# PROCEEDINGSISSN Print: 2518-4245SN Online: 2518-4253Vol. 55(2), June 2018A. Physical and Computational Sciences



PAKISTAN ACADEMY OF SCIENCES ISLAMABAD, PAKISTAN

## PAKISTAN ACADEMY OF SCIENCES

Founded 1953

President:	M. Qasim Jan
Secretary General:	M. Aslam Baig
Treasurer:	G. A. Miana

**Proceedings of the Pakistan Academy of Sciences**, published since 1964, is quarterly journal of the Academy. It publishes original research papers and reviews in basic and applied sciences. All papers are peer reviewed. Authors are not required to be Fellows or Members of the Academy, or citizens of Pakistan.

#### Editor:

Irum Iqrar, Pakistan Academy of Sciences, Islamabad, Pakistan; editor@paspk.org

#### **Discipline Editors:**

Chemical Sciences: Peter Langer, University of Rostock, Rostock, Germany; <u>peter.langer@uni-rostock.de</u> Chemical Sciences: Syed M. Qaim, Universität zu Köln D-52425, JÜLICH, Germany; <u>s.m.qaim@fz-juelich.de</u> Computer Sciences: Sharifullah Khan, NUST, Islamabad, Pakistan; <u>sharifullah.khan@seecs.edu.pk</u> Engineering Sciences: Fazal A. Khalid, University of Engineering & Technology, Lahore, Pakistan; <u>vc@uet.edu.pk</u> Mathematical Sciences: Muhammad Sharif, University of the Punjab, Lahore, Pakistan; <u>msharif.math@pu.edu.pk</u> Mathematical Sciences: Jinde Cao, Southeast University, Nanjing, Jiangsu, China; <u>jdcao@seu.edu.cn</u> Physical Sciences: M. Aslam Baig, National Center for Physics, Islamabad, Pakistan; <u>baig77@gmail.com</u> Physical Sciences: Stanislav N. Kharin, 59 Tolebi, Almaty, Kazakhastan; <u>staskharin@yahoo.com</u>

#### Editorial Advisory Board:

David F. Anderson, The University of Tennessee, Knoxville, TN, USA; anderson@math.utk.edu Ismat Beg, Lahore School of Economics, Pakistan; ibeg@lahoreschool.edu.pk Rashid Farooq, National University of Sciences & Technology, Islamabad, Pakistan; farooq@sns.nust.edu.pk R. M. Gul, University of Engineering & Technology, Peshawar, Pakistan; rmgul@uetpeshawar.edu.pk M. Asghar Hashmi, The Islamia University of Bahawalpur, Pakistan; mhashmi@iub.edu.pk Aynur Keskin Kaymakci, Selcuk University, Konya, Turkey; akeskin@selcuk.edu.tr Tahir I. Khan, Professor of Materials Engineering, University of Bradford, Bradford, UK; T.Khan20@bradford.ac.uk Zhou Lang, Nanchang University, Nanchang, Jiangxi, 330031, China, Izhou@ncu.edu.cn Shaukat Mahmood, Mirpur University of Science & Technology, Mirpur, Pakistan; shau meph@yahoo.com Waqar Mahmood, University of Engineering & Technology, Lahore, Pakistan; waqar@uet.edu.pk Onaiza Maqbool, Quaid-i-Azam University, Islamabad, Pakistan; onaiza@qau.edu.pk Nadeem Mufti, University of Engineering & Technology, Lahore, Pakistan; namufti@uet.edu.pk Adele Maria Muscolo, University Mediterranea di Reggio Calabria, Italy; amuscolo@unirc.it Naveed K. Piracha, John Carroll University, University Heights, OH, USA; npiracha@jcu.edu Martin C. Richardson, University of Central Florida, FL, USA; mcr@creol.ucf.edu Mudasser Faraz Wyne, National University, San Diego, CA, USA; mwyne@nu.edu Muhammad Younas, Oxford Brookes University, Oxford, OX33 1HX, UK; m.younas@brookes.ac.uk

Annual Subscription: Pakistan: Institutions, Rupees 2000/- ; Individuals, Rupees 1000/-Other Countries: US\$ 100.00 (includes air-lifted overseas delivery)

© *Pakistan Academy of Sciences*. Reproduction of paper abstracts is permitted provided the source is acknowledged. Permission to reproduce any other material may be obtained in writing from the Editor-in-Chief.

The data and opinions published in the *Proceedings* are of the author(s) only. The *Pakistan Academy of Sciences* and the *Editors* accept no responsibility whatsoever in this regard.

#### HEC Recognized, Category Y; PM&DC Recognized

Published by Pakistan Academy of Sciences, 3 Constitution Avenue, G-5/2, Islamabad, Pakistan Tel: 92-5 1-920 7140 & 921 5478; Fax: 92-51-920 6770; Website: <u>www.paspk.org</u>

Printed at PanGraphics (Pvt) Ltd., No. 1, I & T Centre, G-7/l, Islamabad, Pakistan Tel: 92-51-220 2272, 220 2449 Fax: 92-51-220 2450 E-mail: pangraph@gmail.com



# CONTENTS

Volume 55, No. 2, June 2018	Page
Review Article	
Significance of Strangeness Conservation/Violation Studies at BESIII — Aneela Amin, Khadija Saeed, Farzana Younas, and Ghalib ul Islam	01
Research Articles	
Analysis of Enterprise Resource Planning Implementation to Identify Critical Factors and Development of a Framework for its Success — Muhammad Umar, Nawar Khan, Rab Nawaz Lodhi, and Chandan Lal	13
Identification of Failure Modes on Electrostatic Chuck through Reliability Centered Maintenance: A Case Study — Mehroz Sana, Umer Saleem, Muhammad Farooq, Adnan Qamar, Muhammad Mehmood A Bhutta, and Saad Zafar	21
A Quasi Lindley Pareto Distribution — Asad Ali, Qaisar Rashid, Muhammad Zubair, and Muhammad Tariq Jamshaid	33
Managing Disorientation of Time and Place in Dementia Patients Using Bluetooth Sensors — Sarwat Iqbal, Kamran Ahsan, Muhammad Azhar Hussain, Adnan Nadeem, Muhammd Saeed, and Sohaib Ahmed	41
Didactic Strategy for Learning Theory of Automata & Formal Languages — Muhammad Shumail Naveed, and Muhammad Sarim	55
Application of Pulse Electric Field for Chemical Extraction Process — Prima Asmara Sejati, Ardhi Wicaksono Santoso, Rella Mareta, and Arief Budiman	67
Physical, Elastic and Thermal Characterization of Ni-Cd Nano Ferrites — Asghari Maqsood, and M. Arshad	77
Obituary	
Mr. Tajammul H. Hashmi	85
Instructions for Authors	86

*Submission of Manuscripts:* Manuscripts may be submitted as E-mail attachment at editor@paspk.org. Authors must consult the *Instructions for Authors* at the end of this issue or at the Website: www.paspk.org



Review Article

### Significance of Strangeness Conservation/Violation Studies at BESIII

Aneela Amin<sup>1</sup>\*, Khadija Saeed<sup>1</sup>, Farzana Younas<sup>1</sup>, and Ghalib ul Islam<sup>2</sup>

<sup>1</sup>Centre for High Energy Physics, University of the Punjab, Lahore (54590), Pakistan <sup>2</sup>Department of Physics, The University of Lahore, Lahore (53700), Pakistan

Abstract Strangeness violation and conservation have been studied in Charmonia and its higher state decays. The data of some prominent decay modes has been collected from BESIII laboratory from the years 2009 to date. The strangeness violating decays play an important role in the study of weak interactions. On the other hand, strangeness conserving decays describe the strong interactions. An overview of strangeness conserving decays and strangeness violating decays has been given and the decay modes are presented in tabular form. The study reveals that associated production occurs only in strangeness conserving decays rather than strangeness violating decays. Experimental and theoretical results are presented in order to arrange phenomenological developments and queries may search new domains in Experimental High Energy Physics, and will explore new prospects of strangeness, a basic quantum number of hadrons and its associated production.

Keywords: Strangeness, Charmonia, Strangeness conserving decays, Strangeness violating decays, Standard model

#### **1. INTRODUCTION**

The study of particles and the interaction between them shows that quarks and leptons are the basic constituents of matter [1]. These quarks exist in bound states. There are six type of quarks, named as, up (u), down (d), strange (s), charm (c), bottom (b), top (t) quark. Similarly, there are six type of leptons, electron(e), muon( $\mu$ ) and tau( $\tau$ ) alongwith their neutrinos electron neutrinos( $v_e$ ), muon neutrino( $v_{\mu}$ ) and tau neutrino( $v_{\tau}$ ) [2].

According to the quark model, these quarks are combined together to form hadrons. Hadrons are strongly interacting particles and are divided into two categories, named as, Baryons and Mesons [3]. In 1960, these particles are arranged in Eightfold way-classification according to their quantum numbers. Baryons consist of three quarks or three anti-quarks. Mesons consist of a quark and anti-quark. The baryons and mesons are arranged into octets and decuplets according to their spin, charge and strange quantum numbers. This classification of baryon and meson is shown in the Fig. 1 to Fig. 4.

In 1970, a new theory was predicted which

described the interactions among these particles known as Standard Model. According to Standard Model, three types of interactions exist among these particles i.e. electromagnetic, strong and weak interaction [4-5].

In this paper, all those decay processes have been studied in which strangeness exists. These processes involve strange baryons and strange mesons and the list of these strange mesons and baryons are listed in Table 1 and Table 2 respectively. The data involving strangeness has been collected from BESIII Laboratory for the period 2009 to 2017. It was observed that some decay processes are those in which law of conservation of strangeness holds. This fact is according to the theory of Standard Model. On the other hand, some strangeness violating reactions have also been observed in BESIII, which show that evidences for the strangeness violations are increasing day by day. Such kind of decays, showing weak interactions are discussed and highlighted in many decay modes in BESIII and their branching fractions have also been reported. An important property of strangeness, called associated production, has also been introduced which is very prominent in the strangeness

Received, December 2017; Accepted, June 2018

<sup>\*</sup> Corresponding Author: Aneela Amin; anilaamin@hotmail.com

conserving decays of Charmonia. The decays modes showing associated production are listed in the Table 3(a) to 3(d). These decay modes are governed by strong interactions only [2].

The data consisting of strangeness conserving decays and strangeness violating decays along with their branching fractions have been arranged in the Table 3(a) to 3(d) and Table 4(a) to 4(e).

#### 2. Strangeness

Strangeness 'S' [6] is a quantity associated with all hadrons. Strangeness is basically an additive quantum number. Like baryon number, lepton number, this quantum number is assigned to all hadrons named as strangeness quantum number. It became necessary to introduce this quantum number for the study of properties of particles. The reasons for introducing this quantity are few reactions which are quite different in nature from the other decay processes. For example, in the following reaction, a proton and pion interacts very strongly to produce a  $\Lambda^0$  baryon.



**Figure 1.** The spin <sup>1</sup>/<sub>2</sub> baryons arranged in baryon octet [4-5]



Figure 3. The meson nonet with spin 0 [4-5]

$$\pi^{-} + P \longrightarrow \Lambda^{0} + K^{0}$$
$$\pi^{0} + P \longrightarrow \Lambda^{0} + K^{+}$$

Here  $\Lambda^0$  is the baryon with mass  $M_{\Lambda^0} = 1.115 MeV$  [6]. Since  $\Lambda^0$  baryon is very unstable particle, so it decays further into some other particles as shown in the following reaction;

$$\Lambda^0 \longrightarrow \pi^- + P$$

Baryon number is conserved in this reaction, therefore  $\Lambda^0$  should decay via strong interaction and its life time should be of the order of ~  $10^{-23}$  seconds. But it has been observed that its decay time is of the order of ~  $10^{-8}$  seconds which is approximately equal to the life time of weak decays. So  $\Lambda^0$  baryon decays via weak interaction and it shows strange behavior [6].

A similar strange behavior has been observed in the decay of kaon meson. This reaction is also given below;

$$\mathrm{K}^+ \longrightarrow \pi^+ + \pi^0$$



Figure 2. The spin 3/2 baryons arranged in baryon decuplets [4-5].



Figure 4. The meson nonet with spin 1 [4-5]

This decay has baryon number B = 0. So it must be carried out via strong interaction. But this does not happen. Its life time is again observed to be  $10^{-8}sec$  rather than  $10^{-23}sec$  which shows that it is a weak decay. Again, this is the Strange Behavior [6]. Strangeness [6] leads to a new conservation law. This law is known as Law of Conservation of Strangeness.

Strangeness values could be 0, 1, -1. The strangeness quantum number violates in those reactions which do not decay via strong interaction but this quantum number is conserved in strong interactions. The results of three reactions indicating the strangeness conservation and strangeness violation as under;

$$\pi^0 + P \longrightarrow \Lambda^0 + K^+$$

(decays via strong interaction)

 $\Lambda^0 \rightarrow \pi^- + P$  (decays via weak intercation)  $K^+ \rightarrow \pi^+ + \pi^0$  (decays via weak interaction)

It has been observed from the above three reactions that law of strangeness is violated in the processes which decay through weak interactions and it is conserved in strong decays [6]. The conservation of strangeness via strong interaction is discussed in terms of associated production in the section below.

#### 3. Associated Production and its Significance

In 1952, Abraham Pais observed some neutral particles (V<sup>0</sup>'s) produced in cloud chamber with larger cross section (~  $10^{-27}$  cm<sup>2</sup>) and these particles decayed through smaller cross section (~  $10^{-40}$  cm<sup>2</sup>) [6]. This phenomenon happened in strange particles as strange particles are produced abundantly having life time of 10<sup>-23</sup> seconds but their decay time is relatively slow about 10<sup>-10</sup> seconds. This shows that their production mechanism is different from their disintegration mechanism. So one can say that strong force governs the production of strange particles whereas weak force is responsible for their decay. So if a strange particle is produced in strong interaction, they are always produced in pairs of particles of opposite strangeness so as to conserve the total strangeness. This phenomenon is called Associated Production [6].

Some strange mesons have been listed in the Table 1 along with their quark contents and strangeness,  $S = \pm 1$ . Similarly, some strange baryons having strangeness  $S = \pm 1, \pm 2, \pm 3$  are listed in the Table 2 [7]. In next section, a brief description of BESIII experimental setup is given.

Mesons	Quark Contents	Strangeness
<i>K</i> +	$uar{s}$	+1
$K^{-}$	$s \overline{u}$	-1
K <sup>0</sup>	$d\bar{s}$	+1
$\overline{K}^{0}$	$sar{d}$	-1
$K_S^0$	$\left(d\bar{s}+s\bar{d}\right)/\sqrt{2}$	(*)
$K_L^0$	$\left(d\bar{s}-s\bar{d} ight)/\sqrt{2}$	(*)
$K^{*+}$	$uar{s}$	+1
$K^{*0}$	$d\bar{s}$	+1
Charmed+ Strange Mesons	Quark Contents	Strangeness
$D_{S}^{+}$	cs	+1
$D_{S}^{-}$	<i>c</i> s	-1
$D_{s}^{*+}$	cs	+1
$D_{\rm S}^{*-}$	<i>cs</i>	-1
Bottom +Strange Mesons	Quark Contents	Strangeness
$B_S^0$	$s\overline{b}$	-1
$\bar{B}_{S}^{0}$	$b\bar{s}$	+1
$B_{S}^{*0}$	sb	-1

Table 1.	List of Strange Mesons with	$S = \pm 1$ [7]
----------	-----------------------------	-----------------

#### 4. **BESIII Experimental Setup**

This paper is about the theoretical study of strangeness conservations and violation of Charmonia, based on the data collected from BESIII detector. BESIII detector uses the BESIII offline software system (BOSS), CLHEP libraries and Root software to study the charmonium spectroscopy [8-9].

The upgraded version of BES is BESIII that consists of BEPCII  $e^-e^+$  collider and BESIII detector. BESIII detector is specifically used to study the Tau-Charm Physics within energy range BESIII detector became of 2 to 5 GeV. operational from 2009 [8]. BESIII detector has four main components named as Main Drift Chamber (MDC), Electromagnetic Calorimeter (EMC), Time of Flight System (TOF) and Muon Chamber System (MUC). These parts of detector detect various particles and their specific properties such as their momentum, energy, energy losses, position and time etc. within certain energy range of Charmonia. For more detail, for example, MDC used to measure the momentum and energy loss information of charged particles. Electromagnetic Calorimeter (EMC) is used to measure the energy and position of electron and photons only. Time of Flight System (TOF) is used to measure the time of flight of charged particles from the point of interaction to the detector. Since most of the collisions processes decays into muons, so Muon Chamber (MUC) is used to detect the paths and positions of muons produced during the  $e^-e^+$  or  $P\overline{P}$  collisions [8-9]. All the parts and efficiencies of BESIII experimental setup are related and much dependent on BOSS (BESIII Offline Software System) [9]. A brief introduction to BESIII Offline Software (BOSS) is given in next section.

#### 5. BESIII Offline Software (BOSS)

BESIII Offline Software System (BOSS) uses the C++ language and object oriented programming and works on Scientific Linux Operating System. BESIII Offline System is based upon Gaudi Framework which provides interfaces and its utilities for simulating the data and physics analysis. Software Configuration is managed by configuration management tool (CMT). It provides different packages, libraries and their utilities. Information and specification of detector is stored in Geometrical Description Markup Language (GDML). BOSS provides many services to meet the requirement of analysis such as navigation and reconstruction of MC tracks. This Data processing and physics analysis software system has three main functions i.e. Simulation, Reconstruction and Calibration. BESIII detector simulation is based upon GEANT4 package which gives information about the detector, particle tracking and their interaction with the detector [9].

#### 6. CHARMONIUM SPECTROSCOPY

In 1974, the discovery of charmonium meson  $J/\psi$  at BNL (Brookhaven National Laboratory) and SLAC (Stanford Linear Accelerator Center) has opened up a new horizon in the field of research. After that, some other states of charmonium were discovered at some higher energies named as  $\psi'$ ,  $\eta_c$ ,  $\eta_c'$ ,  $\chi_{c0,c1,c2}$ ,  $h_c$  and D states. The decays of these charmonium and its higher states were mainly studied at BES (Beijing Electron Spectrometer) Lab [8-10].

The charmonium and its higher energy states being discussed here, contain charm quark as one of its quark content. The decays of these charmonium states are categorized as the strangeness conserving and strangeness violating decays. These decays are listed in Table 3 (a) to 3(d) and Table 4(a) to 4(e).

#### 7. DISCUSSIONS AND CONCLUSION

Strangeness has been observed in  $J/\psi$ ,  $\psi'$ ,  $\eta_c$ ,  $\eta_c'$ ,  $\chi_{c0,c1,c2}$ ,  $h_c$  and D-decays. The data of these decays has been collected from BESIII Laboratory. The branching fractions of strangeness conserving and strangeness violating decays have been studied from the years 2009 to 2017. In Table 3(a), the decays of  $I/\psi$ , in which strangeness conservation occurs, are given [11-16]. Table 3(b) consists of  $\psi'$  decays containing strange baryon anti-baryon pair along with single non-strange meson to conserve the strangeness [14-22]. Table 3(c) shows only 2-body strangeness conserving decays of strange baryon-anti-baryon pair or strange meson-anti-meson pair [13, 23-24]. In the same way, 2-body, 3-body and 4-body strangeness conserving decays of  $\chi_{cl}$  are listed in table 3(d) [18, 25-28]. From this data, it is clear that associated production takes place in strangeness conserving decays. These decays are the manifestation of strong interactions.

Strange Baryons	Quark Contents	Strangeness
Λ	uds	-1
$\overline{\Lambda}$	$\overline{uds}$	+1
Sigma Strange Baryons	Quark Contents	Strangeness
$\Sigma^+$	uus	-1
$\Sigma^{*+}(1385)$	uus	-1
$\Sigma^0$	uds	-1
$\Sigma^{*0}(1385)$	uds	-1
$\Sigma^{-}$	dds	-1
$\Sigma^{*-}(1385)$	dds	-1
Xi Strange Baryons	Quark Contents	Strangeness
$\Xi^{0}$	uss	-2
$\Xi^{0}(1530)$	uss	-2
$\Xi^{*0}(1530)$	uss	-2
Ξ-	dss	-2
$\Xi^{-}(1530)$	dss	-2
$\Xi^{*-}(1530)$	dss	-2
$\Xi_c^0$	dsc	-1
$\Xi_c^{\prime 0}$	dsc	-1
$\Xi_c^{'0}(2645)$	dsc	-1
$\Xi_c^+$	usc	-1
$\Xi_c^{'+}$	usc	-1
$\Xi_{c}^{*+}(2645)$	usc	-1
$\Xi_b^0$	usb	-1
$\Xi_b^{*0}$	usb	-1
$\Xi_b^{'0}$	usb	-1
$\Xi_b^-$	dsb	-1
$\Xi_b^{'-}$	dsb	-1
$\Xi_b^{*-}$	dsb	-1
Omega Strange Baryons	Quark Contents	Strangeness
$\Omega^{-}$	SSS	-3
$\Omega_b^-$	ssb	-2
$\Omega_b^{*-}$	ssb	-2
$\Omega_{bb}^-$	sbb	-1
$\Omega_{bb}^{*-}$	sbb	-1
$\Omega_c^0$	SSC	-2
$\Omega_{c}^{*0}(2770)$	SSC	-2
$\Omega_{cc}^+$	SCC	-1
$\Omega_{cc}^{*+}$	SCC	-1
$\Omega_{cb}^{0}$	scb	-1
$\Omega_{cb}^{'0}$	scb	-1
$\Omega_{ch}^{*0}$	scb	-1

6

Decay Channel	No. of Events	<b>Branching Fraction</b>	Year
$J/\psi \to \Xi^0 \overline{\Xi}^0$ $J/\psi \to \Xi^- \overline{\Xi}^+$ $I/\psi \to \Sigma^0 \overline{\Sigma}^0 [11]$		$\begin{array}{c} (1.2 \pm 0.24) \times 10^{-3} \\ (0.9 \pm 0.2) \times 10^{-3} \\ (1.29 \pm 0.09) \times 10^{-5} \end{array}$	2009
$J/\psi \rightarrow \Sigma^0 \overline{\Sigma}^0 [12]$		$(1.5 \pm 0.24) \times 10^{-3}$	2009
$J/\psi \to \Lambda \overline{\Sigma}^0$ $J/\psi \to \overline{\Lambda} \Sigma^0 [13]$	$(225.2 \pm 2.8) \times 10^{6}$	$(1.37 \pm 0.12 \pm 0.11) \times 10^{-5} (1.46 \pm 0.11) \pm 0.12) \times 10^{-5}$	2012
$J/\psi \to \Xi^0 \overline{\Xi}^0$ $J/\psi \to \Sigma^0 (1385) \overline{\Sigma}^0 (1385) [14]$	$1310.6 \times 10^{6}$ $1310.6 \times 10^{6}$	$(11.65 \pm 0.04) \times 10^{-4}$ $(10.71 \pm 0.09) \times 10^{-5}$	2016
$J/\psi \to \Xi^- \Xi^+$ $J/\psi \to \Sigma(1385)^- \Sigma(1385)^+ [15]$	$(223.7 \pm 14) \times 10^{6}$ $(223.7 \pm 14) \times 10^{6}$	$(0.58 \pm 0.04 \pm 0.08) \ (-0.58 \pm 0.05 \pm 0.09)$	2016
$J/\psi \to \Sigma(1385)^0 \overline{\Sigma}(1385)^0$ $J/\psi \to \Xi^0 \overline{\Xi}^0 [16]$	$(1310.6 \pm 7.0) \times 10^{6}$ $(1310.6 \pm 7.0) \times 10^{6}$	$(10.71 \pm 0.09) \times 10^{-4}$ $(11.65 \pm 0.04) \times 10^{-4}$	2017

**Table 3 (b).** Strangeness Conserving Decays of  $\psi$  Studied at BESIII

Decay Channel	No. of Events	<b>Branching Fraction</b>	year
$\psi' \to K_2^* (1430)^+ K^- + c.c [17]$	$(106 \pm 4) \times 10^{6}$	$(7.12 \pm 0.62^{+1.13}_{-0.61}) \times 10^{-5}$	2012
$\psi' \longrightarrow \bar{P}K^+\Sigma^0 + c.c \ [18]$	$1.06 \times 10^{8}$	$(1.67 \pm 0.13 \pm 0.12) \times 10^{-5}$	2013
$\psi(3686) \longrightarrow \omega K \overline{K} \pi$ [19]	$1.06 \times 10^{8}$	$(0.878 \pm 0.233 \pm 0.096)$	2013
$\psi(3770) \rightarrow \Lambda \overline{\Lambda} \pi^+ \pi^- [20]$		$< 4.7 \times 10^{-4}$ at C.L 90%	2013
$\psi(3770) \rightarrow \Lambda \overline{\Lambda} \pi^0$		$< 0.7 \times 10^{-4}$ at C.L 90%	
$\psi(3770) \rightarrow \Lambda \overline{\Lambda} \eta$		$< 1.9 \times 10^{-4}$ at C.L 90%	
$\psi(3770) \rightarrow \Sigma^+ \overline{\Sigma}^-$		$< 1.0 \times 10^{-4}$ at C.L 90%	
$\psi(3770) \longrightarrow \Sigma^0 \overline{\Sigma}^0$		$< 0.4 \times 10^{-4}$ at C.L 90%	
$\psi(3770) \rightarrow \Sigma^{-}\Sigma^{+}$		$< 1.5 \times 10^{-4}$ at C.L 90%	
$\psi(3/70) \rightarrow \Xi \Xi$		$< 1.4 \times 10^{-4}$ at C.L 90%	
$\psi(3770) \rightarrow \Xi^0 \Xi^0$		$< 2.9 \times 10^{-4}$ at C.L 90%	
$\psi(4040) \rightarrow \Lambda \Lambda \pi^+ \pi^-$		$< 0.9 \times 10^{-4}$ at C.L 90%	
$\psi(4040)  ightarrow \Lambda \overline{\Lambda} \pi^0$		$< 3.0 \times 10^{-4}$ at C.L 90%	
$\psi(4040)  ightarrow \Lambda \overline{\Lambda} \eta$		$< 1.3 \times 10^{-4}$ at C.L 90%	
$\psi(4040) \longrightarrow \Sigma^+ \overline{\Sigma}^-$		$< 0.7 \times 10^{-4}$ at C.L 90%	
$\psi(4040) \longrightarrow \Sigma^0 \overline{\Sigma}^0$		$< 1.6 \times 10^{-4}$ at C.L 90%	
$\psi(4040) \rightarrow \Xi^- \overline{\Xi}^+$		$< 1.8 \times 10^{-4}$ at C.L 90%	
$\psi(1010) \longrightarrow \Xi^0 \overline{\Xi}^0$			
$\varphi(4040) \rightarrow \Xi \Xi$	$1.06 \times 10^{8}$	$(140 \pm 0.03 \pm 0.13) \times 10^{-4}$	2013
$\psi(3686) \rightarrow \Lambda \Sigma \pi + c.c[21]$	$1.00 \times 10^{10}$ 1.06 × 10 <sup>8</sup>	$(1.10 \pm 0.03 \pm 0.13) \times 10^{-4}$	2015
$\psi(3686) \longrightarrow K^2 \mathcal{H} + \mathcal{C}\mathcal{C}$ $\psi(3686) \longrightarrow \mathcal{C}K^+ \mathcal{K}^- [22]$	$1.00 \times 10^{8}$	$(1.51 \pm 0.01 \pm 0.13) \times 10^{-4}$	2014
$\psi(3000) \rightarrow \omega \kappa \kappa [22]$	1.00 × 10	$(1.34 \pm 0.04 \pm 0.11) \times 10$	2014
$\psi(3686) \rightarrow$			2016
$\Sigma^{0}(1385)\overline{\Sigma}^{0}(1385)[14]$	$1310.6 \times 10^{6}$	$(0.78 \pm 0.06) \times 10^{-4}$	
$\psi(3686) \rightarrow \Xi^{-}\Xi^{+}$	$(106.4 \pm 0.9) \times 10^{6}$	$(0.91 \pm 0.13 \pm 0.14)$	2016
$\psi(3686) \rightarrow$	$(106.4 \pm 0.9) \times 10^{6}$	$(0.64 \pm 0.40 \pm 0.27)$	
$\Sigma(1385)^{-}\Sigma(1385)^{+}[15]$			
$\psi(3686) \longrightarrow \Sigma(1385)^0 \overline{\Sigma}(1385)^0$	$(447.9 \pm 2.9) \times 10^{6}$	$(0.69 \pm 0.05) \times 10^{-4}$	2017
$\psi(3686) \rightarrow \Xi^0 \overline{\Xi}^0[16]$	$(447.9 + 2.9) \times 10^{6}$	$(2.73 \pm 0.03) \times 10^{-4}$	

Decay Channel	No. of Events	Branching Fraction	year
$\eta_c' \longrightarrow K^{*0} \overline{K}^{0*}[23]$	$1.06 \times 10^{8}$	$< 5.4 \times 10^{-3}$ at 90% C.L	2011
$\eta_c \rightarrow \Lambda \bar{A}[13]$	$(225.2 \pm 2.8) \times 10^{6}$	$(1.16 \pm 0.12 \pm 0.19) \pm 0.28 \times 10^{-3}$	2012
$\eta_c \longrightarrow \Sigma^+ \overline{\Sigma}^-$ [24]	$2.25 \times 10^{8}$	$(2.11 \pm 0.28 \pm 0.18 \pm 0.5) \times 10^{-3}$	2013
$n \rightarrow \Xi^{-}\overline{\Xi}^{+}[24]$	$2.25 \times 10^{8}$	$(0.89 \pm 0.16 \pm 0.08 \pm 0.21) \times 10^{-3}$	

Table 3 (c). Strangeness Conserving Decays of  $\eta_c$  Studied at BESIII

**Table 3 (d).** Strangeness Conserving Decays of  $\chi_{cJ}$  Studied at BESIII

Decay Channel	No. of Events	<b>Branching Fraction</b>	year
$\chi_{c0} \longrightarrow P\overline{P} K^+ K^-$	$106 \times 10^{6}$	$(1.24 \pm 0.20 \pm 0.18) \times 10^{-4}$	2011
$\chi_{c1} \longrightarrow \mathrm{P}\overline{\mathrm{P}}\mathrm{K}^+\mathrm{K}^-$	$106 \times 10^{6}$	$(1.35 \pm 0.15 \pm 0.19) \times 10^{-4}$	
$\chi_{c2} \rightarrow P\overline{P} K^+ K^-[25]$	$106 \times 10^{6}$	$(2.08 \pm 0.19 \pm 0.30) \times 10^{-4}$	
$\chi_{c0} \longrightarrow \Lambda \overline{\Lambda} \pi^+ \pi^-$	$106 \times 10^{6}$	$(119.0 \pm 6.4 \pm 11.4)$	2012
$\chi_{c1} \longrightarrow \Lambda \overline{\Lambda} \pi^+ \pi^-$		(31.1 ± 3.4 ± 3.9)	
$\chi_{c2} \longrightarrow \Lambda \overline{\Lambda} \pi^+ \pi^- [26]$		$(137.0 \pm 7.6 \pm 15.7)$	
$\chi_{c0} \longrightarrow \Lambda \bar{\Lambda}$	$1.06 \times 10^{8}$	$(33.3 \pm 2.0 \pm 2.6) \times 10^{-5}$	2013
$\chi_{c1} \longrightarrow \Lambda \bar{\Lambda}$		$(12.2 \pm 1.1 \pm 1.1) \times 10^{-5}$	
$\chi_{c2} \longrightarrow \Lambda \bar{\Lambda}$		$(20.8 \pm 1.6 \pm 2.3) \times 10^{-5}$	
$\chi_{c0} \longrightarrow \Sigma^0 \overline{\Sigma}^0$		$(47.8 \pm 3.4 \pm 3.9) \times 10^{-5}$	
$\chi_{c1} \longrightarrow \Sigma^0 \overline{\Sigma}^0$		$(3.8 \pm 1.0 \pm 0.5) \times 10^{-5}$	
$\gamma_{-2} \longrightarrow \Sigma^0 \overline{\Sigma}^0$		$(4.0 \pm 1.1 \pm 0.5) \times 10^{-5}$	
$\chi_{c2} \longrightarrow \Sigma^+ \overline{\Sigma}^-$		$(45.4 \pm 4.2 \pm 3.0) \times 10^{-5}$	
$\chi_{c0} \rightarrow \Sigma^{+}\overline{\Sigma}^{-}$		$(5.4 \pm 1.5 \pm 0.5) \times 10^{-5}$	
$\chi_{c1} \rightarrow \Sigma^+ \overline{\Sigma}^- [27]$		$(4.9 \pm 1.9 \pm 0.7) \times 10^{-5}$	
$\chi_{c0} \longrightarrow \bar{P}K^+\Lambda + c.c$	$1.06 \times 10^{8}$	$(13.2 \pm 0.3 \pm 1.0) \times 10^{-4}$	2013
$\chi_{c1} \longrightarrow PK^+\Lambda + c.c$	$1.06 \times 10^{8}$	$(4.5 \pm 0.2 \pm 0.4) \times 10^{-4}$	
$\chi_{c2} \longrightarrow \bar{P}K^+\Lambda + c.c[18]$ $\chi_{c2} \longrightarrow \Sigma^+\overline{\Sigma}^-$	$1.06 \times 10^{8}$ (448.1 + 2.9) × 10 <sup>6</sup>	$(8.4 \pm 0.3 \pm 0.6) \times 10^{-4}$ 50.4 + 2.5 + 2.7	2017
$\chi_{c0} \longrightarrow \Sigma^{-} \overline{\Sigma}^{-}$ $\chi_{c0} \longrightarrow \Sigma^{+} \overline{\Sigma}^{-}$		$3.7 \pm 0.6 \pm 0.2$	2017
$\chi_{c1}$ , $\Sigma$ $\Sigma^+ \overline{\Sigma}^-$		$35 \pm 0.7 \pm 0.3$	
$\chi_{c2} \rightarrow \Sigma \Sigma$		$3.3 \pm 0.7 \pm 0.5$	
$\chi_{c0} \longrightarrow \Sigma^0 \Sigma^0$		$47.7 \pm 1.8 \pm 3.5$	
$\chi_{c1} \longrightarrow \Sigma^0 \overline{\Sigma}^0$		$4.3 \pm 0.5 \pm 0.3$	
$\chi_{c2} \longrightarrow \Sigma^0 \overline{\Sigma}^0[28]$		$3.9 \pm 0.5 \pm 0.3$	

Table 4 (a). Strangeness	Violating Decays of	$J/\psi$ Studied at BESIII
--------------------------	---------------------	----------------------------

Decay Channel	Branching Fraction	year
$J/\psi \rightarrow D_S^- \rho^+$	$< 1.3 \times 10^{-5}$ at C.L 90%	2014
$J/\psi \longrightarrow \overline{D}{}^{0}\overline{K}{}^{*0}[29]$	$< 2.5 \times 10^{-6}$ at C.L 90%	
$J/\psi \rightarrow K_S K_L$	$(1.13 \pm 0.03 \pm 0.05)\% \times 10^{-4}$	2017
$J/\psi \rightarrow K_{\rm S}K_{\rm S}[30]$	$< 1.4 \times 10^{-8}$ at 95% C.L	

Table 4 (b). Strangeness Violating Decays of  $\psi$ 'Studied at BESIII

Decay Channel	Branching Fraction	year
$\psi(3686) \longrightarrow K_S^0 K^{\pm} \pi^{\mp} \pi^+ \pi^- [31]$	$(7.03 \pm 2.10 \pm 0.70) \times 10^{-6}$	2013
$\psi(3686) \longrightarrow K^- \Lambda \overline{\Xi}^+ + c.c [32]$	$(3.86 \pm 0.27 \pm 0.32) \times 10^{-5}$	2015

Table 4(c). Strangeness Violating Decays of D-meson Studied at BESIII

Decay Channel	Branching Fraction	year
$D^+ \longrightarrow K_L^0 e^+ \nu_e[33]$	$(4.481 \pm 0.027 \pm 0.103)\%$	2015
$D^+ \longrightarrow K^- \pi^+ e^+ \nu_e[34]$	$(3.77 \pm 0.03 \pm 0.08)$	2016
$D^+ \longrightarrow \overline{K}{}^0 \mu^+ \nu_\mu [35]$	$(8.72 \pm 0.07 \pm 0.18)\%$	2016
$\begin{array}{c} D_{S}^{+} \longrightarrow \eta e^{+} \nu_{e} \\ D_{S}^{+} \longrightarrow \eta' e^{+} \nu_{e} [36] \end{array}$	$(2.30 \pm 0.31 \pm 0.08)\%$ $(0.93 \pm 0.30 \pm 0.05)\%$	2016
$D^+ \longrightarrow K^0_S K^0_S K^+$ $D^+ \longrightarrow K^0_S K^0_S \pi^+$ $D^0 \longrightarrow K^0_S K^0_S K^0_S$ $D^0 \longrightarrow K^0_S K^0_S K^0_S [37]$	$\begin{array}{l} (2.54 \pm 0.05 \pm 0.12) \times 10^{-3} \\ (2.70 \pm 0.05 \pm 0.12) \times 10^{-3} \\ (1.67 \pm 0.11 \pm 0.11) \times 10^{-4} \\ (7.21 \pm 0.33 \pm 0.44) \times 10^{-4} \end{array}$	2016
$D^+ \longrightarrow \overline{K}^0 e^+ \nu_e[38]$	$(8.60 \pm 0.06 \pm 0.15) \times 10^{-2}$	2017
$D_{S}^{+} \longrightarrow \phi e^{+} \nu_{e}$ $D_{S}^{+} \longrightarrow \phi \mu^{+} \nu_{\mu}$ $D_{S}^{+} \longrightarrow \eta \mu^{+} \nu_{\mu}$ $D_{S}^{+} \longrightarrow \eta' \mu^{+} \nu_{\mu} [39]$	$(2.26 \pm 0.45 \pm 0.09)\%$ $(1.94 \pm 0.53 \pm 0.09)\%$ $(2.42 \pm 0.46 \pm 0.11)\%$ $(1.06 \pm 0.54 \pm 0.07)\%$	2017

Table 4 (d). Strangeness Violating Decays of  $\Lambda_c$  Studied at BESIII

Decay Channel	Branching Fraction	year
$\Lambda_c^+ \to \Lambda e^+ \nu_e[40]$	$(3.63 \pm 0.38 \pm 0.20)\%$	2015
$\Lambda_{\rm c}^+ \longrightarrow PK^-\pi^+[41]$	$(5.84 \pm 0.27 \pm 0.23)\%$	2016
$\Lambda_c^+ \longrightarrow \Sigma^- \pi^+ \pi^- \pi^0 [42]$	$(2.11 \pm 0.33 \pm 0.14)\%$	2017
$\Lambda_c^+ \longrightarrow n K_S^0 \pi^+ [43]$	$(1.82 \pm 0.23 \pm 0.11)\%$	2017

Table 4 (e). Strangeness Vi	iolating Decays of $\chi_{cJ}$	Studied at BESIII
-----------------------------	--------------------------------	-------------------

Decay Channel	Branching Fraction	year
$\chi_{c0} \longrightarrow K^0_S K^{\pm} \pi^{\mp} \pi^0$	$\frac{1}{2} \times (2.52 \pm 0.34) \times 10^{-2}$	2013
$\chi_{c1} \longrightarrow K^0_S K^{\pm} \pi^{\mp} \pi^0$	$\frac{1}{2} \times (9.0 \pm 1.5) \times 10^{-3}$	
$\chi_{c2} \longrightarrow K_S^0 K^{\pm} \pi^{\mp} \pi^0 [44]$	$\frac{1}{2} \times (1.51 \pm 0.22) \times 10^{-2}$	

Recently, it was observed that when  $I/\psi$ decays into neutral strange meson pairs such as K<sub>S</sub>K<sub>L</sub> and K<sub>S</sub>K<sub>S</sub>, strangeness always violate as given in Table 4(a) [29-30]. In Table 4(b), 3-body and 7-body strangeness violating decays are presented alongwith their branching fractions [31-32]. The table 4(c) contains higher state of charmonia named as D-meson. In years 2016 and 2017, a lot of work has been done on the D-meson decays and these are all strangeness violating because D meson is the lightest meson with mass 1.864  $\text{GeV/c}^2$  having single charm quark. It is necessary for the decay of D meson, one of its charm quark transform into some other quark. This transformation occurs via weak interaction and this decay is always mediated by W boson [33-39]. The 3-body and 4-body decay modes of  $\Lambda_c$ , given in Table 4(d) shows the strangeness violating decay modes [40-43]. In Table 4(e), the strangeness violating decays of  $\chi_{cl}$  are shown and their branching fractions are also mentioned [44]. From this study of strangeness violating decays, it can be concluded that associated production doesn't take place in strangeness violating decays and these decays corresponds to the weak interactions.

#### 8. SUMMARY

This was a review of experimental results of BES-III experiment for studying significance of strangeness conservation-violation results of hadrons. Although no final explanation have been given in experimental results and theoretical exertions, but some positive concepts have been introduced. A detailed list of strange mesons and baryons is given along with their quark contents and strangeness values. Strangeness conserving and strangeness violating decay modes of  $J/\psi$ ,  $\psi'$ ,  $\eta_c, \eta_c', \chi_{c0,c1,c2}$ ,  $h_c$  and D-mesons have been presented in tabular form with proper details of number of events, Branching Fractions and the year in which that specific phenomenon was observed. The understanding of such kinds of complex decay modes is very important for the scientists to learn about the universe at its most fundamental level. Experimental and theoretical results shed light on new phenomenology and may explore new worlds in High Energy Physics, although systematic efforts are difficult to carry out for charmonium systems. This study concludes that experimental trials will be more effective rather than comparing theoretical perceptions. Although, we may not reach up to revolutionary

ideas of existing impressions but from any struggle, a new episode of experimental High Energy physics may be released from studying "significance of strangeness conservationviolation decays of strange mesons".

#### 9. ACKNOWLEDGEMENTS

We pay our gratitude to Higher Education Commission of Pakistan for their financial support under Indigenous PhD Fellowship Program, Phase VI. We are highly indebted to Prof. Dr. Haris Rashid, Dr. Talab Hussain and Dr. Abrar Ahmad Zafar for their valuable guidance and moral support.

#### **10. REFERENCES**

- 1. Halzen, F. & A.D. Martin. *Quarks and leptons: an introductory course in modern particle physics*. John Wiley and Sons, Inc., America (1984).
- Perkins, D. H.. Introduction to High Energy Physics. Addison-Wesley Publishing Company, Inc. Third Edition, United Kingdom (1987).
- Mandl, F. & G. Shaw. *Quantum Field Theory*. John Wiley and Sons, Inc., Manchester, United Kingdom (1988).
- Lakhina, O. Study of meson properties in quark models. PhD Thesis. Physics Department, University of Pittsburgh (2006).
- Blundell, H. G. Meson Properties in the Quark Model: A Look at Some Outstanding Problems. PhD Thesis. Corletaton University, Canada (1996).
- Kovacs, J.S. & C.L. William. Conservation Laws for Elementary Particle Reactions. Michigan State University, Peter Signell for Project PHYSNET, Physics-Astronomy Bldg., E. Lansing, MI 48824 517: 355-3784 (2001).
- Patrignani, C., M. Antonelli, K. Agashe, G. Aielli, et al. Review of Particle Physics, Particle Data Group. *Chinese Physics* C 40: 100001-101810 (2016).
- Ablikim, M., Z.H. An, J.Z. Bai, X.Y. Ma, H.X. Yang, et al. Design and Construction of the BESIII Detector. Nuclear Instruments and Methods in Physics Research Section A: Accelerators, Spectrometers, Detectors and Associated Equipment 614: 345-399 (2010).
- Deng, Z., H. Liu, Y. Yuan, M. He, Y. Liang, G. Cao & Z. You. BESIII Simulation Software. *Proceedings of Science* 043: 1-7 (2007).
- Nakamura, K., K. Hagiwara, K. Hikasa, H. Murayama, M. Tanabashi, et al. Review of Particle Physics. *Journal of Physics G: Nuclear and Particle Physics* 37: 075021-075024 (2010).
- Wei, D.H. The SU(3) symmetry breaking in J/ψ decays. *Journal of Physics G: Nuclear and Particle Physics* 36: 115006-115012 (2009).

- Ablikim, M., Y. Bai, Y. Ban, X. Cai, H. F. Chen, J. C. Chen, et al. J/ψ decays into Σ<sup>+</sup>Σ<sup>-</sup> and Ξ<sup>-</sup>Ξ<sup>+</sup>. BES Collaboration. *Physical Review* D 78: 092005 -092012 (2008).
- Ablikim, M.,M. N. Achasov, A. Calcaterra, O. Bondarenko, N. Berger, M. Bertani, E. Boger, et al. First observation of the isospin violating decay J/ψ → ΛΣ<sup>0</sup> + c. c. BESIII Collaboration. *Physical Review* D 86: 032008-032018 (2012).
- 14. Ablikim, M., M. N. Achasov, X. C. Ai, S. Ahmed, et al. Study of  $J/\psi$  and  $\psi(3686) \rightarrow \Sigma^0(1385)\overline{\Sigma}^0(1385)$  and  $\Xi^-\overline{\Xi}^+$ . BESIII Collaboration. *Physics Letter* B 770: 217-225 (2016).
- 15. Ablikim, M., M.N. Achasov, X. C. Ai, O. Albayrak, M. Albrecht, D. J. Ambrose, et al. Study of decays to the  $\Xi^-\overline{\Xi}^+$  and  $\Sigma(1385)^+\overline{\Sigma}(1385)^\pm$  final states. BESIII Collaboration. *Physical Review* D 93: 072003- 072013 (2016).
- 16. Ablikim, M., M.N. Achasov, S. A. N. Ahmed, M. Albrecht, Z Ning, et al. Study of J/ $\psi$  and  $\psi$ (3686)  $\rightarrow \Sigma^0(1385)\overline{\Sigma^0}$  (1385) and  $\Xi^-\Xi^+$ . BESIII Collaboration. *Physics Letter* B 770: 217-225 (2017).
- 17. Ablikim, M., M.N. Achasov, O. Albayrak, D. J. Ambrose, F. F. An, Q. An, et al. Experimental Study of  $\psi'$ decays to  $K^+K^-\pi^0$  and  $K^+K^-\eta$ . BESIII Collaboration. *Physical Review* D 86: 072011-072024 (2012).
- Ablikim, M., M.N. Achasov, O. Albayrak, D. J. Ambrose, F. F. An, et al. Measurements of ψ' → P̄K<sup>+</sup>Σ<sup>0</sup> and χ<sub>cJ</sub> → P̄K<sup>+</sup>Λ. BESIII Collaboration. *Physical Review* D 87: 012007-012017 (2013).
- 19. Ablikim, M., M. N. Achasov, J. Becker, M. Bertani, et al. Study of  $\psi(3686) \rightarrow \omega K \overline{K} \pi$  decays. BESIII Collaboration. *Physical Reviews* 092017 (2013).
- 20. Ablikim, M., M.N. Achasov, R. A. Briere, X. Cai, H. L. Dai, et al. Search for Baryonic Decays of  $\psi(3770)$  and  $\psi(4040)$ . BESIII Collaboration. *Physical Review* D 87: 112011-112021 (2013).
- Ablikim, M., M.N. Achasov, X. C. Ai, O. Albayrak, D. J. Ambrose, et al. Observation of the decay ψ(3686) →ΛΣ<sup>±</sup>π<sup>±</sup> + c.c. BESIII Collaboration. *Physical Review* D 88: 112007-112016 (2013).
- 22. Ablikim, M.,M.N. Achasov, X. C. Ai, F. F. An, J. Z. Bai, et al. Measurement of the branching fraction for (3686)  $\rightarrow \omega K^+ K^-$ . BESIII Collaboration. *Physical Review* D 89: 112006-112014 (2014).
- 23. Ablikim, M., M.N. Achasov, J. Becker, N. Berger, J. Z. Bai, et al. Search for  $\eta_c'$  decays into vector meson pairs. BESIII Collaboration. *Physical Review* D 84: 091102--091109 (2011).
- 24. Ablikim, M., M.N. Achasov, J. Z. Bai, J. C. Chen, M. Y. Dong, et al. Observation of  $\eta_c$  decay

into  $\Sigma^+\overline{\Sigma}^-$  and  $\Xi^-\overline{\Xi}^+$  final states. BESIII Collaboration. *Physical Review* D 87: 012003-012012 (2013).

- 25. Ablikim, M., M.N. Achasov, L. An, M. L. Chen, C. D. Fu, et al. Observation of  $\chi_{cJ}$  decaying into  $P\overline{P}K^+K^-$  final state. BESIII Collaboration. *Physical Review* D 83: 112009-112018 (2011).
- 26. Ablikim, M., M.N. Achasov, L. B. Guo, K. Goetzen, W. X. Gong, et al. Observation of  $\chi_{cJ}$  decays to  $\Lambda \overline{\Lambda} \pi^+ \pi^-$ . BESIII Collaboration. *Physical Review* D 86: 052004-052012 (2012).
- 27. Ablikim, M., M.N. Achasov, J. Z. Bai, G. F. Cao, S. A. Cetin, X. Cai, et al. Measurements of Baryon Pair Decays of  $\chi_{cJ}$  Mesons. BESIII Collaboration. *Physical Review* D 87: 032007-032016 (2013).
- 28. Ablikim, M., M.N. Achasov, S. Ahmed, S. Fegan, D. Dedovich, A. Denig, et al. Improved measurements of  $\chi_{cJ} \rightarrow \Sigma^+ \overline{\Sigma}^-$  and  $\Sigma^0 \overline{\Sigma}^0$  decays. BESIII Collaboration. *Physical Review* D 97: 052011-052020 (2018).
- Ablikim, M., M.N. Achasov, S. Braun, J. P. Dai, W. G. Li, K. L. He, et al. Search for the rare decays J/ψ → D<sub>S</sub><sup>-</sup>ρ<sup>+</sup> and J/ψ → D̄<sup>0</sup>K̄<sup>\*0</sup>. BESIII Collaboration. *Physical Review* D 89: 071101-071109 (2014).
- 30. Ablikim, M., M.N. Achasov, A. Amoroso, J. Z. Bai, D. W. Bennet<u>t</u>, et al. Branching fraction measurement of  $J/\psi \rightarrow K_S K_L$  and search for  $J/\psi \rightarrow K_S K_S$ . BESIII Collaboration. *Physical Review* D 96: 112001-112008 (2017).
- Ablikim, M., M.N. Achasov, O. Albayrak, D. J. Ambrose, T. Hu, F. A. Harris, et al. Evidence for η<sub>c</sub>(2S) in ψ(3686) → K<sub>S</sub><sup>0</sup>K<sup>±</sup>π<sup>∓</sup>π<sup>+</sup>π<sup>-</sup>. BESIII Collaboration. *Physical Review* D 87: 052005-052013 (2013).
- 32. Ablikim, M., M.N. Achasov, X. C. Ai, O. Albayrak, J. M. Bian, et al. Measurements of ψ(3686) → K<sup>-</sup>ΛΞ<sup>+</sup> + c. c. BESIII Collaboration. *Physical Review* D 91: 092006-092017 (2015).
- 33. Ablikim, M.,M.N. Achasov, J. Z. Bai, C. Hu, L. Y. Dong, G. Cibinetto, et al. Study of decay dynamics and CP asymmetry in  $D^+ \rightarrow K_L^0 e^+ v_e$  decay. BESIII Collaboration. *Physical Review* D 92: 112008-112023 (2015).
- 34. Ablikim, M., M.N. Achasov, A. Calcaterra, G. Chelkov, R. Kliemt, H. Loehner, et al. Study of D<sup>+</sup> → K<sup>-</sup>π<sup>+</sup>e<sup>+</sup>ν<sub>e</sub>. BESIII Collaboration. *Physical Review* D 94: 032001-032018 (2016).
- 35. Ablikim, M., M.N. Achasov, X. Chen, C. Dong, D. Dedovich, et al. Improved measurement of the absolute branching fraction of  $D^+ \rightarrow \overline{K}^0 \mu^+ \nu_{\mu}$ decay. *European Physical Journal* C 76:369-379 (2016).
- 36. Ablikim, M., M.N. Achasov, X.C. Ai, F.F. An, J.V. Bennett, et al. Measurement of the absolute branching fractions for  $D_{+}^{+} \rightarrow ne^{+}\nu$  and

 $D_S^+ \rightarrow \eta' e^+ v_e$ . BESIII Collaboration. *Physical Review* D 94: 112003-112010 (2016).

- 37. Ablikim, M., M.N. Achasov, R. A. Briere, G. Chelkov, J. C. Chen, et al. Measurements of the branching fractions for  $D^+ \rightarrow K_S^0 K_S^0 K^+, K_S^0 K_S^0 \pi^+$  and  $D^0 \rightarrow K_S^0 K_S^0, K_S^0 K_S^0$ . BESIII Collaboration. *Physics Letter* B 765: 231-237 (2017).
- Ablikim, M., M.N. Achasov, S. Ahmed, Y. Ban, c J. F. Chang, et al. Analysis of D<sup>+</sup> → K<sup>0</sup>e<sup>+</sup>ν<sub>e</sub> and D<sup>+</sup> → π<sup>0</sup>e<sup>+</sup>ν<sub>e</sub> Semileptonic Decays. BESIII Collaboration. *Physical Review* D 96: 012002-012017 (2017).
- Ablikim, M., M.N. Achasov, M. Albrecht, A. Dbeyssi, S. L. Niu, et al. Measurements of the branching fractions for the semi-leptonic decays D<sup>+</sup><sub>s</sub> → φe<sup>+</sup>ν<sub>e</sub>, φμ<sup>+</sup>ν<sub>μ</sub>, ημ<sup>+</sup>ν<sub>μ</sub>, and η'μ<sup>+</sup>ν<sub>μ</sub>. BESIII Collaboration. *Physical Review* D 97: 012006-012015 (2018).
- Ablikim, M., M. N. Achasov, J. Z. Bai, Q. An, et al. Measurement of the absolute branching fraction for Λ<sup>+</sup><sub>c</sub> → Λe<sup>+</sup>ν<sub>e</sub>. BESIII Collaboration. *Physical Review Letters* 115: 221805-221812 (2015).

- Ablikim, M., M. N. Achasov, X. C. Ai, O. Albayrak, J. Dong, et al. Measurements of absolute hadronic branching fractions of Λ<sup>+</sup><sub>c</sub> baryon. BESIII Collaboration. *Physical Review Letter* 116: 052001-052008 (2016).
- 42. Ablikim, M., M. N. Achasov, S. Ahmed, M. Albrecht, et al. Observation of the decay  $\Lambda_c^+ \rightarrow \Sigma^- \pi^+ \pi^- \pi^0$ . BESIII Collaboration. *Physics Letters* B 772: 388-397 (2017).
- 43. Ablikim, M., M. N. Achasov, A. Amoroso, S. Ahmed, J. Z. Bai, et al. Observation of  $\Lambda_c^+ \rightarrow nK_s^0\pi^+$ . BESIII Collaboration. *Physical Review Letters* 118: 112001-112008 (2017).
- 44. Ablikim, M., M.N. Achasov, D. J. Ambrose, F. F. An, et al. Search for hadronic transition  $\chi_{cJ} \rightarrow K_S^0 K^{\pm} \pi^{\mp} \pi^0$  and observation of  $\chi_{cJ} \rightarrow K \overline{K} \pi \pi \pi$ . BESIII Collaboration. *Physical Review* D 87: 012002-012015 (2013).



Research Article

## Analysis of Enterprise Resource Planning Implementation to Identify Critical Factors and Development of a Framework for its Success

Muhammad Umar<sup>1\*</sup>, Nawar Khan<sup>2</sup>, Rab Nawaz Lodhi<sup>3</sup>, and Chandan Lal<sup>4</sup>

 <sup>1</sup>Pakistan Telecommunication Company Limited, Islamabad, Pakistan
 <sup>2</sup> Department of Engineering Management, NUST College of Electrical and Mechanical Engineering, Rawalpindi, Pakistan
 <sup>3</sup> Institute of Business and Management, University of Engineering and Technology Lahore, Pakistan

<sup>4</sup>Department of Business Administration, Shah Abdul Latif University, Khairpur, Pakistan

Abstract: Unlike advanced countries, organizations in developing markets face distinct challenges for standard ERP implementation. The less than appreciable internal and external environment potentially undermine the promising returns in developing world. A study that may thoroughly articulate critical issues and possible remedies in ERP implementation is clearly missing in Pakistan's case. Therefore, the present study aims to present a framework based critical success factors of ERP implementation that can optimistically help the corporate sector in Pakistan while confronting country specific issues. To obtain the expected framework of ERP implementation, the present study concludes based on semi-structured interviews that top level management commitment, change management, project management, vendor support, business process re-engineering, training and education are the major six focused areas while implementing ERP system. However, appear to be weakly associated with ERP success to gain success in ERP. The result extracted from the study is based on these important factors and has a valuable contribution for the ERP implementers.

Keywords: Critical Factor, ERP Implementation, Framework for Success

#### 1. ERP SYSTEM: A NEED OF INDUSTRY

Many organizations invest huge amount of money to implement ERP system, supposedly it is expecting a positive impact on the organization and its functions. Organizational variables influence directly or indirectly the information system. Most of the studies inspected that system success is inefficient in small organizations as compare to large. If employees give proper time to an application, they can get more accurate results from system. Most of the studies found that individual has impact that influence them to enclose a wide range of intuitive measurements like courage in decisions made and problem solving, and the time acquire to get a decision.

Integration is the combination to collect

information and processes that specify the departments of the firm and that is the one advantage of regularity. Well ERP system connect overall enterprise functions and operations and performing sections for all subsets, thus all subsets have connection with related knowledge as proceedings happened. When any organization employed ERP system, its accountability increases [1]. A positive attitude of individuals, senior management and other workforce towards the system is very important because if they believe that the system will be helpful they pay full attention to improve the system. ERP system increases the work efficiency of the organization. It saves time and eliminates errors automatically. Education/training is necessary to operate the ERP system.

Top management support is necessary to

Received, June 2016; Accepted, June 2018

<sup>\*</sup> Corresponding Author: Muhammad Umar; m.umar@ptcl.net.pk

develop confidence, interest between workers who operate ERP system. Consultants and coordinator backing is an initiative calculate of the intensity of inspiration bring them and capable by a talented worker in allocating the information with other colleagues, guide them properly, employing solutions to work relevant issues, acceptance of communication, freedom for direct interactions and automated meetings to share and use information [2]. ERP system has many benefits to the organization where it is implemented. However, the first phase is to reduce the critical success factors of ERP implementation and to develop a framework for its success. This is neglected area particularly in Pakistan. No study was found where the framework was provided for the industry of Pakistan where ERP system has been implemented or it is in implementation phase. The present study aims to identify the critical success factors and develop a framework to reduce the rate of failure.

#### 2. CRITICAL SUCCESS FACTORS OF ERP IMPLEMENTATION SUCCESS

Yu (2005) [3] defined different stages of ERP system i.e., implementation pre-implementation, implementation, and post-implementation. Ifinedo, et al [4] argued that critical success factors are commonly involved in implementation and pre-implementation stage of ERP system while the result in term of performance is measured in post-implementation stage of ERP system. Critical success factors are the factors which become the reasons of successful implementation of ERP project [5].

ERP project specification, budget and time are the key proxies which have been commonly used to measure the implementation success of ERP project [6, 7] which means ERP is successfully implemented if the project is completed within the specification, budget and time. ERP project is very time taking, costly and complex and it has a high failure rate reported in the past studies due to over budget and time. A number of resources are required for its succesful implementation [8]. Budget, time and ERP project scope are considered as the measures of ERP system/project implementation success in many studies.

Different studies reported different critical success factors for example Motwani, et al. [9]

applied case study approach and found that cultural readiness has a positive influence on the successful implementation of ERP project. Similarly, Ngai, et al. [10] selected 10 organizations and applied case study analysis. They reported that business plan, data management, appropriate business and IT legacy systems, ERP teamwork and composition, project management, change management, communication, culture and program, project reengineering. champion. business process and evaluation of performance, monitoring software development, top management support, organizational characteristics, testing, ERP vendor, ERP strategy, troubleshooting, fit between ERP and business process and implementation methodology are the critical success factors of ERP successful implementation. In the same lines, Nattawee & Siriluck (2008) [11] applied case study approach in 10 Thai SMEs. They found that competence and knowledge sharing, vendor support and user involvement are very influential factors for the successful implementation of the system. In Pakistani few studies identified critical success factors of ERP project e.g., Shah, et al. [12]; Shad, et al. [13]; Nelson & Somers [14]; Ijaz, et al. [5].

Ehie & Madsen [15] found that project management, feasibility and evaluation, consulting services, cost issues and business process reengineering are the most influential determinants of ERP project successful implementation. Yingjie [16] identified many critical success factors in the context of Finland industry these are: effective project management, user involvement, top management support, suitability of software and hardware, education and training, business process reengineering. Similarly, Fang & Patrecia [17] found that project team, top management support, BPR, Effective communication, change management have a significant influence on the successful implementation of ERP system. In the same lines, Shah, et al. [12] also explored technical and socio-technical factors influencing the ERP project success. Khattak, et al. [18] compared the critical success factors in both Pakistani and Chinese organizations.

#### **3. RESEARCH METHODOLOGY**

The present study has employed survey research design to investigate the critical success factors and to develop the framework to reduce the failure of ERP implementation. This study is qualitative in nature. In the first phase, extensive literature review has been conducted to identify the common critical success factors in the literature. After the effort total 87 critical success factors were identified. However, finally 60 factors were finalized with the comparison of the literature. These factors were divided into five major categories based on the expert opinion. The purpose was only to identify the failure reasons and develop a strategy to handle these critical factors.

Data was collected through semi-structured interviews of the representatives of the organization. Total 40 participants from twenty different organizations were participated in the interview sessions. Each interview comprises of 30 to 40 minutes recording. Convenience sampling was applied which is given preferences in qualitative research. Thematic analysis was employed on the qualitative data with the help of NVivo 10 software. The purpose was to identify different critical factors of ERP implementation success and to develop a framework to implement ERP system successfully. Tree maps, word clouds, tag clouds, word tree etc. are the different tools which are commonly used for the data analysis. The present study has applied tree map analysis and hieratical of themes analysis.

#### 4. FINDINGS OF THE STUDY

#### 4.1 Tree Map Analysis

Tree map shows the significance/importance of each theme of the study just the  $\beta$  (beta) values in regression. In regression analysis those independent variables which have more  $\beta$  (beta) values means they have more influence on the dependent variable. In the same lines, tree map shows the colorful regions for different themes of the study i.e., critical success factors of ERP system implementation. Themes in the larger regions show more critical success factors while themes in the smaller regions are less critical success factors. Fig. 1 shows that effective planning, Training, motivate people, clarity in objective and good leadership is found to be more significant themes of the study.

#### 4.2 Critical Factors for ERP System Implementation Success

All qualitative data was entered in NVivo software to apply thematic analysis to find out the key themes

of the study. Data coding was done after the critical reading of the statements of different people during their interviews. Initially 87 factors were identified. However, total 60 critical success factors were finalized with the support of the literature. These 60 critical success factors were categorized into 6 main categories, i.e., top level management commitment, change management, project management, training and education, vendor management and business process reengineering.

#### 5. CONCLUSION AND RECOMMENDATIONS

Despite ERP implementation failures, as evident from the literature, such management policy has gained considerable weight in strategic intentions of organizations across the globe. This apparently yields conflicting realities about ERP significance. The present study aimed to present a framework based critical success factors of ERP implementation that can optimistically help the corporate sector in Pakistan while confronting country specific issues. With the empirical efforts, the following six categories of the critical success factors were identified:

1. Top Level Management Commitment: The study concludes that top level management commitment is the key factor while implementing ERP system. Top management decides the realistic time line for the EPR projects. The project can be sustained with the support and involvement of top management. In the same lines, the ERP project implementation can be ensured within the specific period without any delay. If management is committed, they also empowered their lower management to take the immediate decisions based on the best information. They identified the key end users and assigned them the key role and responsibilities which leads to the successful implementation of ERP project. Top management's ownership also leads to implement better technological infrastructure for ERP project implementation they also provide sufficient funds for the technology and the people. They pay high rewards to the team involved in ERP project implementation. Ultimately, the project can be aligned with the key business processes and fulfill the need of the business

#### Muhammad Umar et al

	wolve f	Avoid	ilnvolv	t Suffic	/endor	odMon	la Sha	0 Trai	rainUs	bda
	ternet Ir	dopiASA	tenInteg	tht Righ	/endor	sLearM	sa RoleSt	tTeanT		TimeU
	fluentid	ork on A	Estab	DC clRig	JAT fro		sta Pha	EstaPM	Eval PO	Hire Res
	entify In	sion of W	Effect	M Mdv	pddnsy	Thoro			TOT	
	P teald	IndentVis	ardDefin	ld Know	palKnow	mMap		INOMIN	finePM to	
	eminaER	ase-\Sta	in wAw	I spe	3	8	jt b	3	NW X	-
	n loyaEle	LE O	nsulta Pla			ERP	or and a second		ucaiteRis	-
	elatiWir	tize Cla	Co K	Der	ly de	8	ă	Т	vin the	-
	26 PMr	tmPrior	r reQuic	_	r seTime	PMTMI		_	froTMv	_
	raEnforc	SEXPER	e Gathe		atHighe	almuh			eLeam	
	Avoid to	Busine	Capabl		Cooper	Effactiv			Effectiv	
	Strong fu	TM M&(		l'rust cor		Jser aw			Avoid re	
	rrientati	M daily-		M upda		roper R		tandera		
	stake 0	ange rP		cumerP	Ì	diawodi		olve a S		
	stic tilAll	aditicCh		erize Do		ical aEn		yalitylnv		
	xReala	FShift to		kStand		ndTechn		u Win lo		
	omain e	mpower		ocus on		egacy ai		M team		
	/ protolD	v in ex		omizati		e who		ain exd		
	isidShow	lai Clari		nifi Custo	_	00 Defin		IstDom		
	arity of v	ining of cl		arket ber		odule ao		M relation		
ſ	lize pi Cl	Ŧ	046 F6	2	choic	2	timin	Ē	-	
S	er Optin		Hem		Right		Diaht			
tion Succes	Good teche		Willingness		Clarity in so	-		Minimize cl	•	
plemental	le people		g throug		in object			ve planni		
ERP Im	Motivat		Trainin		Clarity			Effectiv		

Fig. 1. Tree map of the themes

S. No.	Themes Extracted	S. No.	Themes Extracted
1	Time Line	31	Competency of the Vendors
2	Understanding of Business Processes	32	Continuous Monitoring of Progress
3	Understanding of Key Requirements	33	Setting Data Collection Strategy
4	Top Management Involvement	34	Readiness to change
5	Effective Training Sessions	35	Project Ownership
6	Effective Training Material	36	Avoid the Early Retirement
7	Clear Scope	37	Volunteers Committee Composition
8	Change Management Strategy	38	Defining Job Description
9	Motivating Teams	39	Interdepartmental Coordination
10	Top Management Support	40	Module integration issue handling
11	Skillful personnel	41	Remove Fear
12	Continuous Improvement	42	Sharing of Benefits regarding Job Safety
13	Risk Management	43	Quick implementation and release
14	Time Management	44	Effective financial Management plan
15	Involvement of Power Users	45	Evaluation of Vendors
16	Vendor Support	46	Stability of employees
17	Domain Exert Committee	47	Alignment between IT and Business Strategies
18	Identification of Master Trainers	48	Strategic Fit between system and business
19	Management Persuasions	49	Sufficient Financial Resources
20	Effective Project Management Team	50	Optimal Utilization of Business Processes
21	Continuous Testing	51	Strong IT Infrastructure
22	Strategy for Integration Issues	52	User Acceptance Testing
23	Setting of KPIs	53	Stability in Job Postings
24	Clear Vision	54	Maintenance of Daily Activity Log
25	Inter-team cooperation	55	Quick Decision Making
26	User Support	56	Sharing Proposed Benefits of the System
27	Effective Planning and Documentation	57	Standard of the Project
28	Project Management Effectiveness	58	Good Relationship Building
29	Setting Task Prioritization	59	Vender Partnership
30	Effective Communication	60	Trust Building

Table 1. Critical Factors for the implementation of ERP System

2. Project Management: The study also concludes that ERP project is very complex project. The clear scope, defined objectives, timelines, resources, and cost are the key areas of planning the ERP project implementation. There are different phases of ERP project. The first thing is to develop a competent team who will be responsible for ERP project planning and execution. The team should have employees from the cross functional areas including ERP consultants and internal staff members. In the beginning, clear and realistic milestone and end-dates should be decided. After the execution of the project monitoring is very important element found in this study. With the help of monitoring, daily logs, meetings and follow up, delays can be reduced. Role of project management is also very critical.

3. Change Management: The present study also

found that the change management is the key factor which influences the successful implementation of ERP system. Change has different levels in the organization, e.g., individual level change, group level change and organizational change. Creating a knowledge sharing culture encourage the employees to learn the new system of ERP. In the same lines, reducing fear of the use of ERP system and fear regarding their jobs and authority can be reduced with the effective change management at the individual level. Similarly, the group level change in the departments is very critical. After the implementation of ERP system all departments should work jointly because the output of one department becomes the input for another department. Therefore, all groups should change their existing behavior within the department and across the organization and leadership play a very important role for bringing the change in the departments.

- 4. Business Process Reengineering: Business process reengineering is another critical success factor found in this study. Alignment of ERP system with the legacy system of the organization is very important. Therefore, organizations must change their existing processes as per need of the ERP system. On the other side, minimal customization in the ERP system according to the need of the organization is also critical. Organizations should adjust the process according to the system and vice versa. Therefore, involvement of the domain expert having both business and technical knowledge about the information system is very important. These experts must test the user acceptance and alignment of the processes with the system to ensure the successful implementation of ERP system.
- Education: 5. Training and Training and education is also very critical factor of ERP implementation in Pakistani industry. Companies should arrange formal and effective training sessions for the end user relating to the business processes, documentations, dealing with the data on ERP system. Organizations should arrange the right master trainer and trainees with the right training material and training environment. Hands-on-practical training is very essential to learn the usage of

ERP system to save their time and resources. Effective training ultimately build trust between employees and employer and reduce the maximum level of fear of working on entirely new information system.

6. Vendor Management: In the present study vendor/consultant management is very critical factor of ERP implementation success. Selection of the right and experienced vendor/consultant is very important step in the beginning which has ultimately a chain effect throughout the implementation phases of ERP system. They play an important role in adequate development, configuration, and testing of the completion information system. Moreover, organizations should select and manage the vendors who have multiple skills e.g., functional, technical, and interpersonal.

#### 6. REFERENCES

- Gattiker, T. F., & Goodhue, D. L. Understanding the local-level costs and benefits of ERP through organizational information processing theory. *Information & Management* 41(4): 431-443 (2004).
- Kulkarni, U. R., Ravindran, S., & Freeze, R. A knowledge management success model: theoretical development and empirical validation. *Journal of management information systems* 23(3): 309-347 (2007).
- Yu, C. S. Causes influencing the effectiveness of the post-implementation ERP system. *Industrial Management & Data Systems* 105(1): 115-132 (2005).
- Ifinedo, P., B. Rapp, A. Ifinedo, & K. Sundberg. Relationships among ERP post-implementation success constructs: An analysis at the organizational level. *Computers in Human Behavior* 26(5): 1136-1148 (2010).
- Ijaz, A., Lodhi, R. N., & Irfan, S. Critical Success and Failure Factors of ERP System: A Case Study of an Electric Supply Company of Pakistan. 10th Asian Academy of Management International Conference 2013 (AAM 2013): Malaysia (2013).
- Sun, A. Y., Yazdani, A., & Overend, J. D. Achievement assessment for enterprise resource planning (ERP) system implementations based on critical success factors (CSFs). *International Journal of Production Economics* 98(2): 189-203 (2005).
- 7. Khattak, M. A. O., Yuanguan, S., Irfan, M., Khattak,

R. A., & Khattak, M. S. M. Examining critical success factors affecting ERP implementations in enterprises of Pakistan. *Interdisciplinary Journal of Contemporary Research in Business* 3(10): 606 (2012).

- Saatcioglu, O. What determines user satisfaction in ERP projects: benefits, barriers or risks? *Journal of Enterprise Information Management* 22(6): 690-708 (2009).
- Motwani, J., Subramanian, R., & Gopalakrishna, P. Critical factors for successful ERP implementation: Exploratory findings from four case studies. *Computers in Industry* 56 (6): 529-544 (2005).
- Ngai, E.W.T., Law, C.C.H., Wat, F.K.T. Examining the critical success factors in the adoption of enterprise resource planning. *Computers in Industry* 59 (6): 548–564 (2008).
- Nattawee, A., & Siriluck, R. Developing ERP Implementation success factors of Thai SME's. GMSARN International Conference on Sustainable Development: Issues and Prospects for the GMS 12-14 (2008).
- Shah, S. I. H., Khan, A. Z., Bokhari, R. H., & Raza, M. A. Exploring the impediments of successful ERP implementation: A case study in a public organization. *International Journal of Business and*

Social Science 2(22): 289-296 (2011).

- Shad, S. A., Chen, E., & Malik, F. Enterprise Resource Planning- Real Blessing or a blessing in Disguise: An Explorationo of the Contextual Factors in Public Sector. Retrieved from http://arxiv.org/ftp/ arxiv/papers/1207/1207.2860.pdf (2012).
- Nelson, K., & Somers, T.. Exploring ERP success from an end-user perspective. *AMCIS* 2001 *Proceedings* 206 (2001).
- Ehie, I.C., & M. Madsen. Identifying critical issues in enterprise resource planning (ERP) implementation. *Computers in Industry* 56 (6): 545–557 (2005).
- 16. Yingjie, J. Critical success factors in ERP implementation in Finland. *The Swedish School of Economics and Business Administration* 71 (2005).
- Fang, L., & S. Patrecia.. Critical Success Factors in ERP Implementation. *Jönköping International Business School, Jönköping University, Sweden* (2009).
- Khattak, M. A. O., She, Y., Memon, Z. A., Syed, N., Hussain, S., & Irfan, M. Investigating Critical Success Factors Affecting ERP Implementation in Chinese and Pakistani Enterprises. *International Journal of Enterprise Information Systems* 9(3): 39-76 (2013).



Research Article

## Identification of Failure Modes on Electrostatic Chuck through Reliability Centered Maintenance: A Case Study

#### Mehroz Sana<sup>1\*</sup>, Umer Saleem<sup>1</sup>, Muhammad Farooq<sup>1</sup>, Adnan Qamar<sup>1</sup>, Muhammad Mehmood A Bhutta<sup>2</sup>, and Saad Zafar<sup>3</sup>

<sup>1</sup>Mechanical Engineering Department, University of Engineering & Technology Lahore KSK Campus, Pakistan <sup>2</sup>Mechanical Engineering Department, University of Engineering and Technology, Lahore, Pakistan <sup>3</sup>United Energy Pakistan, Karachi, Pakistan

**Abstract:** Quality of any reliability analysis depends strongly on the analyst's ability to identify all required functions. Failure is a basic concept of any reliability analysis. Also, the plant equipment's reliability is of vital importance in any production operation. The objective of the present study was to investigate the failure modes of critical systems in the manufacturing process of micro-chips by using Reliability Centered Maintenance (RCM) technique. In industries, RCM is employed to decide maintenance strategies using reliability data. The most critical component of the system was found to be Electrostatic Chuck (ESC) used in etching process. This technique was helpful in reducing the failure modes of critical equipment. Analyses were performed to observe the improvement in the system's efficiency. Downtime data was collected due to various faults in critical equipment. In the current research, various RCM analysis were performed on electrostatic chuck to ensure that shifting the maintenance technique to RCM would increase the revenue generation for the industry. This analysis was performed in Texas Instruments, UK. The results for optimum life of equipment, obtained after performing RCM, were quite high. Proper scheduling and planning improved the time of productive maintenance from 25% to 35%. Planning through Computerized Maintenance Management System (CMMS) boosted the efficiency up to 90%. The obtained results were compared with the current maintenance techniques; e.g., corrective maintenance. Solutions were recommended for the identified modes of failures and ways to eliminate the factors that cause failures on ESC.

**Keywords:** Backside cooling, computerized maintenance management system, decision making grid, dry vacuum pump, electrostatic chuck, reliability centered maintenance

#### 1. INTRODUCTION

The corrective maintenance analyses were of no use for augmenting the life and reliability of the Wafer Etching System (WES), if it is not integrated into an operative preventive maintenance program successfully. The aim of this research was to find out how the RCM analysis could be performed for the ESC (LAM4520). The key struggle was to achieve the aims by collecting the life data of electrostatic chuck and dry vacuum pump and its downtime due to numerous faults. RCM analysis was carried out for increasing the availability of the ESC and DVP. Investigation of transformation processes of wafer disc into final product was performed on ESC (LAM-4520). The research determined the ways by which the ESC and DVP failed to fulfill their functions then the RCM analysis to determine the cause of failures. The objective of RCM was to improve maintenance actions in the most economical and technical way.

RCM to guarantee that equipment continues to perform its functions as their operators require doing in its present operating environment [1]. It is a well-organized process that focuses on aspects of reliability while determining plans of maintenance. It helps to create equilibrium

Received, March 2017; Accepted, June 2018

<sup>\*</sup> Corresponding Author: Mehroz Sana; mehrozsana@hotmail.com

between preventive and corrective maintenance [2]. The research was extended and applied to the railway, manufacturing, electricity, petrochemical and various other industries [3]. It was originated from the extensive examination of some specific questions about the equipment [4]. RCM incorporates reactive maintenance, preventive maintenance, predictive maintenance and proactive techniques of maintenance in an assimilated mode in order to escalate the probability of the equipment that performs its functions as required by the user for at least its designed life period [2].

The process for development of RCM requires about a failure on a given asset [5]. Performance standards and functions of a given asset were studied to describe the failure due to which asset is not properly functioning [6,]. After that causes, effect and result of each functional failure were observed on the basis of this information tasks to prevent each failure were predicted and performed. Analyses were carried out to recognize the most applicable and economical maintenance way in order to cut down the impact and risk of failure in system. Results were compared with the other maintenance techniques which are being used at present. Solutions to avoid failure mode were recommended accordingly. This helps to maintain the system and equipment in the most economical manner. The outcomes of suggested RCM planning direct the plant to a saving of at least 80% of the total downtime-cost as compared with the strategy used in plant i.e. Run to Failure or reactive maintenance. Decrease in the labor cost increased the reliability of system. The program was developed for the spare parts of plant (boiler, feed water pump and turbogenerator). The results showed that about 22.17% of the yearly spare parts charges were saved when RCM is implemented [7-10].

#### 2. MATERIALS AND METHODS

#### 2.1 Method of Data Collection

The data was collected from the company's personnel, interviews with skilled and experienced plant workforce in order to get their details about the plant. Time constraints, availability of personnel and asset, schedules and operating conditions of the asset were considered for analysis. The manuals of the assets and reports of past six months were

examined to analyse. The data was collected from CMMS to carry out the RCM analysis. It is German system for the analysis and program development. The component for maintenance planning is unified with the components and sub-components of the SAP that includes the components for application for plant maintenance i.e. lists of maintenance activities, orders for maintenance, and notifications of maintenance along with work clearance management, the components for application for customer services After the collection of data from SAP, tables, graphs and reports were generated to get the required results. An early review was conducted by using maintenance and strategy techniques. SAP generates the failure reports whenever fault detected in the system in real time.

#### 2.2 Decision Making Grid

Decision making grid (DMG) guides to choose the type of maintenance, i.e., RCM, TPM or CBM and its proper use by tracking the condition of worst machines in terms of performance, which were segregated on the base of different criteria. The information for the development of DMG was mainly extracted from SAP. DMG anticipated model was applied on the ESC (LAM 4520) which reduced the total breakdowns hours. To construct DMG, the data of last twelve months was collected. The data was calibrated through LAM Bench Viewer (LBV) which shows the number of failures w.r.t. time. The collected data shows that the number of failures increased with the passage of time. The investigation to find the reason of failure of LAM-ESCs revealed that the main reason of failure was problem in backside cooling of the wafer and improper vacuum in the chamber due to the dry vacuum pump that is attached directly to the ESC. Fig. 1 shows the breakdown trends of 12 months of a typical facility closed for the analysis.

Frequency of failures and downtime hours of wafer etcher (LAM-4520) failures were used to evaluate the classifying information using criterion evaluation method on DMG. Fig. 2 shows the categorization on frequency of machines failures. Both electrostatic chucks LAM4520-2 and LAM4520-7 failed 21 and 15 times respectively in 12 months, but LAM4520-3 was categorized in medium level group while LAM4520-6 in Low level group. The categorization of downtime was carried







Fig. 2. Criterion analysis on frequency of failure

out using query selection method. LAM4520-4 categorized in the high downtime. Note that LAM4520-2 downtime is more than LAM4520-4 & 7 but both categorized in the same cluster.

Fig. 2 shows the misleading on the interval of high, medium, and low categorization and confusing categorization on LAM4520-7 and 4.

#### 2.3 LAM4520 (Electrostatic Chuck) Availability and Failures History

Fig. 3 shows the availability of LAM4520 electrostatic chuck of one year with breakdown. The objective was to get 100% availability which means even not a single breakdown out of 85 events. However in 12 months breakdown trend has increased and maximum number of breakdowns

occurred from October, 2012 to March, 2013. This research focused on the reason of unavailability of ESC and recommended solution using RCM analysis.

Etching performance found declined due the production stoppage of microchips. Six of the electrostatic chucks exhibited major defects. Data of the failure was collected and electrostatic chucks (LAM) were sorted by wafer sizes (150mm and 200mm diameters). The failure data obtained from LAM viewer exhibited that 85% of back side cooling (BSC) failure attributed to 150mm tools i.e. 51 out of 59 failures were attributed to LAM 4520-3, 4 and 7. It was witnessed that the maximum breakdowns occurred in LAM 4520. Fig. 4 shows that out of 7 ESC of the same model named as LAM-4520 electrostatic chuck. The maximum



Fig. 3. Availability of ESC (LAM4520)



Fig. 4. ESC (7-LAMs) breakdown of INTERCON by tool



Fig. 5. Scheduled-unscheduled maintenance of INTERCON by tool



**Fig. 6.** Normal pressure of helium using graphs



Fig. 7. Exceeded pressure of helium using graphs

failures occurred in LAM4520-2, 4 and 7 which was obtained directly from the LAM-Viewer and SAP-Intercon software.

Most of the maintenance tasks performed was unscheduled rather than scheduled. This unscheduled maintenance was carried out due to the failure of large part of 3 LAM4520 which can be evaluated by using the bar chart as shown in Fig. 5. The total 11 PMs were performed and 66% of those 11 PMs were unscheduled activities. The most common failures of all electrostatic chuck were due to the excess of helium flow, ESC voltage, and manometer pressure. Failure common to three LAM4520 of 150mm Electrostatic systems was hardware confirmed well, red: helium flow, green: helium manometer pressure and blue: ESC voltage as shown in Fig. 6. When the pressure went up more than 3-time of normal pressure, ESCs failed as shown in the pulse graph of SAP below: Helium flow > 25 sccm (unit of pressure) limit.

#### 2.4 LAM4520 BSC Failures By Occurrence Last 12 Months

The Table 1 shows that maximum failures were due to BSC of wafer disc. The specific criteria that the process satisfied about wafer grip input and sense output standards were high. The wafer grip input was pulled to low value in order to command grip. When the wafer was sensed, then the wafer sense line was pulled low. These conditions were vital before gripping. For this research, the gripping of wafer was started upon sensing, before it hit the surface of chuck. This produced trifling lateral position shift of wafer. When wafer grip was achieved, then the output of "wafer gripped" is pulled low. After that the potentials of chuck electrode to curtail grip forces were enhanced. The lift pins before/without clamping a substrate/

Fails / Month	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar
BSC	37	30	42	38	37	36	26	36	30	19	40	54	59
Endpoint				12	11	10	14	5	4	4	5	1	5
Handling				30	30	22	11	2	9	4	4	2	7
RF				2	4	2	6	5	6	3	1	1	0
Gap					0	0	0	10	7	1	1	1	3
Control stem PSU, Lam PC)								4	5	2	2	2	7
Intensity											10	3	2
PM01 work orders	153	170	170	119	133	100	76	82	74	51	84	75	101
Wafers processed	30704	33293	39411	37914	35638	30730	29195	33002	34784	25978	33191	33101	33054
Fails / 10k	50	51	43	31	37	33	26	25	21	20	25	23	31
Target Fails / 10k	48	47	46	45	44	43	42	41	40	39	39	38	38
PM02 work orders				48	52	40	42	37	32	26	41	32	29
PM02's / 10K	0	0	0	13	15	13	14	11	9	10	12	10	9
	20%										10%		





Fig. 8. Functional block diagram of ESC

wafer to an ESC surface was dropped throughout wafer acceptance. Small wafer discs astride onto a bigger electrostatic chuck by a carrier film made up of polyester, with a supporting ring of Silicon. Cooling was poor due deficiency of backfill gas under the wafer that was being processed. Wafer discs became heat sunk on the carrier Silicon wafer with the help of silicon diffusion pump wax or oil for small remains. Proper cleaning was done to avoid any sort of contamination. Wafer grip and lift was harmonized to curtail lateral shift.

Then the backpressure was smeared. Initially the gas flow was high, then it felled to the steady state leakage amount. The amount was higher than directed in the datasheet of electrostatic chuck due to the high stiffness of substrate, dirt particles, substrate bow, and damage to chuck. After plasma processing ended, wafer popping was caused by wafer release due to backfill pressure and was eliminated before release. After that RF processing was commenced by an indication from the host control computer. The two valves V90 and V 93 were used for helium supply at 15 to 20 psi. Backside pressure of wafer was measured by using a manometer of rang 10 Torr. The output achieved from 10 Torr manometer was then fed back into a Unit Pressure Controller (UPC). At the very same instant, the helium entered on two other valves operates V92 and V90A. The functional block diagram for the procedure is introduced in the Fig. 8

#### 3. RESULTS AND DISCUSSION

#### 3.1 Root Cause Failure Analysis (RCA) of System

RCA is used for analyzing severe adverse events in the equipment. RCA of Electrostatic Chuck (LAM-4520) covers failure mode, reason and root cause of failure for equipment. This root cause analysis was done by finding the answers to certain questions to complete the data of the failures occurred in ESC. For the electrostatic chuck, a lot of problems were identified while performing root cause analysis.

The subsystems becoming reasons of failure of ESC were identified to be Backside cooling system (BSC), water handler, vacuum chamber, plasma production chamber, helium pressure and vacuum stabilizer and RF stabilizer. Analyses were then further performed to find the reason of failures of these subsystems. The reason obtained by RCA for BSC failure was the stoppage of water etching process. When the detailed study was done the reasons pointed out for this were insufficient clamping voltage, insufficient Helium Flow, inaccurate measurement of Backside Manometer and a fault in Unit Pressure Controller (UPC).

Water handler caused a problem because of the wafer in the entrance cassette did not pick up by the water shuttle and the wafer lost in the chamber or got stuck up with the donut of ESC. To improve the optimum life of the equipment it was very necessary to find the main reason of these failures which by performing RCA were found to be the improperly loaded wafer e.g. cross slot in the cassette, Photoresist on top of the wafer not properly hard-baked, sticking of Soft photo-resist to the helium clamp after plasma heating, sticking of wafer to the helium clamp which cannot be unloaded and most majorly the sticking of wafer to the lower electrode after plasma heating.

RCA was performed on other subsystems of ESC to find even the minute causes of failure and were identified. The vacuum chamber stopped working as the back side of wafer was too rough or contaminated with particles/film. Along with wafer Shuttle vacuum problem which created a default in alarm of vacuum chamber. There were few errors due to improper working of chiller which caused error in plasma production chamber ultimately making a role in ESC failures. Hence after performing RCA we can identify all the major failures of a system to the minutest details.

#### 3.2 Failure Mode and Effect Analysis (FMEA) / Primary Information Sheet

A Failure Mode Effect Analysis was accomplished to recognize the possible modes of failure for a process or a product. The RPN technique requires the team for analysis to use past know-how and engineering decision to rate each possible problem. Primary FMEA sheet along with RPN analysis for the electrostatic chuck and dry vacuum pump were generated by further observing the functions and failure modes of sub systems and components and then the effect of these failure modes on that

Item	Function
Back Side Cooling System	To Provide Cooling at backside of wafer with Helium gas at pressure 18 SCCM and balance wafer in ESC
Check Valves (V90,V92,V93)	To stop the backward flow of air after creating Vacuum in the chamber
Helium Cooling Manometer(UPC)	To control the Helium flow up to 1 sccm accurate pressure this is directly flow from Helium Chamber to ESC chamber.
Chamber Pump	To rapidly create vacuum in the chamber and sucks extra Helium from etching process chamber to Pumping chamber
Air Filter	To purifier air by removing contaminants from the air to avoid dirt in the ESC donut
Four Pin Wafer Lifter	To Lift the wafer up at distance of $0.005$ inch to $0.025$ inch from the surface of chuck
ESC Power Supply	To apply the voltage of 700v to clamp wafer and -1700V to de-clamp wafer.
Clamp Ring	To hold pieces of glassware above the Head after/during process and to make separate EMI Gasket and ring to avoid failure of gasket.
Dielectric Material	To maintain the electrostatic attraction even with high Voltage from -350 to +1700 with no failure of dielectric
Safety Valve	To release the pressure when it exceeds above 18Sccm
(V90A, V85)	To make capacitor by charging donut and base +350 and -350 respectively to produce plasma.
Electrodes (Donut & Base)	To Pick the wafer from Etcher system and drop on the next system to process
Wafer Handler	To supply the Helium gas inside the ESC
Piping System	To exhaust the harmful gases and by- products out of the system
Exhaust Piping System	To prevent reverse flow of gas from the exhaust through the pump to the vacuum chamber, when pump is stopped
Exhaust Check Valves	To prevent reverse flow of gas from the exhaust through the pump to the vacuum chamber, when pump is stopped
Pump casing	To protect the pump
Bearings	To bear the thrust loads
Eye Bolts	For loading and unloading of the pump

**Table 2.** List of functions of ESC and DVP

component itself, the system ESC or dry vacuum pump and to the whole plant. Then the RPN was calculated by each of the failure modes. Higher RPN shows higher risk factor and vice versa. It was seen that the most risks are due to Backside Cooling of single wafer etcher and this finding was verified by the RPN analysis.

The RPN of ESC due to failure of BSC mechanism was greater than 100 because of its higher severity, higher rate of occurrence and almost unlikely detection of fault. When the pressure exceeded too much i.e. about 23 sccm then due to much more severe effects and low detectability of fault the risk priority number reached above 200, thus stopping the production and causing very drastic effects on plant. Failure mode and effect analysis is a technique that inspects process failures,

estimates priorities of risks, and helps to determine corrective actions to evade identified problems. A detailed FMEA analysis was performed on FMEA sheet which is attached as Table 3. On the basis of FMEA "the final information sheet" was generated and is given in the table below.

#### 3.3 Generation of Information Sheet and Decision Worksheet

The final information sheet was generated according to the item no. of the component. This information sheet was developed so that one may have a complete overview of the failure history of the ESC just by going through the information sheet and finally on the basis of all the information of equipment we formulated a decision sheet on what maintenance task should be performed on

Item	em Function Function		Failure Mode	Effect				
Item	Function	Failure	Fanure Moue	RPN	Local	System	Plant	
Back Side Cooling System	To Provide Cooling at backside of wafer	Failed to maintain pressure and	Pressure exceeds to 23sccm	24	Wafer balancing failed	Etching Process Failed	Production Stopping	
	with Helium gas at pressure 18 SCCM and	balance of wafer	Pressure exceeds to 23sccm	144	Wafer balancing failed	Etching Process Failed	Production Stopping	
	ESC		Cooling System Failed	70	Wafer wasted	LAM-donut failed	Production Stopping	
			Failed to maintain gap b/w wafer & Donut	80	Wafer wasted	No effect	Production Stopping	
			Insufficient clamping voltage	64	Wafer Wasted	LAM-donut failed	Production Stopping	
			Backside Manometer Faulty	28	Manometer Failed	Etching Process Failed	Production Stopping	
Check Valves	To stop the	Valve is not	Fails to Open	135	Low Effect	High Effect	Low Effect	
90,V92,V93)	backward flow of	acting as	Remain Open	84	Low Effect	Low Effect	No Effect	
	Vacuum in the chamber	non-return stop valve	Crack Valve	20	Low Effect	Low Effect	No Effect	
Helium Cooling nometer(UPC)	To control the Helium flow upto 1 sccm accurate	Failed to control Helium	Incorrect measurement of Pressure	24	ESC Trip	Full LAM- Etcher Shut Down	No Effect	
	pressure which is directly flow from Helium	flow from Helium chamber	Failed to send signal to Computer PC9	120	ESC Trip	LAM- Etcher Slow Down	Low Effect	
Chamber to ESC to E chamber fail	failed to send signal	Insufficient supply of Helium	32	ESC Trip	LAM Shut Down	No Effect		
		back to UPC	He Flow Full more than 50 sccm but the maximum flow is set at below 50 sccm the UPC flow sensor can sense	144	UPC Collapsed	LAM Shut Down	Low Effect	

**Table 3.** FMEA analysis of ESC

equipment to get the optimum life. The generation of Decision Worksheet dealt with consequences of failure and preventative tasks. The decision work Sheet was generated by Logic Tree analysis. Then after getting the information about failure and its consequence preventive or proactive tasks were suggested for the better performance of the equipment and this all information is given in decision work sheet. The decision Worksheet spots the Consequences of failure by dividing it into the following headings:

- H : Hidden Failure Consequences
- S: Safety & Environmental Consequences
- O: operational Consequences
- N: Non-Operational Consequences

The information sheet and decision making sheets are attached in table 4 and 5 respectively. As the maintained is quite a neglected field all over the world and still not much work is done on RCM

Table 4. Final information sheet of ESC	Table 4.	Final	Information	sheet	of ESC
---	----------	-------	-------------	-------	--------

	Site: GFAB Plant TI		Unit: 1		RCM INFO Texa	RMATION SHEET FOR s Instruments, UK
	Main Assembly : Wafer Etc	her Ass	embly		Date:	Sheet 1 of 1
	Sub Assembly: LAM-4520				Carried out by:	Mehroz, Umer
	Component: Electrostatic	Chuck			Signed off by:	
NO.	Function		Function Failure		Failure Mode	Failure Effects
1	To Provide Cooling at backside of wafer with Helium gas at pressure 18 SCCM and balance wafer in ESC	A	Failed to maintain pressure	1	Pressure exceeds to > 25 SCCM	The whole batch of wafers will be wasted which causes the Electrostatic chuck stop. A 12 In. wafer has 113 Sq. In. to be used for chips at \$200 that's only \$1.77 per Sq In. only 17 cents more than 2 times the ammount lost. Total loss of production > \$1000
				2	Surge in Helium Cooling flow	ESC takes time to set it to normal condition which causes the Etching Process system stop ultimately there will be more loss in Production once it set up permanently.
				3	Helium Flow is not consistent wafer to wafer	ESC is at low performance which causes the Etching system trip hence Lower production leading lower profit per wafer.
		В	Failed to balance the wafer	1	Wafer is not clamped even on 700Volts	ESC trip, Steam system trip, Production stooping
				2	Helium Pressure is very low (<18sccm)	same as 2-A-3
				3	Wafer unbalanced during etching process	ESC trip, Steam system trip, Lower production, downtime of 1 day
2	To stop the backward flow of air after creating Vacuum in the chamber		Valve was not acting as non-return stop valve	1	Fails to Open	Low effect on ESC and on system but there will be no effect on overall plant until Full etching process fails. Downtime for changing check valve is 3.5 hours
		А		2	Remain Open	ESC trip, Etching system trip, Production stooping
				3	Crack Valve	Once valve is cracked ESC will trip, Etching system trip and Production will be stopping. Downtime to change valve =1 hour

				5 2											
RCN DEC	A CISION	J	Item LAM-4520 Wafer Etcher							System: Etching Process				Sheet No. 1 of 1	
WORKSHEET			Component: Electrostatic Chuck							Unit No: 1					
Information Reference			Consequence Evalu- ation				H1	H2	H3						
							S1	S2	S3	Default Task		sk	Proposed Task	Initial Interval	Can be done by
							01	02	03						
F	FF	FM	Н	S	Е	0	N1	N2	N3	H4	H5	S4			
1	A	1	Ν	Ν	Ν	Y	Ν	Y					Implement Extended Precoat on Novellus 150mm Tool	Weekly	Tech Op
1	А	2	N	N	N	Y	N	N	Y				Fix BSC Spacer Etcher for LAM4520- ESC	Weekly	Tech Op
1	А	3	Y	N	Ν	Y	Y						Generate OCAP (Out of Control Action Plan)	Weekly	Tech Op
1	В	1	Y	N	N	Y	Y						Check previous process (Dopping-Undopping), Change Novellus System	Weekly	Tech Op
1	В	2	Y	N	Ν	Y	Y						Vent the main reaction chamber	Weekly	Tech Op
1	В	3	N	N	N	Y	Ν	N	Y				Verify that the Chamber Clamp Flow (Envision) or He Flow Full Scale (sccm) is set to 50 sccm	4 Weekly	LAM- Engineer
2	А	1	Y	Ν	N	Y	Y						Replace check valve	Six monthly	Tech Op
2	А	2	Y	N	N	Y	Y						Replace check valve	Six monthly	Tech Op
2	А	3	N	N	N	Y	N	Y					Replace check valve	Six monthly	Tech Op

 Table 5. RCM Design sheet for ESC

as the analysis seemed to be quite simple but these analysis make a major difference in the availability of plant.

#### 4. CONCLUSIONS

This research revealed that when reliability-oriented maintenance was carried out at the production facility, it maximized the life and utility of plant and critical equipment for a much longer time. Even in today's world, maintenance is considered as a necessary evil and is thought be a simple process and a wastage of time. However, this study proved that by implementation of RCM at the production facility, the production in the prevalent conditions was achieved in a most cost-effective way. The decrease in downtime clearly revealed that the research proved fruitful; however, little betterment in future such as replacement of LAM- 4520 unit with advance LAM 6 Rainbow etcher or replacement of dry vacuum pump model may lead to more economical and greater levels of production. Results of the RCM technique implemented on the plant suggested that the management must go for advanced predictive maintenance techniques.

This study also suggested to curtail reactive maintenance and encouraged to perform maintenance tasks at regular intervals. The planned labor program was also proposed, which showed that the labor cost falled from 295200 \$/year to 220800 \$/year which was 25.2% of the total labor cost. Insufficient maintenance and operational procedures and flaws in designs were exposed and corrected while constructing the fault tree. RCM planning directed a saving of about 80% of the total downtime cost as compared to pre-existing maintenance (RTF). Decreasing the labor cost increases reliability of system. The planned spare parts program for the components of plant was generated. The results showed that about 22.17% of the yearly spare parts charges were saved by implementing RCM. The whole plant underwent predictive maintenance and gave maximum from the given input.

#### 5. REFERENCES

- 1. Moubray, J. *Reliability-centred Maintenance*. Butterworth-Heinermann, Oxford, United Kingdom (1991).
- Manouchehrabadi, M., K., *RCM: Wind Power Project Management (WPPM)*. University of Gotland, Wind Energy Department, Gotland (2011).
- Chen, Y. & T. Zhang. Application and development of reliability-centered maintenance (RCM) in china's nuclear energy field", Proceedings of International Conference on Quality, Reliability, Risk, Maintenance and Safety Engineering, 543 pp. (2012).
- Nowlan F.S. & H. F. Heap . Reliability-centered Maintenance, Technical report AD/A066-579.

National Technical Information Service, US Department of Commerce, Springfield, Virginia, (1978).

- Ying, M., B.Wanga, C. Kwai-Sang, G.K. Poonb. Risk evaluation in failure mode and effects analysis using fuzzy weighted geometric mean, Institute of Soft Science, Fuzhou University, China (2009).
- Weir, B., Computerized Maintenance Management Systems: "An Impartial View of CMMS Functions, Selection and Implementation", CMMS (2009).
- 7. TI, *Plasma Etch: Used, Surplus, Refurbished Equipment For Sale, Auctioned and Wanted.* Texas, United States (2012).
- Garg, A., S.G., Deshmukh, (2006), "Maintenance management: literature review and directions", Journal of Quality in Maintenance Engineering, Vol. 12 Iss: 3, pp.205 – 238, (2006).
- Ebara-Pumps, 1-2 Cochrane Square, Brucefield Industrial Estate, Livingston EH54 9DR, Ebara Pumps UK, Ebara, Ebara Europe, Surface and submersible pumps. (2013).
- Reason J. Managing the risks of organisational accidents. Aldershot: Ashgate Publishing Ltd.; 1998.


Research Article

## A Quasi Lindley Pareto Distribution

## Asad Ali<sup>1\*</sup>, Qaisar Rashid<sup>2</sup>, Muhammad Zubair<sup>2</sup>, and Muhammad Tariq Jamshaid<sup>2</sup>

## <sup>1</sup>Department of Quantitative Methods, SBE, University of Management and Technology, Lahore, Pakistan <sup>2</sup>Department of Statistics, University of Sargodha, Pakistan

**Abstract:** In applied sciences, the lifetime's data models have been constructed to facilitate better modeling and significant progress towards the reliability analysis or survival analysis. For this purpose, a new distribution "Quasi Lindley Pareto Distribution (QLPD)" has been introduced. It's Moments generating function, moments, mean, variance, coefficient of variation, skewness, kurtosis, survival function, hazard function, and distribution of extreme order statistics have been discussed. The maximum likelihood method has been discussed for estimating its parameters. The distribution has been fitted to real life data set to check its goodness of fit to which earlier the Lindley distribution and Quasi Lindley distribution have been fitted and it is found that QLPD provides closer fits than those by the Lindley distribution.

Keywords: Moments, Order statistics, Survival, Hazard, Goodness of fit

## 1. INTRODUCTION

The modeling of lifetime data is crucial in many fields of applied sciences like engineering, biological, finance and insurance. Exponential, Gamma, Weibull and Rayleigh distributions have been developed for this purpose. Lindley [1] had developed one parameter Lindley distribution for lifetime data analysis. Sankaran [2] developed discrete Poisson-Lindley distribution from Lindley and Poisson distributions. He also discussed its different properties, parameter estimation and goodness of fit. Ghitany et al. [3] worked on Lindley distribution with considering waiting times before service of the banking customer's. Shanker and Mishra [4] derived Quasi Lindley distribution (QLD). Shanker and Mishra [5] derived two-parameter Lindley distribution and discussed its various properties. Shanker et al. [6] introduced another two-parameter Lindley distribution. Shanker and Amanuel [7] developed new Quasi Lindley distribution. Shanker and Tekei [8] determined a new Quasi Poisson Lindley distribution. Shanker and Mishra [9] developed Poisson mixture of Quasi Lindley distribution and also described various statistical and mathematical properties, parameter estimation and applications. Lazri and Zeghdoudi [10] introduced a distribution for modeling lifetime data called Lindley Pareto distribution (LP) and also discussed its various properties and application. In this paper, we have derived Quasi Lindley Pareto distribution and its different properties are also discussed here.

Let Y be a random variable following the two parameter Quasi Lindley distribution ( $\alpha$ ,  $\theta$ ) with the following probability density function:

$$f(y; \alpha, \theta) = \frac{\theta(\alpha + y\theta)e^{-\theta y}}{(\alpha + 1)} \ y > 0, \ \alpha > -1, \ \theta > 0 \quad (1)$$

Pareto distribution was established by Pareto [11] to elaborate the unequal distribution of wealth. There are many studies on Pareto distribution such as the generalized Pareto distribution was derived by Pickands [12], the beta-Pareto distribution was discussed by Akinsete et al. [13] and the beta generalized Pareto distribution was proposed by Mahmoudi [14].

Received, June 2017; Accepted, March 2018

<sup>\*</sup> Corresponding Author: Asad Ali; F2017204002@umt.edu.pk

The mixed distribution is one of the most important concepts for developing a new distribution. For example, Zakerzadeh and Dolati [15] used gamma ( $\alpha$ ,  $\theta$ ) and gamma ( $\alpha + 1$ ,  $\theta$ ) to create a Generalized Lindley distribution (GLD). Nedjar and Zeghdoudi [16] determined a new distribution, based on gamma (2,  $\theta$ ) and one parameter Lindley distribution known as gamma Lindley distribution.

The T-X family of distributions defined by Alzaatreh et al. [17] is a new method to generate families of the continuous distributions. The cumulative distribution function (CDF) or distribution function (DF) of this family is defined as:

$$G(y) = \int_0^{\frac{F(y)}{1 - F(y)}} f(t) dt$$
(2)

Using Quasi Lindley distribution, (2) becomes Quasi-Lindley X-family of distribution with CDF and Probability density function (pdf) such that:

$$G(y) = 1 - \exp(-\theta\delta)\{1 + \left(\frac{\theta}{\alpha+1}\right)\delta\}$$
(3)

Where 
$$\delta = \frac{F(y)}{1 - F(y)}$$
  
$$g(y) = \left[\frac{\theta}{(\alpha+1)}\right] \left[\frac{f(y)}{\{1 - F(y)\}^2}\right] \left[\gamma + \frac{F(y)}{1 - F(y)}\right] \times e^{-\theta \left\{\frac{F(y)}{1 - F(y)}\right\}}$$
(4)

We considered CDF and pdf a Pareto distribution as:

$$F(y) = 1 - \left[\frac{\beta}{y}\right]^k \qquad f(y) = \frac{k\beta^k}{y^{k+1}} \qquad y > \beta$$

#### 1.1 A Quasi Lindley Pareto Distribution

By utilizing (3) and (4), we get CDF and pdf of Quasi Lindley Pareto distribution (QLPD) with scale parameter(s)  $\alpha$  and  $\gamma$ , shape parameter(s)  $\theta$ ,  $\beta$  and k is given by respectively:

$$Q(y) = 1 - \exp\left[\gamma - \theta\left(\frac{y}{\beta}\right)^{k} - 1\right] \left[1 + \left(\frac{\theta}{\alpha+1}\right) \left\{\left(\frac{y}{\beta}\right)^{k} - 1\right\}\right] \qquad y > 0, k, \alpha, \gamma, \theta, \beta > 0$$
(5)

and

$$q(y) = \left[\frac{\theta k e^{\theta}}{\beta(1+\alpha)}\right] \left[ \left(\gamma - \theta\right) \left(\frac{y}{\beta}\right)^{k-1} + \theta \left(\frac{y}{\beta}\right)^{2k-1} \right] \exp\{-\theta \left(\frac{y}{\beta}\right)^k\}$$
(6)

The nature of QLPD for different values of its parameters  $\alpha, \gamma, \theta, \beta$  and k has shown graphically in the Fig. 1 (a), (b), (c) and (d). In Fig.1 (d) seven choices of QLPD parameters have been combined for comparisons.

#### 2. SOME PROPERTIES

**Survival Function:** The Survival function for random variable Y from QLPD(Y;  $k, \gamma, \alpha, \theta, \beta$ ) is given as:

$$S(y) = \exp\left[-\theta\left(\frac{y}{\beta}\right)^{k} - 1\right] \left[1 + \left(\frac{\theta}{\alpha+1}\right) \left\{\left(\frac{y}{\beta}\right)^{k} - 1\right\}\right]$$
(7)













Fig.1 (d)

**Hazard Function:** The failure rate function has also been called hazard function, determined, by Eq. (6) over survival function Eq. (7). So, hazard function of QLPD(Y; k,  $\gamma$ ,  $\alpha$ ,  $\theta$ ,  $\beta$ ) is:

$$H(y) = \frac{\theta k [(\alpha - \theta) + \theta \left(\frac{y}{\beta}\right)^k] \left(\frac{y}{\beta}\right)^{k-1}}{\beta \left[ (1 + \alpha) + \theta \left\{ \left(\frac{y}{\beta}\right)^k - 1 \right\} \right]}$$
(8)

**Moment Generating Function:** The moment generating function of QLPD(Y;  $k, \gamma, \alpha, \theta, \beta$ ) is:

$$M_{y}(t) = \frac{e^{\theta}}{(1+\alpha)} \Big[ (\alpha - \theta) \sum_{i=0}^{\infty} \{ \Gamma\left(\frac{i}{k} + 1, \theta\right) + \Gamma\left(\frac{i}{k} + 2, \theta\right) \Big] \frac{\beta^{i}}{\theta^{i/k}} \cdot \frac{t^{i}}{i!}$$
(9)

This function has been utilized to determine  $i^{th}$  number of moment about origin.

**Moments:** The *i*<sup>th</sup> moment about origin of random variable Y from QLPD(Y;  $k, \gamma, \alpha, \theta, \beta$ ) are given below:

$$E(y^{i}) = \frac{e^{\theta}}{(1+\alpha)} \Big[ (\alpha - \theta) \Gamma\left(\frac{i}{k} + 1, \theta\right) + \Gamma\left(\frac{i}{k} + 2, \theta\right) \Big] \frac{\beta^{i}}{\theta^{\frac{i}{k}}}$$
(10)

By putting i = 1, 2, 3 and 4 in Eq. (10), first four moments about origin have been derived to determine the mean, variance, coefficient of variation, skewness and kurtosis.

First four moments about mean are defined as:

$$\mu_1 = m_1 - m_1 \tag{11}$$

$$\mu_2 = m_2 - (m_1)^2 \tag{12}$$

$$\mu_3 = m_3 - 3m_2m_1 + 2(m_1)^3 \tag{13}$$

$$\mu_4 = m_4 - 6m_3m_1 + 3m_2m_1 - 4(m_1)$$
(14)

From Eq. (10), we have,

$$m_1 = E(y^1) = \frac{e^{\theta}}{(1+\alpha)} \Big[ (\alpha - \theta) \Gamma\left(\frac{1}{k} + 1, \theta\right) + \Gamma\left(\frac{1}{k} + 2, \theta\right) \Big] \frac{\beta}{\theta^{\frac{1}{k}}}$$
(15)

$$m_2 = E(y^2) = \frac{e^{\theta}}{(1+\alpha)} \Big[ (\alpha - \theta) \Gamma\left(\frac{2}{k} + 1, \theta\right) + \Gamma\left(\frac{2}{k} + 2, \theta\right) \Big] \frac{\beta^2}{\theta^2}$$
(16)

$$m_3 = E(y^3) = \frac{e^{\theta}}{(1+\alpha)} \Big[ (\alpha - \theta) \Gamma \Big( \frac{3}{k} + 1, \ \theta \Big) + \Gamma \Big( \frac{3}{k} + 2, \ \theta \Big) \Big] \frac{\beta^3}{\theta^3_k}$$
(17)

$$m_4 = E(y^4) = \frac{e^{\theta}}{(1+\alpha)} \Big[ (\alpha - \theta) \Gamma \Big( \frac{4}{k} + 1, \ \theta \Big) + \Gamma \Big( \frac{4}{k} + 2, \ \theta \Big) \Big] \frac{\beta^4}{\theta^4}$$
(18)

From above equations, we have,

$$\mu_1 = 0 \tag{19}$$

$$\mu_2 = Var(y) \tag{20}$$

$$\mu_{3} = \frac{e^{\theta}}{(1+\alpha)} \Big[ (\alpha - \theta) \Gamma \Big( \frac{3}{k} + 1, \ \theta \Big) + \Gamma \Big( \frac{3}{k} + 2, \ \theta \Big) \Big] \frac{\beta^{3}}{\theta^{\frac{3}{k}}} - 3 \frac{e^{\theta}}{(1+\alpha)} \Big[ (\alpha - \theta) \Gamma \Big( \frac{2}{k} + 1, \ \theta \Big) + \Gamma \Big( \frac{2}{k} + 2, \ \theta \Big) \Big] \frac{\beta^{2}}{\theta^{\frac{2}{k}}} \times \frac{e^{\theta}}{(1+\alpha)} \Big[ (\alpha - \theta) \Gamma \Big( \frac{1}{k} + 1, \ \theta \Big) + \Gamma \Big( \frac{1}{k} + 2, \ \theta \Big) \Big] \frac{\beta}{\theta^{\frac{1}{k}}} + 2 \Big( \frac{e^{\theta}}{(1+\alpha)} \Big[ (\alpha - \theta) \Gamma \Big( \frac{1}{k} + 1, \ \theta \Big) + \Gamma \Big( \frac{1}{k} + 2, \ \theta \Big) \Big] \frac{\beta}{\theta^{\frac{1}{k}}} \Big]$$

$$\mu_{4} = \frac{e^{\theta}}{(1+\alpha)} \Big[ (\alpha - \theta) \Gamma \Big( \frac{4}{k} + 1, \ \theta \Big) + \Gamma \Big( \frac{4}{k} + 2, \ \theta \Big) \Big] \frac{\beta^{4}}{\theta^{\frac{4}{k}}} - 6 \frac{e^{\theta}}{(1+\alpha)} \Big[ (\alpha - \theta) \Gamma \Big( \frac{3}{k} + 1, \ \theta \Big) + \Gamma \Big( \frac{3}{k} + 2, \ \theta \Big) \Big] \frac{\beta^{3}}{\theta^{\frac{3}{k}}} \times \frac{e^{\theta}}{(1+\alpha)} \Big[ (\alpha - \theta) \Gamma \Big( \frac{1}{k} + 1, \ \theta \Big) + \Gamma \Big( \frac{1}{k} + 2, \ \theta \Big) \Big] \frac{\beta^{2}}{\theta^{\frac{2}{k}}} \times \frac{e^{\theta}}{(1+\alpha)} \Big[ (\alpha - \theta) \Gamma \Big( \frac{1}{k} + 1, \ \theta \Big) + \Gamma \Big( \frac{1}{k} + 2, \ \theta \Big) \Big] \frac{\beta}{\theta^{\frac{1}{k}}} - 4 \Big( \frac{e^{\theta}}{(1+\alpha)} \Big[ (\alpha - \theta) \Gamma \Big( \frac{1}{k} + 1, \ \theta \Big) + \Gamma \Big( \frac{1}{k} + 2, \ \theta \Big) \Big] \frac{\beta}{\theta^{\frac{1}{k}}} \Big]$$

**Mean:** The mean of random variable Y from QLPD(Y;  $k, \gamma, \alpha, \theta, \beta$ ) is defined as:

$$E(y) = \frac{e^{\theta}}{(1+\alpha)} \left( \frac{\beta}{\theta^{\frac{1}{k}}} \right) \left[ (\alpha - \theta) \Gamma \left( \frac{1}{k} + 1, \theta \right) + \Gamma \left( \frac{1}{k} + 2, \theta \right) \right]$$
(23)

**Variance (Var):** The variance of random variable Y from QLPD(Y;  $k, \gamma, \alpha, \theta, \beta$ ) is obtained as follow:

$$\operatorname{Var}(\mathbf{y}) = \frac{e^{\theta}}{(1+\alpha)} \left( \frac{\beta}{\theta^{2}_{k}} \right) \left[ \left\{ (\alpha - \theta) \Gamma \left( \frac{2}{k} + 1, \theta \right) + \Gamma \left( \frac{2}{k} + 2, \theta \right) \right\} - \left\{ (\alpha - \theta) \Gamma \left( \frac{1}{k} + 1, \theta \right) + \Gamma \left( \frac{1}{k} + 2, \theta \right) \right\}^{2} \frac{e^{\theta}}{(1+\alpha)} \right]$$

$$(24)$$

**Coefficient of Variance (C.V):** The coefficient of variance for random variable Y from QLPD(Y;  $k, \gamma, \alpha, \theta, \beta$ ) is obtained as follow:

$$C.V = \sqrt{\frac{Var(y)}{E(y)}}$$
(25)

$$C.V = \sqrt{\frac{(1+\alpha)}{e^{\theta}} \frac{\left[(\alpha-\theta)\Gamma\left(\frac{2}{k}+1, \theta\right) + \Gamma\left(\frac{2}{k}+2, \theta\right)\right]}{\left[(\alpha-\theta)\Gamma\left(\frac{1}{k}+1, \theta\right) + \Gamma\left(\frac{1}{k}+2, \theta\right)\right]} - 1}$$
(26)

Similarly, Skewness and Kurtosis will be determined by using Eq. (21, 22 and 24):

$$Skewness = \frac{\mu_3^2}{\mu_2^3} \tag{27}$$

$$kurtosis = \frac{\mu_4}{\mu_2^2} \tag{28}$$

**Order Statistics (OS)**: Ordering of positive continuous random variables is an important tool for judging the comparative behavior. Let,  $Y_1, Y_2, ..., Y_n$  are random samples from QLPD(Y;  $k, \gamma, \alpha, \theta, \beta$ ) and  $Y_{r.n}$  is the  $r^{th}$  order statistics with pdf given as follow;

$$q_{r.n}(y) = \frac{n!}{(r-1)!(n-1)!} q(y) [Q(y)]^{r-1} [1 - Q(y)]^{n-r}$$
<sup>(29)</sup>

Asad Ali et al

$$q_{r.n}(y) = \frac{n!}{(r-1)!(n-1)!} \left[ \left\{ \frac{\theta k e^{\theta}}{\beta (1+\alpha)} \right\} \left\{ (\gamma - \theta) \left( \frac{y}{\beta} \right)^{k-1} + \theta \left( \frac{y}{\beta} \right)^{2k-1} \right\} \exp\{-\theta \left( \frac{y}{\beta} \right)^{k} \} \right] \times \left[ 1 - \exp\left[ -\theta \left( \frac{y}{\beta} \right)^{k} - 1 \right] \right]^{r-1} \times \left[ \exp\left\{ -\theta \left( \frac{y}{\beta} \right)^{k} - 1 \right\} \left[ 1 + \left( \frac{\theta}{\alpha+1} \right) \left\{ \left( \frac{y}{\beta} \right)^{k} - 1 \right\} \right] \right]^{n-r}$$
(30)

So, the pdf of the smallest OS at r=1,  $q_{1,n}(y)$  and the largest OS at r=n,  $q_{n,n}(y)$  are obtained by:

$$q_{1,n}(y) = n \left[ \left\{ \frac{\theta k e^{\theta}}{\beta(1+\alpha)} \right\} \left\{ (\gamma - \theta) \left( \frac{y}{\beta} \right)^{k-1} + \theta \left( \frac{y}{\beta} \right)^{2k-1} \right\} \right] \times \left[ 1 + \left( \frac{\theta}{\alpha+1} \right) \left\{ \left( \frac{y}{\beta} \right)^k - 1 \right\} \right]^{n-1} \times \left[ \exp\{ -\theta \left( \frac{y}{\beta} \right)^k \} \right]^n (31)$$

and

$$q_{n,n}(y) = n \left[ \left\{ \frac{\theta k e^{\theta}}{\beta (1+\alpha)} \right\} \left\{ (\gamma - \theta) \left( \frac{y}{\beta} \right)^{k-1} + \theta \left( \frac{y}{\beta} \right)^{2k-1} \right\} \exp\{-\theta \left( \frac{y}{\beta} \right)^k \} \right] \times \left[ 1 - \exp\left[ -\theta \left( \frac{y}{\beta} \right)^k - 1 \right] \left[ 1 + \left( \frac{\theta}{\alpha+1} \right) \left\{ \left( \frac{y}{\beta} \right)^k - 1 \right\} \right] \right]^{n-1}$$

$$(32)$$

#### 3. ESTIMATION OF PARAMETERS

Let,  $y_1, y_2, ..., y_n$  be a random sample of size n from the Quasi Lindley Pareto distribution and the likelihood function of QLPD is defined as:

$$L = \left[\frac{\theta k e^{\theta}}{\beta(1+\alpha)}\right]^n \prod_{i=1}^n \left[ (\gamma - \theta) \left(\frac{y_i}{\beta}\right)^{k-1} + \theta \left(\frac{y_i}{\beta}\right)^{2k-1} \right] \exp^{\sum_{i=1}^n \left\{ -\theta \left(\frac{y_i}{\beta}\right)^k \right\}}$$
(33)

Further, the log likelihood function is obtained as follow:

$$logL = nlog\left[\frac{\theta k e^{\theta}}{\beta(1+\alpha)}\right] + log\left[\frac{(\gamma-\theta)}{\beta^{k-1}}\prod_{i=1}^{n} y_i^{k-1} + \frac{\theta}{\beta^{k-1}}\prod_{i=1}^{n} y_i^{2k-1}\right] - \sum_{i=1}^{n} \left\{-\theta\left(\frac{y_i}{\beta}\right)^k\right\}$$
(34)

By taking partial derivatives with respect to parameters, following estimates are obtained:

$$\widehat{\alpha_{\text{mle}}} = -1 \tag{35}$$

$$\widehat{\beta_{\text{mle}}} = \left[ \frac{-k\theta \sum_{i=1}^{n} y_i^k}{-n-3k+2} \right]^{1/k}$$
(36)

$$\widehat{\theta_{mle}} = \frac{n}{\sum_{i=1}^{n} \left(\frac{y_i}{\beta}\right)^k - n}$$
(37)

 $\widehat{\gamma_{mle=}}\theta$ 

$$\widehat{k_{mle}} = \frac{3\ln[\ln\beta - \sum_{i=1}^{n}\ln y_i] - \ln n + \ln\theta - \ln\left[\sum_{i=1}^{n}\ln\frac{y_i}{\beta}\right] + \ln\left(\frac{y_i}{\beta}\right)}{-2\ln}$$
(39)

#### 4. GOODNESS OF FIT

The Quasi Lindley Pareto Distribution (QLPD) has been fitted to a data set to which earlier the Lindley distribution (LD) and Quasi Lindley Distribution (QLD) have been fitted and it was found that QLPD provides better fit than those by LD and QLD. Here the fitting of the QLPD to the data set have been presented in the Table 1. The data is regarding the survival times (in days) of 72 guinea pigs infected

(38)

**Table 1.** Data of survival times (in days) of 72 guinea pigs infected with virulent tubercle bacilli, observed and reported by Bjerkedal [18]

Suminal Time (in days)	Observed frequency	Expected frequency				
Survival Time (in days)	Observed frequency	LD	QLD	QLPD		
0-80	8	16.14	10.71	10.24		
80-160	30	21.91	26.95	27.73		
160-240	18	15.39	17.71	17.66		
240-320	8	9.00	9.14	8.59		
320-400	4	5.47	4.26	4.53		
400-480	3	1.80	1.86	2.31		
480-560	1	2.29	1.34	0.94		
Total	72	72.00	72.00	72.00		

with virulent tubercle bacilli, observed and reported by Bjerkedal [18].

In Table 1, the expected frequencies according to the Lindley distribution and Quasi Lindley distribution have also been given for ready comparison with those obtained by the Quasi Lindley Pareto distribution. It can be seen that the QLPD gives much closer fits than the LD and QLD of Shanker and Mishra [4] and thus provides a better alternative to the LD and QLD.

#### 5. SUMMARY

In applied sciences, the lifetime's data models are constructed to facilitate better modeling and significant progress towards the reliability analysis or survival analysis. In this paper, we introduced five-parameter Quasi Lindley Pareto Distribution (QLPD). The probability distribution function with different values of its parameters has been shown graphically. Several properties such as probability density function, distribution function, survival function, hazard function, moment generating function, moments, mean, variance, coefficient of variance, skewness, kurtosis and distribution of extreme order statistics have been derived. The estimation of parameters by the method of maximum likelihood has been discussed. Finally, the proposed distribution has been fitted to a real life data set to check its goodness of fit to which earlier the Lindley distribution (LD) and Quasi Lindley distribution (QLD) have been fitted and it is found that the OLPD provides closer fits than

those by the LD and QLD. Therefore, it is suggested to use QLPD as a lifetime's data model for better estimation.

#### 6. **REFERENCES**

- Lindley, D. V. Fiducial distributions and Bayes' theorem. Journal of the Royal Society, series B, 20: 102-107 (1958).
- Sankaran, M. The Discrete Poisson-Lindley Distribution. Biometrics, 26(1): 145-149 (1970).
- Ghitany, M. E., Atieh, B. & Nadarajah, S. Lindley Distribution and Its Application. Mathematics and Computers in Simulation, 78: 493-506 (2008).
- Shanker, R. & Mishra, A. A quasi Lindley distribution, African Journal of Mathematics and Computer Science Research, 6(4): 64 – 71 (2013 a).
- Shanker, R. & Mishra, A. A two-parameter Lindley distribution, Statistics in Transition-new series, 14(1): 45- 56 (2013 b).
- Shanker, R., Sharma, S. & Shanker, R. A two-parameter Lindley distribution for modeling waiting and survival times data, Applied Mathematics, 4: 363 368 (2013).
- Shanker, R. & Amanuel, A. G. A new quasi Lindley distribution, International Journal of Statistics and Systems, 8(2): 143 – 156 (2013).
- Shanker, R. & Tekei, A. L. A new quasi Poisson-Lindley distribution, International Journal of Statistics and Systems, 9(1): 79 – 85 (2014).
- Shanker, R. & Mishra, A. A quasi Poisson- Lindley distribution, to appear in Journal of Indian Statistical Association. (2016).
- Lazri, N. & Zeghdoudi, H. On Lindley-Pareto Distribution Properties and Application. GSTF Journal of Mathematics, Statistics and Operations Research (JMSOR),3(2) (2016).

- Pareto, V. Cours d'Économie Politique. Geneva: Droz. (1896).
- 12. Pickands, J. Statistical inference using extreme order statistics. Annals of Statistics, 3: 119-131 (1975).
- Akinsete, A., Famoye, F. & Lee C. The Beta-Pareto distribution. Statistics, 42(6): 547–563 (2008).
- 14. Mahmoudi, E. The beta generalized Pareto distribution with application to lifetime data. Mathematics and Computers in Simulation, 81(11): 2414–2430 (2011).
- 15. Zakerzadeh, H. & Dolati, A. Generalized Lindley distribution, Journal of Mathematical extension,

3(2): 13-25 (2009).

- Nedjar, S., & Zeghdoudi, H. Gamma Lindley distribution and its application. Journal of Applied Probability and Statistics, 11(1) (2016).
- Alzaatreh, A., Lee, C. & Famoye, F. A new method for generating families of distributions. Metron, 71: 63-79 (2013).
- Bjerkedal, T. Acquisition of resistance in guinea pigs infected with different doses of virulent tubercle bacilli. American Journal of Epidemiol, 72(1): 130-148 (1960).



Research Article

## Managing Disorientation of Time and Place in Dementia Patients Using Bluetooth Sensors

Sarwat Iqbal<sup>1\*</sup>, Kamran Ahsan<sup>1</sup>, Muhammad Azhar Hussain<sup>1</sup>, Adnan Nadeem<sup>1,2</sup>, Muhammd Saeed<sup>3</sup>, and Sohaib Ahmed<sup>4</sup>

<sup>1</sup>Department of Computer Science, Federal Urdu University of Arts, Science and Technology, <sup>2</sup>Faculty of Computer and information System, Islamic University of Madinah KSA, <sup>3</sup>Department of Computer Science – UBIT, University of Karachi, <sup>4</sup>Department of Software Engineering, Bahria University Karachi Campus

**Abstract:** Assistive technology has the potential to support persons with dementia (PWDs) in their daily life activities and provide them quality of life services. This paper proposes a novel mechanism in order to manage disorientation or time and place problem of PWD through the use of Bluetooth low energy devices, smart watch and smart phone/ tablet. The proposed mechanism was verified in a real environment having the facilities an ordinary PWD avail in his home environment and also in lab environment. All of the participants were volunteers from research group personal contacts. Volunteers spend time in the environment and results were generated. Experimental result showed that the proposed mechanism provided an accurate real time ubiquitous monitoring of PWD. Successful detection of PWD presence in real time and notification to caregiver observed in all cases.

Keywords: Dementia, mobile technology, low energy sensors, real time monitoring through wearable

## 1. INTRODUCTION

The world population has moved towards a greater portion of elderly people. Elderly population is facing different physical and mental problems due to the decline in health condition. The most common problems are Alzheimer and dementia. According to World Health Organization (WHO) 47.5 million of the world's population is experiencing dementia and in each year 7.7 million people are adding to this figure [1]. Dementia mostly effects older population and it is the foremost cause of the disability and dependency among the population. Dementia directly affects the part of the brain which is involved in learning. Dementia, the most serious form of memory disorder, is a group of symptoms caused by different disorders. Alzheimer, stroke, brain injury that affect the brain are different causes of dementia.

Dementia syndrome creates different types of physical, social and economic burden on family and caregivers. Dementia effects differently in each person. Three major stages of dementia have been identified so far, namely, early stage dementia, middle stage dementia and late stage dementia. More than half of the persons with dementia (PWDs) may face intellectual decline state. In this case PWDs lose their ability to remember, to comment, to make judgment and they may not be able to act independently. In all three major stages the most unfavorable problem faced by dementia patient is forgetfulness. Due to the forgetfulness problem the patient faces problems in performing ADL (activities of daily life).

In the middle stage of dementia the patient's forgetfulness problem may become severe, even patient may be lost in its own home environment. The patient may wander in its own home environment and even may face difficulty in finding different places (such as bedroom, washroom, lounge, etc.). As a result, PWD may be in one place in sitting or standing position alone and could not find a rest place. The inability of dementia patient to perform a series of tasks which are required

Received, January 2018; Accepted, June 2018

<sup>\*</sup> Corresponding Author: Sarwat Iqbal; s.iqbal@fuuast.edu.pk

to complete a particular job (such as making a cup of tea, changing clothes, brushing teeth, etc.) makes their life difficult. It is often observed that dementia patient, if sitting in a particular place or doing some activity, remains involved in the same activity which in turn may be harmful for their health. For example a PWD may continue to sit in front of television (TV) even he has watched his favorite TV show and no program of his interest is running on TV. This sitting may create different postural problems such as hunchback, forward hip tilt, muscle fatigue, aching muscle, and corns.

To conclude, the proposed system aims to detect the condition of disorientation of time and place for PWD using Bluetooth low energy (BLE) bacons, smart watch and mobile phone. BLE beacons are small devices which are positioned on a place which is relatively suitable in particular environment [2]. Bluetooth beacons are most suitable in indoor environment position as (Global Positioning System) GPS signals (the most widely used outdoor positioning technology) may not work in indoor environment due to the presence of walls and other obstacles. The algorithm proposed in the system analyzes the signals received from smart watch on smart phone/tablet and takes appropriate action.

#### 1.1. Problem Statement

PWDs face a lot of challenges even when they are present in their own home environment; as a result, different types of psychological disorders such as aimless movement, repetitive locomotion with no identifiable goals develop in their personality. One of the problems with PWDs is that they become disoriented with time and place. This happens usually at the early stage of dementia and becomes worse in the late stages of dementia. The ultimate cause of this behavior may be the destruction of memory cells in the brain and trouble in recognizing people and objects. They also face difficulty in judging the passing time, passing events and confuse day and night. The other problem related to disorientation of day and time are that PWDs often get ready for appointments which are far away and they think that an event which has taken place in past days has just happened. These types of inabilities took PWD as well as their caregiver in a very frustrating situation. As a consequence the PWDs ability to function may reduce. Management strategies with the PWD having disorientation of time and place have been proposed in medical science such as hanging calendar with their bedside wall, placing labels, signs and directional signs on different place in a PWD environment. This is observed that more familiar environment leads to more safe and satisfied to PWDs.

#### 1.2. Outcomes of the Problem

Dementia patient feels unsafe in the unfamiliar places and this may lead to a PWD in a worse condition. If PWD is present aimless in an environment it can be harmful to his health. For example sitting on a sofa with long hours may increase the risk of heart disease, diabetes, obesity, and more. The condition becomes worse for a PWD if he is sitting in an uncomfortable place such as stool, floor mat, wash room seats, toilet seat, etc. Remaining in an uncomfortable posture may cause neck pain, headache, low back pain, fatigue, Joint stiffness, pain etc.

#### 2. RELATED RESEARCH

Assistive technology has the potential to provide care to PWDs in their different problems. Research has proposed several assistive solutions to address the challenges faced by PWDs in the following areas such as medication adherence system, memory loss problem, incontinence problem, wandering, remote control operating problem and sleepiness problem.

PWD's most troubling problem is forgetfulness. Due to forgetfulness the caregiver as well as a PWD face different problem in order to manage the activities of daily life. Proper medication at proper time is very critical for the health of PWDs. The study by Moshnyaga et al. [3] assists caregiver as well as PWD in order to get proper medication at proper time. The system uses Kinect as visual sensor, speaker, reed-switches, sensor, actuators and (light-emitting diode) LEDs to assist PWD and sends notification to caregivers about medication intake.

In order to improve quality of life of dementia patients the technique of memory places has been used [4]. Method of Loci and augmented reality technique were used which help PWD to create their own memory places. This work exploited the fact that a PWD can also learn new things and use this phenomenon in their application. Engagement in meaningful activities may play a positive vital role to improve the memory problems of PWDs. MemPics program has been developed for PWDs for Long term care residents [5].

One of the most occurring problems of PWD is wandering. Due to their memory decline the PWD often wander in their familiar places and could not find the safe way to reach their destination. The main problem of wandering behavior is that nobody can predict at what time or in which situation wandering behavior will occur and at which intensity it will affect the PWD. This problem makes the detection of wandering a challenging task [6]. The framework proposed by Ou et al. [7] transmits the GPS trajectory from the device worn by elderly to caregiver smart device or laptop ubiquitously. The caregiver remains aware about the presence of its loved one anytime anywhere.

Wang et al. [8] proposed usability study of WanderHelp application. The application helps PWD to lessen the risk of wandering and as a result endures the safety of PWD. On the basis of spatial and temporal dimensions the PWD environment has been divided and then three types of zones have been created, namely, green zone, red zone and amber zone. As soon as the location of PWD is detected in danger zone the location of elderly is send to caregiver mobile.

A wandering monitoring system has been introduced by Sansrimahachai [9]. This system analyzes the travelling pattern in real time. The stream event input is based on GPS data obtained from mobile device. Speed, altitude and heart-rate data was also used as stream input. In this work, the geolocation data was processed dynamically as soon as collected without any storage. Message oriented middleware (MOM) provides infrastructure support in message transportation between servers and clients. Geolocation data combined with heart rate sensor data is sent to wandering detection system (WDS) through MOM. WDS continuously and dynamically detect wandering episode over stream events.

The Alziomo app [10] provides geofencing and activity recognition for PWD and detects fall through the use of Android smart phone. The caregiver may set certain predefined activities and physical zones as dangerous for PWD and may associate the notification upon these activities recognitions.

Operating mobile phone may be a difficult task for PWD as they cannot keep track of sequence of activities in order to complete a job. The system proposed by Sasaki [11] detects the repetitive incorrect button pressing of remote control through smart phone antenna. The smart phone antenna receives the electromagnetic signals from PWD remote control and input these signals to the algorithm which detects the phase change of the waves. In case of detection of phase change the smart phone will send an alert to PWD caregiver to inform them that their loved one is having problem in operating remote control. Through this way the behavior problems of elderly can be detected.

An assistive system using sensors to detect soiled diaper for PWD is proposed by Wai et. al [12]. The sensor deployed/attached to diaper senses the wetness event and immediately send an alert to nursing staff. The system provides context-aware intervention of wetness event so that caregiver could monitor patient's diaper condition anywhere anytime. The reminders are sent to caregiver along with the location of PWD. Therefore, the system is applicable to a nursing home in which more than one patient needs to be monitored continuously. The context of patient is detected through sensors attached in patient bad or wheelchair. This helps caregiver to care a PWD without any annoyance and waste of time.

Sleep monitoring and support system for early dementia patients through the use of sensors placed on patient's bed and PIR (passive infrared sensor) sensor on bedroom wall is presented in [13]. The bed sensor is used to detect in and /out of the base status and PIR sensor is used to pick up the motion of PWD in his room. The sleep pattern data obtained from sensor has been visualized to support PWD. This work also proposed a set of measures that can be used to assess the quality and quantity of sleep.

Android based mobile application has been developed [14] to support a PWD in different tasks such as calling caregiver or medical professional in case of emergency and playing mind games to improve mental skills. The application detects fall using built in sensor on mobile device.

# 3. RESEARCH DESIGN AND METHODOLOGY

In PWDs the disorientation of time and place is an issue which creates health problems for them as well as it is a great challenge for caregiver to cope with this. Disorientation of time and place problem may be minimized by using different methods such as providing visual cues in the environment, putting a clock and simple calculator with PWDs, putting easily readable labels in PWDs environment, etc. Mostly the PWDs are accompanied by their caregiver. The absence of caregiver may create problems for PWDs. No real time ubiquitous method has been proposed in this situation. The use of pervasive assistive solution to provide real time monitoring for the detection of episodes of disorientation which also may notify the caregiver about the severity of situation holds much attraction to provide assistance to PWD and caregiver.

# 3.1. PWDs Specific Need and Technical Challenges

The episode of disorientation may occur anytime with PWDs. In order to monitor a PWD aimless presence in his home environment and to notify about the episode of disorientation to caregiver (and PWD himself) it is necessary that PWDs presence in its home environment should be observed in real time manner. BLE has the potential to detect the presence of PWD in his home environment. BLE technology enables smart devices to perform some action when in close proximity to a beacon. When PWD worn smart device reaches to close proximity to these BLE devices then smart devices may perform action which has been programmed in it.

## 3.2. Required Features and Advantages

In order to detect the presence of elderly, the system should report the PWD's aimless presence in real time. The system should inform caregiver (as well as PWD) about the danger situation must be done in seamless way so not to create any sensory overload and without imposing constraints to parties which are involved in the process.

The anticipated features of the proposed system include:

• Real time monitoring of PWD in his home environment

• Providing ubiquitous notification to caregiver about the situation

The benefits of acquiring the proposed system are:

- Caregiver does not need to be present in PWD environment
- Caregiver may give instruction to PWD through some pre-define SMS, voice message or even he may call to his loved one if he finds PWD in uncomfortable position.
- PWD doctor or Psychologist may use the data of PWD's presence to see which area in PWD's environment is mostly chosen by him

## 3.3. Placing BLE Devices in Home Environment

Different BLEs may be installed in the PWD environment such as:

- 1. Kitchen
- 2. Washroom-1
- 3. Washroom-2
- 4. Garden/Lawn area
- 5. Bedroom-1
- 6. Bedroom-2
- 7. Car porch
- 8. Living Room/TV lounge
- 9. Terrace /Balcony
- 10. Hallway
- 11. Study

Different BLEs installed in the home environment so that elderly presence can be detected. Fig. 1 depicts a possible placement of BLE beacons a home environment.

## 3.4. Home Environment Zone Division

On the basis of the criticality of PWD's presence, the home environment has been divided into the following four zones.

## 3.4.1. Highly Risk Zone

Highly risk zone is the area of PWD home environment in which the aimless presence of PWD is considered very unsafe and dangerous even for a short period of time. Kitchen, store and wash rooms are the places in PWD environment which are considered in highly risk zone. The other areas of PWD environment including in highly risk zone may be boundary areas and car garage of home.

#### 3.4.2. Moderate Risk Zone

Moderate risk zone is the area of PWD home environment in which the aimless presence of elderly is considered at low level of risk. The PWD may be present in the locations of this area in order to perform his daily life activities like watching TV or reading books in library. The caregiver may set the danger time for elderly presence according to specific elderly needs.

#### 3.4.3. Low Risk Zone

It is the safer area in PWD environment in which presence of PWD is considered at very low risk. The time slot of presence of elderly will be greater as compared to highly and moderate risk zone.

#### 3.4.4. No Risk Zone

It is the safest area in PWD environment in which presence of PWD is considered at resting position.



**Fig. 1.** Possible Placing of Bluetooth beacons (Green circles show BLE beacon placing)

The time slot of presence of elderly will be greatest in this zone.

#### 3.5. System Architecture

To overview the proposed architecture a system diagram is presented in Fig. 2. The proposed architecture mainly has a network of miniature BLEs installed in the PWD environment, smart watch which is worn by the PWD and a smart phone which is available in the PWD environment.



Fig. 2. The System Architecture

The caregiver has desktop application for profile building and watch PWD activity data, and smart phone to receive messages about danger situation. The details of the components of the system are given below.

## 3.5.1. BLE Network

Each BLE beacon may broadcasts its ID; the RSSI (received signal strength indication) may be used if a network of BLE nodes is deployed in an environment. RSSI can be used to extract position information about the BLE device as BLE beacons can only broadcast their IDs not any other information. The BLE receiver can calculate the distance of BLE by solving the free space lose equation. This work exploits the method used to find the position information of the respective BLE [15]. According to proposed architecture every BLE be installed on different position in the home environment of a PWD (for example as described in the Fig. 2) so that beacons may be received on smart watch. Every BLE has a unique identifier which will act as its ID. Every beacon will send a scanning message to master beacon every  $\lambda$  seconds interval. The Bluetooth available on smart watch will act as a Master Beacon and the other deployed BLEs in home environment will act as Slave Beacon. The processing flow of the proposed system starts with the Slave BLE beaconing. The algorithm which will run of smart watch is given below.

## 3.5.2. Smart Watch Application

The smart watch application listens to BLE installed in the environment. As PWD moves in its home environment with smart watch on his wrist, different BLEs may communicate with smart watch. As soon as the smart watch enters in the range of BLE, the BLE starts communication about its presence. This ID actually tells the location of PWD in its home environment. The BLE communicates its ID with

Algorithm:

Step-1 Start pairing with Slave BLEs
Step-2 Receive signals from paired slave BLE
Step-3 Discard signals which have lower RSSI if signals are received from more than one BLE
Step-4 Prepare data packet containing the ID of BLE and RSSI
Step-5 Add time stamp to data packet
Step-6 Send data packet to smart phone

smart watch, upon receiving the ID signals from smart watch the application installed on wrist watch adds a few parameters and then send this data packet to smart phone which is already paired with it. The function of smart watch is like a bridge which sends the location information to smart phone of PWD.

## 3.5.3. Mobile Application

The mobile application running on smart device such as smart phone or tablet plays vital role in proposed architecture. The smart phone should be present in home environment of PWD or PWD may be trained to put this device near him. The main algorithm to detect the danger situation is installed on smart phone. The mobile application provides infrastructure support for receiving the data from PWD worn smart watch. The application runs on mobile phone as selected by caregiver. Upon receiving the data from smart watch it calculates the occurrence of danger situation.

If application receives beacon from *Master BLE* then it starts the detection algorithm. The algorithm will wait for the next beacon and upon receiving the next beacon from the *Master BLE* the time difference of the current profile will be calculated. If this difference is less than the threshold set by the caregiver then no action will be taken and algorithm will set the position of elderly profile with total time reflecting the presence of PWD in a specific region of the home. This process

## Algorithm:

Step-1 Receive data packet(s) form Master BLE. Step-2 Mark PWD presence in respective zone (Highly Risk Zone, Moderate Risk Zone, Low Risk Zone, No Risk Zone) Step-3 Accumulate data packet(s) with the same source, calculate time interval and update time interval and profile variables Step-4 Match time interval with threshold time (set by caregiver) **Step-5** If (time interval  $\geq$  threshold time) then send alert to caregiver or PWD (depends upon caregiver choice) with PWD presence information in critical zone and time interval. **Step-6** If (time interval < threshold time) go to step-3. Step-7 Maintain PWD profile data through profile variables and send it to cloud database (on daily/ weekly/monthly basis)

will continue in coming times and time counter will reflect the total time elapsed in a same position. If the elapsed time found to be equal to or greater than the preset threshold time then the situation will be set at danger situation.

## 3.5.4. Web-based Desktop Application

The web based application intended to provide support to caregiver in order to maintain a PWD specific need's profile. It has an easy interactive interface which enables a caregiver to perform different actions which may improve the quality of life of PWD. The caregiver may login to the web based application anytime anywhere to create or edit the profile of its loved one. The caregiver may create the critical zones according to its choice and set the danger time slot. This time slot will be used by the mobile application to detect the danger situation. The caregiver may send PWD mobility data to medical professional for better treatment of PWD.

#### 3.5.5. Profile Building

Caregiver may interact with the web application in order to create PWD detailed profile in which he can specify the special needs of the PWD. All PWDs may have different needs and their time and place profile may reflect diverse needs. Profile building facility makes caregiver freedom over specifying the special needs of his loved one. At any time caregiver may alter the profile and edit any information regarding his priorities.

#### 3.5.6. Notification to Caregiver

As soon as the mobile device detects a danger situation it will inform caregiver about the situation. Mobile device may send an alarming message to caregiver about the position of elderly. The action to be taken in danger situation will be based on the preference set by caregiver. Caregiver may set a reminder voice message in order to inform PWD to change his position if PWD is found in trouble or may take appropriate action depending upon the health/mental status of PWD. The reminder to PWD in this case may be in the form of a voice message, in a loud sound so that PWD may hear it easily. The text of the message may be set and altered by caregiver anytime depending on the mental health status of a specific PWD. The profile will be maintained on daily basis and will be saved in a cloud database which can be used for future processing of some other task. The profile may be used by the doctor of PWD in order to find out the facts about PWD mobility in his home environment.

#### 4. **RESULTS**

#### 4.1. Experimental Evaluation

The main objective of this evaluation is to discuss the performance of the proposed mechanism. The system has been tested to evaluate its effectiveness and how it can detect the presence of PWD in its home environment and provide alerts to caregiver about danger event. The system tested for the following parameters.

Is system providing real time detection of elderly presence in his home environment?

Is system detecting context aware real time danger situation?

Is system providing alert to caregiver in case of the detection of danger situation?

Is system providing caregiver the facility of defining user specific profile?

Is system providing enough support to caregiver to define four risk zones?

Is system supporting doctor to view the mobility pattern of PWD?

The smart watch used in the system evaluation was supported by Android OS having android Wear platform. The compatible beacons with smart watch were used. The mobile application has been developed on an Android smart phone having Marshmallow 6.0 API. Web application was hosted on a Linux PC with 3.10GHz Intel Core i3-2100 processor and 4 GB memory. For the initial study the research group tested the proposed system in a real environment as well as lab environment. The evaluation of the mechanism was done on the following parameters:

- Test case
- Functional Testing and Usability Testing
- Performance Testing

- Security and Compliance Testing
- Compatibility Testing
- Recoverability Testing
- Device Testing

## 4.1.1. Test Case Participants and Test Environment

The experimental setup for test case-1 and testcase-2 have been built in a home having 4 different rooms, one kitchen, 4 wash rooms, a lawn area, a car garage, a store room, and boundary wall area on three sides. Different BLEs were installed in the testing environment. Initially the ranges of every BLE beacon have been tested for their possible communication. Every BLE was checked whether it is working perfectly or not (it is giving beacons to its Master BLE about its presence). A total of 18 BLEs were installed in the environment. Every volunteer spent a total of 20 hours in the environment in different timings of the day. For the system testing initially the algorithm was set to send notification to caregiver if volunteer presence is found in a zone in a short period of time (5 min, 7min, 9 min, 10 min, etc.).

Every beacon was set to send beacon on every 10 second hence a total of 6 beacons may be received in one minute interval from a BLE. Transmitting power of every beacon was analyzed and it is made sure that Bluetooth of smart watch is receiving the beacons from every BLE in the environment. The presence of participant was considered in a particular zone from which beacon it is getting the high RSSI.

*Test cases*: Research group created several test cases in order to check the performance of the proposed mechanism on mobile devices. Beside with the flow of a use case various business rules are also tested.

The following activities were communicated to perform during this test case.

- Watching TV for at least half hour
- Afternoon sleep for one hour
- Usual washroom activities
- Making breakfast and afternoon meal ready to eat
- Walk in the car porch area for 30 minutes
- Taking two rounds of inside boundary of

home

- Ordinary walk inside the environment
- Dishwashing in kitchen
- Visit in store room once
- Spend some time in lawn area

*Test case-1:* In test case-1 two male volunteers spent 12 hour times in the specially built environment which was discussed above. Both volunteers spend the time in the environment and performed activities of daily life which were communicated to them beforehand. Each volunteer performed at least 7 activities so that its presence in real time may be observed and the communicated through the system. In this test case the notification was first delivered to volunteer in the form of loud voice message which was preset by research group in the mobile application. Upon receiving the notification through voice the volunteer was advised to push a button provided on mobile application for the indication of successful event.

*Test case-2:* In test case-2 two female volunteers spent 16 hour times in the specially built environment which was discussed above. Both volunteers spend the time in the environment and performed activities of daily life which were communicated to them beforehand. Each volunteer performed at least 7 activities so that its presence in real time may be observed and the communicated through the system. In this test the notification was not delivered to volunteer through voice instead a volunteer a group member himself called the volunteer to inform about the event.

The result from these test cases have been observed satisfactory and based on these results functional and usability testing with different volunteers has been done.

#### 4.1.2. Functional and Usability Testing

The system has been evaluated with 16 technology experts (mean age = 37 years, SD = 3.9) who were either the users of mobile technology or the persons who belong to the field of software development and 16 undergraduate student participants (mean age = 24 years, SD = 2.21). The expert participants acted as caregiver and student participants acted as dementia patient. The research group used department of computer science building for the evaluation purpose as the building had necessary equipment and gathering study participant was very much convenient there. The same experiment was repeated in two consecutive days, with total of 8 participants each day, in order to get an acceptable number of results. For the experiment two class rooms, three teachers' rooms, two wash rooms, and a kitchen were selected as these locations were available in the close proximity in the department of computer science. BLEs were installed in these locations and paired with smart watches. This arrangement reflected the setting of an ordinary dementia patient's home environment.

The participants of the study were called through personal invitation. Their consent was taken before involving them into the study. The purpose and objectives of the study were made clear to all of them.

All of the participants were invited in a 4 hours long session. The research group explained the overall working of the proposed system in detail. Each expert participant of the group was paired with one student participant. Expert participants were explained the use of web application installed on the desktop computers of the lab. The participants were then allowed to login to the web application with their mock IDs. The process of profile building for a specific dementia patient was demonstrated to them in detail and given a sheet on which dementia levels were listed so that they can select any one level for their patient's profile and may set appropriate time duration for patient's presence. They were given choice on creating a patient's specific profile reflecting the dementia levels as indicated in Table 1.

Expert participants were requested to set a short interval of time (all intervals less than 13 minutes)

Table 1. Clinically Defined Dementia Stages

Levels	Dementia Stage
Level-1	No Cognitive Decline
Level-2	Very Mild Level
Level-3	Very Mild Cognitive Decline
Level-4	Mild Cognitive Decline
Level-5	Moderate Cognitive Decline
Level-6	Moderately Severe Cognitive Decline
Level-7	Very Severe Cognitive Decline

for each zone so that results can be obtained without waiting too much. Each student participant had their smart phone on which the proposed mobile application was installed. Each participant was provided a smart watch to be worn throughout the experiment. Each participant was given a schedule to be followed to remain in a specific area so their presence in that specific area can be recorded and communicated through mobile application to their peer expert participant.

The same process on mobile application was also explained to them so that they can build their patient's profile on their ease. Each expert participant built one mock profile to mimic one elderly dementia patient. Student participants also installed proposed mobile applications on their mobile phones. Smart watches were given to student participants and their role of participation was explained to them. Student participants saved their peer's mobile numbers on student participant mobile applications. Expert participants saved the mobile numbers of their peer student participants on their mobile phones as the notification will be received on their pone by these numbers. All students participant were asked to strictly follow the schedule of presence in the environment. This schedule which was handed over to student participants is reflected in the Table 2.

The research group did several functional testing during the development of the desktop application, smart watches application and mobile application. Desktop application was tested according to the parameters which were necessary to be observed in the system. The user interface was designed in a manner so that caregiver and medical professional do not feel any difficulty in operating the application. The smart watch application was built so that it can receive and send BLE beacons and may send these messages to smart phone application. The main algorithm which detects the episode of disorientation runs on mobile phone so special contribution was given to it so that algorithm runs successfully. For usability testing the three applications (smart watch, mobile phone and desktop) have been tested on the basis of learnability, easy to use, error rate, satisfaction, interface and design and user friendly so that system can be used with its full context of use. During the usability testing the experts suggested valuable improvement in the design of

~	Λ
Э	U

Table 2. Schedule Given to Student Part
---

Managing	Disorientation	of Time	e and	Place in	Dementia	Patient	Evaluation
Date-							

Student Participant Name:								
Time Slots	Time	Zone	Time Duration	Check List				
Time Slot-1	10:00 AM to 10:15 AM	High Risk Zone	15 minutes	Yes / No				
Time Slot-2	10:20 AM to 10:40 AM	Medium Risk Zone	15 minutes	Yes / No				
Time Slot-3	10:45 AM to 11:05 AM	Low Risk Zone	15 minutes	Yes / No				
Time Slot-4	11:10 AM to 11:20 AM	No Risk Zone	15 minutes	Yes / No				
Time Slot-5	11:30 AM to 11:50AM	High Risk Zone	15 minutes	Yes / No				
Time Slot-6	12:15 PM to 12:35 PM	Medium Risk Zone	15 minutes	Yes / No				
Time Slot-7	12:40 PM to 01:00 PM	Medium Risk Zone	15 minutes	Yes / No				
Time Slot-8	01: 00 PM to 01:20PM	Low Risk Zone	15 minutes	Yes / No				

the application. Functional testing was done on the basis of efficiency, system performance, control and flexibility, and context and purpose. All expert participants were given a list on which they were asked to report the received message's exact time at which they received messages. The list which was given to their peer participant was then shared to them so that they can match the time of event and the time of received messages.

After experimental session a carefully designed 7 points Likert scale questionnaire [16], containing ratings from strongly disagree to strongly agree, was given to each expert participant to take their views about the system. This questionnaire was designed with the help of benchmark questionnaires SUS [17] and SUMI [18]. Their responses against usability attributes and system performance were then analyzed. Their response against efficiency, system performance, control and flexibility, context and purpose, learnability, easy to use, error rate, satisfaction, interface and design and user friendly have been summarized in the Table 3. It was observed that expert participants were mostly satisfied with system performance (mean = 6.69, SD = 0.602) and error reconciliation rate (mean = 6.69, SD = 0.602). Most participants found the system difficult to use (mean = 5.69, SD = 0.704) and suggested valuable improvement in the design of mobile application and desktop application. Interface and design also received a lower rating as compared to other attributes. All attributes were rated in the range of 5 to 7, no attributes received low rating, which reflects that all the participant were very much in the favor of the system. In order to depict the responses variability a graph has been

	Efficiency	System Perfor- mance	Control and Flex- ibility	Context and Pur- pose	Learn- ability	Easy to Use	Error Rate	Satisfac- tion	Inter- face and Design	User Friendly
Ν	16	16	16	16	16	16	16	16	16	16
Mean	6.06	6.69	6.00	6.44	6.06	5.69	6.69	6.38	5.88	6.00
Median	6.00	7.00	6.00	6.00	6.00	6.00	7.00	6.00	6.00	6.00
Minimum	5	5	5	6	5	5	5	5	5	5
Maximum	7	7	7	7	7	7	7	7	7	7
Std. Deviation	0.680	0.602	0.516	0.512	0.680	0.704	0.602	0.619	0.806	0.516

Table 3. Participants Response Summary Reflecting Mean, Median, Minimum, Maximum and Standard Deviation



Fig. 3. Participants Response Summary with Mean and Standard Deviation

shown in Fig. 3.

## 4.1.3. Performance Testing

The performances of the applications have been tested under different conditions. Initially a less number of BLEs were installed in the PWD environment so that performance of the system may be checked and as the performance was observed satisfactory more BLEs were installed which overall cover a PWD environment. The notification capability of the application was checked in different conditions.

## 4.1.4. Security and Compliance Testing

As the applications were in their evolutionary stages no security and compliance test has been done. The research group is planning to conduct a comprehensive security and compliance test in order to ensure that application's data and networking security requirements are met as per standard guidelines.

#### 4.1.5. Compatibility Testing

Since the algorithm to detect episode of disorientation runs on mobile application and this mobile application runs as a background process it is necessary to check that the voice notification is allowed all the time on mobile application and also mobile phone is not in silent/vibrate mode so that voice notification as well as call sound can be heard by PWD. This is made sure that the algorithm doses not suspend its working during any voice call and/or any other application. The PWD may use his smart watch anytime without disturbing the BLE signal receiving process. Different tests on screen size of mobile devices, screen resolution and network connectivity were also done.

#### 4.1.6. Recoverability Testing

Recoverability parameters such as crash recovery and transaction interruptions have been checked up to some initial level. Obviously both smart watch and mobile phone should be power on during the PWD observation time. This is the responsibility of the caregiver to keep the BLE and mobile devices charged so that no interruption observed during the process on battery basis. This was observed during the test cases that if battery of any device involved in the process discharges the whole process is disturbed and algorithm needs to recover itself from this situation.

#### 4.1.7. Device Testing

The research group used Android smart watch with android Wear operating system, the compatible BLE beacons, android smart phone running Marshmallow 6.0 version and Linux PC with i3 processor. No other devices were used to run the system but in future the research group is planning to use BLE beacons form other commercial vendors and different mobile devices running the operating system other than Android OS.

## 5. DISCUSSION AND IMPLICATIONS

The experimental results showed that the proposed mechanism is providing real time aimless presence detection in a home environment. The presence of participants was recorded through the proposed architecture and then matched with the previously discussed profile. As every participant strictly observed the discussed profile of his presence the experimental checking was made possible. The system produced satisfactory results against each participant's presence. The system has also been checked for sending the notifications. The system produced real time notification to caregivers' mobile devices in all cases. The system provided caregiver the facility to build four different zones in a home environment. All the parameters described in experimental evaluation section were tested in initial study and pleasing results were found.

The evaluation of the proposed study has some limitations. The results were evaluated with small number of participants who were not dementia patient. One of the reasons was that the research group found only a small number of dementia patients in their contacts and the research group had limited number of recourses through which the experimental setup was not feasible to perform. The research group is planning to do the evaluation with real dementia patients in future. The evaluation has been performed on Android devices only, no other devices has been used. The proposed work needs to be tested in other platforms.

#### 6. CONCLUSION

This paper presents application and implementation of context aware aimless presence detection of PWD in its home environment using Bluetooth low energy (BLE) beacons. Mobile devices are used with BLE beacons which capture the beacons from BLE and then this data is used to find the presence of PWD. PWD may observe the episode of disorientation of time and place and may be aimlessly present in different location in his home environment. This problem may lead to serious health issues and caregiver may need to be present 24 hours with PWD. By using assistive technology systems on PWD mobile device real time presence in home environment is monitored. The proposed system assists caregiver by providing alerts/ notifications if the danger situation is detected. The caregiver may build a PWD special profile fulfilling the special needs a particular PWD and may alter the profile anytime anywhere according to the need of PWD. In this way the proposed system can enhance the quality of life of PWD and caregiver.

#### 7. ACKNOWLEDGEMENTS

The authors are highly thankful to all four participants who took part in the study and provided their valuable comments.

## 8. Conflict of Interest

All authors declared no conflict of interest.

## 9. REFERENCES

- World Health Organization, Dementia (May, 2017). Retrieved From http://www.who.int/mediacentre/ factsheets/fs362/en/.
- 2 Faragher, R. & R. Harle. Location fingerprinting with Bluetooth low energy beacons. *IEEE Journal on Selected Areas in Communication* 33(11): 2418-2428 (2015).
- 3 Moshnyaga, V., M. Koyanagi, F. Hirayama, A. Takahama & K. Hashimoto. A medication adherence monitoring system for people with dementia. *Proceedings of 2016 IEEE International Conference on Systems, Man, and Cybernetics* (SMC): 194-99 (2016).
- 4 Morel, A., K. Bormans, & K. Rombouts. Memory palaces to improve quality of life in dementia. 2015 Conference on Raising Awareness for the Societal and Environmental Role of Engineering and (Re) Training Engineers for Participatory Design (Engineering 4 Society): 80-84 (2015).
- 5 Mansbach, W. E., R. A. Mace, K. M. Clark, & I. M. Firth. Meaningful activity for long-term care residents with dementia: A comparison of activities and raters. *The Gerontologist* 57(3): 461-468 (2017).
- 6 MacAndrew, M., E. Beattie, M. O'Reilly, A. Kolanowski & C. Windsor. The trajectory of tolerance for wandering-related boundary transgression: An exploration of care staff and family perceptions. *The Gerontologist*: 57(3), 451-460 (2017).
- 7 Ou, Y. Y., T. W. Kuan, J. F. Wang, A. C. Tsai & P. C. Chen. A GPS tracking device embedded in prayer beads for early-stage dementia detection. *Proceedings of the ASE Big Data & Social*

Informatics 2015: 58 (2015).

- 8 Wan, J., C. A. Byrne, M. J. O' Grady & G. M. O' Hare. 2015. Managing wandering risk in people with dementia. *IEEE Transactions on Human-Machine Systems* 45(6): 819-823 (2015).
- 9 Sansrimahachai, W. Stream-based wandering monitoring system for elderly people with dementia. 2015 15<sup>th</sup> International Symposium on Communications and Information Technologies (ISCIT): 1-4 (2015).
- 10 Helmy, J. & A. Helmy. The Alzimio App for dementia, autism & alzheimer's: Using novel activity recognition algorithms and geo-fencing. *IEEE International Conference on (Smart Computing (SMARTCOMP)*: 1-6 (2016).
- 11 Sasaki, H. A smart phone app provides preventive care for the elderly with dementia. 2016 IEEE 32<sup>nd</sup> International Conference on Data Engineering Workshops (ICDEW): 50-53 (2016).
- 12 Wai, A. A. P., F. S. Fook, M. Jayachandran, J. Biswas, J. E. Lee & P. Yap. Implementation of context-aware distributed sensor network system for managing incontinence among patients with dementia. 2010 International Conference on Body Sensor Networks (BSN): 102-105 (2010).

- 13 Wang, H., H. Zheng, J. C. Augusto, S. Martin, M. Mulvenna, W. Carswell & K. McSorley. Monitoring and analysis of sleep pattern for people with early dementia. 2010 IEEE International Conference on Bioinformatics and Biomedicine Workshops (BIBMW): 405-410 (2010).
- 14 Acharya, M. H., T. B. Gokani, K. N. Chauhan & B. P. Pandya. Android application for dementia patient. *International Conference on Inventive Computation Technologies (ICICT)*: 1-4 (2016).
- 15 Schwiegelshohn, F., P. Wehner, F. Werner, D. Gohringer, & M. Hubner. Enabling indoor object localization through Bluetooth beacons on the RADIO robot platform. 2016 International Conference on Embedded Computer Systems: Architectures, Modeling and Simulation (SAMOS): 328-333 (2016).
- 16 Likert, R. A technique for the measurement of attitudes. Archives of psychology, (1932).
- Brooke J. SUS-A quick and dirty usability scale. In: Usability evaluation in industry. CRC Press, p. 189-194 (1996).
- 18 Kirakowski, J. & M. Corbett. SUMI: The software usability measurement inventory. *British Journal of Educational Technology* 24(3): 210-212 (1993).



Research Article

## Didactic Strategy for Learning Theory of Automata & Formal Languages

Muhammad Shumail Naveed<sup>1\*</sup>, and Muhammad Sarim<sup>2</sup>

<sup>1</sup>Department of Computer Science, University of Balochistan, Quetta, Pakistan <sup>2</sup>Department of Computer Science, Federal Urdu University of Arts, Science & Technology, Karachi, Pakistan

Abstract: Formal languages and automata theory have a strong association with the core of information in the area of computer science. However, the courses on formal languages and automata theory is a challenging task and students generally do not find these courses very attractive and experience intricacy and impediment in learning the concepts. These intricacies stem from the difficult and unusual abstract concepts and the essential mathematical background. This paper presents a didactic strategy to simplify the hardness of the courses on formal languages and automata theory and aids to increase the interest and commitment of students in these courses. The proposed strategy supports a more imperative learning of the topics in formal languages and automata theory in an effective and fruitful way. The strategy initially evaluated and primary results are quite encouraging.

**Keywords:** Learning formal languages and automata theory, theory of computing, students' disappointment, simulation tools, pair programming, education.

## **1. INTRODUCTION**

The formal languages and automata theory (FLAT) is a core of computer science curriculum [1, 2], and usually offered at undergraduate level. FLAT has a significant role in different areas, particularly in the theory of computation, artificial intelligence and compiler construction. However, many students usually find these courses tedious and complex [3, 4, 5]. Students usually find FLAT courses to be archaic and cannot associate their topics to other courses in the computer science curriculum or computer applications [6], and therefore students taking a course on FLAT be likely to be unenthusiastic and are unmotivated. Verma [7] argues that this frequently leads to student disappointment and high dropout rate in FLAT courses than other courses.

The FLAT courses are mostly introduced without the use of computers and generally do not include any programming [8]. A very few FLAT courses comprised of practical project such as the development of lexical analyser for a compiler. In fact, the induction of practical aspects of the FLAT courses is infrequent and typically embraced in courses that include further topics like parsing.

Normally the conventional approaches are used to introduce the FLAT courses, which are generally based on the integration of lectures with tutorials. Conventional chalk-and-board approaches are followed to teach students the different concepts of FLAT courses. With tutorials the students study the FLAT concepts by working through exercises which are presented for assessment.

It has been observed that a large majority of students is less motivated in understanding the concepts of FLAT courses. The lack of interest is not only due to the difficulties of the topics themselves but also due to the facts that the orientation and method of teaching many of the topics in FLAT courses are not towards computer science but biased towards mathematics. In most of the computer science undergraduate curriculum a Discrete Mathematics is a perquisite of FLAT

Received, January 2017; Accepted, June 2018

<sup>\*</sup> Corresponding Author: Muhammad Shumail Naveed; mshumailn@gmail.com

courses.

In order to increase the learning of students in FLAT courses, this paper presents a didactic strategy based on an amalgamation of existing techniques with some new concepts. The central aim of the proposed strategy is to overcome the complexity and abstractness of topics by turning the FLAT course more computer-oriented and interesting.

The paper is organized as follows. In section 2 the related work conducted in the support of FLAT courses is discussed. The main facets of a proposed strategy are described in section 3. The results of the initial evaluation and discussion of a proposed strategy are illustrated in section 4. Finally, section 5 describes the conclusion.

## **2. RELATED WORK**

A lot of work has been conducted to increase the learning of FLAT courses. In [9], a strategy based on constructivist approach is defined by integrating different teaching approaches to increase the interest of students and the initial results of its application are quite satisfactory. In [10], D'antoni et al. elucidate automatic feedback in the learning of deterministic finite automata constructions by analyzing the binary and counterexample-based feedback. The initial response of automatic feedback is quite encouraging.

Moura and Dias [11] introduced L-FLAT, a Logtalk Toolkit for teaching formal languages and automata theory. It supports regular expressions, finite state automata, context-free grammar, pushdown automata and Turing machines. L-FLAT units are defined using object-oriented aspects of Logtalk. The significance of L-FLAT in pedagogical environment is increased by bracing Mooshak, a web-oriented application which supports automatic ranking of presented programs.

The FSM is described to present students with the prospect to work and verify the designs by using regular expressions, state machines and grammars [12]. In [13], the use of pen-based computing to promote the learning in formal languages and automata theory is proposed. Dol [14] suggests the use of Think-Pair-Share, which is a cooperative learning strategy to increase the students learning about the course. Educational software tools are used to augment teaching strategies and particularly software simulators present association between theory and practice. Several educational software tools have been designed to support the simple and interactive learning of formal languages and automata theory. SELFA (Software for Learning Formal languages and Automata theory) is an educational simulation tool, developed to improve the standard of teaching in formal language and theory of automata courses [15]. The endeavour of SELFA tool is to make it simple to teach the concepts of the subject, whose level of abstraction make the process complex.

Thoth is technique which helps in teaching FLAT courses [16]. It can simulate push-down automata, Turing machines and other classical concepts like regular expressions, finite automata and context-free grammars. The tool is specially designed to allow easy interaction with different concepts of FLAT courses and allows students to easily experiment with different designs and observe the step-by-step evaluation of algorithms. Thoth has a simple and friendly user interface which allows the easy and rapid design of the automata. The interface of Thoth is available in English, German, French and Spanish.

FLUTE (Formal Languages and aUTomata Environment) is one of an important effort made to simplify the learning of formal languages and automata [17]. Basically FLUTE is an intelligent tutoring system that helps students in learning individually about FLAT.

Nóbrega et al. [18] described to use a Semantic Wiki as a tool to help FLAT course by associating tools like JFLAP. Its main objective is to increase the engagement of students in FLAT course.

JFLAP is one of an educational tools used in FLAT courses. Several studies [19, 20, 21] have been conducted on the use of JFLAP in FLAT courses and reported significant improvement in controlling the hardness of these courses. Jarvis and Lucas [22] have modified JFLAP through which it is possible to develop Java programs that change the actual automaton itself and found it very useful in increasing the student's capability to understand fundamental concepts like Church-Turing thesis and the undecidability. Automata Tutor is an online tool that aids students to comprehend essential notions in the theory of computation, such as regular expressions and finite automata. It also provides feedback when students define wrong solutions, and also supports instructors in organizing large classes by grading homework assignments. The tool has been used in several universities by many students. The Automata Tutor is analyzed and it has been reported that students were more engaged with the course content by interacting with the tool [23]. Similarly, the use of a tool increased average grade on the assignments of homework and teachers enjoyed the tool.

de Souza et al. [24] introduced a teachinglearning methodology to aid the formalism model construction about FLAT. According to that methodology, for every topic of FLAT, the instructor must recommend a simulator development as classwork or homework to help the student in formalism learning. A simulator based Multi-Formalism Modeling is developed and include icon-based interface and the initial results of the proposed methodology are quite positive.

A Combined Methodology based on simulator development is introduced to provide the knowledge required in the theoretical computer science area during the classes of FLAT, compilers and computer science theory [25]. The methodology was statistically analysed and found very effective. Neeman described the use of software testing techniques to elucidate some concepts of the theory of automata. The method utilizes equivalence partitioning and provides a guide for the various concepts of automata theory [26].

#### **3. DESIGN & METHOD**

The topical research on FLAT courses including the studies referred in the previous sections demonstrate that the abstract nature of concepts and notations involved in the course, hard background of mathematics, conventional style of teaching and student's perception on the irrelevancy of a FLAT course with the computer science are the contributing factors behind the hardness of FLAT course.

The contemporary solutions for FLAT courses usually addressed the single or a few issues whereas

the didactic strategy presented in this paper aims to overcome the intrinsic complexity of FLAT by considering the multiple issues involved in the learning of formal languages and theory of automata and perhaps this is a main novelty of the proposed didactic strategy. Principally, the proposed strategy is based on five principles.

## 3.1 Illustration of the Course in Linking with Computer Science History

Adding the details of the historical development of the theory of computing in conjunction with the topics of the formal language and automata theory has recognized very useful and encouraging for students [9], and therefore it is a first principle of the proposed strategy. The course on FLAT is not based on history of computer science; but it can be augmented by adding details related to the historical background in which the topic appeared as a new discipline. Including historical information would help the students in discovering how several concepts developed over time, and how research works and contribute to the expansion of a new field. For example, when introducing the concept of procedure and Turing-Church thesis it is useful to describe significant essentials about Alonzo Church and Alan Mathison Turing. So, the students come to know that both Alan Mathison Turing and Stephen Cole Kleene did their doctorate under the direction of Alonzo Church and therefore their research dimensions were following similar targets. Avram Noam Chomsky initiated the area of formal language theory in 1950s to define formal description of the structure of natural languages [27], so during introducing the types of grammar and particularly the context-free grammar it is fruitful to describe some pertinent work and development made by Noam Chomsky in the area of linguistics. Different methods like biographical notes, conventional lectures and videos may be used to describe the historical development; however, it is important to consider the cognitive load while including these details.

## 3.2 Pair Programming

Students usually encounter anxiety when they begin to learn a course on FLAT and therefore students are motivated and encouraged to work in a pair. Working in a pair is a second principle of the proposed strategy. Pair programming has been largely utilized in computer science education because of the benefits it provides to students [28].

Pair programming is an active research discipline and one of a useful area of Extreme Programming. In this method, two programmers work together at one computer on the same task. A person who holds the keyword is called the *driver* and the person who sits alongside the driver is called *navigator*. The basic duty of a driver is to develop the code. The navigator reviews the code and looks for possible errors that a driver leaves the code by mistake.

During FLAT course, the students are motivated to work in a pair as it is favourable for students and increased their confidence and performance. During problem solving, the driver develops the logic and solves the problem; while the other, the navigator analysed the logic. The students switch roles frequently.

## 3.3 Induction of Software Tools for Active Learning

The conventional chalk-and-board education style used to teach the concepts in FLAT courses is hard for students to learn the different concepts and proofs [29, 30], and therefore the pedagogy of FLAT courses is shifting from pencil and paper environment to a technological environment which use educational software to work with different concepts in the course [19]. Morazan and Antunez in [12] described that FLAT courses should be taught by using tools to define computation. In many areas of computer science, the visualization tools, simulators and other educational software are productively used to illustrate and visualize the abstract concepts. The third principle of a proposed strategy is to use different software tools to teach the FLAT courses. The use of suitable software would allow the students of FLAT courses to work and experiment the concepts that would be hard and complex to do on paper, and to get immediate response to the problem solving. Chudá and Rodina in [31] reported that the use of software tools like simulators in FLAT courses can significantly affect the pedagogical process.

Large varieties of tools have been developed to stimulate students' interest and help them in comprehending the FLAT concepts. These tools help students to easily learn and experiment the concepts which are usually tedious to do on a paper. Many visualization tools allow animation of different constructs and proofs and most of these tools are freely and widely available. Simulation of automata for educational purposes is itself a significant area in computer science education research [32]. Chesñevar et al. [1], discussed the main aspects of different educational software used for teaching FLAT and categorized these tools into multi-purpose tools and single-purpose tools. The multi-purpose tools and single-purpose tools are both helpful in the active learning of FLAT courses.

RegeXeX (Regular expression exercises) is one of a useful tool that can be used in active learning of regular expressions [33]. It provides a collection of exercises controlled by a system and provides advice to students on the precision of solutions. RegeXeX is also very useful during lectures to describe how the regular expression is generated.

CAVE (Constructive Algorithm Visualization Environment) is a pedagogical help to support instructors to describe the construction of deterministic finite automata and combining DFAs using different operators [1]. FSME (Finite State Machine Explorer) provides an environment that allows the students to construct finite state machines and verify them on different inputs. It also provides the conversion between equivalent classes of finite state machines.

MACH0 is a graphical simulation tool of deterministic finite state automata. It accepts the definition of deterministic finite automaton and displays its transition diagram and simulate the working of any input string. It uses colourful animation to increase learning and could be used to enhance the learning of FLAT courses.

Mealy and Moore machines are the essential components of FLAT courses and these machines can be introduced with TAGS (Transducer Automata Graphical Simulator) which allows defining and running these machines [34]. It also allows the rewinding of simulation. The tool also allows stepwise or continuous simulation.

The FSA Simulator is a program developed to enable students to work with finite state automata [35]. It also allows comparing the languages of two automata. FSA simulator is one of a popular tool and could be used in FLAT courses. Proof

59

Checker is a graphical environment that allows students to generate deterministic finite automaton and verify its correctness [36]. Proof Checker is an elegant tool that may be used to aid the students in comprehending the FLAT courses.

Formal Language and Automata Package (FLAP) is a simulation tool to design and simulate finite automata, pushdown automata and Turing machines [37]. It also supports numerous deterministic and nondeterministic dialects of these automata. The tool allows the simple and easy generation of automata by simply clicking and dragging of a mouse. JFLAP is free and interactive educational software to learn the topics in formal languages and automata theory. It is used to support the FLAT contents, including regular languages, context free languages, unrestricted grammars, pumping lemmas and Turing machines and recognized as a useful tool to reduce the gap between students and FLAT contents [5].

The Abstract Machine Simulator is another tool designed to help student to comprehend finite state automata and transducers [38]. It accepts the description of an automaton in tabular form. Text based and graphical simulation modules are available in the system.

Language Emulator is another powerful tool for the simulation of finite state automata, Mealy machine and Moore machines [39]. The tool is available in English and Portuguese. It accepts the description of the automaton and simulates its behaviour. It also allows the conversion of NFA to DFA, minimization of finite automaton and conversion between Mealy machine and a Moore Machine.

The Turing Machine Simulator is a tool for the simulation of Turing machine [40]. It allows the stepwise simulation of the Turing machine with descriptive comments. Turing Machine Simulator was originally developed by McFall and Dershem to design and simulate finite state automata and Turing machines [41]. The tool allows both nondeterministic and deterministic automaton. It also permits the use of sub-machines in the definition of an automaton. Turing's world is another tool developed to design and simulates Turing machine and very effective for pedagogical purpose. It also supports sub-machine for complex Turing machines.

Turing Building Block is a tool developed by Luce and Rodger to design and simulate Turing machines [42]. It also supports modular design. The tool includes a graphical editor for interactive and visual designing of a machine.

Interactive Pushdown Automata Animation is a tool developed by McDonald to design and simulate pushdown automata [43]. The tool allows instantaneous and stepwise simulation. It also supports high graphics and very effective for learning. Finite State Automata Simulator is another tool to design the deterministic and nondeterministic finite state automata [44]. The tool allows instantaneous and stepwise simulation.

Finite State Machine Simulator [45] is a tool developed to design and simulates deterministic and nondeterministic finite automata in a visual manner. It also supports the conversions of a nondeterministic finite state automaton to an equivalent deterministic finite state automaton and also supports the minimizing of a finite state automaton.

Java Finite Automata Simulation Tool is a very helpful tool to design and simulate finite state automata, pushdown automata, Turing machines and other forms of automata [46]. The tool also supports nondeterministic and deterministic machines. SimStudio is a simulation tool developed for finite state automata, pushdown automata and Turing machines [31]. The tool also supports nondeterministic and deterministic machines.

Apart from the above tools, there are other tools like FAdo, IPAA (Interaction Pushdown Automata Animation), Visual Turing, Minerva, DEM, JCT and A to CC which are highly amenable for comprehending the FLAT courses. Though there are several tools for learning FLAT courses and it's possible to use multiple tools to introduce the concepts; however it is recommended to use a single or minimum tools to cover the topics in a course otherwise it would increase the learning load.

#### 3.4 Computational View of a Course

The mathematical nature of FLAT makes the courses more abstract and difficult for students

[7, 39]. The students of computer science undergraduate programs usually have no strong background of mathematics and consequently they have little interest and motivation in FLAT courses. However, it is possible to increase the interest of students and reduce the hardness by introducing the FLAT courses in the context and application of computer science and this is the central theme of a fourth principle of a proposed didactic strategy. Devedzic et al. [47], argued that interest of students can be increased by illustrating them where they can implement the knowledge they have acquired. The applications helpful in the realization of the fourth principle of a proposed didactic strategy include formal verification and logic programming [7], programming languages, query languages, data definition languages, regular expressionsbased text searches and communication protocols [48]. Finite state automata and regular expression can be introduced to describe the lexical analyser, nondeterministic finite automaton can be used to model a critical processing with a binary semaphore [49]; finite automaton may be used in user interface design; grammar can be used in the definition of word processors and programming languages; pushdown automaton can be used to describe the syntax analyser and halting problem can be introduced in connection with antivirus problems.

Model-based testing is a central element of contemporary test automation. In this technique a software is evaluated by analysing the run time behaviour against predications defined by a proper specification. The well-established techniques use finite state machines as a foundation to select test inputs [50].

Partial order reduction is a technique used for concurrent asynchronous systems and use model checking [51]. Model checking is a technique to verify sequential circuit diagrams and communication protocols. In this system, proportional temporal logic is conventionally used to define the specifications, and the system is modelled as a state-transition graph.

#### 3.5 Use of Heuristics in Problem Solving

Construction of different machines and logics in FLAT courses are usually non-trivial for beginners because there is no mathematical formula or welldefined recipe for their construction, and every problem has its own requirement and entails a different approach for its solution and consequently it is usually very hard for beginners to apply the knowledge of one problem in the direct solution of other problems. However, it is possible to define some heuristics as shortcuts to ease the construction of automata and other problems. Use of heuristics in FLAT courses is a fifth principle of the proposed strategy. These heuristics work as an educated guess or a rule of thumb to understand and define solutions more quickly.

The heuristics can be easily identified with experience, observation and judgment and every course instructor needs to establish his own heuristics for FLAT courses and therefore the paper does not define any exhaustive list of heuristics. However, the authors have established and experienced the following heuristics for FLAT courses.

1. Although the finite state automaton can be constructed in any arbitrary fashion; however, it is better to construct the automaton in topdown and left-right manner as shown in the example illustrated in Fig. 1.



Fig. 1. Sample finite automaton for heuristic 1 [52]

This heuristic not only increased the understandability of a finite automaton, but also helps students in tracing the strings.

2. Any language defined by a finite automaton can be constructed with the regular expression, and the regular expressions always generate the regular languages. Therefore, the shape of transition graph of an automaton should follow some regular or symmetrical pattern. Although the structure of transition graph solely depends on the structure of an underlying language, yet it is better to construct the transition graph in a form of rectangle, square, pyramid, diamond, oval or their combination. As an example, consider a finite automaton shown in Fig. 2.



Fig. 2. Sample automaton for heuristic 2 [53]

Above automaton only accepts the strings *a*, *aab*, and *bab* and it is apparent that it follows one of a prescribed shape.

3. If an empty string is a part of a regular language, then the initial state of its deterministic finite automaton should be a final state or one of a final state of a machine. As an example, consider an FA (shown in Fig. 3) developed over the alphabet  $\Sigma = \{0, 1\}$ , accepting all strings with an even number of 0's and even number of 1's:



Fig. 3. Sample finite automaton for heuristic 3 [54]

In this example, the empty string is a valid string in a language; therefore, the initial state is also a final state of a machine. The same heuristic can be used in a definition of a pushdown automaton. If a context-free language includes empty string, then its respective pushdown automaton usually contains an empty move from the first input state which may check the stack and switch to the acceptance of a string. As an example, consider the Fig. 4.



Fig. 4. Sample pushdown automaton for heuristic 3 [53]

This pushdown recognized a language  $a^nb^n$ . The language includes an empty string and the first input state of the pushdown automaton check the  $\epsilon$ -input and accepts it after verifying the stack.

4. If a regular language is finite, then its' respective regular expression never contains a closure and similarly the equivalent finite automaton never contains a loop. Conversely, if a language is infinite, then its respective regular expression and its equivalent finite automaton should contain the loop(s) which could either be a direct or indirect.

Consider a language {aa, aabb}\*{b}. The language is infinite and therefore its regular expression (i.e., (aa+aab)\*b)) contains a closure and the respective finite automaton contains a loop as shown in Fig. 5.



Fig. 5. Finite automaton involving indirect loop [55]

In the definition and use of heuristics, it is important to realize that heuristic is simply an educated guess, but not a firm rule so the exceptions are always possible.

# 4. PRELIMINARY EVALUATION AND DISCUSSION

A small study is conducted to determine whether the proposed solution is justifiable and fruitful to reduce the complexity of FLAT course and increase the interest of students. The study comprised of two parts. In the first part, an online survey was conducted in which the undergraduate computer science students of Pakistan who have taken a course on FLAT were asked the following question:

## "Formal language and automata is one of a useful and influential subject/course of computer science"

The respondent can reply with 5-item Likert Scale. During the survey, 183 responses are received from the different regions of Pakistan. The number of respondents participated from the different regions of Pakistan and shown in Fig. 6.



Fig. 6. Geographical locations of respondents

During online survey, 23% response is received from Balochistan, 33% from Sindh, 19% from Punjab, 9% from Khyber Pakhtunkhwa and 3% from Azad Jammu & Kashmir.

The region wise responses received from the partcipants are shown in Fig. 7.

It can be seen that a large majority of students do not recognize the FLAT course, as a useful and influential subject of computer science and the large majority of students disagree with the usefulness of FLAT course. The same information can be better understood with the Fig. 8.



Fig. 7. Region wise response of participants

The feedback received from the students indicates that 24% of students strongly disagreed and 39% are disagreed with the useful and influence of FLAT course, whereas 20% agreed, 4% strongly agreed and 13% neither agreed nor disagreed with the significance of FLAT courses.



Fig. 8. Percent wise illustration of feedback

The overall response received from the survey suggest that undergraduate computer science students of Pakistan do not recognize the FLAT as a useful and persuasive course which implied the need of a didactic strategy that could increase the performance and motivation of students. Therefore, as a second part of an evaluation a small study is conducted. During the study, 64 students in the undergraduate computer science program who have already studied different subjects including: introduction to computing, programming

S. No.	Group	Students	Pass	Fail	Mean	Std. Deviation	Std. Error
1	Control	32	17	15	50.09	20.31	3.59
2	Treatment	32	20	12	58.81	19.30	3.41

Table 1. Results of evaluation

fundamentals, object-oriented programming and discrete structures in previous semesters are selected and randomly divided into a control group and treatment group. A same instructor to both group of studies offers a course on formal language and automata theory of three credit hours.

During the study, a conventional approach is followed for the control group, while the proposed strategy described in the previous section is utilized in a treatment group. For the realization of first principle, the historical notes outlined in the previous section and many other historical notes are followed to introduce the course. Traditional lectures with multimedia-oriented lectures are delivered to link the FLAT course with the computer science history.

During problem solving and class activities, the students were motivated to work in a pair. It is suggested that different concepts in FLAT courses can be introduced in the context of a particular programming language and it is also widely recognized that automata play a significant role in the design of the compiler [9,54]. So, during the evaluation of proposed strategy the FLAT course is introduced in the context of programming language and compiler construction. A small grammar of C-type language is developed to introduce the context-free grammar and its recognition is described by introducing pushdown automaton and parsing. Similarly, the lexical aspects of a designed programming language are described by the use of finite automata and regular expressions.

JFLAP is mainly used to introduce the FLAT course to treatment group; however a slight concept of RegeXeX is also introduced to the students of treatment group. During the course, students of treatment group are introduced with different heuristics which help them to understand the problems and generate their solutions.

After the completion of course, the control and treatment groups are internally evaluated in this

study. Table 1 shows the summary of the results.

The pass rate in the control group is 53.13 whereas 62.5 in the treatment group. Fig. 9 illustrates the



Fig. 9. Box plots of marks

box plots of marks obtained by both groups.

The quartiles of the box plots show that the performance of students in the treatment group is much better than the students of a control group.

The significance of a proposed didactic strategy is analysed by applying the independent sample t-test on the marks secured by the students, and the calculated t-value is 1.76, and p-value is .042, so the result is statistically significant at p < .05.

Maintaining the interest of students is one of a main challenge in FLAT courses. So, in order to identify whether the proposed didactic strategy increased the interest and motivation of students, the following question has been asked before the exams to the both groups of students:

#### "I am enthusiastic about this course"

The students can reply on Likert scale ranging from 1 (strongly disagree) to 5 (strongly agree). The feedback received from the students is shown in Fig. 10.

Fig. 10 shows that interest and motivation level of students in the treatment group is much higher than the control group.



Fig. 10. Students interest in FLAT course

Overall, the results acquired from the initial evaluation suggest that the proposed didactic strategy is useful to simplify the hardness of the course on formal languages and automata theory and useful to increase the interest of students. The results of evaluation naturally implied that the abstract nature of the notions involved in the FLAT course, traditional style of teaching and student's

Table 2.	Com	parison	of	didact	ic	strategies
----------	-----	---------	----	--------	----	------------

perception on the irrelevancy of a FLAT course with the computer science are the major factors behind the hardness of FLAT course.

The results obtained from the initial evaluation of the proposed strategy are quite encouraging. The comparison of a proposed didactic strategy and the other strategies is shown in Table 2.

The results shown in Table 2 indicate that the proposed study is quite fruitful and supportive in increasing the performance of students in FLAT courses and thereby comparable to the other didactic strategies.

#### **5. CONCLUSION**

The courses on formal languages and theory of automata present various issues for the instructors. Top among these is the student disappointment and high dropout due to the abstract nature of a course and material, students' perception on the irrelevancy of FLAT course in computer science and the firm background in mathematics. This paper presents a didactics strategy and reports on its initial evaluation. In its current state, the strategy is based on five

S. No.	Study	Method	Results
1	Pillay [2]	No practical study is reported	Proposed model was judged on observation and on projected benefits
2	Chesnevar et al. [9]	No practical study is reported	Proposed model was analyzed on observation and on projected benefits
3	D'antoni et al. [10]	Detailed study is conducted	Statistically significant, p < 0.005
4	Moura, P. & A.M. Dias [11]	No study is reported	Proposed model was analyzed on observation and on projected benefits
5	Morazan and Antunez [12]	No study is reported	Proposed model was analyzed on observation and on projected benefits
6	Castro-Schez et al. [15]	Two studies are conducted	Average pass rate of students in two studies is 61%
7	Nóbrega, G., F. Lima & D. Freire [18]	No study is reported	Proposed model was analyzed on observation and on projected benefits
8	Neeman [26]	Survey based questions	60% students understood the major concepts of FLAT.
9	Singh and Isah [27]	No study is reported	Proposed model was analyzed on observation and on projected benefits
10	Brown and Hardisty [33]	Classroom experience	Mean score of control group is 30. T-test was statistically significant with a p-value of 0.034
11	Proposed Strategy	Practical study is conducted	Average pass rate of students is 62.5 and results are statistically significant with a p-value of 0.42

rational principles. The proposed strategy initially applied to a small group of students and the results are quite satisfactory. The initial results suggest that illustration of FLAT course in linking with computer science history, motivating the students to work in a pair, use of software tools during lectures, introducing the computational view of a course and the use of heuristics for problem solving can overcome the intrinsic hardness of FLAT courses and may increase the interest of students. Further study is underway in four dimensions i) definition of viable methods for the pairing of students ii) comparative analysis of FLAT tools iii) analysing the significance of constructivism in FLAT courses iv) evaluation of proposed didactic strategy on a large group of students.

## 6. ACKNOWLEDGMENTS

The authors are grateful to the Department of Computer for the support. The authors would also like to thank all the students who participated in the study.

#### 7. REFERENCES

- 1. Chesñevar, C.I., M.L. Cobo. & W. Yurcik. Using theoretical computer simulators for formal languages and automata theory. *ACM SIGCSE Bulletin* 35: 33-37 (2003).
- Pillay, N. Teaching the theory of formal languages and automata in the computer science undergraduate curriculum. *South African Computer Journal* 12: 87-94 (2008).
- 3. Pillay, N. Learning difficulties experienced by students in a course on formal languages and automata theory. *ACM SIGCSE Bulletin* 41: 48-52 (2010).
- Lakshmi. & R. Sukumaran. Use of ICT in learning theory of computation: An experimental study. In: *IEEE International Conference in MOOC Innovation and Technology in Education*, Jaipur, India. p. 109-113 (2013).
- 5. Paul, J. Using jFlap to engage students and improve learning of computer science theory: tutorial presentation. *Journal of Computing Sciences in Colleges* 31: 145-148 (2015).
- Korte, L., S. Anderson, H. Pain. & J. Good . Learning by game-building: a novel approach to theoretical computer science education. *ACM SIGCSE Bulletin* 39: 53-57 (2007).
- Verma, R. M. A visual and interactive automata theory course emphasizing breadth of automata. *ACM SIGCSE Bulletin* 37: 325-329 (2005).
- 8. Moreira, N. & R. Reis. Interactive manipulation of regular objects with fado. *ACM SIGCSE Bulletin*

37: 335-339 (2005).

- Chesnevar, C.I., M.P. Gonzalez. & A.G. Maguitman. Didactic strategies for promoting significant learning in formal languages and automata theory. *ACM SIGCSE Bulletin* 36: 7-11 (2004).
- D'antoni, L., D. Kini, R. Alur, S. Gulwani, M. Viswanathan. & B. Hartmann. How can automatic feedback help students construct automata?, *ACM Transactions on Computer-Human Interaction* 22: (2015).
- 11. Moura, P. & A.M. Dias. L-flat: Logtalk toolkit for formal languages and automata theory. In: *Proceedings of the 11th International Colloquium on Implementation of Constraint Logic Programming Systems*, Kentucky, USA, (2011).
- Morazan, M.T. & R. Antunez. Functional automata formal languages for computer science students. In: *Proceedings of Trends in Functional Programming in Education*, Soesterberg, The Netherlands, 19-32 (2014).
- 13. Berque, D., D.K. Johnson. & L. Jovanovic. Teaching theory of computation using pen-based computers and an electronic whiteboard. *ACM SIGCSE Bulletin* 33: 169-172 (2001).
- 14. Dol, S.M. Tps (think-pair-share): An active learning strategy to teach theory of computation course. *International Journal of Educational Research and Technology* 5: 62-67 (2014).
- Castro-Schez, J. J., E.E. Castillo, J. Hortolano. & A. Rodriguez. Designing and using software tools for educational purposes: Flat, a case study. *Transactions on Education* 52: 66-74 (2009).
- García-Osorio, C., I. Mediavilla-Sáiz, J. Jimeno-Visitación. & N. García-Pedrajas. Teaching pushdown automata and turing machines. *ACM SIGCSE Bulletin* 40: 316 (2008).
- Devedzic, V., J. Debenham. & D. Popovic. Teaching formal languages by an intelligent tutoring system. *Educational Technology & Society* 3: 36-49 (2000).
- Nóbrega, G., F. Lima & D. Freire. Integrating the semantic wiki approach to face to face courses. In: *World Conference on Computers in Education*, Bento Gonçalves, Brazil. p. 1-19 (2009).
- Rodger, S. H., J. Lim. & S. Reading. Increasing interaction and support in the formal languages and automata theory course. *ACM SIGCSE Bulletin* 39: 58-62 (2007).
- 20. Cavalcante, R., T. F. Cornell. & S. H. Rodger. A visual and interactive automata theory course with jflap 4.0. *ACM SIGCSE Bulletin* 36: 140-144 (2004).
- Rodger, S. H., E. Wiebe, K. M. Lee, C. Morgan, K. Omar. & J. Su. Increasing engagement in automata theory with jflap. *ACM SIGCSE Bulletin* 4: 403-407 (2009).
- 22. Jarvis, J., J.M. Lucas. Incorporating transformations

into jflap for enhanced understanding of automata. *ACM SIGCSE Bulletin* 40: 14-18 (2008).

- D'Antoniy, L., M. Weavery, A. Weinertz & R. Alury. Automata tutor and what we learned from building an online teaching tool. *Bulletin of EATCS* 3; (2015).
- de Souza, G.S., C. Olivete, R.C. Correia. & R.E. Garcia. Teaching-learning methodology for formal languages and automata theory. In: *IEEE Frontiers in Education Conference*, El Paso, USA. p. 1-7 (2015).
- de Souza, G.S., G.P.H. Gomes, R.C.M. Correia, C. Olivete, D.M. Eler. & R.E. Garcia. Combined methodology for theoretical computing. In: *Frontiers in Education Conference*, Erie, USA. p. 1-7 (2016).
- Neeman, A. Buy one get one free: automata theory concepts through software test. *Journal of Computing Sciences in Colleges* 31: 90-96 (2016).
- Singh, D. & A.I. Isah. An outline of the development of the theory of formal languages. *International Journal of Latest Trends in Computing* 5: 172-181 (2014).
- Myller, N., R. Bednarik, E. Sutinen. & M. Ben-Ari. Extending the engagement taxonomy: Software visualization and collaborative learning. *ACM Transactions on Computing Education* 9: 7:1-7:27 (2009).
- 29. McDonald, J. Interactive pushdown automata animation. *ACM SIGCSE Bulletin* 34: 376-380 (2002).
- Chud'a, D. Visualization in education of theoretical computer science. In: *Proceedings of the 2007 international conference on Computer systems and technologies*,; Rousse, Bulgaria. p. 84:1-84:6 (2007).
- Chud'a, D. & D. Rodina. Automata simulator. In: Proceedings of the 11th International Conference on Computer Systems and Technologies and Workshop for PhD Students in Computing on International Conference on Computer Systems and Technologies, Sofia, Bulgaria. p. 394-399 (2010).
- 32. Chakraborty, P., P.C. Saxena. & C.P. Katti. Fifty years of automata simulation: a review. *ACM Inroads*; 2: 59-70 (2011).
- Brown, C.W. & E.A. Hardisty. Regexex: an interactive system providing regular expression exercises. ACM SIGCSE Bulletin 39: 445-449 (2007).
- Esmoris, A., C.I. Chesnevar & M.P. Gonzalez. Tags: a software tool for simulating transducer automata. *International journal of electrical engineering education* 42: 338-349 (2005).
- 35. Grinder, M.T. A preliminary empirical evaluation of the effectiveness of a finite state automaton animator.

ACM SIGCSE Bulletin; 35:157-161 (2003).

- Stallmann, M.F., S.P. Balik, R.D. Rodman, S. Bahram, M.C. Grace. & S.D. High. Proofchecker: an accessible environment for automata theory correctness proofs. *ACM SIGCSE Bulletin* 39: 48-52 (2007).
- Rodger, S.H. Integrating hands-on work into the formal languages course via tools and programming. In: *International Workshop on Implementing Automata* Ontario, Canada. p. 132-148 (1996).
- Lee, M.C. An abstract machine simulator. *Lecture* Notes in Computer Science 438: 129-141 (1990).
- Vieira, L.F., M.A. Vieira. & N.J. Vieira. Language emulator, a helpful toolkit in the learning process of computer theory. *ACM SIGCSE Bulletin* 36: 135-139 (2004).
- 40. Hamada, M. Supporting materials for active e-learning in computational models. *Computational Science* 5102: 678-686 (2008).
- McFall, R. & H.L. Dershem. Finite state machine simulation in an introductory lab. ACM SIGCSE Bulletin 2: 126-130 (1994).
- Luce, E. & S.H. Rodger. A visual programming environment for Turing machines. In: *Proceedings* of *IEEE Symposium on Visual Languages*, Bergen, Norway, p. 231-236 (1993).
- 43. McDonald, J. Interactive pushdown automata animation. *ACM SIGCSE Bulletin*; 34:376-380 (2002).
- 44. Grinder, M.T. A preliminary empirical evaluation of the effectiveness of a finite state automaton animator. *ACM SIGCSE Bulletin* 35: 157-161 (2003).
- 45. Hamada, M. & K.A. Shiina. Classroom experiment for teaching automata. *ACM SIGCSE Bulletin* 36:261-261 (2004).
- White, T.M. & T.P. Way. jfast: A java finite automata simulator. ACM SIGCSE Bulletin 38: 384-388 (2006).
- Devedzic, V., J. Debenham. & D. Popovic. Teaching formal languages by an intelligent tutoring system. *Educational Technology & Society* 3: 36-49 (2000).
- 48. Wermelinger, M. & A.M. Dias. A prolog toolkit for formal languages and automata. *ACM SIGCSE Bulletin* 37: 330-334 (2005).
- 49. Schreyer, B., W. Wawrzynski. Finite automata models for CS problem with binary semaphore. *ACM SIGCSE Bulletin* 38: 330-330 (2006).
- Meinke K. & N. Walkinshaw. Model-Based Testing and Model Inference. In: Margaria T., Steffen B. (eds) Leveraging Applications of Formal Methods, Verification and Validation. Technologies for Mastering Change, Lecture Notes in Computer Science, Springer, Berlin, Heidelberg 7609 (2012).
- 51. Clarke E. M, O. Grumberg, M. Minea. & D. Peled.

State space reduction using partial order techniques. International Journal on Software Tools for Technology Transfer 2: 279-87 (1999).

- 52. Sipser, M. Introduction to the Theory of Computation, 2nd ed. Boston. Thomson Course Technology Boston, USA (2006).
- 53. Cohen, D.I. *Introduction to computer theory*. 2nd ed. Wiley, New York, USA (1991).
- 54. Hopcroft, J.E., R. Motwani. & J.D. Ullman. Introduction to Automata Theory, Languages, and Computation, 2nd ed. Addison Wesley, New York, USA (2001).
- 55. Martin, J.C. *Introduction to Languages and the Theory of Computation*, 4th ed. McGraw-Hill, New York, USA (1991).


### **Application of Pulse Electric Field for Chemical Extraction Process**

Prima Asmara Sejati<sup>1\*</sup>, Ardhi Wicaksono Santoso<sup>1</sup>, Rella Mareta<sup>1</sup>, and Arief Budiman<sup>2</sup>

<sup>1</sup>Department of Electrical Engineering and Informatics, Vocational College, Universitas Gadjah Mada, Yogyakarta, Indonesia <sup>2</sup>Department of Chemical Engineering, Faculty of Engineering, Universitas Gadjah Mada, Yogyakarta, Indonesia

Abstract: This paper discusses the material and method of designing the electric circuits of Pulse Electric Field (PEF) hardware that can accommodate Direct Current (DC) voltage with modulation frequencies that could be controlled. The main circuit has several parts that are input, processor, and output. The keypad is used to set the frequency, the duty cycle, the number of Pulse with Modulation (PWM), and time variables. A microcontroller will process these parameters as the processor. The outputs consist of a display, separator, driver, and chamber. The separator is used to secure the processor. The driver is a voltage regulator for the circuit. A PEF chamber is used to treat the sample. The sample used in this study is 40 mL of water for hardware testing. The test procedure is using  $\pm$  128 VDC as the voltage source with a variant value of frequency, duty cycle, and time. This test aims to get the best value of these variables that produces optimum condition during the extraction process. Thus, it can be concluded that the hardware is able for the extraction of water-based processes. It can operate over a voltage range from 15 VAC to 128 VAC (up to 172 VDC after rectification), the frequency in 1 Hz to 5 Hz, duty cycle of 1 % to 5 %, and the treatment time in 10 s to 25 min. This PEF hardware design could be used for the microalgae as the water-based raw material by electric shock method.

Keywords: Electric shock, extraction, microalgae, microcontroller, Pulse Electric Field.

#### 1. INTRODUCTION

Nowadays the usage of energy depends on fossilfuel energy. As we know, that it is kind of nonrenewable energy which is decreasing significantly. The main problem of biofuel development from the renewable natural feedstock is the depletion of fossil energy and greenhouse effect [1]. Palm oil is one of the most common raw materials used to produce biodiesel as biofuel in addition to soybean oil and sunflower oil. In Indonesia, the use of these raw materials for energy conversion contradicts the fulfilment of the food sector, although palm oil is the best biodiesel feedstock in quality and quantity to replace fossil diesel fuel [2].

To overcome this problem, cheap raw materials such as used cooking oil and palm oil distillate are being utilized. Also, microalgae recently explored as promising new biodiesel feedstocks [3]. Microalgae are simple cellular microorganisms that live in an aquatic environment. They need enough light, water, and  $CO_2$  to bring photosynthesis in high biomass productivity [4]. They can be cultivated in extreme media, such as in wastewater, and  $CO_2$ supplied from flue gas [5]. Meanwhile, the lipid content is potentially converted into biodiesel.

Conversion of microalgae into biodiesel (oil extraction) is a problem to be solved. Some methods that can be used for algal oil extraction include: mechanical, electrical and chemical methods [6]. In mechanical method, pressurized conditions are used to remove oil from the main cells of microalgae. In chemical methods, chemical solvents such as n-hexane [7] and CO<sub>2</sub> are used in supercritical conditions [8]. Both of these methods utilize dry microalgae as raw materials, which require high energy and take more time in the drying process. Electrical methods use electrical energy to move algal oil out of the algal cells. One of the proposed electrical methods is the Pulse Electric Field (PEF), which extracts algae oil by disrupting the cell wall of microalgae in an electric field [9].

Received, April 2017; Accepted, June 2018

<sup>\*</sup> Corresponding Author: Prima Asmara Sejati; prima.asmara.s@ugm.ac.id

According to [10], PEF is a method that widely used in non-thermal food processing by using highintensity electric shock. PEF was applied to the liquid material. The process is short between one microsecond to a millisecond with short pulses. The process of PEF is based on short pulse applications at high voltages (20 kV.cm<sup>-1</sup> to 80 kV.cm<sup>-1</sup>) to the food placed between two electrodes. PEF was categorized as a non-thermal process because the food was processed at room temperature or below for a few seconds. It can minimize the loss of any nutrients caused by heating.

The main purpose of PEF method is to extract the lipid content by applying an electric field to destruct the cell wall of microalgae. By using this technology, energy was obtained from a high voltage of source stored in one or more capacitors and released through the food material to produce electric fields required. The energy stored in the capacitor could be released quickly with a very high power. Therefore, the objective of this research is to design a PEF device for the water-based microalgae extraction process. The indicator of the PEF performance can be concluded by analyzing the sample behavior and device stability by varying the voltage input, switching frequency, and treatment time. The proposed design is laboratory scaled and expected to be used in the next research.

#### 2. MATERIALS AND METHOD

This section explains the materials and method used to build PEF hardware. The PEF can accommodate Direct Current (DC) voltage with controlled frequencies. It is used for the water-based extraction process. The PEF system diagram design is shown in Fig. 1.

In Fig. 1, keypad is used for user input to set the variables and parameters that need to be adjusted in

the PEF operation. These variables are frequency, duty cycle ( $t_{on}$  and  $t_{off}$ ), the number of Pulse with Modulation (PWM) waveform, and treatment time. The next part is the PEF system processor that will process the Input variables and parameters. This study used AVR ATMEGA16 microcontroller as a processor which controls the voltage output waveform. Further, the last part is the outputs. This part consists of several sections. Liquid Crystal Display (LCD) used as an indicator for the user. The optoisolator is used to secure the processor circuit from overvoltage and short circuit. Next, the MOSFET gate driver is used to drive the N-Channel MOSFET and voltage through PEF chamber. PEF chamber is used to place the water-based sample for the extraction process. It is related to further studies that will apply the PEF hardware for the extraction process of the water-based sample. A 40 mL of sample is used for PEF hardware testing.

In hardware testing, the voltage value is fixed at  $\pm$  128 VDC with a variant value of frequency, duty cycle, and treatment time. This test aims to get the best value of these variables that produce optimum conditions during the water-based extraction process. The design and testing of PEF hardware is described in the next section.

#### 3. RESULTS AND DISCUSSION

This section describes the process of hardware testing presented in several stages. These stages are the series of experiments that aim to produce PEF hardware that could be used for the water-based extraction process.

#### **3.1. Design of PEF Chamber**

The PEF chamber is designed at the first stage. The size of this chamber affects the calculation of the electric field needed for the extraction process and



Fig. 1. PEF system diagram

determines the hardware to be used. This calculation is given by Equation (1) [11]:

$$E = \frac{V}{d}$$

Where *E* is the electric field strength, *V* is the voltage source, and *d* is the gap between two parallel plates. This PEF chamber consists of eight pieces of 100 mm × 180 mm x 1 mm stainless steel sheet. These are arranged vertically and placed in 165 mm × 145 mm × 42 mm acrylic containers that is shown in Fig. 2.

In PEF chamber, the distance between the plates is one mm and there is one mm thick glass that is placed between the plates. This glass is used as a translucent insulator and heat-resistor between the plates. According to Equation (1), it aims to get the electric field of 1.28 kV.cm<sup>-1</sup> when the voltage passing through the plates is 128 VDC.

In the PEF chamber, eight plates are arranged alternately with the order of the electrode (-) and (+) so that the plates will be charged (-) in the end plate. This configuration is shown in Fig. 3.

Figure 3 shows that electrodes are marked in red and given a positive voltage, while the gray



Fig. 2. Design of PEF chamber

is connected to ground. The installation of PEF Chamber is shown in Fig. 4.

The composition of the electrode plates is placed inside a three mm acrylic container.

#### 3.2. Design of Transformer

In the electronic parts, the main step is to design the transformer by using two step-down transformers



Fig. 3. Electrode and polarity



Fig. 4. PEF Chamber installation

32 V 5 A CT to produce the voltage as needed in the extraction process. Ampere meter is used as an additional instrument to determine the load current measurement.

Both transformers are connected in series to gain a larger voltage. This configuration produces two times the voltage which is generated by one transformer. The serial transformer circuit diagram is shown in Fig. 5.



Fig. 5. Serial transformer circuit diagram

Fig. 5 shows how to obtains 128 VAC transformer output voltage with 5 A current. Thus, the maximum electric field can be applied 1.28 kV/ cm (AC), assuming that there is no change in the voltage when rectified.

#### 3.3. Design of Rectifier

The rectifier circuit consists of full-wave diode bridge used to cope with high loads. The circuit of



Fig. 6. Rectifier circuit diagram

rectifier is shown in Fig. 6.

The DC output voltage value generated may reach 172 VDC due to the capacitor added in this circuit.

#### 3.4. Design of Processor and User Interface

The ATMEGA16 chip processor serves as a controller chip that sets a variable frequency, timer, and duty cycle. The user interface design is shown in Fig. 7.



Fig. 7. User interface design

The keypad is used to set a variable of input. LCD is added to display the variable and as a user interface.

#### 3.5 Design of Separator and MOSFET Driver

This section serves to get the optimum performance and behavioral voltage control circuit in the PEF chamber. The separator section used two optocoupler TLP521 as a non-contacted connector between the controller and the driver that also functions as a conduit logic to MOSFET Gate Driver (MGD) circuit, as shown in Fig. 8.



Fig. 8. Optocoupler separator circuit

In Fig. 8, OC1 and OC2 are two optocouplers working alternately by a square wave pulse with the voltage level of 5 V sent from PORTD.6 microcontrollers. When the wave of logic is one (high), then optocoupler OC1 would be active, and OC2 would be inactive. Otherwise, when the wave of logic is zero (low), then the optocoupler OC1 would be active, and its run continuously. This process will generate the output waveform and become the input, but the level is boosted to 12 V and separated electronically from the input. Strengthening the voltage level has to be done, considering that the MGD components used requires 12 V voltage levels to work. The MGD circuit is shown in Fig. 9.



Fig. 9. MOSFET gate driver (MGD) circuit

The driver circuit in Fig. 9 only uses a single MOSFET. It merely uses part of the low side. The

reason for using this configuration is that when two MOSFETs (high side and low side) parts are used, the part that cannot handle the load is that of the step-down transformer. Based on the results of previous trials, the high-side MOSFET part was frequently damaged.

#### 3.6 Assembling PEF

Earlier described are compiled into a PEF device. The overall integration of the input part, processor, and output is shown in Fig. 10 and Fig. 11.

Figure 10(a) is an input voltage from the transformer 5 A; this input is used to generate a voltage of 128 V in the extraction process. Figure 10(b) is a power supply that provides power to the circuit. Figure 10(c) shows the part of the 5 A serial transformers circuit. Figure 10(d) is an interface, which is used to set parameters and to see the information on the LCD. Ampere meter is used to read the current value indicated in the Fig. 10(e). Fig. 10(f) is part of the rectifier that serves to rectify AC into DC voltage. Separator and MOSFET gate driver circuit are shown in Fig. 10(g) and Fig 10(h) shows a microcontroller as a processor. Figure 11 shows the assembled PEF unit and the PEF chamber.

Figure 11(a) is an assembled PEF unit as described before. Figure 11(b) is an oscilloscope, an additional instrument for measuring the frequency



Fig. 10. PEF Assembly unit, (a) Input from transformer 5A, (b) Power supply, (c) Serial Transformer 5A, (d) Interface, (e) Ampere meters, (f) Rectifier, (g) Separator and driver, and (h) Microcontrollers



Fig. 11. Overall PEF set, (a) PEF assembled unit, (b) Oscilloscope, and (c) PEF chamber

used in the extraction operation. Fig. 11(c) is the PEF chamber, a place to put the sample for the extraction process. After PEF is assembled properly, then the experiment is made to test the ability of the designed PEF for the extraction process.

#### 3.7 PEF Test

To test PEF, 100 mL of 7 % salt water as a sample was used. Then the tests were made for a variety of experimental variables with the voltage from 15 VAC to 128 VAC (up to 172 VDC after rectification), the frequency from 1 Hz to 8 Hz, the duty cycle from 1 % to 15 %, and treatment time from 10 s to 15 min, aiming to determine the value of the fine parameter for optimum operation condition.

The first test used various VAC input voltages intended to assess the device's performance against increasing input voltages. The data in Table 1 shows the results of the PEF testing.

This test was performed for 30 s for the increasing values of voltage. When the input is set to 15 VAC, the current measured is 5 A, the sample was unreacted and the device was in a stable condition. This condition happened until the input value was 32 VAC. After voltage was set to

64 VAC, device condition was stable, the voltage measured was 92 VDC with 6 A current, at this moment in the PEF chamber some bubbles began to appear. When the input voltage was raised to 128 VAC, the voltage rise to 180 VDC, and current was 8 A, where the device's condition was still steady and more bubbles appeared.

The second test was performed with varying duty cycle values, with the static input of 128 VAC and frequency of 1 Hz. The data in Table 2 shows the results of the second PEF testing.

From the data of the second experiment it could be seen that the changes in the duty cycle value brought changes to the current flowing. The output was stable in 172 VDC, where the device was relatively stable for each change made, but the sample on the PEF chamber was unreacted.

The third test performed using varying frequencies and duty cycle values, while input was static in 128 VAC with time treatment of 1 min. The data in Table 3 shows the results of the third PEF testing.

The last test performed using varying time of treatment, while input was static in 128 VAC, the

AC Voltage (V)	Current (A)	DC Voltage (V)	Sample Behavior	<b>Device Performance</b>
15	5		unreacted	stable
18	5		unreacted	stable
25	5		unreacted	stable
32	5		unreacted	stable
64	6	92	bubbles appear	stable
128	8	180	bubbles appear	stable

Table 1. PEF testing in frequency 1 Hz and 1 % duty cycle with time of treatment 30 s

Table 2. PEF testing with 128 VAC, frequency 1 Hz, and time of treatment 30 s

Duty Cycle (%)	Current (A)	DC Voltage (V)	Sample Behavior	Device Performance
5	11	172	unreacted	stable
4	10	172	unreacted	stable
3	9	172	unreacted	stable
2	8	172	unreacted	stable
1	7	172	unreacted	stable

Table 3. PEF testing with 128 VAC and time of treatment 1 min

Freq. (Hz)	Duty Cycle (%)	Voltage (V)	Current (A)	Sample Behavior	Device Performance
1	1	172	7	unreacted	stable
2	2	172	7	bubble appears	stable
3	3	172	8	bubble appears more	stable
5	5	172	6	bubble appears more	stable

Table 4. PEF testing with 128 VAC, frequency 1 Hz, and 2 % of duty cycle

Time (s)	Voltage (V)	Current (A)	Sample Behavior	<b>Device Performance</b>
300	172	9	bubbles appear	stable
600	172	9	bubbles appear. water level rise pulsing as frequency	stable
900	172	9	bubbles appear. water level rise pulsing as frequency	stable
1200	172	9	bubbles appear. water level rise pulsing as frequency sample coagulates	stable
1500	172	9	bubbles appear. water level rise pulsing as frequency sample coagulates	stable

frequency was 1 Hz, and the duty cycle was 2 %. The data in Table 4 show the results of the last PEF testing.

The data from Table 3 and Table 4 shows that the device works steadily. Changes in the frequency and the duty cycle values give some effects on the testing tool, mainly the changes in the current passing through the circuit. The length of treatment



Fig. 12. Effect of frequency to yield of microalgae oil



Fig. 13. Effect of the duty cycle to yield of microalgae oil



Fig. 14. Effect of time to yield of microalgae oil

time affects the extraction of the sample. From the experiments, it is known that the extraction process is marked by the emergence of bubbles in PEF chamber, a rise in water level, pulses in the frequency and the coagulated sample. This coagulated sample is the result of extraction performed by this device.

The device can run well with no damage for various combinations of these variables. Therefore, this circuit can be used in the process of collecting, testing, and analyzing data. By using this design and vary the duty cycle, switching frequency, and the treatment time, the experimental result shows these variables can affect the extracted lipid amount [12]. Fig. 12, Fig 13, and Fig.14 show the experimental data of this effect.

The results concluded that the lipid yield would increase by enlarging the duty cycle and treatment time also reduces the switching frequency due to the device limitation as described before (1 Hz to 5 Hz frequency, 1 % to 5 % duty cycle, and 10 s to 25 minutes treatment time. However, the detailed analysis and mathematical modeling of this behavior data will be conducted in another research [13].

#### 4. CONCLUSION

The PEF Hardware is designed to have the ability to do the water-based extraction processes. It can operate over a voltage range from 15 VAC to 128 VAC, the frequency from 1 Hz to 5 Hz, the duty cycle from 1 % to 5 %, and a treatment time from 10 s to 25 min.

#### 5. FUTURE RESEARCH

In the future research, the PEF will be implemented into microalgae extraction processes, aiming to extract microalgae into biodiesel feedstock in the form of lipids.

#### 6. ACKNOWLEDGMENTS

The authors gratefully acknowledge for the support from Laboratory of Instrumentation and Control, Department of Electrical Engineering and Informatics, Vocational College, Universitas Gadjah Mada and Process System Engineering Research Group, Department of Chemical Engineering, Faculty of Engineering, Universitas Gadjah Mada.

#### 7. REFERENCES

- Arvindnarayan, S., Prabhu, K.K.S., Shobana, S., Dharmaraja, J., & Pasupathy, A. Algal biomass energy carriers as fuels: An alternative green source. *Journal of the Energy Institute*, 90, 300-315 (2017).
- Sudibyo, H., Pradana, Y.S., Samudra, T.T., Budiman, A., Indarto, & Suyono, E.A. Study of cultivation under different colors of light and growth kinetic study of *Chlorella zofingiensis* Dönz for biofuel production. *Energy Procedia*, 105, 270-276 (2017).
- Suganya, T., & Renganathan, S. Optimization and kinetic studies on algal oil extraction from marine macroalgae *Ulva lactuca. Bioresource Technology*, 107, 319-326 (2012).
- Demirbas, M.F. Biofuels from algae for sustainable development. *Applied Energy*, 88, 3473-3480 (2011).
- Pradana, Y.S., Kusumastuti, Y., Rahma, F.N., & Effendy, N. Chitosan Flocculation-sedimentation for Harvesting Selected Microalgae Species Grown in Monoculture and Mixed Cultures. *Chemical Engineering Transactions*, 56, 1549-1554 (2017a).
- Pradana, Y.S., Sudibyo, H., Suyono, E.A., Indarto, & Budiman, A. Oil algae extraction of selected microalgae species grown in monoculture and mixed cultures for biodiesel production. *Energy Procedia*, 105, 277-282 (2017b).
- Shin, H.Y., Ryu, J.H., Bae, S.Y., Crofcheck, C., & Crocker, M. Lipid extraction from *Scenedesmus sp.* microalgae for biodiesel production using hot

compressed hexane. Fuel, 130, 66-69 (2014).

- Santana, A., Jesus, S., Layyaroz, M.A., & Filho, R.M. Supercritical carbon dioxide extraction of algal lipids for the biodiesel production. *Procedia Engineering*, 42, 1755-1761 (2012).
- Nafis, G.A., Mumpuni, P.Y., Indarto, & Budiman, A. Combination pulsed electric field with ethanol solvent for *Nannochloropsis sp.* extraction. *AIP Conference Proceedings*, 1699, Art. Num. 30021, DOI: 10.1063/1.4938306 (2015).
- Apriliawan, H. Laban Electric: Alat Pasteurisasi Susu Kejut Listrik Tegangan Tinggi (Pulsed Electric Field) Menggunakan Flyback Transformer [Tool Pasteurization of Milk with High Pulsed Electric Field using Flyback Transformer], Jurusan Teknik Pertanian, Fakultas Teknologi Pertanian Universitas Brawijaya, Malang, Indonesia (2010) (in Bahasa Indonesia).
- 11. Carl, R.N. *Work and Voltage: Constant Electric Field*, Department of Physics and Astronomy, Georgia State University (2001).
- Sejati, P., Aditama, F., B., Budiman, A. Pulsed Electric Field (PEF) Assisted Extraction of Microalgae Tetraselmis Chuii Sp. for Biodiesel Feedstock. Regional Conference in Chemical Engineering, Yogyakarta (2014).
- Sejati, P.A., Pradana, Y.S., Kurniawan, A., Budhijanto, and Budiman, A. Modeling of Algal Oil Extraction from Tetraselmis sp. Using Pulsed Electric Field (PEF). International Conference on Engineering and Technology for Sustainable Development, Yogyakarta (2017).



Research Article

### Physical, Elastic and Thermal Characterization of Ni-Cd Nano Ferrites

#### Asghari Maqsood<sup>1\*</sup>, and M. Arshad<sup>1</sup>

<sup>1</sup>Nano-Scale Physics Laboratory, Department of Physics, Air University, Islamabad, Pakistan

**Abstract:** The soft spinel ferrite system  $Ni_{1-x}Cd_xFeO4$  (x=0.0, 0.2, 0.4, 0.6) have been synthesized by the coprecipitation method. The prepared samples are characterized by the x-ray diffraction (XRD) and FTIR techniques. The XRD data have been used to obtain lattice constants, average crystallite size, specific surface area, dislocation density and strain of the nanoferrites. The data also provided the cation distribution, indicating that Fe<sup>3+</sup> occupies both the A and B-sites. The elastic properties of this system are studied through infra-red spectroscopy and XRD data. The force constants for tetrahedral ( $k_1$ ) and octahedral ( $k_0$ ) sites are estimated along with the Poisson's ratio and the Debye temperature ( $\Theta_D$ ).

**Keywords:** Co-precipitation synthesis, x- ray diffraction, Debye temperature, specific surface area, elastic properties, magnetic materials, metallic ferrites

#### **1. INTRODUCTION**

Spinel nanoferrites are considered superior to other magnetic materials because they have low eddy current losses due to high electrical resistivity. The possibility of preparing ferrites at the nano-scale has extended the application in biotechnology as well as in medicines. Polycrystalline nanoferrites are important because of their well-defined structural, electrical and magnetic properties that depend upon several factors like synthesis techniques, cation substitution and their microstructure. In these polycrystalline materials, doping of minor cations can alter the properties of the entire final product. The ferrites constitute of iron oxide along with other metal with a general formula  $MeFe_2O_4$ , where Me is divalent metal ion such as  $Cd^{2+}$ ,  $Mn^{2+}$ , Mg<sup>2+</sup>, Ni<sup>2+</sup> and Co<sup>2+</sup> etc.[1]. It is well defined that in inversed spinel structure the Me<sup>II</sup> divalent metal cation (likeCd<sup>2+</sup>) occupies the tetrahedral A-site. Recently, a study of Cd-Ni nanoferrites describing the fabrication, structural and electrical studies has been carried-out by Arshad et. al. [1]. There is a very little work on the elastic properties of Cd-Ni spinel nanoferrites as compared to their dielectric and magnetic properties. In continuation of this work, the investigation of the elastic properties

of Cd<sup>2+</sup> substituted Ni<sup>2+</sup> nanoferrites is reported. In the present work, a technique discussed by Modi et. al. [2] based on IR-spectroscopy was used to investigate the elastic behaviour of spinel nanoferrites. Infrared or IR spectroscopy deals with the IR region of the electromagnetic spectrum with a larger wavelength compared to visible light. The IR spectrum of a sample under study is recorded by passing a beam of IR light through the sample. When the frequency of the IR matches with the vibrational frequency of a bond or collection of bonds, absorption occurs. An instrument called Fourier Transform Infrared Spectroscopy (FTIR) is used to record the wavelength/energy at which the absorption occurs. This technique is mainly used to determine the functional groups in molecules. More detail is available on the Wikipedia. The results of that study are presented in this paper.

#### **2. EXPERIMENTAL**

#### **2.1 Preparation of Materials**

The Cd doped nanoferrites with the formula  $Ni_{1-x}$ Cd<sub>x</sub>Fe<sub>2</sub>O<sub>4</sub> (x= 0.0, 0.2, 0.4, 0.6) were prepared by a co-precipitation technique. The detail is already published by the authors [1] along with dielectric

Received, January 2018; Accepted, June 2018

<sup>\*</sup> Corresponding Author: Asghari Maqsood; asghari.maqsood@mail.au.edu.pk

characterization of these samples. In summary, the prepared material was characterized by the x-ray diffraction technique at room temperature. The lattice was fcc with the lattice constants varying between 8.351 to 5.595 Å depending upon the replacement of  $Cd^{2+}$  in  $Ni_{1-x}Cd_xFe_2O_4$ . Similarly the average crystallite size varied in the range of 21 to 28nm. The x-ray density, porosity, dislocation density, strain on the lattice and specific surface area of the nanocrystallites were also determined using the standard relations [1]. The obtained values of these parameters are tabulated in Table 1.

#### 2.2 Characterization

The x-ray diffraction patterns of the samples were made using  $\text{CuK}_{\text{alpha}}$  radiation source for determining crystal structure and related properties at room temperature. FTIR spectra were recorded from 300 cm<sup>-1</sup> to 900 cm<sup>-1</sup> for all the samples by taking KBr and sample in the ratio 99:1 respectively at room temperature.

#### **3. RESULTS AND DISCUSSION**

#### **3.1 Cation Distribution and Structural Related Properties**

Fig. 1 shows the x-ray diffraction patterns of all the samples and it confirmed the single phase spinel structure. A nonlinear increase in lattice constant is observed with increasing cadmium concentration. This increase in lattice constant is expected in view of the larger size of Cd as compared to Ni and is already discussed by Arshad *et. al* [1]. Here the cation distribution in the Cd-Ni nanoferrites sample



Fig. 1. Indexed XRD pattern of Cd-Ni nanoferrites

is under taken. NiFe<sub>2</sub>O<sub>4</sub> is reported to be inversed spinel structure. In inversed spinel structure the cadmium and nickel ions due to their high crystal field stabilization prefer tetrahedral and octahedral sites respectively while the iron ions are equally distributed among A and B-sites [2]. The distribution of cations for the initial composition was achieved using equations (1-3) and is presented in Table 1.

The average cation radii as a function of  $Cd^{2+}$  concentration of A-site and B-site can be calculated using the relation [3].

$$r_{A} = \left[ x \, r_{Cd(A)} + (1 - x) r_{Fe(A)} \right] \tag{1}$$

$$r_B = \frac{1}{2} \left[ (1-x)r_{Ni(B)} + (1+x)r_{Fe(B)} \right]$$
(2)

where  $r_{Cd}$ ,  $r_{Ni}$  and  $r_{Fe}$  are the radii of Cd, Ni and Fe respectively. Ionic radii values used in the calculations are: Cd<sup>2+</sup> (0.86 Å), Ni<sup>2+</sup> (0.69 Å), Fe<sup>3+</sup> (0.49 Å) and Fe<sup>+2</sup> (0.645 Å) as mentioned by Desai et.al [3].

Using the above values oxygen positional parameter (u) can be estimated through the following expression [3].

$$r_{A}^{=}(u - 0.25) a(1.732) - R_{a}$$
 (3)

where *a* is the measured lattice constant and  $R_{o}$  (1.40 Å) is the oxygen ionic radius.

The lattice constant can be calculated using the formula [4]

$$a_{th} = \left(\frac{8}{3}/\sqrt{3}\right) \left\{ \left[r_A + R_0\right] + \sqrt{3} \left[r_B + R_0\right] \right\}$$
(4)

The observed (a) and theoretical  $(a_{th})$  lattice constants,  $r_{A_{,}}r_{B}$ , u and  $R_{o}$  are tabulated in Table 2. For completeness of the parameters that could be determined from the x-ray diffraction data, the

**Table 1.** Cation distribution for  $(Cd_x^{2+} Fe_{1-x}^{3+})_A [Ni_{1-x}^{2+} Fe_{1-x}^{3+}]_B O_4^{2-}$ 

Composition (x)	A-Site	B-Site
0.0	Fe <sub>1</sub> <sup>3+</sup>	$Ni_1^{2+}Fe_1^{3+}$
0.2	$Cd_{0.2}^{2+} Fe_{0.8}^{3+}$	$Ni_{0.8}^{2+} Fe_{1.2}^{3+}$
0.4	$Cd_{0.4}^{2+} Fe_{0.6}^{3+}$	$Ni_{0.6}^{2+} Fe_{1.4}^{3+}$
0.6	$Cd_{0.6}^{2+} Fe_{0.4}^{3+}$	$Ni_{0.4}^{2+} Fe_{1.6}^{3+}$

$(S.s)$ , avg. cation radius $(r_A)$ , avg. cation radius $(r_B)$ , oxygen position parameter (u), dislocation density and strain on					
the lattice of $Ni_{1-x}$ Cd <sub>x</sub> Fe <sub>2</sub> O <sub>4</sub> nanoferrites. The detail is already published by the authors [1].					
Composition (x)	x=0.0	x=0.2	x=0.4	x=0.6	
Observed lattice constant $a_o(\text{\AA})$	8.351	8.354	8.465	8.595	
Theoretical lattice constant $a_{th}$ (Å)	8.419	8.515	8.610	8.706	
Average crystallite size $\tau_{(311)}$ (nm)	24.24	21.21	28.24	28.18	
Measured density $\rho m$ (g.cm <sup>-3</sup> )	2.173	2.182	2.188	2.191	
X-ray density $\rho x$ (g.cm <sup>-3</sup> )	5.352	5.586	5.604	5.578	
Vol. of the unit cell $(Å)^3$	582	583	607	635	
Specific surface area S.s (m <sup>2</sup> g <sup>-1</sup> )	114.09	129.68	97.22	97.44	
Average cation radius $r_{A}$ (Å)	0.490	0.561	0.633	0.702	
Average cation radius $r_{B}(\text{\AA})$	0.667	0.663	0.658	0.654	
Oxygen position parameter u	0.381	0.385	0.388	0.391	
Dislocation density $(m^2)x10^{15}$	1.17	2.22	1.25	1.26	
Strain %	0.1432	0.1635	0.1229	0.1233	

**Table 2.** X-ray diffraction related parameters: Observed lattice constant (a), theoretical lattice constant  $(a_{th})$ , average crystallite size  $(\tau_{(311)})$ , measured density  $(\rho_m)$ , x-ray density $(\rho_x)$ , volume of unit cell (Vol.), specific surface area (S.s), avg. cation radius  $(r_A)$ , avg. cation radius  $(r_B)$ , oxygen position parameter (u), dislocation density and strain on the lattice of Ni<sub>1-x</sub> Cd<sub>x</sub> Fe<sub>2</sub>O<sub>4</sub> nanoferrites. The detail is already published by the authors [1].

average crystallite size, density related properties, specific surface area, dislocation density and strain on the lattice are also mentioned in the same table. The detailed investigation is already published by our group [1].



# Temperatures

3.2 Force Constants, Elastic Moduli and Debye

The crystal structure of Cd-Ni spinel ferrite is shown in Fig.2 along with A and B- sites. The distribution of cations is tabulated in Table1 for different values of 'x'. Fig. 3 shows the FTIR spectra of pure Ni-Cd ferrite and the composition with x = 0.2, 0.4 and 0.6 in the range 300 cm<sup>-1</sup> to 900 cm<sup>-1</sup>. The absorption band at 397 cm<sup>-1</sup> is attributed to stretching vibration of Fe-O bond at octahedral sites. The absorption

**Fig. 2.** Diagram of crystal structure of Cd- Ni spinel ferrite, showing tetrahedral (A) and octahedral (B) sites. Ref: Crystallization in Spinel Ferrite Nanoparticles, Advances in Crystallization Processes, Yitzhak Mastai (Ed.), ISBN: 978-953-51-0581-7, Intech



Fig. 3. FTIR spectrum of Cd-Ni nanoferrite.

band near 580 cm<sup>-1</sup> is characteristics of intrinsic stretching vibration of metal-oxygen (Me-O) bonds present at tetrahedral sites [3, 5]. However, the absorption bands at tetrahedral and octahedral sites are shifted to slightly higher wave number with increasing the cadmium concentration and may be due to distortion in the structure because the lattice constant increased.

Using the values of vibration frequencies, force constant can be estimated [5]. Force constant (k) is the second derivative of potential energy with respect to inter nuclear separation. They are associated with the unit displacement of a Me-O in the tetrahedral A-site and octahedral B-sites. The force constant for A-site  $(k_i)$  and B-site  $(k_o)$  are estimated using the relations [2, 6].

$$k_t = 7.62 \times M_1 \times v_1^2 \times 10^{-7} \, N/m \tag{5}$$

$$k_o = 10.62 \times \left(\frac{M_2}{2}\right) \times v_2^2 \times 10^{-7} N/m$$
 (6)

where 
$$M_1$$
 and  $M_2$  are estimated from the

cation distribution equations and are the molecular weight of cations on tetrahedral A and octahedral B-sites respectively. The values of force constants are shown in Table 3. It can be observed that the values of force constant  $k_i$  and  $k_o$  both increased with the increase in cadmium concentration. This increase in the force constants may be due to the difference of ionic radii of Cd<sup>2+</sup>, Ni<sup>2+</sup> and Fe<sup>3+</sup> ions. The combined radii of Cd<sup>2+</sup> and Ni<sup>2+</sup> are greater than the Fe<sup>3+</sup> ion. A similar result has been discussed by Modi et. al.[2]. They introduced a new technique to study the elastic properties of spinel nano ferrites based on infrared spectroscopy. The bulk modulus (B), the elastic or the Young's modulus (Y) and Rigidity (R) modulus as well as Debye temperature  $(\theta_{D})$  and Poisson's ratio ( $\sigma$ ) of Ni<sub>1x</sub>Cd<sub>x</sub>Fe<sub>2</sub>O<sub>4</sub> where x = 0.0, 0.2, 0.4, 0.6, were calculated from the longitudinal elastic wave velocity V<sub>1</sub> and transverse elastic wave velocity  $V_T$  and x-ray density, using the following relations taken from [3,5,7]. The results are indicated in Table 3.

The bulk modulus (B) of solids in-terms of

**Table 3.** FTIR related elastic parameters: tetrahedral band position  $(v_1)$ , octahedral band position  $(v_2)$  tetrahedral force constant  $(k_1)$ , octahedral force constant  $(k_0)$ , average force constant  $(k_{avg})$ , longitudinal elastic wave velocity  $(v_1)$ , transverse elastic wave velocity  $(v_1)$ , mean elastic wave velocity  $(v_M)$ , mean atomic volume  $(v_A)$ , bulk modulus (B), rigidity modulus (R), Young's modulus (Y), Poisson ratio  $(\sigma)$  and Debye temperature  $(\theta_D)$  of Ni<sub>1,2</sub> Cdx Fe<sub>2</sub>O<sub>4</sub>.

Composition (x)	x=0.0	x=0.2	x=0.4	<i>x=0.6</i>
Tetra. band position $v_1 \times 10^2 \text{ (m}^{-1}\text{)}$	580.15	583.3	587.85	589.25
Octa. band position $v_2 \times 102 \text{ (m}^{-1}\text{)}$	393.50	396.87	398.62	399.30
Tetra. force constant $k_{t} \times 102 \text{ (Nm}^{-1}\text{)}$	1.431	1.739	2.064	2.375
Octa. force constant $k_{o} \times 102 \text{ (Nm}^{-1}\text{)}$	0.941	0.952	0.956	0.955
Avg. force constant $k_{avg} \times 102 \text{ (Nm}^{-1)}$	1.186	1.345	1.510	1.663
Long. Elastic wave velocity $v_L$ (ms <sup>-1</sup> )	5150.9	5368.6	5640.6	5888.2
Trans. Elastic wave velocity $v_T (ms^{-1})$	2973.8	3099.5	3256.6	3399.6
Mean Elastic wave velocity $v_m$ (ms <sup>-1</sup> )	3301.5	3441.1	3615.4	3774.2
Mean atomic volume $v_A \times 10^{-6} (m^3)$	6.255	6.268	6.522	6.827
Bulk modulus B (GPa)	142.01	161.02	178.31	193.41
Rigidity modulus R (GPa)	47.34	53.66	59.43	64.46
Young's modulus Y (GPa)	127.71	144.88	160.46	174.04
Poisson ratio σ	0.35	0.35	0.35	0.35
Debye temp. $\theta_{\rm D}({\rm K})$	450.58	469.47	486.59	500.50

stiffness constants may be given by:

$$B = \frac{1}{3} [C_{11} + 2C_{12}] \tag{7}$$

The stiffness constants  $C_{11}$  and  $C_{12}$  were defined by Waldron [5, 8] that with cubic symmetry like in garnets and spinel ferrites  $C_{11} \approx C_{12}$  for isotropic materials therefore,  $B = C_{11}$ . The force constant (k) is associated to the stiffness constant [5, 8]:

$$C_{11} = \frac{k}{a} \tag{8}$$

where *k* is the average force constant estimated as:

$$k_{avg} = \left(\frac{k_t + k_o}{2}\right) \tag{9}$$

The values of the transverse elastic wave velocity  $(V_T)$  and the longitudinal elastic wave velocity  $(V_L)$  can be calculated as follows [5, 8]:

$$V_{\rm L} = (C_{11}/\rho_{\rm X})^{1/2} \tag{10}$$

$$V_{\rm T} = V_{\rm L}/\sqrt{3} \tag{11}$$

The distinction in transverse elastic wave velocity  $(V_T)$  and longitudinal elastic wave velocity  $(V_L)$  as a function of Cd<sup>2+</sup> composition are shown in Table 3. It can be seen that both  $V_T$  and  $V_L$  increase with the substitution of Cd<sup>2+</sup> ions. The values of  $V_T$  and  $V_L$  are used to compute the elastic moduli of the spinel nanoferrites samples using the following relations [5, 8]:

$${}^{3}/_{V^{3}}_{m} = {}^{1}/_{V^{3}}_{L} + {}^{2}/_{V^{3}}_{T}$$
 (12)

$$\theta_D = \frac{h}{k_B} \left[ \frac{3N_a}{4\pi V_A} \right]^{\frac{1}{3}} V_m \tag{13}$$

$$R = \rho_x V_T^2 \tag{14}$$

$$\sigma = \frac{(3B-2R)}{2(3B+R)} \tag{15}$$

$$Y = (1 + \sigma)2R \tag{16}$$

Table 3 shows the measured values of different elastic moduli for the nano-ferrites. It shows that R, B and Y-moduli increased with increasing the  $Cd^{2+}$  concentration. It is due to the strengthening of interatomic binding between the various atoms of the spinel lattice with increasing  $Cd^{2+}$  content. According to Modi *et. al.*[2] the strengthening of

interatomic bonding suggests that the deformation in given solids is difficult and they have the strong affinity to spring (analogues to planes with in a solid held to-gather by atomic bond), back to its equilibrium position [6]. Similar results are reported by Mazen *et. al.* in Li-Mn ferrites [8].

However, the Poisson's ratio ( $\sigma$ ) remains constant for different compositions of ferrite samples and equal to 0.35. This value lies between the range (-1 to 0.5) which is in agreement with the theory of isotropic elasticity as discussed by Wooster [9]. The Debye temperature ( $\theta_D$ ) was estimated by using equation (13) as stated above, where  $V_A$  is the mean atomic volume given by:

$$V_A = \binom{M}{\rho_x}/q \tag{17}$$

'M' is the molecular weight,  $\rho_x$  is the x-ray density, q is the number of atoms in the formula units (i.e. 7) and N<sub>a</sub> is the Avogadro's number.

The measured values are listed in Table 3. The increase in ' $\theta_{D}$ ' suggests that due to cadmium ion substitution the lattice vibrations are hindered. This might be the reason that length of interatomic bonding increase with the replacement of nickel ions by cadmium ions. An increase in the size of the lattice constants was noticed from the x-ray diffraction (Table 1) in confirmation with the above statement. It is interesting to note that the average mean sound velocity increases almost linearly with the Debye temperature (Table 3). Similar results were also reported by Mazen et. al. [8] for Li-Mn ferrite system and Ravinder et. al [10] for Ni-Cd ferrite system. This confirmed the relationship between acoustic parameter (i.e., average mean sound velocity) and the thermodynamic parameter  $(\theta_{p})$  in this system.

#### 4. CONCLUSIONS

The Ni<sub>1-x</sub>Cd<sub>x</sub>Fe<sub>2</sub>O<sub>4</sub> ( $0 \le x \le 0.6$  samples with the step size of 0.2) nano-sized particles were prepared successfully with co-precipitation method and the detail is published by the authors already [1]. The cation distribution has been estimated by x-ray diffraction. The process of functional group has been identified by Fourier transform (FTIR) spectra and the tetrahedral and the octahedral bond positions are determined. The force constants

corresponding to tetrahedral  $(k_t)$  and octahedral  $(k_o)$  positions are estimated. Both  $k_t$  and  $k_o$  increase with Cd concentration. The elastic bulk modulus (B), Young's modulus (Y) and rigidity modulus (R) are dependent on Cd concentration and approximately increase linearly.

#### 5. ACKNOWLEDGEMENTS

The authors would like to acknowledge Pakistan Academy of Sciences (PAS) for providing financial support for this work.

#### **6. REFERENCES**

- Arshad, M., A. Maqsood, I. H. Gul & M. Anisur-Rehman. Fabrication, electrical and dielectric characterisation of Cd-Ni nanoferrites. *Materials Research Bulletin* 87: 177-185 (2017).
- Modi, K.B., M.K. & M.C. Chhantbar. Study of infrared spectroscopy and elastic properties of fine and coarse grained nickel- cadmium ferrites. *Journal* of Materials Science 41: 7308–7318 (2006).
- Desai, S.S., R. A. Pawar, S. S. Jadhav, S. E. Shirsath & S. M. Patange . Role of coupling divalent and tetravalent metal ions on elastic and electric

properties of  $CoFe_2O_4$  ferrites prepared by sol-gel method. *Journal of Superconductor and Novel Magnetism* 29: 2635-2640 (2016).

- Mansour,S.F., M. A. Abdo & M. A.,El-Dek, S.I., Improvement of physic-mechanical properties of Mg-Zn nanoferrites via Cr<sup>3+</sup> doping. *J.Magn. Mag. Mat.* 422:105-111 (2017).
- Waldron, R.D. Infrared spectra of ferrites. *Physical Review* 99: 1727-1735 (1955).
- Naseri, M.G & E. B. Saion. Crystallization in spinel ferrites nanoparticles. Doi: 10.5772/35731.
- Nazir, M.A., Misbah-Ul-Islam, I. Ali, H. Ali, B. Ahmad, S. M. Ramay, N. Raza, M. F. Ehsan & M. N. Ashiq. Structural, electrical and dielectric properties of multiferroic-spinel ferrite composites. *Journal of Electronic Materials* 45: 1065-1072 (2016).
- Mazen, S. A & N. I. Abu-Elsaad. IR spectra, elastic and dielectric properties of Li-Mn ferrites. *ISRN Condensed Matter Physics* 907257 (2012) Doi: 10.5402/2012/907257.
- 9. Wooster, W. A. Physical properties and atomic arrangements in crystals. *Reports on Progress in Physics* 16: 62-82(1953).
- Ravinder, D & T. A. Manga. Elastic behavior of Ni– Cd ferrites. *Materials Letters* 41:254-260 (1999)

Proceedings of the Pakistan Academy of Sciences: A. Physical and Computational Sciences 55 (2): 85 (2018) Copyright © Pakistan Academy of Sciences ISSN: 2518-4245 (print), 2518-4253 (online)

### **Obituary**

### Mr. Tajammul H. Hashmi (1924–2018)

Mr. Tajammul H. Hashmi was born on Ist January 1924, in Gujrat, British India. Mr. Hashmi earned his MS degree from Michigan State University, USA in 1948. His main research areas were bridge design, Road Transport, Utilization of Sub-surface space, Control of water logging Salinity and Soil Mechanics.

Mr. Hashmi was Inter-Regional Advisor, United Nations Department of Technical Cooperation for Development, 1981-1991. Federal Secretary, Government of Pakistan, 1971-1973; Assistant Chief Engineer, Ministry of Railways and Communication, Government of Pakistan, 1949-1970.

Mr. Hashmi was honored with two Civil Awards in recognition to his services by Govt. of Pakistan. He was Past President and Fellow of Institute of Engineers Pakistan; Fellow, American Society of Civil Engineers, Executive Member of International Road Federation. Mr. Hashmi was elected as Fellow Pakistan Academy of Sciences in 1977.

On 24th May 2018, Mr. Hashmi left us all to meet his creator. We will miss him; so will his family. May Allah (SWT)



bless him with highest ranks in Jannah. Ameen

### **Proceedings of the Pakistan Academy of Sciences** Instructions for Authors

Aims and Scope: Proceedings of the Pakistan Academy of Sciences is official journal of the Academy, published quarterly, in English. This open access journal publishes research papers in Engineering Sciences & Technology, Life Sciences, Medical Sciences, and Physical Sciences. State-of-the-art reviews (~20 pages, supported by recent references) summarizing R&D in a particular area of science, especially in the context of Pakistan, and suggesting further R&D are also considered. Manuscripts undergo double-blind review. Authors are not required to be Fellows or Members of the Pakistan Academy of Sciences or citizens of Pakistan.

#### **Manuscript Format**

*Manuscript may contain* Abstract, Keywords, INTRODUCTION, MATERIALS AND METHODS, RESULTS, DISCUSSION (or RESULTS AND DISCUSSION), CONCLUSIONS, ACKNOWLEDGEMENTS and REFERENCES and any other information that the author(s) may consider necessary. The Manuscript sections must be numbered, i.e., 1. INTRODUCTION, 2. MATERIALS AND METHODS, and so on.

Manuscripts, in *Times New Roman*, 1.5-spaced (but single-space the Tables), with line numbering and one-inch margins on all sides on A-4 size paper, should not exceed 20 pages including Tables and Figures. Number manuscript pages throughout. The text (in **Font Size 11**, except for the sections mentioned in **Font Size 10**) must be typed in a single column across the paper width. All Tables and Figures must be placed after the text, i.e., after REFERENCES section.

(a) **Title** of the article (Capitalize initial letter of each main word; font size 16; **bold**), max 160 characters (no abbreviations or acronyms), depicting article's contents; (b) Author' first name, middle initial and last name (font size 12, **bold**), and professional affiliation (i.e., each author's Department, Institution, Mailing address and Email; but no position titles) (font size 12); (c) Indicate the corresponding author with \*; (d) **Short running title**, max 50 characters (font size 10).The **next Page** should start with **Title** of the Article, followed by entire manuscript. **Headings and Subheadings** (font size 11): All flush left

#### LEVEL-1: ALL CAPITAL LETTERS; bold

#### Level-2: Capitalize each main word; bold

#### Level-3: Capitalize each main word; Bold, Italic

# *Level-4*: *Run-in head*; *Italics, in the normal paragraph position. Capitalize the initial word only and end in a colon (i.e., :)*

Abstract (font size 10; max 250 words): Must be self-explanatory, stating rationale, objective(s), methodology, main results and conclusions of the study. Abbreviations, if used, must be defined on first mention in the Abstract as well as in the main text. Abstract of review articles may have variable format.

Keywords (font size 10): Three to eight keywords, depicting the article.

**INTRODUCTION:** Provide a clear and concise statement of the problem, citing relevant recent literature, and objectives of the investigation.

**MATERIALS AND METHODS:** Provide an adequate account of the procedures or experimental details, including statistical tests (if any), in a concise manner but sufficient enough to replicate the study.

**RESULTS:** Be clear and concise with the help of appropriate Tables, Figures and other illustrations. Data should not be repeated in Tables and Figures, but must be supported with statistics.

**DISCUSSION:** Provide interpretation of the RESULTS in the light of previous relevant studies, citing published references.

ACKNOWLEDGEMENTS (font size 10): In a brief statement, acknowledge financial support and other assistance.

**REFERENCES** (font size 10): Cite references in the text **by number only** in **square brackets**, e.g. "Brown et al [2] reported ..." or "... as previously described [3, 6–8]", and list them in REFERENCES section, in the order of citation in the text, Tables and Figures (not alphabetically). Only published (and accepted for publication) journal articles, books, and book chapters qualify for REFERENCES.

List of REFERENCES must be prepared as under:

#### a. Journal Articles (Name of journals must be stated in full)

- 1. Golding, I. Real time kinetics of gene activity in individual bacteria. Cell 123: 1025–1036 (2005).
- 2. Bialek, W. & S. Setayeshgar. Cooperative sensitivity and noise in biochemical signaling. *Physical Review Letters* 100: 258–263 (2008).
- 3. Kay, R.R. & C.R.L. Thompson. Forming patterns in development without morphogen gradients: differentiation and sorting. *Cold Spring Harbor Perspectives in Biology* 1: doi: 10.1101/cshperspect.a001503 (2009).

#### b. Books

- 4. Luellen, W.R. Fine-Tuning Your Writing. Wise Owl Publishing Company, Madison, WI, USA (2001).
- 5. Alon, U. & D.N. Wegner (Ed.). An Introduction to Systems Biology: Design Principles of Biological Circuits. Chapman & Hall/CRC, Boca Raton, FL, USA (2006).

#### c. Book Chapters

- Sarnthein, M.S. & J.D. Stanford. Basal sauropodomorpha: historical and recent phylogenetic developments. In: *The Northern North Atlantic: A Changing Environment*. Schafer, P.R. & W. Schluter (Ed.), Springer, Berlin, Germany, p. 365–410 (2000).
- 7. Smolen, J.E. & L.A. Boxer. Functions of Europhiles. In: *Hematology, 4th ed.* Williams, W.J., E. Butler & M.A. Litchman (Ed.), McGraw Hill, New York, USA, p. 103–101 (1991).

**Tables**, with concise but self-explanatory headings must be numbered according to the order of citation (like **Table 1**, **Table 2**). Round off data to the nearest three significant digits. Provide essential explanatory footnotes, with superscript letters or symbols keyed to the data. Do not use vertical or horizontal lines, except for separating column heads from the data and at end of the Table.

**Figures** may be printed in two sizes: column width of 8.0 cm or page width of 16.5 cm; number them as **Fig. 1**, **Fig. 2**, ... in the order of citation in the text. Captions to Figures must be concise but self-explanatory. Laser printed line drawings are acceptable. Do not use lettering smaller than 9 points or unnecessarily large. Photographs must be of high quality. A scale bar should be provided on all photomicrographs.

**Declaration:** Provide a declaration that: (i) the results are original; (ii) the same material is neither published nor under consideration elsewhere; (iii) approval of all authors has been obtained; and, (iv) in case the article is accepted for publication, its copyright will be assigned to *Pakistan Academy of Sciences*. Authors must obtain permission to reproduce, where needed, copyrighted material from other sources and ensure that no copyrights are infringed upon.

Reviewers: Authors may suggest four relevant reviewers, two local and two from scientifically advanced countries.

Manuscripts must be submitted in Microsoft Word (.doc or .docx format; **pdf** files not acceptable). Figures can be submitted in Word format, TIFF, GIF, JPEG, EPS, PPT.

Manuscripts may be submitted as email attachment at the following email address. In case of any difficulty while submitting your manuscript, please get in touch with:

Editor-in-Chief Pakistan Academy of Sciences 3-Constitution Avenue, G-5/2, Islamabad, Pakistan Email: editor@paspk.org Tel: +92-51-920 7140 Website: www.paspk.org



# CONTENTS

Volume 55, No. 2, June 2018	Page
Review Article	
Significance of Strangeness Conservation/Violation Studies at BESIII — Aneela Amin, Khadija Saeed, Farzana Younas, and Ghalib ul Islam	01
Research Articles	
Analysis of Enterprise Resource Planning Implementation to Identify Critical Factors and Development of a Framework for its Success — Muhammad Umar, Nawar Khan, Rab Nawaz Lodhi, and Chandan Lal	13
Identification of Failure Modes on Electrostatic Chuck through Reliability Centered Maintenance: A Case Study — Mehroz Sana, Umer Saleem, Muhammad Farooq, Adnan Qamar, Muhammad Mehmood A Bhutta, and Saad Zafar	21
A Quasi Lindley Pareto Distribution — Asad Ali, Qaisar Rashid, Muhammad Zubair, and Muhammad Tariq Jamshaid	33
Managing Disorientation of Time and Place in Dementia Patients Using Bluetooth Sensors — Sarwat Iqbal, Kamran Ahsan, Muhammad Azhar Hussain, Adnan Nadeem, Muhammd Saeed, and Sohaib Ahmed	41
Didactic Strategy for Learning Theory of Automata & Formal Languages — Muhammad Shumail Naveed, and Muhammad Sarim	55
Application of Pulse Electric Field for Chemical Extraction Process — Prima Asmara Sejati, Ardhi Wicaksono Santoso, Rella Mareta, and Arief Budiman	67
Physical, Elastic and Thermal Characterization of Ni-Cd Nano Ferrites — <i>Asghari Maqsood, and M. Arshad</i>	77
Obituary	
Mr. Tajammul H. Hashmi	85
Instructions for Authors	86

PAKISTAN ACADEMY OF SCIENCES, ISLAMABAD, PAKISTAN

HEC Recognized, Category Y; PM&DC Recognized

Website: www.paspk.org