long-studied problems, such as the SMTWT problem, they make significant contribution as part of hybrid algorithms.

An LS algorithm starts with an initial solution, searches the neighborhood of the current solution, replaces the current solution with a solution in the neighborhood that has a better objective function value, and repeats itself until it converges to a local minimum. In different LS algorithms, certain aspects of the algorithm may change to increase the solution quality by escaping from local minima or to improve the computational efficiency. Descent method is one of the oldest LS methods. It searches for a neighboring solution that certainly improves the objective function value.

SA algorithm, on the other hand, allows the current solution to be replaced by an *inferior* solution in the neighborhood with an acceptance probability in order to delay convergence and make the heuristic converge to a near-optimal solution instead of a local one. The acceptance probability at each iteration depends on a control parameter and the degradation the move causes in the objective function value. If the lower quality neighborhood solutions are accepted in a deterministic way, these types of approaches are called TA methods. They are similar to SA method except the acceptance level. Decision to move to an inferior solution depends on a predefined function and a threshold value. Various definitions of the function lead to variants of TA methods.

Another LS procedure is the TS method, which is among the most effective, if not the best, to tackle the difficult problems at hand (Gendreau & Potvin, 2010). The approach takes the best neighborhood (or more

commonly a sub-neighborhood) solution as the next solution even it is worse than the current one. The algorithm, thus, resumes even when it reaches to a local optimum, hence prevents the search to get stuck in local minima. TS uses a memory which is called a tabu list to prevent the algorithm to return to a previous solution and cycle. Under specified conditions, named as aspiration criteria, a tabu may be disregarded, and the associated move may be allowed to be taken as long as no cycling occurs. This is in order to prevent the search process to stagnate. Lastly, stopping criteria must be introduced to terminate the search process which unless would iterate forever or fortunately until a global optimum. Various implementations of the algorithm differ in tabu list being in fixed or variable length, and in definitions of aspiration and stopping criteria.

2.2. Evolutionary algorithms

These algorithms are based on solutions undergoing an evolution to produce better solutions till a satisfactory one is reached. Three archetypes of evolutionary algorithms are the GA, ACO and PSO. Other algorithms of this class built on similar foundations.

A well-known class of evolutionary algorithms are GAs. GA is inspired from evolutionary biology and has mechanisms of selection, crossover, mutation, and inheritance. The algorithm starts with a population of solutions (chromosomes), each have an objective function value called fitness. Chromosomes are selected stochastically, where chromosomes with favorable fitness values have higher probability to be selected. The selection procedure can be applied as roulette wheel selection or tournament selection, as two popular selection methods. The selected chromosomes are mated where crossover and mutation take place. The offspring places the individual with the least fitness, and the process continues until the termination criterion.

ACO is inspired from food searching behavior of ants. Each one of a population of artificial ants constructs a solution stochastically using pheromone information and heuristic information. Pheromone is a substance that ants leave behind, which corresponds to a memory model in an algorithm. Heuristic information is based on problem knowledge. A chosen set of best solutions update the memory model and there may be some central actions such as local search for improved solution quality. The process repeats until a termination criterion is met.

PSO is inspired from food searching behavior of bird flocks. A collection of points (particles) is selected in the three-dimensional search space and each particle is represented in vector form as a set of coordinates. Particles stand for feasible solutions of the problem. The algorithm stores the best position of a particle and all particles so far. At each iteration, all particles are moved on the solution space through random perturbations using both local and collective memory. The particles are hoped to converge, as a whole, to a near-optimum solution.

2.3. Other metaheuristics and hybrids

The field of metaheuristics has developed significantly that makes it impossible to define every single approach within the limits of this chapter. The reader is referred to Gendreau and Potvin (2019) for a recent book covering fundamental metaheuristics and hybrids (pp. 385-417), and to Kaveh and Bakhshpoori (2019) for the newest metaheuristic algorithms.

3. Applications of metaheuristics to SMTWT Problem

Prior to reviewing the metaheuristic applications to SMTWT problem, commonly used test data sets in the field are provided in the following subsection.

3.1. Benchmark test problems

Researchers studying SMTWT problem use either the freely accessible OR library – ORLIB – (Beasley 1990) benchmark problem sets of Crauwels et al. (1998) or a second set of instances described below to measure the performance of their algorithms and compare them with other algorithms in the literature. A third set of instances was also proposed recently as detailed below, but still not used in much research.

ORLIB includes 125 instances for each of 40-job, 50-job and 100-job problems, which makes a total of 375 instances. These are often referred to as small-size problems. Optimum solutions for up to 50-job problems had been available since the initial applications of the exact algorithms. For the 100-job problems, however, best-known solutions were used as a reference point up to 2007 when Pan & Shi (2007) solved (at the expense of very long computation times for hard problem instances tough) all 375 benchmark instances of the ORLIB to optimality.

A second set of problems include 500 instances of larger problem sizes, generated in the same manner as the first set instances. The set is composed

of 125 instances of 150-job, 200-job, 250-job and 300-job problems. These larger instances are used in relatively less number of studies and more recently. The optimal solutions for all these larger instances together with the ones for the above-mentioned small size problem instances are found by Tanaka et al. (2009) in competitive cpu times. They have been able to find the optimum solution in much less time (within 40 seconds) than Pan & Shi (2007) for the harder 100-job problems. Optimum objective function values with cpu times can be found under https://sites.google.com /site/shunjitanaka/sips/benchmark-results-sips. The site also supplies the data sets for the 40, 50, 100, 150, 200, 250, 300, 350, 400, 450 and 500-job instances.

The extent of difficulty of the ORLIB problems is one common concern voiced in the field. den Besten el al. (2001) claimed them not to be challenging for the state-of-the-art algorithms. Geiger (2009) considered the issue and further investigated it to reveal that many of the instances include numerous globally optimum points which make them easily solvable by even simple local search heuristics. Thus, Geiger (2010b) introduced two new sets of harder benchmark instances. One set includes 25 instances with 100 jobs. The other set includes larger problems, where 25 instances with 1000-jobs are provided. The two datasets and both the instances and optimal values are available at https://www.hsu-hh.de/ logistik/ research/projects/smtwtp.

3.2. Early LS algorithms

Beginning from 1980s, a number of LS heuristics are applied for the solution of the SMTWT problem. Aarts & van Laarhoven (1985) proposed an SA method to the problem. Later, Matsuo et al. (1989) presented a more computationally efficient implementation of the method by applying a good initial solution generated by a heuristic, along with a small control parameter and low initial acceptance probability.

Potts and Van Wassenhove (1991) proposed descent and SA methods to SMTWT problem and compared the performances of each method. Crauwels et al. (1998) extended their work and presented a thorough comparison of descent, SA, TA, TS and GA applied to SMTWT problem. TS dominated the others in terms of both solution quality and the ability to find an optimum solution, and it performed well both in single start and multi-start tests, and both in small and large problems. They also proposed a new binary encoding scheme to represent solutions and showed that heuristics employing their proposed encoding scheme consistently produce

good quality solutions. They showed that the performance of the GA significantly improves using the binary representation.

Madureira (1999) proposed a multistart LS procedure, called randomized LS, with random initial solutions, and claimed that the algorithm is superior to TS in terms of quicker production of good solutions, ease of implementation, and no great effort needed for parameter tuning.

As the studies revealed, TS algorithm was shown to be superior to other algorithms, thus much effort was devoted through further improvements in the algorithm. Beausoleil (2000) proposed several intensification and diversification approaches for the algorithm. Intensification encourages favorable move combinations and solution features while diversification directs the search process to unvisited regions of the solution space. He favored attractive job locations for intensification purpose and created tabu status for diversification purpose. He showed that an intensification within diversification approach yields good quality solutions and it can be implemented together with large step optimization (another diversification approach) to improve computational efficiency. Additional implementation of a path relinking (PR) strategy improved the solutions further with little extra time. The strategy generates new solutions by exploring trajectories that connect high quality solutions. He made no comparison with the TS of Crauwels et al. (1998).

3.3. Improved results

den Besten et al. (2000) suggested an ACO that found the best-known solutions for *all* the 125 instances within (generally) reasonable computation times. den Besten and his friends were the first to apply a particular ACO algorithm to SMTWT problem. They used Variable Neighborhood Descent (VND) LS algorithm to improve sequences constructed by ants. They used two types of ant colonies each of which used different neighborhood construction mechanisms to increase the robustness of the algorithm. Same researchers later applied (den Besten et al. 2001) an iterated local search (ILS) approach which performed (in average) better than their ACO algorithm in terms of computation times. They used VND LS method in their algorithm. They claimed that the ORLIB benchmark instances are not challenging for the state-of-the-art algorithms. Holthaus & Rajendran (2005) proposed a fast ACO to remedy the low-speed drawback of the algorithm. They use different parameters and local search schemes than den Besten et al. (2000) and introduced a

multi-start approach. The algorithm provided satisfactory computational efficiency.

3.4. Dynasearch: a breakthrough

A breakthrough in neighborhood search has been by the introduction of the popular dynasearch (DS) technique, which uses a polynomial time dynamic programming procedure to search an exponential size neighborhood and allows multiple moves during an iteration in contrast to the single move of the traditional LS approaches. An iterated dynasearch (IDS) algorithm for the SMTWT problem is proposed by Congram et al. (2002). They showed that the algorithm is successful in escaping from local minima and it is superior to other *LS* algorithms, including TS, proposed up to that time both in terms of solution quality and cpu time. Later, Grosso et al. (2004) improved their results greatly by proposing an enhanced DS approach which uses generalized pairwise interchange (GPI) operators that allow both pairwise interchanges and insertions. They also showed their proposed algorithm (GPI-DS) to obtain the same solution quality as ACO with significantly less computation times.

Ergun & Orlin (2006) developed search algorithms that decreased the complexity of neighborhood search to $O(n^2)$ in swap and twist neighborhoods, and in DS neighborhoods that based on either swap or a combination of swap, insertion and twist.

Ding et al. (2016) applied a breakout DS algorithm (BDS) where in addition to DS they apply perturbations to the best solution to lead the search to new solution spaces, hence ensuring diversification. They managed to reach the optimal solutions for all 375 instances of ORLIB within significantly low computation times. For the larger instances (150 to 300 jobs) they managed to find the optimum solutions within very competitive computation times, and hence showed a higher performance than the GPI-DS of Grosso et al. (2004).

DS procedure was also applied in a Hybrid Evolutionary Algorithm (hEA) proposed by Ding et al. (2017). They applied the DS neighborhood search algorithm both to individuals of initial population and to offspring solutions. The algorithm is more detailed on the next subsection.

3.5. Focus on evolutionary algorithms

Borgulya (2002) is proposed an evolutionary algorithm for SMTWT problem, with results need to be further improved compared to best

performing algorithms of that time. In his cluster-based evolutionary algorithm, he simultaneously searched for various local optima, he formed clusters of local optima estimations by grouping similar sequences and then improved the results of these clusters by a complex LS process, and finally refined his estimations.

Avci et al. (2003) proposed a problem space GA that uses certain dominance rules to create a better neighborhood space, which improves the intensification and diversification capabilities of the algorithm. They claimed that the algorithm compares well with the performance of the TS algorithm, it provides robust results, and requires much less increase in computation time as the problem size increases. Liu et al. (2003) offered a GA that performs better than descent methods. They used permutation representation, heuristic based and random initial populations, position and order-based mutations and elitism in their proposed algorithm. Ferrolho & Crisostomo (2006) developed a simulation software tool to compare various crossover and mutation operators used in GA in the literature. They evaluated respective performances of the operators and selected the best performing combination to apply in their GA. Kellegöz et al. (2008) compared performances of eleven common genetic crossover operators. Order based and position-based crossover operators were found to be superior to others in terms of solution quality. Different operators made no difference in the computation time of the algorithm. Chou (2009) proposed a GA which stores the job-job and position-job information in two dynamic matrices and developed a heuristic that uses this information to increase intensification. Position-job matrix includes the intension of a specific job in a specific position. Job-job matrix includes the precedence relationships. They showed that the performance of GA is improved significantly by incorporating the developed heuristic.

Tasgetiren et al. (2004) applied PSO to the problem for the first time. They proposed “smallest position value” rule to determine the sequences of the particles and applied a Variable Neighborhood Search (VNS) in the algorithm. They claimed the algorithm produce promising results that are as good as ILS and ACO. Huang & Tung (2006) proposed another PSO algorithm where they applied a dynamic mutation operator based on a random interchange of jobs to speedup convergence and escape local optima. Performance of original PSO algorithm was further improved by Parsopoulos & Vrahatis (2006) through applying a unified scheme of the algorithm where both global and local neighborhoods are considered simultaneously. They showed that the unified scheme produced more

robust and better-quality results than standard PSO applications. Overall performances of these latter two PSO applications, however, are far below VNS based PSO of Tasgetiren et al. (2004).

Tasgetiren et al. (2006) proposed PSO and a DE approach to the problem, and they applied both DE and PSO to ORLIB benchmark problems. Their DE and PSO algorithms made use of VNS and they showed that the proposed algorithms were capable of finding optimum or best-known values over all runs for all benchmark instances with 40, 50 and 100 jobs in satisfactory computation times.

The hEA proposed by Ding et al. (2017) was an MA that had alternating recombination and perturbation procedures and the DS as the neighborhood search function to improve the solutions visited by the algorithm. It solved all the ORLIB 40, 50 and 100-job instances within 0.04 seconds in average. The algorithm was also tested on the instances with 150, 200, 250 and 300 jobs, and managed to find the optimum at every trial in significantly lower computational times compared to previous best performing BDS algorithm of Ding et al. (2016). hEA was also tested using the newer 25 benchmarks of 1000-job instances by Geiger (2010b). Optimal results of these larger instances were reached at an average of 4 hours by the HEA, where it required two days to compute the optimum of each instance by the exact algorithm of Tanaka et al. (2009).

The results by hEA in 1000-job instances were improved further by an Artificial Bee Colony (ABC) algorithm proposed recently by Sharma et al. (2020). The algorithm was hybridized with a special LS routine, named lunar inspired LS, to increase its exploitation capability. The lunar inspired ABC (luABC) used the sinusoidal illumination process of the moon to determine the step size to update the position of the best swarm.

3.6. Hybrids

The first hybrid approach for the problem is by Nearchou (2004) who combined SA with evolutionary algorithmic approach. He used a population of solutions, generated neighborhoods for each solution through perturbation, and applied a recombination operator on the solution set to prevent stagnation in local optima. In a later study, he proposed again a hybrid approach that combines DE with VNS (Nearchou, 2012). DE supplies global exploration while VNS supplies local exploitation. Lamarckian evolution and Baldwin effect were analyzed as two forms of hybridization. His proposed hybrid approach was able to find all optimum

solutions for the 100-job benchmark instances but in high computation times.

Wang & Tang (2008) proposed a hybrid VNS which makes use of TS in order to intensify the search in the light of past good performing sequences. They used a solution pool to enable diversification of the algorithm by generating several trial solutions at the same time. They showed that the proposed VNS with solution pool could find all optimum solutions for 100-job problems and outperforms the traditional VNS in terms of solution quality and robustness. They also significantly reduced the computation times by using elimination rules and programming tricks. Their algorithm could find all the optimum or best-known solutions for 40, 50 and 100-job instances within competitive computational times. Later, same researchers proposed again a VNS with solution pool algorithm, called population-based VNS, which this time used PR, variable depth search and TS collectively (Wang & Tang 2009). The proposed algorithm outperformed the traditional VNS at an expense of higher computation times, and it is shown to be robust and it produced optimum solutions in all benchmark problem sizes.

The above-mentioned hEA was a recent hybrid proposal for the problem that combines evolutionary procedures with the dynasearch.

3.7. Improved TS algorithms and GRASP

Bozejko et al. (2006) proposed a TS approach which applies a neighborhood with blocks of jobs and elimination criteria and allows multiple moves in a single iteration. Through reduction in neighborhood size and multiple moves, fast convergence of the algorithm is enabled. A dynamic length tabu list is used to escape from local minima. They also used the idea by Ergun & Orlin (2006) to decrease the complexity of neighborhood search. Their algorithm produced better results both in solution quality and computation time compared to TS of Crauwels et al. (1998), IDS of Congram et al. (2002), and GPI-DS of Grosso et al. (2004), and became the best performing one at that time.

Bilge et al. (2007) proposed a robust deterministic TS algorithm where a hybrid neighborhood is used along with a dynamic tenure structure. They showed that their proposed deterministic TS algorithm produce better results than other state-of-the-art TS algorithms, and more robust than the TS of Crauwels et al. (1998).

The study by Arroyo et al. (2008) proposed a Greedy Randomized Adaptive Search Procedure (GRASP) for the problem. Their GRASP algorithm uses PR strategy to favor elite sequences. They compared their algorithm with the TS proposed by Bilge et al. (2007) and showed that the GRASP algorithm with PR strategy is a competitive one and it managed to reach higher number of best-known solutions in 100-job ORLIB benchmark problems.

3.8. Pure VNS algorithms

Geiger (2010a) theoretically examined which neighborhood search operators would yield better results in LS. He then supported his theoretical propositions through an experimental study searching the effect of different neighborhoods on a VNS algorithm. He found that *exchange of jobs* is a superior LS operator, and it was followed by *forward* and *backward shift* neighborhoods, respectively.

Chung et al. (2017) improved the performance of VNS method by applying matching (to guide the search to good solution spaces) and strengthening operations that allow searching beyond local optimum. They changed the neighborhood structures systematically, applied a stochastically determined initial solution, and disturb the best available solution to direct towards better solutions. They compared their so-called multiple VNS (m-VNS) method with original VNS, and two other best performing algorithms: DE-VNS of Tasgetiren et al. (2006) and population-based VNS of Wang and Tang (2009). Their algorithm was able to find optimum solutions for all 125 instances of 40, 50 and 100-job benchmark instances in lower computation times and in a more robust way than the other VNS algorithms. It also performed better in larger problem instances in terms of solution quality and search capabilities.

3.9. Other studies

Kronberger & Braune (2007) proposed two variants of a bandit-based algorithm. Although they were not able to find all best-known solutions for 100-job ORLIB benchmark instances, they manage to find up to 124 of them, and also up to 83 of 200-job problem instances.

A number of relatively new metaheuristic approaches have been applied to the solution of SMTWT problem since 2012. However, they failed to produce high quality solutions as the common good performing algorithms. They are generally in form of improvements in the traditional

or original algorithm and aimed at investigating how the algorithm will perform when applied to SMTWT problem.

Huang et al. (2012) proposed a memetic approach to the problem. A co-evolutionary framework is suggested to enable diversification. Their algorithm converged faster compared to both traditional genetic algorithm and genetic algorithm with elitist strategies and to a traditional ACO algorithm on 40, 100, 125 and 150-job instances.

Santosa & Affandi (2013) proposed a new viral system approach for the problem. The proposed algorithm is a population-based stochastic algorithm with mutation. This first application of the algorithm, however, is not able to reach good performance levels of the other algorithms. Certain steps should be taken in the future to improve this new approach.

Yahyaoui et al. (2013) proposed VND approach for the problem. The method is based on changing between neighborhoods beginning from the neighborhood of the initial solution until the neighborhood of the local minimum is reached. They apply two different neighborhood selection strategies that guide the algorithm which neighborhood to choose in each iteration. They showed that their VND approach produced far better-quality solutions than traditional VND approaches, but with higher computation times.

Kongkaew (2015) proposed a bat algorithm which is a new population-based approach applied in the last few years to solution of some combinatorial optimization problems. He proposed a modified version of the algorithm where they use a heuristic to construct the initial population to speedup convergence, and he searched the neighborhood of any solution even discarded, to enable diversification of the algorithm. He showed that the proposed modifications in the algorithm outperformed the original algorithm in terms of solution quality but at the expense of higher computation times.

Biogeography based optimization is another new approach for the solution of the problem which was applied by Santosa & Safitri (2015). The algorithm was a population-based, stochastic one with migration, mutation and elitism. The algorithm was able to solve all 25 instances of 40 and 50-jobs, however its performance is low in 100-job instances, also the computation times of the algorithm were also high.

4. Performance comparisons of best-performing algorithms

The performances of different metaheuristic algorithms that are reviewed in this paper are summarized in Table 2. Any algorithm that is not included in the table is due to its performance being poor compared to other good-performing algorithms.

The algorithms are compared in terms of solution quality and computational time based on their performances in 125 instances of 40, 50 and 100-job ORLIB benchmark instances. In the table, "No" represents the number of optimal or best-known solutions found among 125 instances, "Avg. Time" is the average computation time of 125 instances, and "Max Time" is the maximum computation time among 125 instances. The measurements are taken from the respective papers; hence they are based on the computational experiments of the research itself. Capabilities of the computers used to run the algorithms by the researchers should certainly be taken into account to evaluate the computation times. Nevertheless, the given times can provide a general insight about the computational efficiency of the specific algorithm.

As can be observed from Table 2, GPI-DS, fast ACO, TS with compound moves, m-VNS, BDS and hEA are the best performing algorithms on the solution of the SMTWT problem. All these algorithms could find the optimum solutions for all problem sizes in significantly low computation times. BDS and hEA algorithms can be seen to be more superior than the others on average. ACO based on VND, ILS based on VND and PSO based on VNS are following best performing algorithms which were all able to find optimum solutions for all problem sizes but in much higher cpu times for large problem instances.

Another point of comparison applied in the literature is due to the robustness of an algorithm, which is commonly measured by relative percentage deviation of the result of the algorithm from the optimal (or best-known) solution. More specifically, average and maximum of percentage deviation values for a set of (generally 125) instances in several runs are used as a measurement. Robustness calculations are restricted to several papers, thus a comparison of the algorithms in terms of robustness is not presented here.

Different algorithm's performances on larger problem instances of 150, 200, 250 and 300-jobs are not presented as well. Only very few recent papers studied those instances. Ding et al. (2016) were able to reach the

optimum solutions of all those large instances with their BDS algorithm in at most 252 seconds, however they failed to hit the optimum at every run of the algorithm. Ding et al. (2017) reported improved results for the benchmark with their hEA algorithm. They managed to reach the optimal solutions at every run in all problem sizes and reported decreased computational times.

Only hEA and luABC algorithms used the different, harder dataset by Geiger (2010b). Both reached the optimal solutions in all 25 1000-job problems. However, luABC had an average of 65.36 hits of optimal solutions in 200 runs, while it was reported as 56.44 by Ding et al. (2017) for hEA. luABC also required slightly decreased computational times than HEA.

5. Conclusions and Future Work

The present review of the metaheuristic algorithms revealed that the dynasearch approach produces the best results for the SMTWT problem. Generalized pairwise interchange based dynasearch and breakout dynasearch are well performing applications of the dynasearch technique. Tabu search is another powerful metaheuristic in the field. Especially, a tabu search with compound moves proved computationally efficient while producing high quality results.

Genetic algorithms seem not performing well for SMTWT problem. Instead of applying a pure evolutionary algorithm, it seems better to incorporate some kind of powerful local search heuristics in it. A hybrid of dynasearch and evolutionary algorithm proved very successful recently.

Variable neighborhood search is one of the promising local search methods as shown in numerous papers. Its hybrid applications produced favorable results in SMTWT problem. Particle swarm optimization with variable neighborhood search is one outstanding example of that. Ant colony optimization has not gained much attention like the other popular algorithms. It may be in part due to its low speed, which later improved tough.

Recent hybrid evolutionary algorithms managed to solve problems with up to 1000 jobs. However, it took hours for the algorithms to reach the optimum in 1000-job instances. The computational times are still high in large instances when compared to 100-job ones which are solved optimally within one second by best performing algorithms. Future research should focus on decreasing computation times of these larger problem instances.

As the ORLIB instances were shown to pose no challenge for the state-of-the-art algorithms, Geiger (2010b) introduced two new sets of harder benchmark instances. To the author's knowledge, except by two recent studies, none of the best performing algorithms have been tested using these datasets in the literature. Previously proposed metaheuristics, which are tested on ORLIB instances, should be tested on these instances or some other newly constructed ones to investigate how they will perform in such harder cases, as a future research.

In recent years, the field observed a decrease in the number of studies that are in form of improving the best results achieved for a set of instances. Instead, various relatively new nature inspired metaheuristics such as viral systems, bat algorithm and biogeography-based optimization were applied to the problem with some poor results. The performances of these new approaches should be improved with either hybridization with other techniques, such as VNS, or through a modification in the algorithm.

Table 2. Comparison of different metaheuristic algorithms on 40, 50 and 100 job instances.

		40-job			50-job			100-job		
	Algorithm	No	Avg. Time (s)	Max Time (s)	No	Avg. Time (s)	Max Time (s)	No	Avg. Time (s)	Max Time (s)
Crauwels et al., 1998	TS (ms)	123	2.64	---	118	5.92	---	103	37.6	---
den Besten et al., 2000	ACO-VND	125	0.088	1.72	125	0.32	10.74	125	6.99	86.26
den Besten et al., 2001	ILS-VND	125	0.04	1.23	125	0.2	8.71	125	5.75	105.5
Congram et al., 2002	IDS	125	0.62	---	125	5.76	---	123.2	36.40	---
Avcı et al., 2003	ps-GA	125	29.3	---	124	41.02	---	103	20.8	---
Tasgetiren et al., 2004	PSO-VNS	125	0.088	5.00	125	0.264	10.00	125	4.237	100.0
Grosso et al., 2004	GPI-DS	125	0.003	0.125	125	0.010	0.562	125	0.107	3.907
Holthaus & Rajendran, 2005	fACO	125	---	---	125	---	---	125	0.2451	5.6986
Bozejko et al., 2006	TS (m)	125	0.002	0.073	125	0.007	0.381	125	0.073	2.571
Tasgetiren et al., 2006	DE-VNS	125	0.20	---	125	0.54	---	125	8.70	---
Bilge et al., 2007	TS (cls)	125	28.46	---	124	170.71	---	108	283.46	---
Arroyo et al., 2008	GRASP-PR	124	4	---	120	14	---	118	174	---
Wang & Tang, 2009	p-VNS	125	6.19	---	125	12.15	---	125	183.47	---
Nearchou, 2012	DE-VNS	125	3.60	---	125	8.20	---	125	1481.49	---
Chung et al., 2017	m-VNS	125	0.012	0.078	125	0.050	0.796	125	0.935	15.834
Ding et al., 2016	BDS	125	0.003	---	125	0.008	---	125	0.058	---
Ding et al., 2017	hEA	125	0.003	---	125	0.006	---	125	0.032	---

--- statistics not given or the problem size not applied in the paper
TS (ms): Multistart TS
ps-GA: Problem space GA
fACO: Fast ACO
TS (m): TS with compound moves
TS (cls): TS based on candidate list strategy
p-VNS: Population based VNS
m-VNS: Multiple VNS

References

Aarts EHL, & van Laarhoven PJM (1985) Statistical cooling: a general approach to combinatorial optimization problems. Philips J. Res 40: 193-226.

Abdul-Razaq TS, Potts CN, & Van Wassenhove LN (1990) A survey of algorithms for the single machine total weighted tardiness problem. Discrete Applied Mathematics 26: 235–253.

Arroyo JEC, Santos AG, Silva FLS, & Araujo AF (2008) A GRASP with path relinking for the single machine total weighted tardiness problem. Proceedings of the 8th International Conference on Hybrid Intelligent Systems: 726-731.

Avci S, Akturk MS, & Storer RH (2003) A problem space algorithm for single machine weighted tardiness problems. IIE Transactions 35(5): 479–486.

Beasley JE (1990) OR-Library: http://people.brunel.ac.uk/~mastjjb/jeb/info.html. Last update: 2018.

Beausoleil RP (2000) Intensification and Diversification Strategies with Tabu Search: One-Machine Problem with Weighted Tardiness Objective. MICAI 2000: Advances in Artificial Intelligence, Springer.

Bilge Ü, Kurtulan M, & Kıraç F (2007) A tabu search algorithm for the single machine total weighted tardiness problem. European Journal of Operational Research 176(3): 1423–1435.

Borgulya I (2002) A cluster-based evolutionary algorithm for the single machine total weighted tardiness-scheduling problem. Journal of Computing and Information Technology 3: 211-217.

Bożejko W, Grabowski J, & Wodecki M (2006) Block approach tabu search algorithm for single machine total weighted tardiness problem. Computers & Industrial Engineering 50(1): 1–14.

Chou FD (2009) An experienced learning genetic algorithm to solve the single machine total weighted tardiness scheduling problem. Expert Systems with Applications 36(2-2): 3857-3865.

Chung TP, Fu Q, Liao CJ, & Liu YT (2017). Multiple-variable neighbourhood search for the single-machine total weighted tardiness problem. Engineering Optimization 49(7): 1133-1147.

Congram RK, Potts CN, & van De Velde SL (2002). An iterated dynasearch algorithm for the single-machine total weighted tardiness scheduling problem. INFORMS Journal on Computing 14(1): 52–67.

Crauwels HAJ, Potts CN, & Van Wassenhove LN (1998) Local search heuristics for the single machine total weighted tardiness scheduling problem. INFORMS Journal on Computing 10: 341–350.

den Besten M, Stützle T, & Dorigo M (2000) Ant colony optimization for the total weighted tardiness problem. Parallel Problem Solving from Nature-PPSN VI: 611–620, Springer.

den Besten M, Stützle T, & Dorigo M (2001) Design of iterated local search algorithms. Applications of evolutionary computing: 441–451, Springer.

Ding J, Lü Z, Cheng TCE, & Xu L (2016) Breakout dynasearch for the single-machine total weighted tardiness problem. Computers & Industrial Engineering 98: 1-10.

Ding, J., Lü, Z., Cheng, T. C. E., & Xu, L. (2017). A hybrid evolutionary approach for the single-machine total weighted tardiness problem. *Computers & Industrial Engineering, 108,* 70-80.

Ergun, Ö., & Orlin JB (2006) Fast neighborhood search for the single machine total weighted tardiness problem. Operations Research Letters 34(1): 41–45.

Ferrolho, A, & Crisostomo M (2006) Genetic algorithm for the single machine total weighted tardiness problem. 1st IEEE International Conference on E-Learning in Industrial Electronics: 17-22.

Geiger, MJ (2009) The single machine total weighted tardiness problem – Is it (for metaheuristics) a solved problem? Proceedings of the 8th Metaheuristics International Conference MIC 2009: 141.1–141.10.

Geiger, MJ (2010a) On heuristic search for the single machine total weighted tardiness problem – Some theoretical insights and their empirical verification. European Journal of Operational Research 207(3): 1235–1243.

Geiger, MJ (2010b) New instances for the single machine total weighted tardiness problem. Research Report.

Gendreau, M., & Potvin J.Y. (2010) Handbook of Metaheuristics, second edition. International Series in Operations Research & Management Science, 146, Springer.

Gendreau, M., & Potvin, J. Y. (2019). *Handbook of Metaheuristics*. Springer International Publishing.

Grosso A, Della Croce F, & Tadei R (2004) An enhanced dynasearch neighborhood for the single-machine total weighted tardiness scheduling problem. Operations Research Letters 32(1): 68–72.

Holthaus O, & Rajendran C (2005) A fast ant-colony algorithm for single-machine scheduling to minimize the sum of weighted tardiness of jobs. Journal of the Operational Research Society 56(8): 947–953.

Huang WH, Chang PC, Lim MH, & Zhang Z (2012) Memes co-evolution strategies for fast convergence in solving single machine scheduling problems. International Journal of Production Research 50(24): 7357–7377.

Huang CL, & Tung CH (2006) Using mutation to improve discrete particle swarm optimization for single machine total weighted tardiness problem. World Automation Congress, July 24-26, Budapest, Hungary.

Kaveh, A., & Bakhshpoori, T. (2019). *Metaheuristics: Outlines, MATLAB Codes and Examples*. Springer International Publishing.

Kellegöz T, Toklu B, & Wilson J (2008) Comparing efficiencies of genetic crossover operators for one machine total weighted tardiness problem. Applied Mathematics and Computation 199(2): 590-598.

Kongkaew, W (2015) Solving the single machine total weighted tardiness problem using bat-inspired algorithm. 2015 IEEE International Conference on Industrial Engineering and Engineering Management (IEEM): 265-269, IEEE.

Koulamas, C (2010) The single-machine total tardiness scheduling problem: Review and extensions. European Journal of Operational Research 202(1): 1-7.

Kronberger G, & Braune R (2007) Bandit-Based Monte-Carlo Planning for the Single-Machine Total Weighted Tardiness Scheduling Problem. Computer Aided Systems Theory – EUROCAST 2007, Springer.

Lawler, EL (1977) A pseudopolynomial algorithm for sequencing jobs to minimize total tardiness. Annals of Discrete Mathematics 1: 331–342.

Liu N, Abdelrahman MA, & Ramaswamy S (2003) A genetic algorithm for the single machine total weighted tardiness problem. Proceedings of the 35th Southeastern Symposium on System Theory: 34-38.

Luke, S (2013) Essentials of Metaheuristics. Lulu, second edition, available at http://cs.gmu.edu/~sean/book/metaheuristics/

Madureira, AM (1999) Meta-heuristics for the single-machine scheduling total weighted tardiness problem. Proceedings of the 1999 IEEE International Symposium on Assembly and Task Planning, Portugal.

Matsuo H, Suh CJ, & Sullivan RS (1989) A controlled search simulated annealing method for the single machine weighted tardiness problem. Annals of Operations Research 21: 85–108.

Nearchou, AC (2004) Solving the single machine total weighted tardiness scheduling problem using a hybrid simulated annealing algorithm. 2nd IEEE International Conference on Industrial Informatics: 513-516.

Nearchou, AC (2012) A hybrid metaheuristic for the single-machine total weighted tardiness problem. Cybernetics and Systems 43(8): 651-668.

Pan Y, & Shi L (2007) On the equivalence of the max-min transportation lower bound and the time-indexed lower bound for single-machine scheduling problems. Mathematical Programming 110(3): 543–559.

Parsopoulos KE, & Vrahatis MN (2006) Studying the performance of unified particle swarm optimization on the single machine total weighted tardiness problem. Proceedings of the 19th Australian Joint Conference on Artificial Intelligence: 760–769.

Potts CN, & Van Wassenhove LN (1991) Single machine tardiness sequencing heuristics. IIE Transactions 23: 346–354.

Sharma, N., Sharma, H., & Sharma, A. (2020). An effective solution for large scale single machine total weighted tardiness problem using lunar cycle inspired artificial bee colony algorithm. *IEEE Annals of the History of Computing*, *17*(05), 1573-1581.

Santosa B, & Affandi U (2013) Application of Viral Systems for Single-Machine Total Weighted Tardiness Problem. IOP Conference Series: Materials Science and Engineering 46(1), IOP Publishing.

Santosa B, & Safitri AL (2015) Biogeography-based Optimization (BBO) Algorithm for Single Machine Total Weighted Tardiness Problem (SMTWTP). Procedia Manufacturing 4: 552-557.

Sen T, Sulek JM, & Dileepan P (2003) Static scheduling research to minimize weighted and unweighted tardiness: A state-of-the-art survey. International Journal of Production Economics 83(1): 1–12.

Tanaka S, Fujikuma S, & Araki M (2009) An exact algorithm for single-machine scheduling without machine idle time. Journal of Scheduling 12(6): 575–593.

Tasgetiren MF, Liang YC, Sevkli M, & Gencyilmaz G (2006) Particle swarm optimization and differential evolution for the single machine total weighted tardiness problem. International Journal of Production Research 44(22): 4737–4754.

Tasgetiren MF, Sevkli M, Liang YC, & Gencyilmaz G (2004) Particle swarm optimization algorithm for single machine total weighted tardiness problem. Proceedings of the 2004 Congress on Evolutionary Computation: 1412-1419.

Yahyaoui H, Krichen S, Derbel B, & Talbi EG (2013) A Variable Neighborhood Descent for solving the Single Machine Total Weighted Tardiness Problem. IEEE 5th International Conference on Modeling, Simulation and Applied Optimization (ICMSAO): 1-6.

Wang X, & Tang L (2008) A hybrid VNS with TS for the single machine scheduling problem to minimize the sum of weighted tardiness of jobs. Advanced intelligent computing theories and applications, with aspects of artificial intelligence: 727–733, Springer.

Wang X, & Tang L (2009) A population-based variable neighborhood search for the single machine total weighted tardiness problem. Computers & Operations Research 36(6): 2105–2110.