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# Proceedings for International Conference on Frontiers in Engineering, Science & Technology: Global Perspective (FESTGP-2025)



Editors: Dr. Rakesh Kumar & Amit Dhar



Excellent Publishers

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# **PROCEEDINGS**

of  
International Conference  
on

## **Frontiers in Engineering, Science & Technology: Global Perspective (FESTGP-2025)**

6<sup>th</sup> & 7<sup>th</sup> August, 2025

Organised by  
Department of Mechanical Engineering  
Elite College of Engineering

Approved by AICTE & Affiliated to MAKAUT  
Accredited with B+ Grade by NAAC  
Sodepur, Kolkata, West Bengal, India

Editors: Dr. Rakesh Kumar and Amit Dhar

## Preface

It is with immense pride and enthusiasm that we present the souvenir of the **International Conference on Frontiers in Engineering, Science & Technology: Global Perspective (FESTGP-2025)**, organized by the Department of Mechanical Engineering, Elite College of Engineering, Sodepur, on **6th and 7th August, 2025**.

In a time marked by rapid technological evolution and global challenges, this international conference serves as a vibrant platform to bring together scholars, researchers, academicians, industry professionals, and students from diverse disciplines to share their insights, experiences, and innovations. The core aim of FESTGP:2025 is to foster interdisciplinary dialogue, encourage collaborative research, and provide fresh perspectives on the ever-expanding frontiers of engineering, science, and technology.

This souvenir is a humble reflection of the vision and dedication of the organizing team, capturing the essence of the conference, from thought-provoking keynote addresses and technical sessions to the collective spirit of innovation and knowledge dissemination. It also includes valuable messages from our esteemed dignitaries, offering encouragement and insight into the importance of academic and industry collaboration.

We sincerely hope that this conference and its proceedings contribute meaningfully to the academic community and inspire further research and innovation. We extend our heartfelt gratitude to all the contributors, sponsors, and participants who made this event possible.

**Let this conference be a step forward in shaping a better, knowledge-driven future.**

**With warm regards,**

*Rakesh Kumar, Editor*

*Amit Dhar, Editor*

# Acknowledgement

The Organizing Committee of FESTGP -2025 would thankfully acknowledge the following organizations for providing the necessary financial and in-kind supports to successfully organize this International Conference:

- Pinnacle Educational Trust, Canal Street, Kolkata, INDIA
- Elite Institute of Engineering and Management, Sodepur, Kolkata, INDIA

Ref. No. ECE/FESTGP/2025/001

Date: 25<sup>th</sup> July, 2025

## Message from the Director (Academics & HR)

On behalf of ELITTE COLLEGE OF ENGINEERING, it is my great pride and privilege to extend a warm and heartfelt welcome to all delegates, speakers, and participants to the International Conference on Frontiers in Engineering, Science & Technology: Global Perspective (FESTGP:2025) organized by the Department of Mechanical Engineering, a national gathering dedicated to aspiring engineering graduates and also for professionals who are already engaged in advancing innovation in mechanical engineering.

Presently, we stand at an important crossroads. Our nation faces challenges, but equally, we hold tremendous opportunities. It is through forums like this, where brilliant minds come together, that we find solutions, share ideas, and inspire one another to build a brighter future.

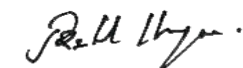
Since its inception, Elitte College of Engineering has strived for academic excellence and the holistic development of students. With a strong foundation in technical education and a commitment to nurturing future technocrats, we are proud to host this prestigious conference as part of our mission to encourage knowledge-sharing and innovation. FESTGP:2025 serves as a valuable platform for the convergence of ideas and collaborative research

Over the next two days, we will engage in insightful discussions, thought-provoking panels, and valuable networking opportunities. I encourage you all to participate wholeheartedly, to ask questions, to challenge each other, and above all, to collaborate. Your presence here is a testament to your commitment to excellence and to the growth of our nation.

I would like to extend my sincere gratitude to our esteemed speakers, panellists, sponsors, and the organizing committee, whose tireless efforts have made this event possible.

Once again, welcome to the International Conference on Frontiers in Engineering, Science & Technology: Global Perspective (FESTGP:2025) and let us make these days memorable, impactful, and transformative. Together, we can pave the way for progress and innovation.

Thank you, and I wish you all a successful and enriching conference.



*Dr. Bazlul Haque*  
Chief Patron, FESTGP-2025  
Director (Academics & HR)  
Elitte College of Engineering

Ref. No. ECE/FESTGP/2025/002

Date: 25<sup>th</sup> July, 2025

## Message from the Director (Operations)

It gives me immense pleasure to share that the Department of Mechanical Engineering, Elitte College of Engineering, is organizing an International Conference on “**Frontiers in Engineering, Science & Technology: Global Perspective (FESTGP:2025)**” on the 6th and 7th of August, 2025.

As a part of our continuous effort to promote innovation, interdisciplinary research, and global academic exchange, this conference aims to bring together leading researchers, academicians, and industry experts from across the world. Their insights and deliberations will certainly enrich our academic environment and offer novel perspectives on current and emerging challenges in the field of engineering and technology.

I am confident that this conference will act as a catalyst in fostering collaboration across disciplines and borders, and will pave the way for a future-ready generation of engineers. I extend my best wishes to the organizing team, participants, and collaborators for making FESTGP:2025 a grand success.

Best wishes.



*Mr. Sajal Ghosh*  
Chief Patron, FESTGP-2025  
Director (Operations)  
Elitte College of Engineering

Ref. No. ECE/FESTGP/2025/003

Date: 25<sup>th</sup> July, 2025

## Message from the Advisor, ECE

I am glad to know that the International Conference on Frontiers in Engineering, Science & Technology: Global Perspective (FESTGP:2025), is scheduled to be organized by the Department of Mechanical Engineering, Elitte College of Engineering from 06/08/2025 to 07/08/2025.

It is my understanding that through this unique academic platform like FESTGP:2025, a gateway shall be opened for interactive sessions which shall open the vista for innovating thoughts, collaborative research activities and many more endeavours to pave the way for rapid societal transformation so far future engineering and science is concerned.

Beyond the classroom activities, this conference will cultivate critical thinking amongst faculty and students which shall help our college to attain a position from where we can play a lead role in developing contemporary science and technology of our country.

I extend my heartfelt congratulations to the organizing committee for their dedication and vision. I am confident that the outcomes of this conference will definitely inspire further academic initiatives and set a benchmark for future endeavours.

With best wishes for a successful and fruitful conference.



*Prof. (Dr.) U.C. Kumar*  
Patron, FESTGP - 2025  
Advisor  
Elitte College of Engineering

Ref. No. ECE/FESTGP/2025/004

Date: 25<sup>th</sup> July, 2025

## Message from the Principal, ECE

It gives me great pleasure to welcome all the participants to the **International Conference on Frontiers in Engineering, Science and Technology: Global Perspective (FESTGP-2025)** at **Elite College of Engineering (ECE), Sodepur, Kolkata, India** — an institution that continually strives for excellence in technical education to contribute to a better and more sustainable society.

ECE has always demonstrated a strong commitment to disseminating the latest developments in engineering, science, and technology among enthusiastic learners and researchers. In continuation of this vision, we are proud to host this international conference, bringing together eminent national and international experts who have graciously agreed to share their insights and experiences.

I am confident that the technical deliberations and interactions throughout the event will substantially enhance the knowledge and professional competence of all participants.

I sincerely hope FESTGP-2025 serves as a valuable platform for both knowledge sharing and knowledge gathering, and I extend my best wishes for the grand success of the conference in every aspect.

With Best Compliments,



*Prof. (Dr.) Krishna Hazra*

Chairperson, FESTGP – 2025

Principal,

Elite College of Engineering

Ref. No. ECE/FESTGP/2025/005

Date: 25<sup>th</sup> July, 2025

## Message from the Convener

It is a great honour to extend a warm welcome to all of you to the international conference on *“Frontiers in Engineering, Science and Technology: Global Perspective (FESTGP-2025)”*, proudly hosted by the **Department of Mechanical Engineering** at **Elitte College of Engineering**, Kolkata.

As the convener of this prestigious event, I am truly delighted to witness such a distinguished gathering of experts, scholars, and participants, united by a shared passion for innovation and technological advancement.

This conference is dedicated to exploring the latest breakthroughs in engineering and aims to bridge the gap between academic research and industrial applications. It provides a comprehensive platform for researchers, industry professionals, and academicians to engage in meaningful dialogue on cutting-edge developments in engineering field. I am confident that the knowledge and insights exchanged during this event will inspire us all to deepen our exploration and drive innovation forward.

I would like to express my heartfelt gratitude to all the speakers, participants and industry delegates for their unwavering dedication and commitment to making this conference a resounding success. Your contribution are invaluable, and I am certain that this event will leave a lasting impact on each one of us.

Wishing everyone a truly enriching and intellectually stimulating experience throughout the course of the conference.



*Dr. Rakesh Kumar*  
Convener, FESTGP – 2025  
Professor & Head,  
Department of Mechanical Engineering  
Elitte College of Engineering

# Message from the Guest of Honour



Government of West Bengal

## Directorate of Technical Education

Bikash Bhawan (10<sup>th</sup> floor), Salt Lake, Kolkata-700 091

Phone & Fax: (033) 2334-7077, mail: [techedndirectoratewb@gmail.com](mailto:techedndirectoratewb@gmail.com)

No : 496(T)

Date : 28/7/25

From : Director of Technical Education, W.B.

To : Dr. Rakesh Kumar  
Professor & Head (Department of Mechanical Engineering)  
& Convener of FESTGP-2025  
Elite College of Engineering, Kolkata

### MESSAGE

It gives me immense pleasure to know that Elite college of Engineering is going to organize an International Conference on "Frontiers in Science, Engineering and Technology: Global Perspective" (FESTGP-2025) during 6<sup>th</sup> to 7<sup>th</sup> August, 2025 at College Campus.

This initiative to bring together academicians, researchers and industry experts on a common platform is highly commendable. Such conferences play a pivotal role in fostering innovations encouraging collaborative research and show-causing the latest developments in emerging technologies. I am confident that the deliberations and exchanges of ideas during this event will contribute significantly to the advancement of scientific and engineering knowledge.

I extend my heartfelt wishes to the organizers, participants and all stakeholders for the grand success of the conference. May this academic endeavor achieve its intended objectives and inspire future initiations of similar kind

Yours faithfully,  
  
Director of Technical Education  
Govt. of West Bengal

Sunday  
28/07/25

## **Organizing Committee**

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- Dr. Bazlul Haque, Director (Academics & HR)
- Mr. Sajal Ghosh, Director (Operations)

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## Keynote Talk Abstract

# DRY MACHINING OF CRYOGENICALLY TREATED Ti-6Al-4V ALLOY: A SUSTAINABLE ENGINEERING APPROACH

**Dr. Mithilesh K. Dikshit\***

*Department of Mechanical and Aerospace Engineering, Institute of Infrastructure, Technology, Research and Management, Ahmedabad  
Center for Aerospace and Defence, IITRAM, Ahmedabad*

*\*Corresponding author*

**ABSTRACT** In recent years, the pursuit of environmentally benign and energy-efficient manufacturing practices has gained momentum, especially in high-performance sectors such as aerospace, automotive, biomedical, and defense industries. Among various strategies, the adoption of dry machining the elimination of conventional cutting fluids has emerged as a viable and sustainable alternative to traditional machining methods. However, the efficacy of dry machining is significantly influenced by the material properties and cutting tool performance, particularly when dealing with difficult-to-machine alloys such as Ti-6Al-4V. Ti-6Al-4V, a widely used  $\alpha+\beta$  titanium alloy, is renowned for its excellent mechanical properties, corrosion resistance, and biocompatibility. Nonetheless, its low thermal conductivity, high chemical reactivity, and poor machinability result in elevated cutting temperatures, rapid tool wear, and suboptimal surface integrity during conventional machining processes. These challenges are exacerbated under dry cutting conditions due to the absence of lubrication and heat dissipation provided by cutting fluids. To address these limitations, cryogenic treatment of the workpiece material has been proposed as a method to enhance its machinability. Cryogenic treatment involves subjecting the material to sub-zero temperatures (typically  $-193\text{ }^{\circ}\text{C}$  using liquid nitrogen) for an extended period, leading to microstructural modifications such as grain refinement, stress relief, and increased hardness and wear resistance. These improvements in material properties may contribute to better thermal and mechanical behavior during dry cutting, potentially enabling enhanced tool life, lower cutting forces, and improved surface finish. Several studies have investigated the cryogenic treatment of cutting tools and work materials independently, with promising results. However, limited attention has been paid to the synergistic integration of cryogenically treated Ti-6Al-4V alloy under dry machining conditions. This research aims to fill this gap by systematically evaluating the machinability of cryogenically treated Ti-6Al-4V during dry turning/milling operations.

**KEYWORDS:** Ti-6Al-4V, Cryogenic treatment, corrosion resistance, and biocompatibility.

# 1. Green Cement

Laboni Saha<sup>1</sup>, Anik Pramanik<sup>1</sup>, Niladri Karmakar<sup>1</sup>, Bikash Bairagi<sup>1</sup>,  
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**ABSTRACT** Concrete remains the most widely used construction material worldwide, largely due to its mechanical strength, durability, and cost-effectiveness. However, the environmental impact of cement production—the primary binder in concrete—has raised significant global concerns. The manufacturing of Ordinary Portland Cement (OPC) contributes approximately 5–7% of total anthropogenic CO<sub>2</sub> emissions, depletes non-renewable resources such as limestone, and generates considerable industrial waste, including cement kiln dust. To address these environmental challenges, the present experimental work explores the development of green cement by partially replacing conventional cement with eco-friendly waste materials that are rich in calcium carbonate and pozzolanic compounds. The materials selected for this investigation include eggshell powder ash, banana leaf ash, and rice husk ash. These waste-derived materials were used in specific combinations and proportions to replace cement at various percentages. In an earlier attempt, fine aggregate replacement was examined; however, due to poor setting and disintegration of test cubes, the focus was shifted toward cement replacement. This study aims to assess the feasibility and strength performance of concrete incorporating these alternative binders, with emphasis on compressive strength. The findings are expected to contribute to the development of sustainable construction materials and the conservation of natural resources.

**KEYWORDS:** Ordinary Portland cement (OPC), Limestone, Eggshell Powder Ash, Rice Husk Ash (RHA), Banana Leaf Ash (BLA).

## Introduction

Concrete is the most extensively utilised construction material globally, owing to its remarkable mechanical properties, cost-effectiveness, and versatility in form and size. Its ability to be molded into various configurations has made it essential for modern infrastructure. Annually, an estimated 6 billion tonnes of conventional concrete are produced worldwide. A critical component of this material is Ordinary Portland Cement (OPC), which has served as the primary binder in concrete for over two centuries, enabling the formation of a solid, load-bearing matrix.

Among global producers, China remains the largest manufacturer of both concrete and cement. In 2012, China's cement production reached 2.15 billion metric tonnes. In comparison, India—

ranked second—produced only 8.6% of China’s output, while the United States, the third-largest producer, generated 29% of India’s production volume. The total global volume of cement production in 2016 was approximately 4174 million tonnes, marking a 24.96% increase over the 2010 output. By August 2020, China alone accounted for 22,489 thousand tonnes of cement, while Malaysia reported 1,866 thousand tonnes by July 2020.

The continuous growth in cement demand has significantly increased the extraction of natural aggregates, particularly limestone, which is a vital raw material in the production of Portland cement. Cement production involves heating limestone and other materials to 1400–1450 °C in a rotary kiln, typically fueled by coal, oil, or other fossil fuels. During this process, calcium carbonate ( $\text{CaCO}_3$ ) decomposes into calcium oxide ( $\text{CaO}$ ) and carbon dioxide ( $\text{CO}_2$ ). The  $\text{CaO}$  then reacts with other materials to form clinker, which is subsequently ground with gypsum to produce cement (Glavind, M., 2009).

Environmental concerns regarding cement manufacturing have intensified due to its contribution to global carbon emissions. According to Stajanča M. and Eštoková A. (2012), the cement industry is responsible for approximately 5–7% of total anthropogenic  $\text{CO}_2$  emissions. Moreover, it generates millions of tonnes of cement kiln dust annually, contributing to air pollution and respiratory health risks. The sector also consumes vast amounts of non-renewable natural resources such as limestone, clay, and sand. As highlighted by Tianming Gao et al. (2016), the industry faces critical challenges, including escalating energy costs, emission reduction mandates, and the limited availability of high-grade raw materials.

In response to these environmental and resource-based challenges, the present experimental work investigates the feasibility of utilizing alternative waste materials rich in calcium carbonate as partial replacements for cement. Materials such as eggshell powder ash, rice husk ash, and banana leaf ash have been selected for their chemical compatibility and pozzolanic potential. These waste-derived materials are blended in specific proportions—for instance, combining eggshell ash with rice husk ash or banana leaf ash with rice husk ash—to partially substitute cement at varying percentages (e.g., 5%, 10%, etc.).

In a prior stage of this research, an attempt was made to develop green concrete by replacing fine aggregates with selected waste materials. However, during the cube casting process, it was observed that the concrete failed to achieve sufficient initial setting even after 24 hours. An additional 24-hour period did not improve the condition, as the cubes remained internally moist and structurally weak. Subsequent immersion in water revealed further disintegration, with visible particle dispersion. Due to these challenges, the research focus was revised, and the study was accordingly renamed “**Green Cement.**”

## Methodolgy

As outlined in the introduction, the present experimental work involves the utilization of waste-derived materials as partial replacements for cement. The selected materials include eggshell powder ash, banana leaf ash, and rice husk ash. This section presents a detailed overview of:

- i) the preparation methods of these materials,
- ii) the experimental procedures adopted in the study, and
- iii) the various tests conducted, with a particular emphasis on the compressive strength test of concrete cubes.

**a) Eggshell Powder Ash :** In 2004, ASTM International updated its C150 standard to permit the use of up to 5% limestone by weight in ordinary Portland cement. Hawkins et al. (2003) found that adding up to 5% limestone to Portland cement does not have any negative impact on its performance. Additionally, Bentz et al. (2009) reported that a higher percentage of limestone can also be used in concrete when the water-to-cement (w/c) ratio is kept low. Amarnath Yerramala(2014) stated that Eggshell, which is rich in calcium, is a type of poultry waste and has a chemical composition very similar to that of limestone. Using eggshell waste as a partial replacement for cement in concrete can offer several advantages—such as reducing cement consumption, conserving natural limestone resources, and making productive use of waste materials. According to studies, the annual generation of eggshell waste is around 190,000 tonnes in India, 150,000 tonnes in the United States, and 11,000 tonnes in the United Kingdom. There is a specific method for preparing eggshell powder ash.

### i) Preparation of Eggshell Powder Ash :-

Raw eggshell goes through a certain process before it can be used to replace cement. First, the eggshells are cleaned with normal water. Aside from cleaning the eggshell from impurity, this process also removes the thin membrane of the eggshell. After cleaning, the eggshells are dried. It is recommended to dry the eggshell as early as possible. The method of drying varies between researches. For some, the eggshell can be dried by simply leaving it out to the sun. The duration of exposure ranges from one day to five days. Apart from air-drying, using oven to dry the eggshell was also attempted. The eggshells were dried in 1800° for 24 hours with the use of hot air oven. However, an oven of 105° is sufficient for the same duration. In another experiment, the eggshells were prepared by heating at 110° for only 12 hours.



The next step is to crush and grind the eggshells into powder form. Many studies do not detail the tools and methods used for this process, but it is reported that the eggshell can be grinded with steel drum or equipment in a flour mill. To process the eggshell by hand, pestle and mortar is a viable grinding option.



Finally, the eggshell powder is sieved to micron size and is ready to be introduced with cement. The sieve size varies between researches, but many studies uses 90um sieve for this process. A smaller size of 75um size has also been studied, and a bigger size of 2.36mm has also been attempted with similar (B.W. Chong et al, 2020).



After that, to produce ash from eggshell powder, it is burned using a Muffle Furnace at a temperature of 550–600°C.



**b) Rice Husk Ash :** Asia leads global rice production, primarily because rice is one of the few food crops that can thrive in the flooded conditions of tropical regions during the rainy season. In this region, rice mills tend to be large-scale operations, which makes the disposal of rice husks a major challenge. Rice husks are the protective outer layer of rice grains, shielding them from physical damage as well as from pests, insects, and diseases during the growing phase. These husks are removed from the grains during the milling process (Solomon Asrat Endale et al., 2023). Ragini Patil et al. (2014) states that Rice Husk contains a high amount of ash, typically ranging from 14% to 25%. When burned, the resulting rice husk ash (RHA) is extremely rich in silica, with a content as high as 90–98%. Because of this high silica content, rice husk ash can be effectively used as a fertilizer in agriculture or as a supplementary material in the production of cement and concrete.



**i) Preparation of Rice Husk Ash :-** Rice husk ash (RHA) is typically produced as an agricultural by-product by burning rice husk under controlled temperatures below 800 °C. This process yields approximately 25% ash that contains about 85% to 90% amorphous silica and around 5% alumina, making it a highly pozzolanic material. Due to the porous and cellular structure of RHA particles, concrete made with RHA tends to require more water to achieve the same consistency.



In one study, RHA obtained from Indian paddy, when reburnt at 650°C for 1 hour, resulted in a highly pozzolanic material with 87% amorphous silica and a low loss on ignition (2.1%). There are two main methods for burning rice husk: **controlled** and **uncontrolled**. Initially, rice husk was burned using the open heap method in villages, at temperatures between 300°C and 450°C. However, this uncontrolled burning often left a large amount of unburnt carbon due to incomplete combustion below 500°C.



In contrast, **controlled burning** at temperatures between 550°C and 700°C for about 1 hour ensures better combustion and allows the silica in the ash to remain in the amorphous phase, which is desirable for pozzolanic activity. The duration of burning can vary from 15 minutes to 24 hours, but several studies suggest that the optimal condition is **burning at 680°C for 6 hours** to produce high-quality RHA.



**c) Banana Leaf Ash** :According to S.Sakthivel et al.(2019), Banana Leaf Ash (BLA), an agricultural waste by-product, has gained attention in recent years as a sustainable alternative material in the construction industry. With the global shift toward environmentally friendly practices, the use of such waste-derived materials is increasingly being explored to minimize environmental degradation. BLA exhibits pozzolanic characteristics, similar to those found in Ordinary Portland Cement (OPC), making it a promising candidate for partial cement replacement. BLA is incorporated into cement at varying replacement levels of 0%, 2%, 4%, and 6%. The objective is to evaluate the

influence of BLA on the strength development of concrete and to assess its potential as a viable cementitious material for sustainable construction applications.

### i) Preparation of Banana Leaf Ash :-

The production of Banana Leaf Ash (BLA) was carried out through controlled combustion at a temperature of approximately 650°C for a duration of 75 minutes. The burning process adhered to established guidelines, maintaining a controlled heating rate of 10°C per minute to ensure consistency. To optimize the amorphous silica content, both the temperature and combustion duration were kept constant throughout the process. Post-combustion, the ash was ground using a ball mill with a 35L capacity operating at 55rpm for 30 minutes. The resulting powder was then sieved through a 200 micron sieve, and only particles smaller than 75 µm were utilized for cement replacement purposes (Md.Hamidul Islam et al, 2024).

PARAMETERS	COMPOSITION OF BANANA LEAF ASH %
Silicon dioxide(SiO <sub>2</sub> )	48.7
Iron oxide(Fe <sub>2</sub> O <sub>3</sub> )	1.4
Aluminum oxide(Al <sub>2</sub> O <sub>3</sub> )	2.6
Sodium oxide(Na <sub>2</sub> O)	0.21
Loss of ignition	5.06



### ii) Experimental procedures

To evaluate the strength development and performance of concrete incorporating waste materials such as eggshell powder ash, rice husk ash, and banana leaf ash as partial replacements for cement, a series of tests were conducted. These tests were designed to assess both the fresh and hardened properties of the modified concrete. The following three test procedures were carried out in accordance with relevant Indian Standards:

- i) Workability Test:**

The workability of fresh concrete was assessed using the slump test, conducted as per the specifications outlined in IS 1199 (Part 2): 2018. This test was performed immediately after mixing all constituent materials to evaluate the ease of placement and consistency of the concrete mix.

- ii) Non-Destructive Test (NDT):**

To determine the in-situ compressive strength of the concrete without causing any structural damage, a rebound hammer test was performed following IS 13311 (Part 2): 1992. This test provided an estimate of the surface hardness and uniformity of the concrete.

- iii) Compressive Strength Test:**

The compressive strength of the concrete specimens was measured using a Compression Testing Machine (CTM) in accordance with IS 516 (Part 1): 1959. Cube specimens were tested

after being cured for a period of 28 days to determine the ultimate load-bearing capacity of the modified concrete.

### iii) Various Tests

- **Workability of Eggshell Powder :-**

The workability of eggshell concrete (ESC) is lower compared normal Portland cement concrete (PC). Increase in percentage of cement by eggshell also reduces the workability of ESC. The workability of concrete is obtained by slump test in compliance with ASTM C 143. Jhatial et al. stated that this trend was attributed to the high water absorption of eggshell powder (esc) which absorbs the water required for achieving a high workability. Apart from that, the particle size of the eggshell powder influences workability. At a finer grind, eggshell powder has a larger surface water, so it absorbs more water and reduces the workability of the mix more adversely. This had been tested in an experiment involving eggshell powder to 50 $\mu$ m and 100 $\mu$ m. The reduction is more prominent the more percentage of eggshell is used as cement replacement. Eggshell affects workability in mortar mix in a similar way as concrete mix (Sharma S, 2018) .



- **Workability of Rice Husk Ash :-**

Research conducted by Arum, Kumapayi, and Aralepo(2013) demonstrated that the workability of concrete increases with higher percentages of rice husk ash (RHA) replacement. This finding suggests that concrete incorporating Ordinary Portland Cement (OPC) and RHA exhibits greater workability compared to the control mix. The recorded slump values ranged between 200–240 mm, with negligible bleeding observed in the control mix. Notably, mixes containing RHA showed no signs of bleeding or segregation, indicating improved cohesion and stability of the fresh concrete. Furthermore, the fresh density of concrete incorporating RHA ranged between

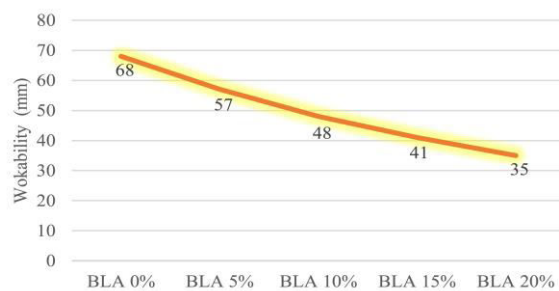
2253 to 2351kg/m<sup>3</sup>. This reduction in density is attributed to the lower specific gravity of RHA, which decreases the overall mass per unit volume of the mix. The use of finer RHA particles contributed to the formation of a denser concrete matrix, enhancing the microstructure and uniformity of the mix (Ghassan Abood Habeeb & Hilmi Bin Mahmud, 2010).



- **Workability of Banana leaf Ash :-**

A slump test was performed for each concrete mix with varying cement-to-BLA ratios to assess the consistency and workability of the mixtures incorporating Banana Leaf Ash (BLA). No superplasticizers were introduced to enhance slump, ensuring that the observed results reflected the natural behavior of the BLA-modified concrete. Visual observations from the slump tests, as depicted in the accompanying figures, revealed a consistent reduction in workability with increasing BLA content.

This decline in workability is primarily attributed to the higher specific surface area of BLA particles, which increases the water demand. A portion of the mixing water, essential for proper hydration of cement, was absorbed by BLA particles, thereby reducing the effective water available in the mix. Moreover, the filling effect of the fine BLA particles, in combination with their irregular shape, contributed to decreased inter-particle spacing and greater internal friction, ultimately resisting the flow of fresh concrete. As a result, additional water was required to achieve the desired workability in concrete mixes with higher BLA content (Shahzeb Bhutto et al. 2024).



### 3. Results and observations

#### Rebound hammer Test :

Initially, the Rebound Hammer Test was conducted on standard M30 grade concrete specimens, followed by testing on concrete cubes in which fine aggregate (sand) was partially replaced with 2% rice husk ash and 2% eggshell powder ash. The results of these tests are presented below.

RHT Value for Replaced M30 Grade Cube

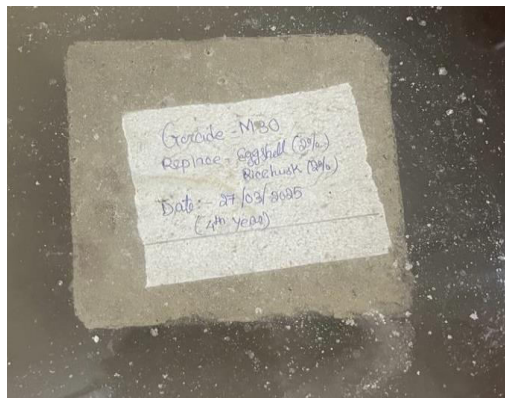
Specimen No.	RHT Value (Front Side)	RHT Value (Back Side)
1	12	12
2	18	16.5
3	23	23
4	21	22



**Rebound Hammer**

#### Compressive Strength Test :

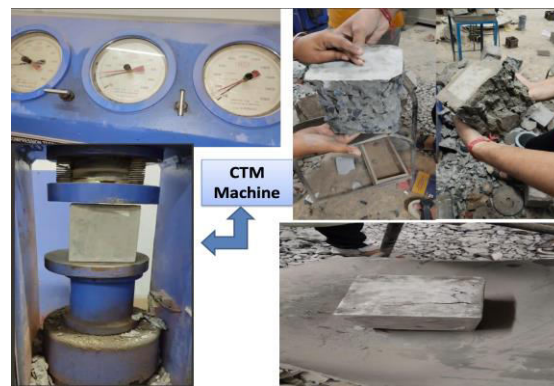
A compressive strength test was first conducted on conventional M30 grade concrete to establish a reference point for performance evaluation. Following this, an experimental mix was prepared by partially replacing fine aggregate (sand) with 2% rice husk ash and 2% eggshell powder ash. Concrete cubes using this mix were cast and tested to assess their structural performance. However, it was observed that the concrete showed poor initial setting behaviour within 24 hours, raising concerns about moisture retention and delayed hardening.



To explore the cause of the abnormal setting behaviour, further trials were conducted using two separate mixes. In these, 2% of the cement was individually replaced—one with rice husk ash and the other with eggshell powder ash. This approach was designed to isolate the effect of each material on the moisture retention properties and setting characteristics of the concrete. The comparative analysis of these mixes helped provide a clearer understanding of how each additive behaves independently.

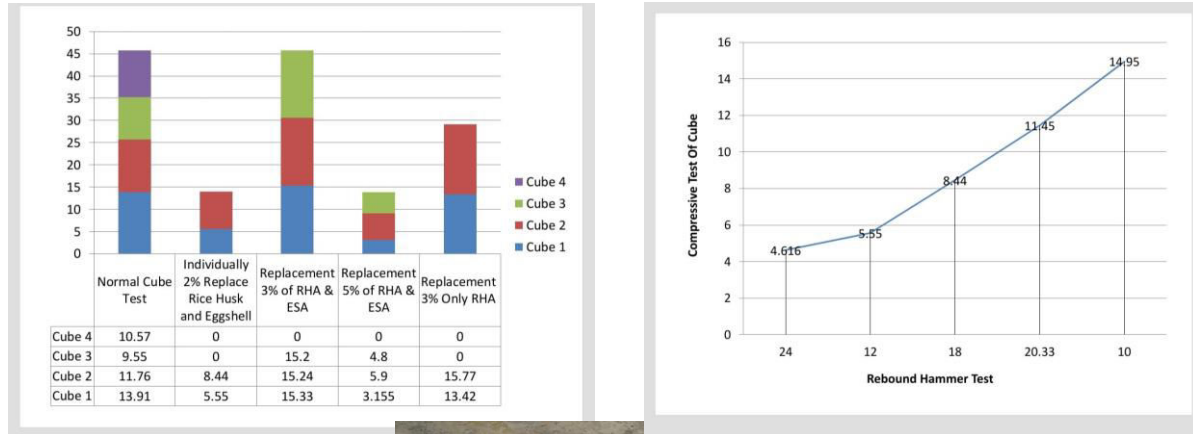


Subsequent tests included a new concrete mix where 3% of the fine aggregate was replaced solely with rice husk ash. The compressive strength performance of this composition was evaluated to determine its suitability for structural applications. In parallel, another mix was created using a 3% fine aggregate replacement with a blend of rice husk ash (60%) and eggshell ash (40%). This trial focused on assessing the combined influence of both materials on strength development, offering insight into their synergistic.



Further testing was carried out using a 5% fine aggregate replacement with the same 60:40 blend of rice husk ash and eggshell ash. These trials helped to examine how increasing the replacement percentage affects compressive strength and overall performance. Based on the experimental

data gathered from all mixes, two comparative graphs were generated to visualise trends and differences in strength outcomes. **We have attached these two graphs below to provide a clearer comparison of the compressive strength results across different mix proportions.**



### Conclusions:

The present experimental study was conducted to explore the feasibility of utilising agricultural waste materials—namely rice husk ash (RHA), eggshell powder ash (ESPA), and banana leaf ash (BLA)—as partial replacements for cement in concrete. The primary objective was to evaluate their influence on the workability, strength, and overall performance of concrete, while also promoting environmental sustainability through the reuse of organic waste. Initially, compressive strength and rebound hammer tests were performed on conventional M30 grade concrete to establish baseline data. Subsequent trials incorporated combinations of RHA and ESPA as partial replacements for fine aggregate, but challenges in early setting behavior were observed. Further analysis revealed that the high moisture retention and delayed setting were attributable to the hygroscopic and porous nature of the waste materials.

To address this, the focus of the study shifted toward the use of these materials as partial cement replacements instead. BLA, in particular, demonstrated promising pozzolanic properties and was processed under controlled thermal and mechanical conditions to maximize amorphous content.

The concrete mixes with varying proportions of BLA (0%, 2%, 4%, and 6%) were evaluated for workability and compressive strength. Results showed a reduction in workability with increasing BLA content, attributed to its high surface area and irregular particle shape, which led to increased water demand. However, despite this, the mixes achieved satisfactory strength values, indicating the viability of BLA as a supplementary cementitious material.

Based on the experimental findings, the partial replacement of fine aggregate with rice husk ash, eggshell ash, and banana leaf ash shows promising potential for enhancing the sustainability of concrete. These materials provide an economical alternative by utilising agricultural waste, which helps reduce construction costs and environmental impact. The compressive strength results indicate that with proper proportioning, these alternative materials can deliver comparable or improved performance. However, it is crucial to assess the long-term durability and resistance to environmental conditions before using such mixes in real construction. Future research should focus on durability evaluations and field-scale trials to establish their practical feasibility.

The experimental outcomes suggest that agricultural waste products, when properly processed and proportioned, can partially replace cement in concrete without compromising structural integrity. Their use not only reduces dependency on non-renewable resources such as limestone but also contributes to the mitigation of environmental pollution caused by agricultural waste. This study highlights the potential for developing green cement alternatives and paves the way for further investigations into multi-material blends and long-term durability performance.

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## 2. Climate Change Impact for A Water Resource System in India

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**ABSTRACT** The research work has been carried out to evaluate the effect of changing climate on DVC (Damodar Valley Corporation) reservoir system performance consisting four multipurpose dams namely Tilaiya, Maithon, Konar and Panchet, a single purpose dam Tenughat and a barrage in Durgapur on Damodar river, India using a simulation model, HEC-5 to assess DVC system performance under impact of changed climate scenario. Projected climate has been taken from predicted climate outcome--A1B scenario of UK Hadley Center's PRECIS Regional Climate Model prepared under IPCC and LMDZ-IITM-RegCM4 under CORDEX-South Asia data set for RCP 4.5 (low emission scenario). Simulations for PRECIS data were executed for 1985-1990 (baseline period) and 2018-2024 (projected period) and for CORDEX data were executed for 2000-2005 (baseline period) and 2018-2030 (projected period) with changed climate data (with current demand and future demand). A comparative study had been performed on evaluation of changing climate impact on DVC reservoir system performance between future climate change scenarios of PRECIS and CORDEX data for projected time frame. The system performance (on seasonal basis) was carried out using 'Performance Indices' (viz. volume reliability, time reliability, flood control index). Significant increase of very high flow in PRECIS data in January to May led to cause embankment to flow completely downstream of Maithon reservoir and flooding downstream of Panchet reservoir in January to May for few future years. Whereas, 100% reliability was noted for flood control operation for future years under CORDEX data. The outcomes through the research will guide the relevant authorities to successfully operate the reservoir into the framework of expected changing climate.

**KEYWORDS:** Climate change; PRECIS; CORDEX; DVC Reservoir System; HEC-5 model

### Introduction

Changing climate is currently an issue of great concern. Expected consequences of changed climate is modification of hydrological cycle, leading to change in precipitation pattern namely distribution, affecting intensities and frequencies of wet and dry spells and associated hydrological events, escalation of drought and related water problems [5, 7]. Consequently water resources would be impacted worldwide including reservoir management which are operated for

meeting various water demands i.e. municipal, industrial and irrigation water demand, controlling flood, power generation, recreational use of the reservoir pool and downstream water quality needs especially during drought and also for flood control [6, 8]. Thus, climate change can impact reservoir operation reasonably (and consequently on its performance) as the operation which caters to various water demands as also control flood, is dependent on climate and weather. South Asia, especially India, appears to be susceptible to changed climate and related detrimental socio-economic impacts. Thus, the forecast of the anticipated climate change on a regional scale is essential for climate change adaptation issues.

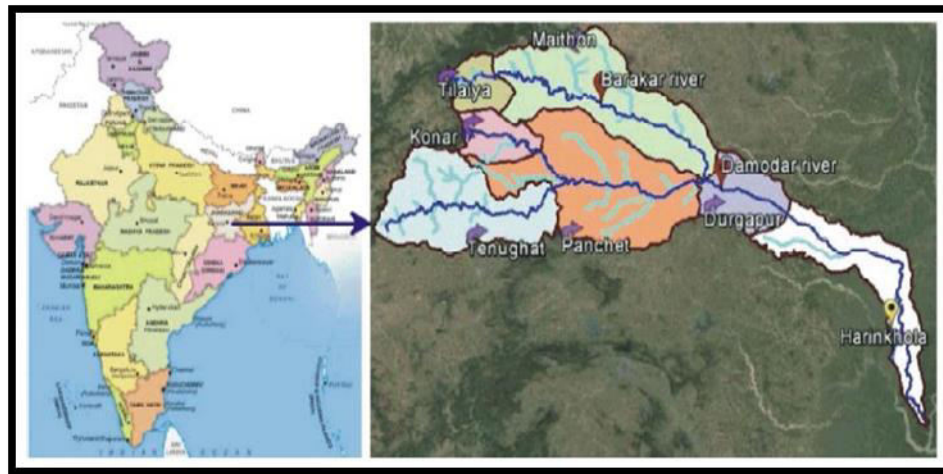
In this background, present research focused on the comparative study that had been performed on evaluation of changing climate impact on DVC (Damodar Valley Corporation) reservoir system performance located on Damodar river in India (Fig. 1) between future climate change scenarios of PRECIS and CORDEX data for projected time frame. HEC-HMS and HEC-5 simulation models had been utilized for the present study. HEC-HMS (Hydrologic Modeling System) model was adopted for generation of inflow to the reservoir system. Simulation model HEC-5 was employed to analyze DVC system performance in fulfilling demands along with controlling flood under changing climate.

A lot of work on evaluation of impact of changing climate on water sector, mostly on various phases of hydrological cycle, including extreme events in river basins has been done worldwide using future climate projections of General Circulation Models (GCMs) or Regional Climate Models (RCMs). Some recent studies were carried out [1, 4, 9, 10 and 11]. Studies on changing climate affecting water area have been carried out globally using climate projections of future GCMs (General Circulation Model) or RCMs (Regional Climate Model) for green house gas emission scenarios.

Ming et al. [13] proposed a search space reduction method, SSRM for both Shuibuya reservoir (single reservoir) and Shuibuya-Geheyan-Gaobazhou cascade reservoir system, China considering firm output limitations. The result indicated that for large scale and complex problems of reservoir operation, the proposed method could be useful in water sector. Mateus and Tullos [12] evaluated the reservoir performance with reliability, sensitivity and uncertainty for varied hydrogeologic settings in Santiam river basin, Oregon, USA under eight General Circulation Models (GCMs) projections for A1B and B1 scenarios for 2030 to 2100. The study showed a greater response of summer flows under climate change in GW basins rather than in SW basins. Shrestha et al. [15] evaluated impact of changing climate on diverted water from Bago river to Moeyingyi wetland in Myanmar using SWAT model and three GCMs of RCP 4.5 and RCP 8.5 scenarios for 2021-50. They reported reduced quantum of diverted water from Bago river to Moeyingyi wetland during dry season and recurring floods during July in future years. Pokhrel et al. [14] worked on impacts of changing climate on hydrological responses for upper basin of Kase river, Japan using MIKE SHE model and two climate scenarios for 2081-2100, one from data generated from RCM 20 under A2 scenario and the other one considering increase in average monthly temperature only.

## Study Area:

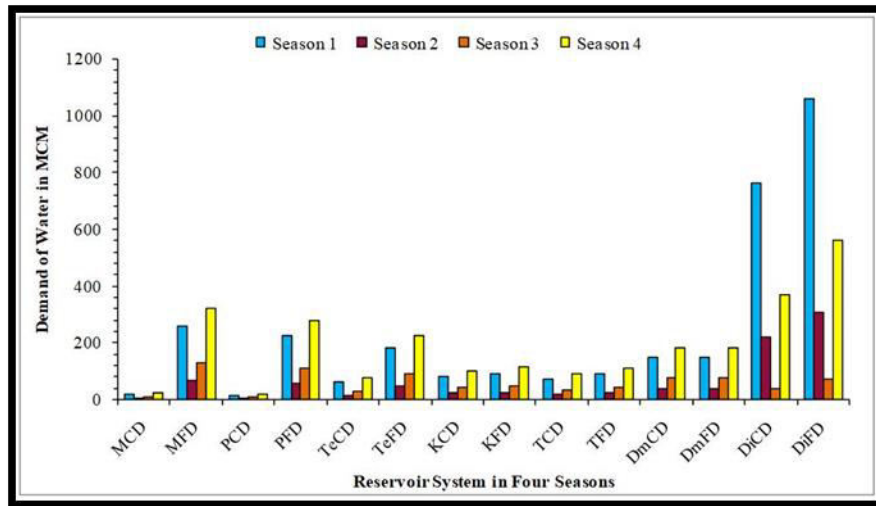
DVC is first river project in India. Location of four multipurpose dams are at Tilaiya-on river Barakar, Konar-on river Konar, Maithon-on river Barakar, downstream Tilaiya dam and Panchet-on river Damodar and Durgapur barrage -on river Damodar, downstream confluence of river Barakar and river Damodar (Fig. 1). A reservoir for conservation purpose was constructed also at Tenughat later in 1978 on river Damodar, upstream of Panchet dam. Tilaiya, Konar, Maithon, Panchet, Tenughat reservoirs and Durgapur barrage are hereafter referred to as T-R, K-R, M-R, P-R, Te-R and D-B for the sake of ready reference.



**Fig. 1:** Location map of study area

## Data Acquisition:

Reservoir operation data comprising of flow, release from reservoir (1996-2013), Muskingum routing parameters, channel capacity, characteristic curves, guide curves of reservoirs and water demand (Fig. 2) were procured from DVC Authority. Information on future demand of water was taken from report chalked out by WAPCOS (Water and Power Consultancy Services) [16]. The gridded daily precipitation (0.5 x 0.5 degree) for 1978-2007 and the gridded daily mean temperature (1 x 1 degree) for 1985-2007 were obtained from National Climatic Centre, IMD, Pune. Other meteorological data (daily for 1985-2007) namely relative humidity and wind speed for four stations and actual sunshine hours for station Ranchi were obtained from IMD, GoI, Kolkata. Future climate data (0.44 x 0.44 degree gridded) for both the scenarios corresponding to  $Q_0$  simulations of A1B scenario of RCM (Regional Climate Model) PRECIS and downscaled RCM viz. LMDZ-IITM-RegCM4 from the CORDEX for South Asia simulations for RCP 4.5 (low emission scenario), was collected from IITM (Indian Institute of Tropical Meteorology), Pune, India for baseline and future years.



**Fig. 2:** Current & future water demands in MCM (at site and downstream) in four seasons (CD denotes current demand and FD denotes future demand; M denotes Maithon M & I, P denotes Panchet M & I, Te denotes Tenughat M & I, K denotes Konar M & I, T denotes Tilaiya M & I, Dm denotes Durgapur M & I and Di denotes Durgapur Irrigation demand)

## METHODOLOGY:

### *HEC-HMS model*

HEC-HMS model simulates precipitation-runoff process of watershed by disintegrating hydrologic cycle in pieces. Many common methods of hydrology have been considered in the model. This model was used for generating inflow to reservoir system [3].

### *HEC-5 model*

The HEC-5 model [2] simulates reservoirs operation (river network) for controlling flood, supplying water, generation of hydropower and preserving water quality.

### *Performance indices*

The impact assessment was done using ‘Performance Indices’ for 1<sup>st</sup> June to 30<sup>th</sup> September (SN-1), October (SN-2), 1<sup>st</sup> November to 31<sup>st</sup> December (SN-3), 1<sup>st</sup> January to 31<sup>st</sup> May (SN-4) separately to consider variability in inflow, pattern of water demand, rule curve operation for four seasons.

The performance indices are:

1. Volume reliability ( $I_1$ ): Ratio of released water volume and target demand.
2. Time reliability ( $I_2$ ): Ratio of stages for which demands could be met and the total stages

in the simulation.

3. Flood Index ( $I_3$ ): Ratio between stages for which river overflows bank and stages for which pool level lies in flood storage zone.

### Results And Discussion:

An attempt has been made to study the changing climate impact on DVC reservoir system performance and outcomes are discussed. Considering flow duration curve for future years compared to baseline scenario for M-R and P-R (Fig. 3 and Fig. 7) (other reservoirs and barrage are not shown), increase of very high flow and high flow was noted for all reservoirs in SN-1 for PRECIS data whereas decrease of very high flow and high flow was noted for all reservoirs in SN-1 for CORDEX data. Decreased high flow and remarkable decrease of very high flow was noted for D-B in SN-1 for both the data. Increase of high flow for PRECIS data and decrease of high flow for CORDEX data was noted in SN-2 for D-B. However, decrease of high and middle flow regime in SN-2 for all reservoirs, increase of middle level flow in SN-3, significant increase of high and middle level flow in SN-4 was noted for all reservoirs and D-B for both the data.

Considering stream flow for future years compared to baseline scenario (Fig. 4 and Fig. 8), increased projected flow (by 1% to 352% for PRECIS data and by 1% to 540% for CORDEX data in SN-3 and by 1% to 7123% for PRECIS data and by 72% to 1986% for CORDEX data in SN-4) was noted for all reservoirs and barrage. For both the data, the result indicated that flow in SN-4 to be highly affected by impact of climate change for all future years for all reservoirs and barrage and seasonal distribution of projected flow was found to follow that of the baseline flow in all seasons for all future years for all reservoirs and barrage.

The study indicated increase of performance (for both volume reliability and time reliability indices) (compared to baseline scenario) in SN-1, SN-3 and SN-4 and decrease of performance (compared to baseline scenario) in SN-2 under PRECIS data with current demand (Fig. 5) for all reservoirs for most of the future years. Also, the present study indicated decrease of performance (compared to baseline scenario) of M-R, P-R (Fig. 9), Te-R and K-R (not shown) under CORDEX data with current demand in SN-1 for some future years and also in SN-2 for all reservoirs for all future years. As obvious, with future demand performance of reservoir system turned out to be poorer than that with current demand for all reservoirs for all seasons for all future years for both the PRECIS and CORDEX data (Fig. 6 and Fig. 10).

Time reliabilities ( $I_2$ ) (not shown) for all reservoirs were found to be less than respective volume reliabilities for all seasons, for all future years and for all operational frameworks for obvious reasons.

Precipitation is found to be decreased by 15% to 84% in SN-3 and by 15% to 81% in SN-4 for CORDEX data compared to PRECIS data (Table 1) which led to decrease of flow by 1% to 79% in SN-3 and by 8% to 92% in SN-4 for CORDEX data compared to PRECIS data (Table 2) for

most of the future years for all reservoirs and barrage. Positive contributions of carry over storage from SN-4 of previous water year was found to be more for PRECIS data compared to CORDEX data leading to higher deficit of water demand in SN-1 for some of the reservoirs for CORDEX data (OF-1).

It may be noted that, for PRECIS data, significant increase of very high flow and high flow in SN-4 led to cause flooding downstream of P-R and bank full flow downstream of M-R in SN-4 for few future years. Whereas, for CORDEX data, 100% reliability for flood control operation for future years may be attributed to decrease of high flow in SN-1 and SN-2 for all reservoirs and consequent requirement of lower flood storage and lower downstream release. However, occurrence of increased high flow in SN-3 and SN-4, when about half of the conservation storage remains empty was not of that magnitude to fill the flood storage and cause downstream flooding and thus leading to 100% reliability for all reservoirs for future years.

Hence, it may be concluded that, due to different climate scenarios, performance indices were found to be differ correspondingly for both the data.

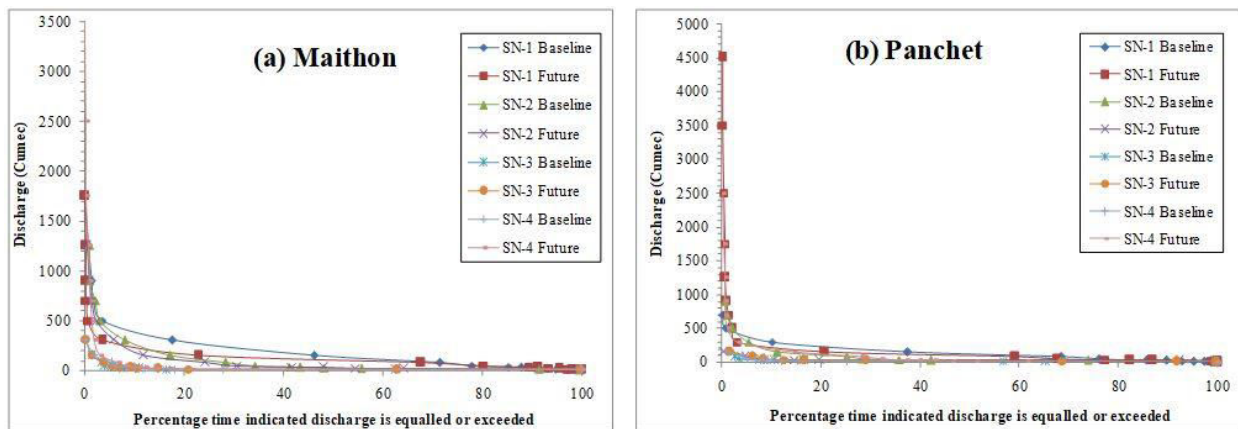
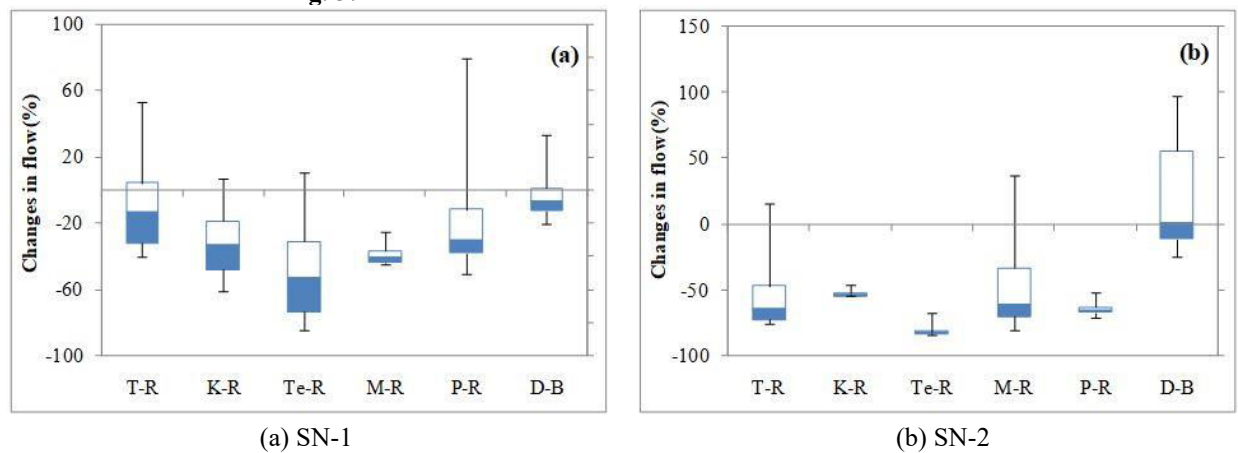
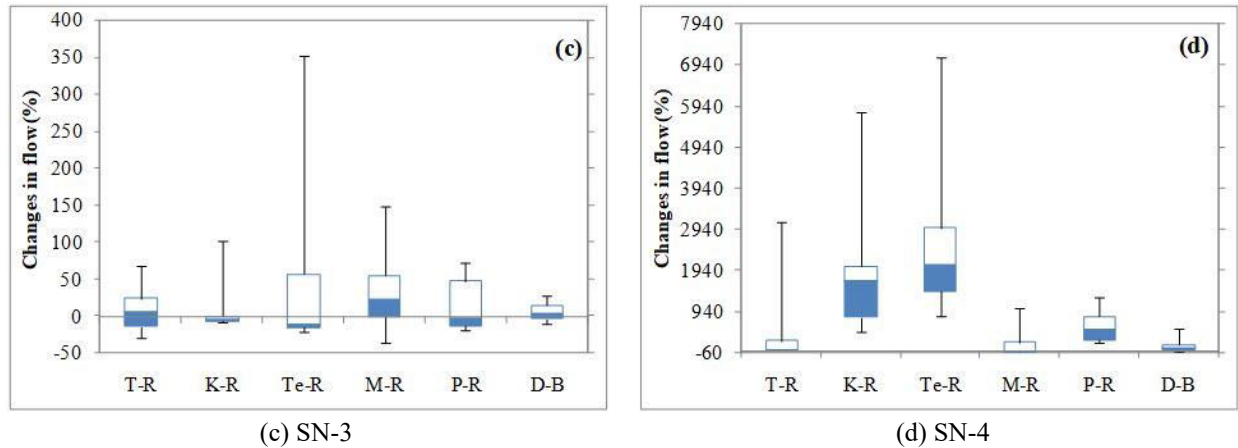
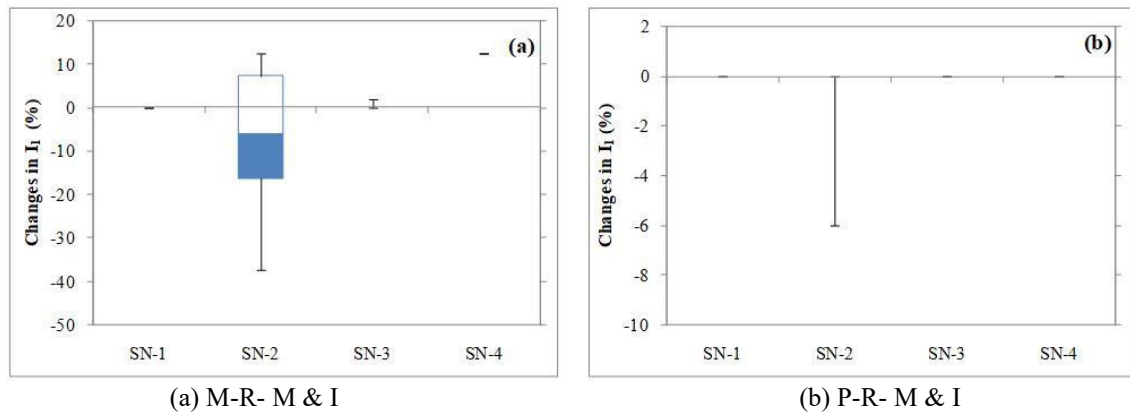


Fig. 3: Flow duration curves for M-R and P-R for PRECIS data

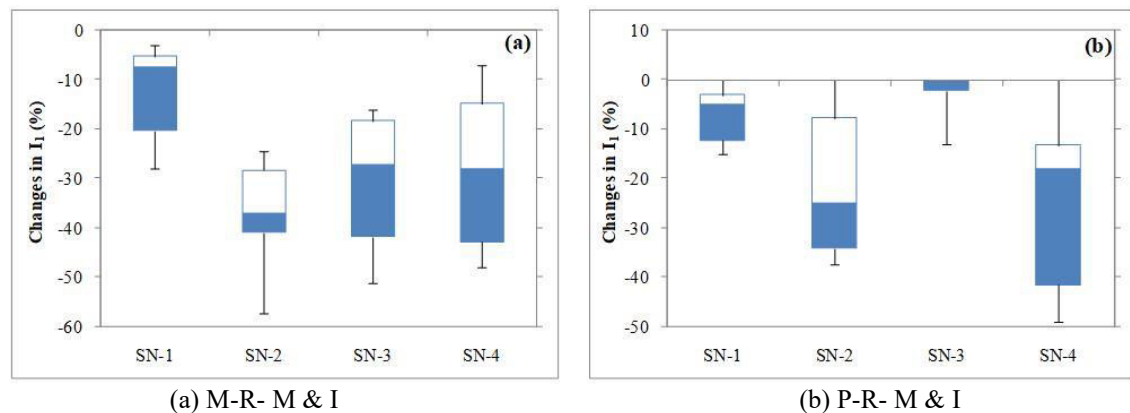




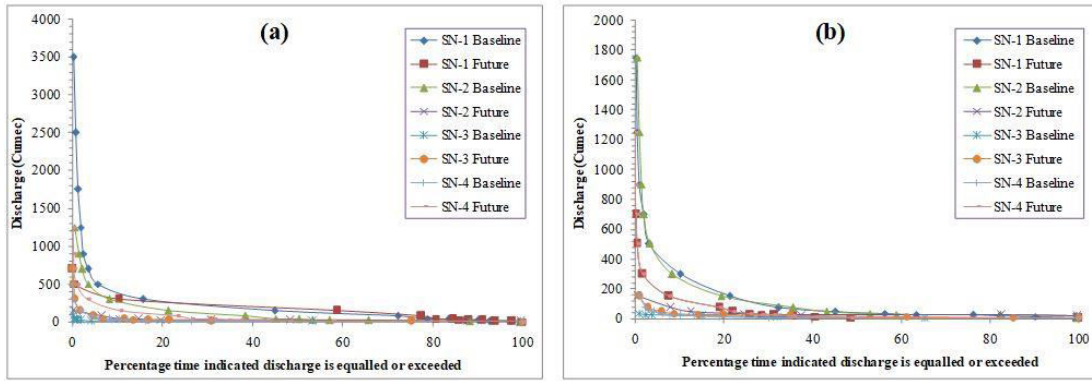
**Fig. 4:** Percentage Change of flow to the reservoir system in SN-1, SN-2, SN-3 and SN-4 for PRECIS data



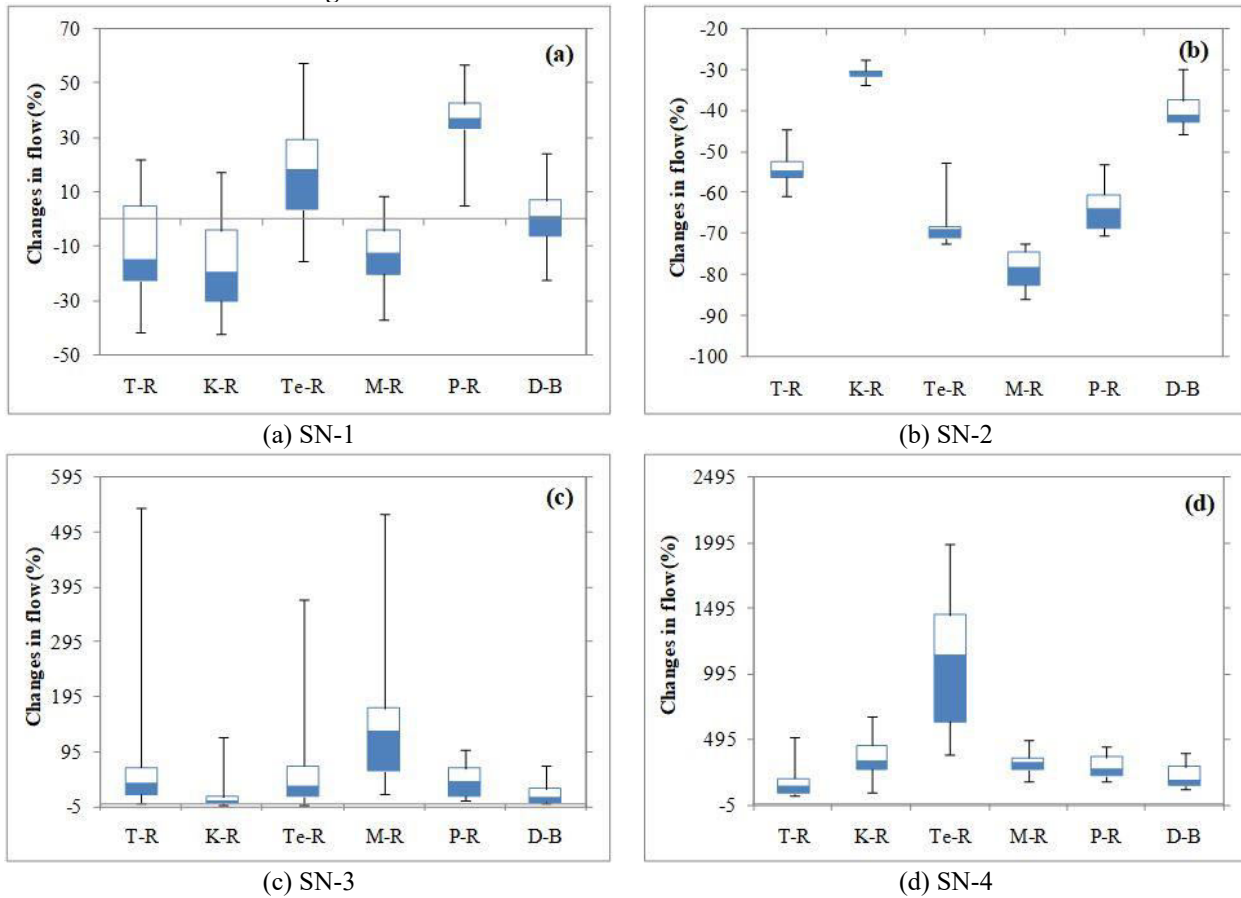
**Fig. 5:** Percentage Change of volume reliability index ( $I_1$ ) for M-R and P-R in four seasons for future years with current demand compared to baseline scenario for PRECIS data (M & I represents municipal and industrial water demand)



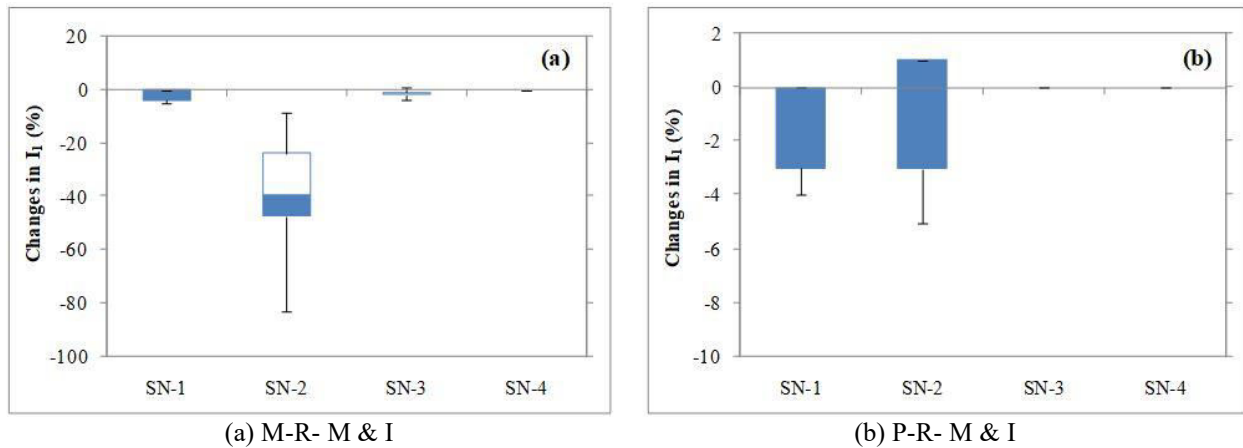
**Fig. 6:** Percentage Change of volume reliability index ( $I_1$ ) for M-R and P-R in four seasons for future years with future demand compared to future years with current demand for PRECIS data (M & I represents municipal and industrial water demand)



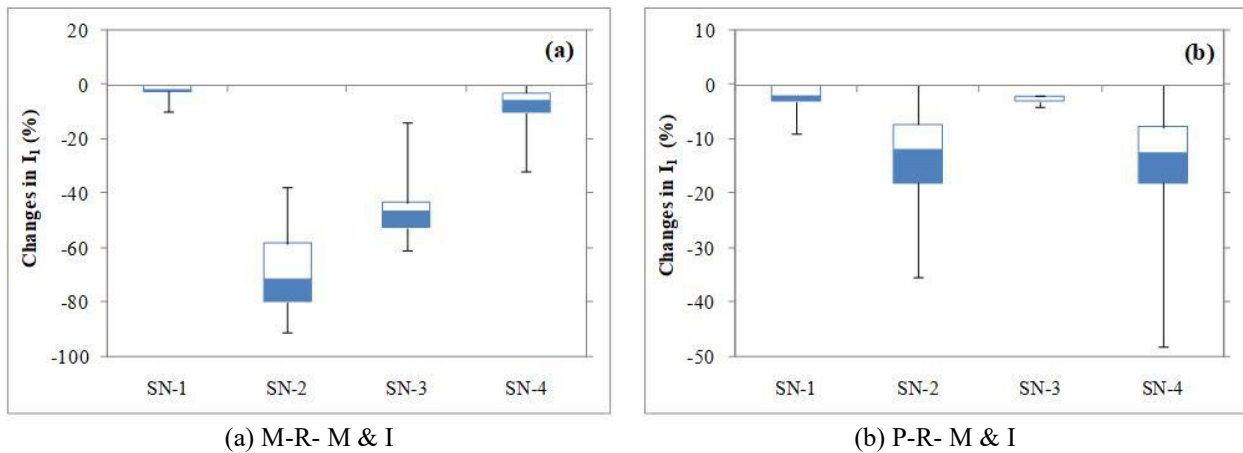
(a) M-R (b) P-R  
**Fig. 7:** Flow duration curves for M-R and P-R for CORDEX data



(a) SN-1 (b) SN-2 (c) SN-3 (d) SN-4  
**Fig. 8:** Percentage Change of flow to the reservoir system in SN-1, SN-2, SN-3 and SN-4 for CORDEX data



**Fig. 9:** Percentage Change of volume reliability index ( $I_1$ ) for M-R and P-R in four seasons for future years with current demand compared to baseline scenario for CORDEX data (M & I represents municipal and industrial water demand)



**Fig. 10:** Percentage Change of volume reliability index ( $I_1$ ) for M-R and P-R in four seasons for future years with future demand compared to future years with current demand for CORDEX data (M & I represents municipal and industrial water demand)

**Table 1** Percentage change of precipitation to the reservoir system in four seasons for future years for CORDEX data (compared to PRECIS data)

SN-1	T-R	K-R	Te-R	M-R	P-R	D-B
Average values	-2.86	38.64	56.84	58.68	75.85	23.18
Range	-38.59 to 20.91	-28.54 to 129.9	-11.31 to 141.48	9.56 to 78.07	1.44 to 145.5	-5.29 to 44.01
SN-2	T-R	K-R	Te-R	M-R	P-R	D-B
Average values	-79.90	1973.38	-19.36	-61.75	221.38	-76.67
Range	-96.29 to 40.56	-91.88 to 2228.26	-87.93 to 61.46	-88.27 to 21.44	-49.32 to 935.66	-97.1 to 30.72
SN-3	T-R	K-R	Te-R	M-R	P-R	D-B

Average values	340.67	665.10	51.67	412.62	68.83	-8.16
Range	-43.1 to 1749.25	-54.76 to 2655.02	-75.98 to 326.64	-15.29 to 1207.19	-84.72 to 345.76	-77.44 to 152.59
<b>SN-4</b>	<b>T-R</b>	<b>K-R</b>	<b>Te-R</b>	<b>M-R</b>	<b>P-R</b>	<b>D-B</b>
Average values	142.71	-52.41	-36.55	312.40	-26.01	160.06
Range	-61.44 to 460.17	-76.84 to -24.29	-81.27 to 48.47	-27.18 to 1109.43	-70.67 to 46.75	-29.53 to 354.34

-ve indicates decreased percentage change of precipitation and +ve indicates increased percentage change of precipitation

**Table 2** Percentage change of flow to the reservoir system in four seasons for future years for CORDEX data (compared to PRECIS data)

<b>SN-1</b>	<b>T-R</b>	<b>K-R</b>	<b>Te-R</b>	<b>M-R</b>	<b>P-R</b>	<b>D-B</b>
Average values	-13.67	15.31	123.49	52.47	50.76	21.99
Range	-51.95 to 38.7	-49.66 to 144.5	-50.01 to 572.73	4.79 to 79.32	-36.53 to 126.52	-11.69 to 53.61
<b>SN-2</b>	<b>T-R</b>	<b>K-R</b>	<b>Te-R</b>	<b>M-R</b>	<b>P-R</b>	<b>D-B</b>
Average values	-44.30	-0.85	-5.00	-53.18	11.48	-43.97
Range	-81.35 to -6.75	-14.74 to 5.73	-43.98 to 17.64	-84.04 to 17.25	-12.97 to 56.09	-70.6 to -10.47
<b>SN-3</b>	<b>T-R</b>	<b>K-R</b>	<b>Te-R</b>	<b>M-R</b>	<b>P-R</b>	<b>D-B</b>
Average values	61.89	8.30	14.61	62.54	-1.52	-7.87
Range	-30.8 to 391.02	-2.81 to 41.24	-79.74 to 74.42	-52.19 to 247.18	-40.21 to 48.11	-31.32 to 22.95
<b>SN-4</b>	<b>T-R</b>	<b>K-R</b>	<b>Te-R</b>	<b>M-R</b>	<b>P-R</b>	<b>D-B</b>
Average values	95.97	-50.63	-24.15	350.46	-24.65	239.91
Range	-92.85 to 223.38	-90.38 to -10.91	-89.61 to 121.38	-62.92 to 1203.98	-79.41 to 49.68	-57.6 to 645.85

-ve indicates decreased percentage change of flow and +ve indicates increased percentage change of flow

## Conclusion:

Simulation model, HEC-5 had been used to assess DVC system performance under impact of changed climate scenario using predicted climate outcome--A1B scenario of UK Hadley Center's PRECIS Regional Climate Model prepared under IPCC and LMDZ-IITM-RegCM4 under CORDEX-South Asia data set for RCP 4.5 (low emission scenario). Inflow to the reservoir system was generated using HEC-HMS model. Simulations of impact of changing climate of DVC reservoir system performance for PRECIS scenario were executed for the period of 1985-1990 (baseline period) and 2018-2024 (projected period) and for the CORDEX scenario were executed for the period of 2000-2005 (baseline period) and 2018-2030 (projected period) to enumerate the impact of changing climate on local catchmental flow of reservoir system.

The study indicated that the impact was found to be manifested in SN-2 with decrease of high and very high flow and poor performance for PRECIS data. Further, the impact was found to be manifested in SN-3 and SN-4 with increase of both high (exceeded 10% of the time) and middle level flows (equalled or exceeded 10-90% of the time) and better performance for CORDEX data. Performance was further aggravated with projected development for future years with future demand compared to current demand for both the data.

From the comparative study of PRECIS and CORDEX data, it may be noted that, for PRECIS data, significant increase of very high flow and high flow in SN-4 led to cause flooding downstream of P-R and bank full flow downstream of M-R in SN-4 for few future years. Whereas, for CORDEX data, 100% reliability for flood control operation for future years may be attributed due to decrease of high flow in SN-1 and SN-2 for all reservoirs and consequent requirement of lower flood storage and lower downstream release. However, occurrence of increased high flow in SN-3 and SN-4, when about half of the conservation storage remains empty was not of that magnitude to fill the flood storage and cause downstream flooding and thus leading to 100% reliability for all reservoirs for future years.

Due to different climate scenarios, performance indices were found to be differing correspondingly for both the scenarios.

The study also indicates towards adoption of reduced pace of development in the Damodar basin in the near future, thereby keeping low level of associated demand of water.

Thus, the study would provide a useful input to concerned authority that water demand management is as important as water supply management and that the former is highly required to complement additional water supply in the background of increasing demand and diminishing resource.

#### **Acknowledgements:**

The authors convey sincere gratitude for kind cooperation extended (supplying data and related matter) by officials and personnel of DVC, Maithon, India; IITM (Indian Institute of Tropical Meteorology), GoI, Pune and IMD (India Meteorological Department), GoI, Kolkata and School of Water Resources Engineering, Jadavpur University.

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### 3. Artificial Intelligence (AI) And Machine Learning (ML) in Rock and Coal Property Classification: Advancements and Future Directions

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**ABSTRACT** The classification of the properties of rock and coal for good resource assessment, mining plan and environmental management is an area of focus in the current research trend in mining technology. Traditional methods such as petrographic analysis, physical sampling and laboratory tests are accurate, but they may be time consuming, expensive and open for human bias. Recent reforms in Artificial Intelligence (AI) and Machine Learning (ML) have changed the area by creating classification methods rapidly, more purpose and scale. These technologies use geological and geophysical to find and classify lithotypes and coal ranks with high level of accuracy. Decisions are trees, support vector machines, random forests, and deep learning networks are some models that have shown a lot of promise in automatic the classification process. It talks about recent developments, shows examples of successful implementation, and talks about problems such as data quality and model generalization. The rock and coal has been considered as materials for the resource assessment to identify. Rock and coal properties in the machine end using AI and ML approach. The decision tree, support vector machines, random forests and deep learning network for identification of Rock and Coal properties from machine end. Approaches used for assessment of the best performance for identifying properties of Coal and Rock. A comparison of various methodologies is done and it is found that Random forest model provide the best classification with an accuracy level more than 95%. ANN performance for the data quality and setting. GBM is performed here for better but not give the accuracy compared to the RF.

**KEYWORDS:** Ordinary Portland cement (OPC), Limestone, Eggshell Powder Ash, Rice Husk Ash (RHA), Banana Leaf Ash (BLA).

## 4. Nature's Blueprint: Biomimicry as A Pathway to Sustainable Material Innovation

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**ABSTRACT** Nature has long served as a source of inspiration for new materials, leading to designs that are both mechanically strong and environmentally friendly[1]. Biomimicry, integrating 'bio' (life) with 'mimicry' (imitation), uses natural patterns to address human challenges, connecting with the Sustainable Development Goals through innovation[2]. Nature offers a multitude of structural and functional design strategies that inspire advanced material engineering. For instance, nacre (mother-of-pearl) exhibits a hierarchical brick-and-mortar architecture composed of aragonite platelets and organic polymers, resulting in a tough, energy-dissipating composite[3]. Similarly, the lotus leaf demonstrates a self-cleaning, superhydrophobic surface due to its hierarchical micro- and nanostructures, which minimize adhesion and promote water droplet roll-off[4]. Gecko footpads employ densely packed, angled setae that exploit van der Waals forces to achieve strong, reversible dry adhesion across diverse surfaces[5]. Furthermore, Bamboo's hierarchical fiber structure gives it exceptional strength, flexibility, and efficiency, making it a model for bioinspired materials[6], upon which current sustainable innovations are increasingly modelled. Building on such examples, the sustainability of biomimetic materials stands out as a significant benefit, with bio-derived polymers such as cellulose, chitin, and silk providing natural biodegradability and environmentally friendly processing methods[7]. This comprehensive review integrates existing literature on advanced biomimetic materials[8], [9], connecting the fields of biology and engineering. This work encompasses hierarchical architectures, composite formulations, and advanced fabrication techniques, such as multi-material 3D printing of nacre-like or silk-inspired composites, while assessing mechanical performance and environmentally friendly characteristics. In conclusion, this study outlines future directions that emphasize the expansion of bioinspired manufacturing, integration of multiple materials, and development of multifunctional material platforms to drive the next generation of sustainable innovations at the intersection of biology and engineering [10].

**KEYWORDS:** Biomimicry, Sustainable materials, Green engineering, Natural composites

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## 5. The Evolution and Impact of Additive Manufacturing

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**ABSTRACT** Additive Manufacturing (AM), commonly known as 3D printing, has undergone significant evolution since its inception in the 1980s. Initially used primarily for prototyping, AM has transformed into a robust manufacturing solution with widespread applications across industries. The core principle of AM—building objects layer by layer from digital models—enables unprecedented design freedom, material efficiency, and rapid production capabilities. Over time, advancements in materials, printing technologies (such as fused deposition modeling, selective laser sintering, and stereolithography), and software integration have expanded AM's potential far beyond its early limitations. The impact of AM on manufacturing is profound. It has revolutionized product development cycles by reducing lead times and enabling rapid prototyping and iteration. In aerospace, AM allows for lightweight, complex parts that were previously impossible to manufacture conventionally. In healthcare, it supports customized implants, prosthetics, and even bioprinted tissues. The automotive, defense, and consumer goods sectors also benefit from reduced material waste, lower tooling costs, and on-demand production capabilities. In industrial settings, AM is increasingly integrated into production lines for small-batch and custom manufacturing, tooling, and maintenance applications. Digital workflows, combined with AM, support decentralized and just-in-time manufacturing models, enhancing supply chain flexibility. However, challenges remain, including standardization, certification, and scalability. Despite this, the continued evolution of AM technologies and materials promises to reshape the future of manufacturing, enabling more sustainable, efficient, and innovative production systems.

**KEYWORDS:** Additive Manufacturing (AM), 3D printing, Digital workflows.

## 6. Hypervelocity Impact Behaviour of Graphene Sheets by Different Sized Fullerene Based on Molecular Dynamics Simulation

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**ABSTRACT** Hypervelocity Impact Behaviour of Graphene (Gr) Layers, impacted by different sized fullerene, has been investigated using molecular dynamics (MD) simulation in this work. To understand the perforation mechanism, different layers of Gr sheets have been impacted with different fullerene (C60, C240 and C720) rigid projectiles with different impact hypervelocity in the simulation domain. Projectile dynamics, deformation and damage of the Gr sheets have been studied during perforation. Perforation mainly occurs when impact velocity is higher than the ballistic limit velocity. Different forms of wave speed in the Gr sheets are investigated to calculate the transmitted energy and the work of perforation done on the Gr sheets. The specific penetration energy (SPE) decreases with the number of Gr layers and increase in the impact velocity of fullerene (C60). Materials Studio (MS17) and open source MD code LAMMPS are used for MD simulation based investigations. The Adaptive Intermolecular Reactive Empirical Bond Order (AIREBO) and COMPASS force fields have been used in the current MD simulation study. Also, high strain rate behaviour of Gr indicates that it can be used as a promising next generation ballistic protection armour materials.

**KEYWORDS:** Graphene sheet, Fullerene, Hypervelocity impact, Molecular dynamics simulation

### Introduction

Numerous research and development works are going on all over the world to develop suitable protective ultrathin armour material for human survival from external dangers and threats [1]. Though steel was the suitable candidate armour materials for last few decades but recently new design strategies and carbon nanofiller (e.g., graphene) based nanocomposite have been attracted within researchers [2, 3]. Also, single layer graphene has been considered the thinnest and strongest carbon based nanofiller for its unique properties [4]. To find out new properties of different graphene layer, researchers have begun the impact behaviour of graphene layers for the ballistic application [5-8]. Also the response of the graphene in high rate loading or impact

loadings are quite different than these at the static and quasi-static loading [9]. Some of few studies showed that different types of defects were generated in the graphene layers after high energy ions or clusters impact [10].

In this paper molecular dynamic simulation of graphene sheets under transverse impact has been conducted to study the penetration resistance, energy absorption and failure modes under dynamic loading. The model consists of one, two and three layers of graphene sheet. The C60 fullerene has been used as the impactor. In the MD simulations, the projectile kinetic energy, displacement, velocity and impact resistance force are also investigated.

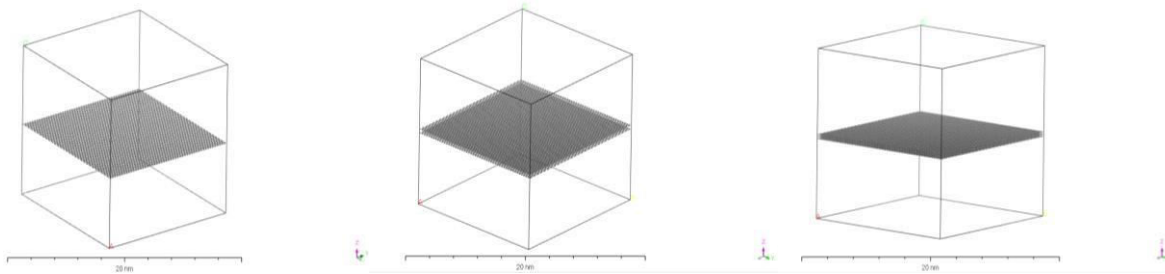
### **MD Simulation models, methods and procedure**

Hypervelocity transverse impact behaviour of graphene layers have been investigated using molecular dynamics simulations. To understand about perforation mechanism, different layer graphene sheets have been impacted with different fullerene (C60, C240 and C720) rigid projectiles with different impact hyper velocities in the range 3.5-7.5 km/s. During perforation, projectile dynamics and the deformation and damage of the graphene sheets have been studied. Perforation mainly occurs when impact velocity is higher than the ballistic limit velocity. In-plane axial-wave and out-of-plane cone-wave speeds in the graphene sheet are determined. Results show that the energy transmitted to the graphene sheet is equal to the work of perforation. The specific penetration energy decreases from 15 MJ/Kg to 0.9 MJ/kg with the increase in number of graphene layers for an impact velocity of 900 m/s of the fullerene C60 impactor. Materials studio and open source MD code LAMMPS is used for MD simulation study. The Adaptive Intermolecular Reactive Empirical Bond Order (AIREBO) force field has been used in the current MD simulation study. Also, high strain rate behaviour of graphene indicates that graphene can be used as promising ballistic protection armour materials. Here cut-off distance is considered as 12.5 Å. The spline and buffer widths are 1 Å and 0.5 Å, respectively. For the projectile, different spherical fullerene molecules with varying diameters are considered in the current study as shown in Fig 1. C180 fullerene is a sphere in shape consisting of 180 carbon atoms and its diameter is 1.22 nm. The square-like graphene is in the XY plane and the fullerene ball is placed on the z axis, normal to the X-Y plane. A 10 nm initial vertical gap is maintained between the graphene sheet and the projectile and lateral position of the projectile is at the centre of the sheet.



**Fig. 1** Different fullerene ball (a) C60 (b) C240 and (c) C720

Graphene sheet consisting of one, two and three graphene layers have been considered as shown in Figure 2. Each layer has the in-plane dimensions of 20 nm by 20 nm and has 15,322 atoms. In case of two and three layers graphene interlayer spacing is 0.34 nm.



**Fig. 2** Different layer graphene sheet models for impact analysis

### MD simulation results and discussion

MD simulation help to calculate the velocity, acceleration and perforation resistance force. Calculation of energies and work done for the perforating impact cases show that the impact energy transferred to the GS is almost equal to the work of perforation.

To study the perforation dynamics under transverse impact loading graphene sheets consisting of one, two and three layers with in-plane dimensions  $L = W = 20 \text{ nm} \times 20 \text{ nm}$  have been considered. The penetration energy is the energy absorbed from a projectile during penetration and reflects the impact resistance of the material. Sharp decreases in the kinetic energy of the impactor reflect significant absorption of impact energy by the materials. Graphene absorbs most of the kinetic energy upon impact.

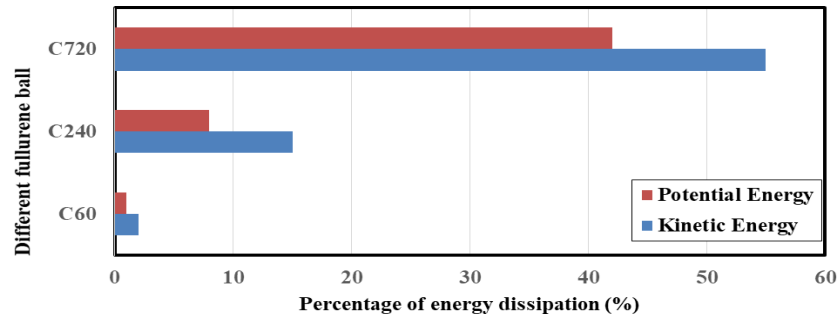


Fig: 3 Relation ship different fullurene ball - penetration energy

**Penetration energy and impact resistance force:**

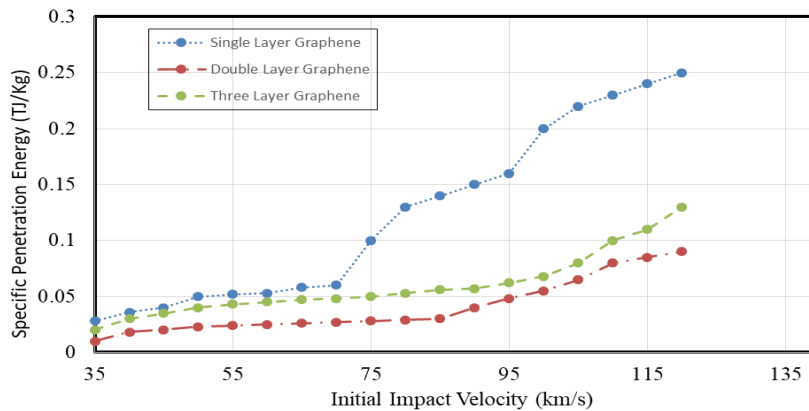
The amount of energy transferred to the graphene sheet is a sum of the work of perforation (WP), the elastic strain energy (SE) and the kinetic energy (KE) after complete perforation.

$$\Delta E_{graphene} = SE + KE + WP$$

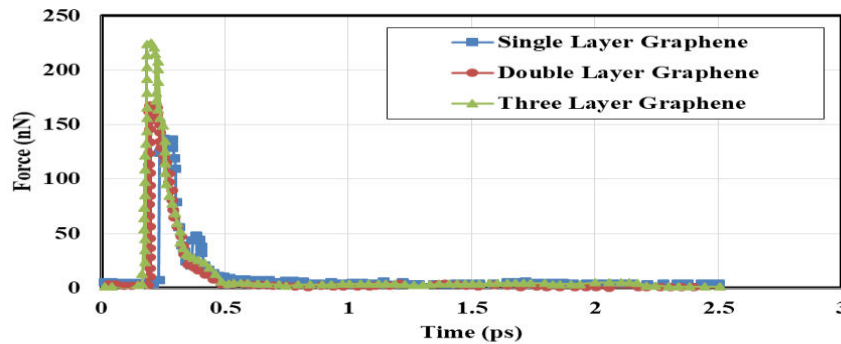
In order to obtain the specific penetration energy (*Specific penetration energy*), this energy has to be divided by the graphene mass within the projectile cross section. The specific penetration energy of graphene is

$$E_{specific\ penetration\ energy} = \frac{\Delta E_{graphene}}{\rho A N t} = \frac{\Delta E_{graphene}}{\pi R^2 N \rho t}$$

Where,  $\rho$  = density of graphene, A= projected area of the spherical projectile on the graphene sheet, R = projectile radius, N = number of layer of graphene, t = thickness of the graphene layer etc.

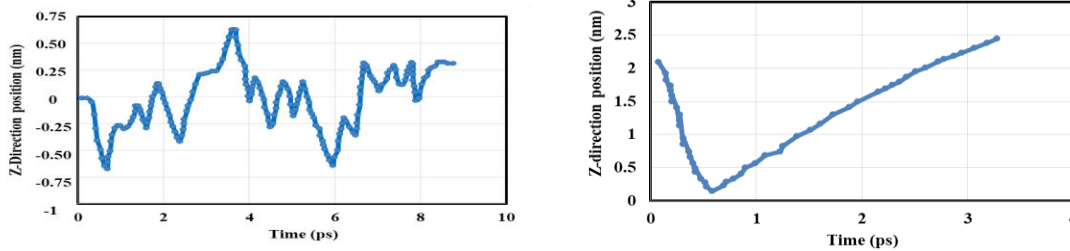


**Fig. 4** Specific penetration energy vs. initial impact velocity for different layer material After penetration, the stored strain energy is released and cause more bonds to break.



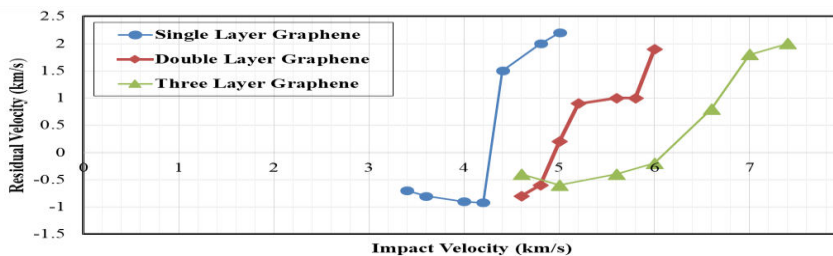
**Fig. 5** Variation of the projectile penetration resistance force with time

**Deformation and damage mode:**



**Fig. 6** Z-direction position of Gr sheet and Fullerene ball in different duration time

As stated earlier, the ballistic limit velocity is the minimum velocity of the projectile required to perforate the target with a zero residual velocity. Ballistic limit velocity ( $V_{BL}$ ) of perforation can be estimated by the work of perforation.



**Fig. 7:** Relative velocity vs. impact velocity for different number of Gr sheet

It has been noticed that due to the impact velocity lower than the ballistic limit velocity, localised damage or deformation occurs i.e., projectile bounces back, projectile stops at the sheet but perforation of the graphene does not occur. It has also been seen that these localized

deformations or damages are recovered due to elastic spring back of the graphene sheets. When impact velocity is higher than the ballistic limit velocity, complete perforation of the sheet occurs. At high impact velocity crack initiates in the sheet through bond breakage and it propagates along the sheets until it reaches the boundary. Due to the fixed boundary conditions, cracks propagate largely due to tensile loading of graphene.

## Conclusion

It can be concluded that MD simulation studies are giving a new direction to investigate nanoscale impact phenomena, including nanoscale hyper velocity impact. Molecular simulations of the impact loading of graphene have been conducted to study the projectile dynamics, the deformation and damage modes of the graphene. Graphene models consisting of one, two and three layers of graphene sheets have been considered with fullerene has been used as the projectile. Simulation results show that with the increase in the layer energy absorbing capacity the ballistic limit increases.

## Acknowledgement

I would like to thanks all faculty members, HOD, Principal and Management of Elite College of Engineering to provide me suitable support to conduct my work. Also, thanks to few research scholar in IEST Shibpur in Mechanical Department to provide necessary support to this work.

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# 7. Smart Materials and Advanced Composites: Redefining the Future of Mechanical Engineering

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**ABSTRACT** Mechanical engineering is experiencing a dynamic and transformative era, largely fueled by groundbreaking advancements in material science. At the forefront of this evolution are smart materials and advanced composites—innovations that go beyond traditional notions of strength and durability to introduce intelligence, adaptability, and sustainability into engineering design. Smart materials, including shape memory alloys (SMAs), piezoelectric materials, and magneto-rheological fluids, exhibit unique properties that allow them to respond to environmental changes such as temperature, stress, or magnetic fields. For example, SMAs like Nitinol can return to a pre-defined shape when heated, making them invaluable for applications in robotics, aerospace, and precision actuation systems. Piezoelectric materials, capable of converting mechanical energy into electrical energy and vice versa, are revolutionizing sensor technologies and enabling energy-harvesting devices that contribute to more autonomous and efficient systems. Simultaneously, advanced composite materials such as carbon fiber-reinforced polymers (CFRPs) and metal matrix composites (MMCs) are reshaping engineering possibilities by combining lightweight characteristics with exceptional mechanical strength, resistance to corrosion, and enhanced durability. These properties are particularly beneficial in industries like automotive and aerospace, where the demand for high performance, fuel efficiency, and reduced environmental impact continues to grow. The design flexibility offered by composites allows engineers to create components with tailored mechanical behaviors, leading to innovations in structural design and manufacturing processes. Another emerging frontier is the development of bio-inspired materials and metamaterials, which draw inspiration from nature or possess engineered microstructures that give rise to extraordinary behaviors, such as negative stiffness, programmable deformation, and tunable elasticity. These materials are finding applications in areas ranging from protective gear and biomedical devices to smart surfaces and next-generation flexible electronics. Driving this wave of innovation is the rise of materials informatics—a multidisciplinary approach that leverages artificial intelligence and big data to accelerate the discovery and optimization of materials. By predicting a material's properties before it is physically synthesized, this approach dramatically reduces development time and enables engineers to tailor materials for specific applications with greater precision and efficiency. In conclusion, the integration of smart materials, advanced composites, bio-inspired structures, and AI-driven design tools is revolutionizing mechanical engineering. These developments are not only enhancing the functionality and sustainability of modern machines and devices but also paving the way for a future where materials are not just passive elements, but active, intelligent components in engineering systems.

**KEYWORDS:** Mechanical engineering, carbon fiber-reinforced polymers (CFRPs) and metal matrix composites (MMCs)

## 8. The Global Oil and Gas Industry: Current Practices, Emerging Technologies, and Future Prospects

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**ABSTRACT** This study explores the integrated nature of the oil, gas, chemical, and petrochemical industries, covering upstream (exploration and production), midstream (transportation and storage), and downstream (refining and renewable fuels) sectors, as well as the specialized domain of petrochemical production. It highlights how these interconnected segments, from drilling and subsea operations to pipelines, refining infrastructure, and the production of olefins, fertilizers, and specialty chemicals, form a complex and vital global energy and materials supply chain. The oil and gas industry are fundamentally structured into three main sectors: upstream, which involves the exploration and production of crude oil and natural gas; midstream, focusing on the transportation and storage of these raw materials through pipelines, terminals, and tankage; and downstream, which encompasses refining crude oil and natural gas into various products, including gasoline, and increasingly, renewable fuels. Beyond these core oil and gas operations, the petrochemical sector is a crucial parallel industry that utilizes petroleum derivatives as feedstocks to produce a wide array of chemical products like olefins, fertilizers, specialty chemicals, and syngas. The efficiency and safety of these sectors are paramount. Midstream infrastructure, particularly pipelines, is essential for the global energy picture, with challenges in heavy oil transport and continuous technological advancements. Subsea production systems in the upstream sector are increasingly employing subsea tie-backs and addressing issues like water depth, facility configurations, and artificial lift methods to maximize economic gain. Downstream operations require specialized refining infrastructure and processes for efficient production and storage. The petrochemical industry, while often driven by chemistry and technological innovation from companies outside the traditional oil and gas structure, also involves large-scale, energy-intensive processes with potential environmental considerations. Furthermore, the study notes the critical role of various chemicals used in oilfield operations, from drilling optimization to improved oil recovery and corrosion protection.

**KEYWORDS:** Crude oil and natural gas, petrochemical industries, Downstream operations

## 9. Aqua Sense -IOT Driven Plant Hydration

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\*Corresponding author

**ABSTRACT** The advancement of technology in agriculture has led to innovative solutions that promote sustainability and efficiency. This project, titled “Aqua Sense: IoT-Driven Plant Hydration,” presents an automated plant watering system designed to optimize irrigation using Internet of Things (IoT) technology. The system incorporates soil moisture sensors, a microcontroller, a water pump, and a relay module. These components work together to monitor real-time soil moisture levels and activate the water pump only when necessary, based on predefined thresholds. This ensures that plants receive the right amount of water at the right time, reducing water wastage and minimizing the need for manual intervention. The system also provides real-time feedback via LCD and serial monitoring, enhancing user awareness and control. Aqua Sense is scalable and suitable for a variety of applications, from home gardens to commercial farms. It highlights how IoT can revolutionize traditional irrigation methods, promoting smart agriculture and sustainable water resource management.

**KEYWORDS:** Iot-based irrigation, Water conversion, Soil Monitoring, Node MCU, Aqua sense

### Introduction

Agriculture plays a crucial role in sustaining human life and supporting economies worldwide, especially in countries like India, where a significant portion of the population relies on farming. However, traditional irrigation techniques are often inefficient, leading to excessive water usage, poor crop health, and increased manual labor. With the rising demand for food and the growing threat of water scarcity, there is a pressing need to adopt smarter, more sustainable agricultural practices. One promising solution lies in the application of the Internet of Things (IoT), which enables automated, data-driven systems for precise irrigation. This project, titled “Aqua Sense: IoT-Driven Plant Hydration,” introduces an intelligent plant watering system that uses soil moisture sensors, a microcontroller (Arduino UNO or NodeMCU), a relay module, and a water pump to automate irrigation based on real-time moisture levels. When the sensor detects low moisture, the microcontroller activates the pump, which waters the soil until the desired moisture threshold is achieved, ensuring optimal hydration. This process significantly reduces water wastage and minimizes human intervention, making irrigation more efficient and sustainable. The system provides real-time feedback through an LCD display and serial monitor, allowing users to track soil conditions and system status. Designed to be scalable and cost-effective, Aqua Sense is suitable for a range of applications, from small home gardens to large-scale farming.

operations. Moreover, the project lays the foundation for future enhancements such as AI-based predictive irrigation, mobile app integration for remote monitoring, and solar-powered modules for off-grid use. By combining IoT technology with practical agricultural needs, Aqua Sense exemplifies how innovation can lead to smarter, more responsible resource management. It not only supports healthier plant growth but also contributes to environmental conservation, making it a valuable tool in the move towards sustainable and technologically advanced farming practices.

## Objectives

Several researchers and developers have proposed IoT-based solutions for automated irrigation to address water wastage and inefficient manual practices. In 2016, Kodali and Soratkal presented an Arduino-based smart irrigation system that uses soil moisture sensors and wireless communication to control water supply, emphasizing cost-effectiveness and real-time monitoring. Gutierrez et al. (2014) developed an automated irrigation system using a wireless sensor network and GPRS module, allowing remote data access and pump control. Similarly, Goap et al. (2018) proposed an IoT-based system that integrates weather prediction with soil moisture readings to enhance decision-making in irrigation. Patil and Kale (2016) focused on smart agriculture using IoT, deploying multiple environmental sensors and automation to reduce human effort. Another study by Pooja et al. (2017) introduced a low-cost soil moisture-based irrigation system targeting small-scale farmers. While these systems achieved improved water management, many lacked features like real-time user feedback, adaptive threshold control, and easy scalability. Aqua Sense builds upon these concepts by offering a more user-friendly and scalable platform that combines moisture detection, automated control, LCD feedback, and IoT connectivity. It is designed for both home gardening and large-scale agriculture, and its flexible design supports future integration with AI, solar power, and mobile monitoring for smarter water management.

## Materials and Methods

### Microcontroller (Arduino UNO / NodeMCU ESP8266):

The microcontroller serves as the brain of the system. It reads data from the soil moisture sensor, processes it, and controls the water pump through a relay. NodeMCU is preferred for its built-in Wi-Fi module, enabling IoT functionality. It outputs analog voltage values that vary depending on soil humidity. Dry soil yields high values (above 950), while moist soil gives lower readings (below 400). The sensor is inserted into the plant's root zone for accurate moisture readings.

### Relay Module:

The relay acts as a switch that allows the microcontroller to control the high-voltage water pump using a low-voltage signal. It ensures safe isolation between the control and power circuits.

## **Water Pump:**

A small DC motor pump is used to irrigate the soil. It turns on when the moisture drops below the set threshold and turns off once the desired moisture level is achieved.

## **Power Supply (5V/12V Adapter):**

The components are powered using an adapter suitable for both the microcontroller and the water pump.

## **16x2 LCD Display:**

Used to display real-time data, including soil moisture level and pump status (ON/OFF), providing easy monitoring for the user.

## **Arduino IDE:**

The code for the microcontroller is written and uploaded using Arduino IDE. The language used is Embedded C/C++. The program involves reading analog values from the soil moisture sensor, comparing them with predefined thresholds, and controlling the relay accordingly.

## **Libraries Used:**

- Wire.h for I2C communication
- LiquidCrystal\_I2C.h to interface with the LCD module

## **Logic Flow:**

- The system continuously reads analog input from the soil moisture sensor.
- If the value is greater than 950 (dry), the relay is activated, switching ON the water pump.
- If the moisture is between 400 and 950 (medium) or below 400 (wet), the relay is deactivated, keeping the pump OFF.
- The LCD displays the current soil status and the pump state.
- Serial Monitor outputs real-time logs for debugging and analysis.

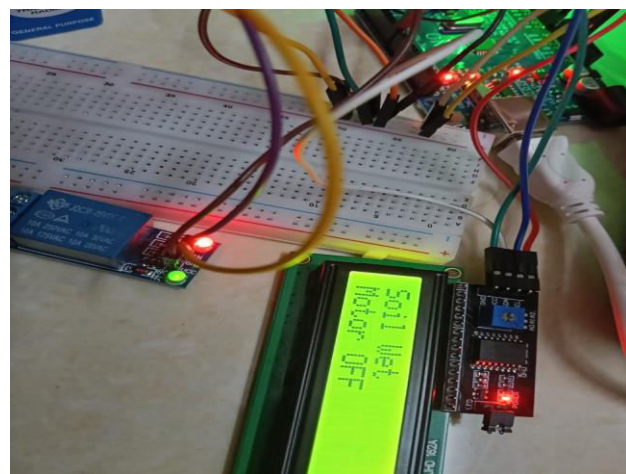
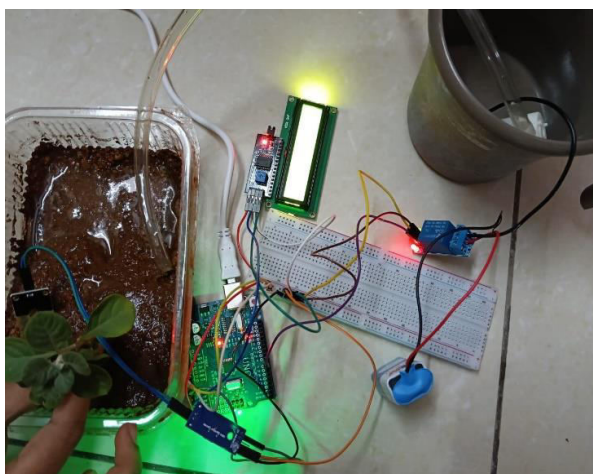
## **Results and Discussion**

The implementation of the Aqua Sense project successfully demonstrated the functionality and effectiveness of an IoT-based automated irrigation system. After assembling the components—including the soil moisture sensor, Arduino UNO (or NodeMCU), relay module, and water pump—the system was tested under different soil moisture conditions to verify its performance. The system accurately detected soil moisture levels and triggered the water pump only when the

soil was dry, as per the programmed threshold. For sensor readings above 950, the system identified the soil as dry and automatically activated the water pump. Once the moisture level increased and readings fell below the threshold (i.e., less than 950), the system turned off the pump, thus preventing overwatering. The LCD display clearly showed the current soil condition (Dry, Medium, or Wet) along with the motor status (ON/OFF), providing real-time visual feedback. Additionally, the serial monitors in the Arduino IDE printed live data from the sensor, helping in system debugging and validation. This output helped confirm that the decision logic executed by the microcontroller was working as expected. The use of the relay module provided safe and efficient control of the pump, allowing seamless switching between ON and OFF states without manual interference. The delay between sensor reading and pump activation was minimal, ensuring timely irrigation. Moreover, the power efficiency of the system was evident as the pump operated only when required, thus conserving energy. The entire setup proved to be reliable, cost-effective, and scalable. In conclusion, the Aqua Sense system effectively automated the irrigation process, reduced water wastage, minimized manual effort, and ensured healthier plant growth through consistent and precise watering. These results confirm the feasibility of deploying the system in both residential gardens and large agricultural fields for smart water management.

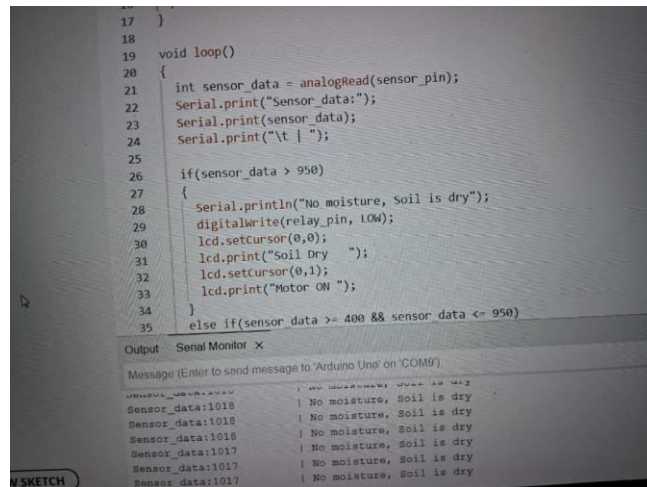
## Conclusion

The Aqua Sense project successfully demonstrates the application of Internet of Things (IoT) in creating a smart, efficient, and automated irrigation system tailored for modern agricultural needs. By integrating essential components such as soil moisture sensors, microcontrollers (Arduino UNO or NodeMCU), relay modules, and a water pump, the system offers a practical solution to the longstanding challenges of water wastage and inefficient manual irrigation. The project addresses these issues by enabling the system to monitor soil moisture levels in real-time and activate the pump only when necessary. This results in precise water delivery, ensuring optimal hydration for plants without human intervention.



**Figure 1: Aqua Sense System**

The LCD display and serial monitoring provide clear feedback to users, making the system highly transparent and user-friendly. Aqua Sense’s design is not only effective but also scalable, cost-efficient, and adaptable to various environments—ranging from household gardens to large-scale agricultural fields. The successful execution of this system validates the feasibility of combining embedded systems and IoT for sustainable farming practices. Moreover, the modular nature of the project allows for future enhancements, such as the integration of weather forecasting APIs to prevent unnecessary watering, solar-powered systems for energy efficiency, and AI algorithms for predictive watering schedules. These upgrades could further transform Aqua Sense into a comprehensive smart agriculture platform. In conclusion, Aqua Sense is a meaningful contribution toward the advancement of smart farming. It not only improves plant health and resource utilization but also supports sustainable agricultural practices by conserving water and reducing manual labour. The project proves that technology can play a pivotal role in addressing agricultural challenges and can lead the way for innovations that balance productivity with environmental responsibility.

**Figure 2 : Soil Wet , Motor OFF**


```

17 }
18
19 void loop()
20 {
21   int sensor_data = analogRead(sensor_pin);
22   Serial.print("sensor_data:");
23   Serial.print(sensor_data);
24   Serial.print("\t | ");
25
26   if(sensor_data > 950)
27   {
28     Serial.println("No moisture, soil is dry");
29     digitalWrite(relay_pin, LOW);
30     lcd.setCursor(0,0);
31     lcd.print("Soil Dry ");
32     lcd.setCursor(0,1);
33     lcd.print("Motor ON ");
34   }
35   else if(sensor_data >= 400 && sensor_data <= 950)

```

Output Serial Monitor X

```

Message (Enter to send message to 'Arduino Uno' on 'COM9')
Sensor_data:1018 | No moisture, Soil is dry
Sensor_data:1018 | No moisture, Soil is dry
Sensor_data:1018 | No moisture, Soil is dry
Sensor_data:1017 | No moisture, Soil is dry
Sensor_data:1017 | No moisture, Soil is dry

```

**Figure 3 : Arduino ID Reading**

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## 10. Smart Home Automation System

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**ABSTRACT** Home Automation with Google Assistant, Alexa, and Manual Switches explains a system architecture that uses voice commands via Google Assistant and Alexa platforms to provide remote control and automation of household items. For smooth voice control, the systems interact with Google Assistant and Alexa speech assistants and use the ESP32 micro controller to interface with the devices. Additionally, manual switches are used in this project to offer a practical backup control technique. With the addition of Voice Assistant, Manual Switches, and an ESP32 micro controller, Home Automation becomes even more convenient and adaptable, providing customers with an array of options for interacting and controlling their smart devices. Voice control tools such as Alexa and Google Assistant provide more control over one's home environment for both individuals and those echo-conscious living. It also appeals to simplify everyday activities, which redefines what modern living means by convenience. The major goal of utilizing Google Assistant, Alexa, and manual switches with home automation is to increase control and convenience when it comes to managing the different e systems and appliances in your house. With impairments. They can use voice commands to carry out tasks like turning on and off lights. With the help of this technology, you should be able to engage more freely with your home environment and jobs will be more straightforward and efficient.

**KEYWORDS:** Home Automation, Google Assistant, Alexa, PIR motion sensor, MQTT, ESP32

### Introduction

Smart home automation refers to the integration of technology into residential systems to enhance convenience, security, energy efficiency, and comfort. It allows homeowners to control devices like lights, thermostats, security cameras, and appliances remotely via smartphones or voice assistants. The system uses sensors, Wi-Fi, and cloud computing to automate tasks based on user preferences or environmental conditions. Real-time data from these devices enables continuous monitoring and control. Home automation systems can also improve energy management by optimizing energy usage. This technology offers greater accessibility for individuals with disabilities. It enhances security with smart locks, surveillance, and alert systems. Additionally, automation can help in predictive maintenance by providing alerts on device malfunctions. Smart homes are becoming more common with the rise of IoT (Internet of

Things) technology. Real-time project implementation in this area involves designing and deploying interconnected devices that respond to user needs in real time.

## 2. OBJECTIVES

The primary objective of this project is to develop an integrated home automation system that leverages Google Assistant, Amazon Alexa, and manual switches using the ESP32 microcontroller as the core control unit. This system is designed to provide users with multiple modes of interaction—voice commands and physical switches—allowing for increased flexibility, accessibility, and convenience in managing various household appliances such as lights, fans, and other electrical devices.

The use of voice assistants like Google Assistant and Alexa enables hands-free control, which is especially beneficial for the elderly and individuals with physical impairments, empowering them to independently interact with their environment. At the same time, incorporating manual switches ensures the system remains functional and accessible during internet outages or when voice control is impractical, offering a fail-safe and user-friendly backup.

## 3. PROBLEM STATEMENT

Despite the growing popularity of smart home technologies, many existing systems rely solely on either voice control or mobile applications, limiting their accessibility and reliability in real-life scenarios. These systems often fail to accommodate users with limited mobility or those unfamiliar with advanced technology, such as the elderly or individuals with disabilities. Additionally, full dependence on internet connectivity makes them unreliable during network outages. There is also a lack of integration between different voice platforms like Google Assistant and Amazon Alexa, restricting user flexibility. Moreover, the absence of manual control options in many smart systems can create inconvenience when voice assistants are not practical to use. To address these challenges, there is a need for a home automation solution that is versatile, user-friendly, and inclusive. This project aims to develop a system that integrates Google Assistant, Alexa, and manual switches using the ESP32 microcontroller, offering multiple modes of control to enhance accessibility, reliability, and convenience in managing household appliances

## 4. PROPOSED SYSTEM

The proposed system is a hybrid home automation solution that integrates Google Assistant, Amazon Alexa, and manual switches with the ESP32 microcontroller to provide users with seamless and flexible control over household appliances. This system is designed to allow users to operate devices through voice commands using popular voice assistants like Google Assistant

and Alexa, as well as through traditional manual switches for added reliability and convenience. The ESP32 serves as the central controller, connecting with the internet to communicate with cloud-based voice platforms while simultaneously managing input from manual switches and controlling the connected appliances. This multi-mode control approach ensures continuous functionality even during network interruptions, making the system more robust and accessible. By combining voice recognition capabilities with a microcontroller-based automation mechanism and physical switches, the system enhances everyday living—particularly for the elderly or individuals with impairments—by simplifying tasks like turning lights or appliances on and off. Overall, the proposed system aims to deliver a smart, efficient, and user-friendly automation experience tailored to diverse user needs and preferences.

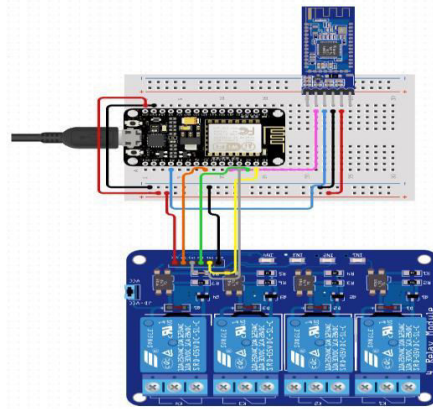


Figure 1: CIRCUIT DIAGRAM

## Hardware and software requirements

### Hardware requirements:

- Raspberry Pi
- PIR Motion Sensor
- LM35 Temperature Sensor
- Relays
- Smart Switches

### Software requirements:

- Arduino IDE
- HTTP
- MQTT

## Technology Description

### Python:

Python is a high-level, interpreted programming language known for its simplicity, readability, and versatility. In the context of home automation, Python is widely used for scripting and automating tasks on platforms like the Raspberry Pi. Its extensive libraries and community support make it ideal for integrating sensors, actuators, and communication protocols such as HTTP and MQTT. Python can be used to write scripts that collect data from sensors (like PIR or LM35), control devices via relays or smart switches, and interface with cloud services or voice assistants like Google Assistant and Amazon Alexa. Its compatibility with libraries such as paho-mqtt, gpiozero, and flask enables quick development of lightweight, efficient automation systems, making it a core technology in IoT and smart home applications.

### Packages Used

The home automation system leveraging Google Assistant, Alexa, manual switches, and the ESP32 microcontroller typically uses several key software packages to ensure smooth operation and integration. For programming the ESP32, the Arduino Core for ESP32 along with libraries such as WiFi.h and ESPAsyncWebServer are commonly used to enable network connectivity and device control. To integrate voice assistants, the Google Actions SDK, Dialog flow, and Firebase Cloud Functions facilitate Google Assistant commands, while the Alexa Skills Kit (ASK) SDK and AWS Lambda support Alexa voice interactions. Communication between the ESP32 and cloud services often uses MQTT protocol libraries like PubSubClient, with Mosquitto serving as a common MQTT broker. Manual switches are managed through ESP32's GPIO control using standard Arduino libraries, sometimes enhanced by debounce libraries such as Bounce2 to ensure reliable input reading. Additionally, libraries like Arduino Json are employed for data formatting and parsing between devices and services. Together, these packages provide a robust foundation for flexible, efficient, and user-friendly home automation.

## Algorithm

### Initialize System

- Configure ESP32 GPIO pins for manual switches and connected appliances (e.g., lights, fans).
- Connect ESP32 to WiFi using stored credentials.
- Initialize MQTT client and connect to the MQTT broker.
- Set up communication protocols for Google Assistant and Alexa integration (via cloud backend or direct API).

### Monitor Inputs

- Continuously check the state of manual switches (using interrupts or polling).
- Listen for incoming MQTT messages from Google Assistant and Alexa via cloud services.
- Process incoming voice commands received through backend or direct messages.

#### Process Commands

- When a manual switch state changes, toggle the corresponding appliance state.
- When an MQTT message (voice command) is received, parse the message to determine the intended device and action (ON/OFF).
- Update the appliance state accordingly.

#### Update State

- Control the appliance (e.g., turn light ON/OFF) by setting the appropriate GPIO pins.
- Publish the updated device state back to MQTT broker to sync with the cloud and voice assistants.

#### Feedback & Synchronization

- Send device status updates to the cloud (Google Home Graph, Alexa Smart Home API) to reflect current state.
- Optionally, provide local feedback via LEDs or an LCD display.

#### Error Handling

- Reconnect WiFi if the connection drops.
- Reconnect to MQTT broker if disconnected.
- Debounce manual switch inputs to avoid false triggers.

#### Repeat

- Continuously loop through monitoring inputs and processing commands to maintain real-time control.

#### Sample Code

```
// Smart Home Automation - Arduino Only
// Components: LM35, Button for presence, 3 LEDs

const int tempPin = A0; // LM35 sensor output to A0
const int presencePin = 2; // Button simulating presence detection

const int lightLed = 8; // Light LED pin
```

```
const int fanLed = 9;    // Fan LED pin
const int climateLed = 10; // Climate control LED pin

// Thresholds
const float TEMP_HIGH = 28.0; // Degrees Celsius - Cooling above this
const float TEMP_LOW = 20.0;  // Degrees Celsius - Heating below this

void setup() {
  pinMode(tempPin, INPUT);
  pinMode(presencePin, INPUT_PULLUP); // Button connected between Pin 2 and GND

  pinMode(lightLed, OUTPUT);
  pinMode(fanLed, OUTPUT);
  pinMode(climateLed, OUTPUT);

  Serial.begin(9600); // Optional: Serial monitor for debugging
}

void loop() {
  // Read presence
  int presence = digitalRead(presencePin);
  // LOW = person detected

  // Read temperature

  int tempReading = analogRead(tempPin);
  float voltage = tempReading * (5.0 / 1023.0);
  float temperatureC = voltage * 100.0; // LM35 gives 10mV per °C

  // Control devices based on readings
  if (presence == LOW) {
    digitalWrite(lightLed, HIGH); // Light ON

    if (temperatureC > TEMP_HIGH) {
      digitalWrite(fanLed, HIGH); // Fan ON
      digitalWrite(climateLed, HIGH); // Cooling ON
    }
    else if (temperatureC < TEMP_LOW) {
      digitalWrite(fanLed, LOW); // Fan OFF
      digitalWrite(climateLed, HIGH); // Heating ON
    }
  }
  else {
```

```

digitalWrite(fanLed, LOW); // Fan OFF
digitalWrite(climateLed, LOW); // Climate OFF
}
}
else {
// No one is present
digitalWrite(lightLed, LOW); // Light OFF
digitalWrite(fanLed, LOW); // Fan OFF
digitalWrite(climateLed, LOW); // Climate OFF
}

// Debugging output
Serial.print("Temperature: ");
Serial.print(temperatureC);
Serial.print(" °C, Presence: ");
Serial.println(presence == LOW? "Yes": "No");

delay(1000); // 1 second delay
}

```

**Output diagrams:**

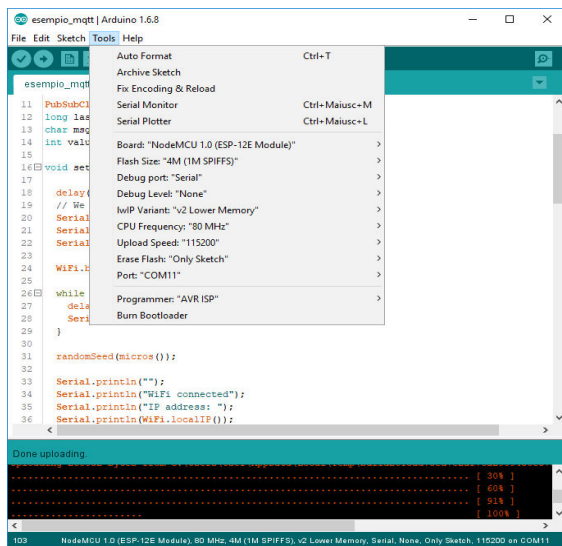


Figure 2: Initialization



Figure 3: OUTPUT

**Testing**

Testing is a crucial phase to ensure that the home automation system works reliably with voice assistants, manual switches, and the ESP32 microcontroller. The following testing steps should be performed:

## Unit Testing

Test individual components separately, such as:

- ✓ Verify ESP32 connectivity to WiFi.
- ✓ Test manual switches by checking if pressing toggles the correct GPIO pin state.
- ✓ Validate MQTT communication by publishing and subscribing to test topics.
- ✓ Test responses from Google Assistant and Alexa through their respective simulators or developer consoles.

## Integration Testing

- o Confirm that the ESP32 properly receives commands from both voice assistants.
- o Check that manual switch actions and voice commands update the device state consistently.
- o Verify synchronization between the device state on the ESP32 and the cloud (Google Home Graph, Alexa Smart Home API).

## Functional Testing

- ✓ Test real-world scenarios such as turning appliances ON and OFF via:
- ✓ Voice commands to Google Assistant and Alexa.
- ✓ Manual switch toggling.
- ✓ Observe if devices respond accurately and promptly.

## Stress Testing

- ✓ Simulate rapid switching of manual switches and repeated voice commands to check system stability.
- ✓ Test WiFi and MQTT reconnect logic by temporarily disconnecting and reconnecting the network.

## User Acceptance Testing

- ✓ Have end users test the system for ease of use, responsiveness, and reliability.
- ✓ Gather feedback on user experience and make necessary adjustments.

## Error Handling Testing

- ✓ Verify that the system recovers gracefully from errors such as lost WiFi connection or failed MQTT publishing.
- ✓ Ensure manual switches still function during cloud or voice assistant outages

## Conclusion

The implementation of a home automation system using Google Assistant, Alexa, manual switches, and the ESP32 microcontroller successfully demonstrates how modern technologies can be combined to create an efficient, flexible, and user-centric smart home environment. This system enhances convenience by allowing users to control household appliances through multiple interfaces—voice commands via popular digital assistants and physical manual switches—catering to various user preferences and scenarios.

Integrating voice control simplifies everyday tasks, especially benefiting individuals with mobility impairments or those seeking hands-free operation. Meanwhile, manual switches provide a dependable fallback, ensuring that control remains uninterrupted during network outages or voice assistant failures. The ESP32 microcontroller serves as a powerful and cost-effective hub, bridging local device control with cloud-based voice services through secure WiFi and MQTT communication protocols.

Moreover, this approach highlights the importance of interoperability between different platforms and hardware, promoting an inclusive ecosystem that can evolve with user needs and emerging technologies. The modular nature of the system allows easy scalability and customization, enabling users to add or modify devices without extensive reprogramming.

Overall, the project underscores the potential of combining IoT devices with voice assistant technologies to redefine home automation, making living spaces smarter, safer, and more adaptable to modern lifestyles. Future enhancements could include incorporating advanced AI for predictive automation, expanding device compatibility, and improving security features to protect user privacy and data.

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# 11. A Personalized Adaptive Learning Framework Using AI and Machine Learning Techniques

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**ABSTRACT** Adaptability is essential in today's dynamic learning environment when it comes to tailoring instructional materials to each student's requirements. Adaptive systems improve learning effectiveness and adaptability by lowering problems like cognitive overload and confusion. Because they provide all students with the same learning materials regardless of their preferences or learning styles, current educational systems sometimes lack adaptability. Individual variations, which are crucial in online learning contexts, are not taken into account by this generic method. In order to bridge this gap, we offer a thorough framework that combines several machine learning (ML) and artificial intelligence (AI) approaches to enable individualized learning pathways. Finding appropriate learning models for each student is the goal of the suggested framework. There are several learning models in academic literature, but there are currently no intelligent systems that can dynamically select the best model for a learner. Our framework bridges this gap by utilizing intelligent interfaces and smart technology to provide tailored, flexible learning experiences. By customizing learning experiences to meet the requirements of each individual student, these methods overcome the shortcomings of conventional educational systems. Four essential components—personal development, individual performance evaluation, learner characteristics, and adaptive learning adjustments—have been investigated in order to create an efficient customized adaptive learning system. Together, these components contribute to the creation of a Personal Adaptive Learning Framework that includes tailored personal learning, Learner profiling, competency-based advancement, learning pathways, and adaptable learning interfaces. Each student's learning experience is dynamically supported and enhanced by the framework, which makes use of AI and machine learning technology. This research also proposes a recommendation mechanism that maps individual learning trajectories and explores different learning model topologies. The goal of this contribution is to further the development of intelligent e-learning systems and open up new avenues for future study in adaptive learning technologies as well as individualized, data-driven teaching methods. Adaptive learning experiences.

**KEYWORDS:** Adaptive Learning, Personalized Learning, Artificial Intelligence, Machine Learning, eLearning, Smart Education, Learner Profiling, Competency-Based Learning, Educational Technology, Intelligent Learning Systems

## Introduction

In increasingly diverse classrooms, the old "one-size-fits-all" approach of education finds it difficult to meet the varied needs, past knowledge, learning styles, and preferences of individual students (UNESCO, 2017) [1]. This approach often leads to disengagement, knowledge gaps for certain students, and unrealized potential for others, which hinders the global aim of inclusive and equitable quality education as expressed in Sustainable Development aim 4 (SDG 4). (United Nations, 2015[2]). Though it has proven challenging to implement effectively on a wide scale, the concept of customized learning is not new; it is rooted in the ideas of differentiated education (Tomlinson, 2001) [3]. Benjamin Bloom's (1984) [4] seminal "2-sigma problem" showed the tremendous potential of this kind of training, as students who got customized coaching fared two standard deviations better than those who received typical group teaching. The advent of digital learning systems provided a path toward customisation. Early e-learning platforms often imitated the online dissemination of static, linear material, although offering flexibility. Learning management systems (LMS) offer structure, but they don't need much adjustment (Dabbagh & Kitsantas, 2012) [5]. The advent of adaptive learning technology was a significant development. These systems dynamically adjust components of the learning path, content, or sequence based on learner interactions and performance data (Shute & Zapata-Rivera, 2012) [6]. Systems like Knewton or ALEKS, which primarily addressed knowledge gaps and pace in certain subjects, such as mathematics (VanLehn, 2011), demonstrated the feasibility of rule-based adaptability [7]. Nevertheless, the depth and scope of personalization that these first-generation adaptive systems can do are constrained by their frequent reliance on preset rules and comparatively basic student models (Brusilovsky & Millán, 2007).[8]

To get over these restrictions and achieve truly personalized adaptive learning (PAL), artificial intelligence (AI) and machine learning (ML) present revolutionary possibilities. To create rich, dynamic learner models, AI/ML techniques allow the analysis of large, complex datasets, including not only quiz scores but also interaction patterns, time-on-task, forum discussions, affective states (where detectable), and multimodal inputs (Baker & Inventado, 2014; du Boulay, 2016) [9,10]. Deep learning can reveal intricate, non-linear patterns in learner behavior (Khajah et al., 2016) [11], collaborative filtering and knowledge tracing can predict the best course of action (Piech et al., 2015) [12], natural language processing (NLP) can personalize feedback on open-ended responses (Dzikovska et al., 2014) [13], and reinforcement learning can optimize pedagogical decisions in real-time (Rafferty et al., 2016) [14]. Despite this promise, many AI-driven PAL systems currently in use concentrate on particular elements (predictive analytics, recommendation engines, etc.) or work in limited fields; they lack a coherent, scalable, and pedagogically sound framework that integrates various AI/ML techniques in a comprehensive manner (Hooshyar et al., 2021; Xie et al., 2019) [15,16]. Additionally, issues with data protection, ethical bias mitigation, model openness (explainable AI, or XAI), and smooth

integration with good pedagogical principles continue to be crucial areas that need more attention (Holmes et al., 2021; Roll & Wylie, 2016) [17,18].

By putting out a thorough Personalized Adaptive Learning Framework (PALF) that is specifically made to take advantage of the complementary strengths of various AI and ML approaches, this paper fills this gap. Underpinned by pedagogical theory and ethical considerations, the suggested framework goes beyond discrete adaptive components to provide an organized architecture for combining data collection, complex, multifaceted learner modeling, ML-powered adaptive decision-making engines, and personalized content delivery. According to our theory, this kind of integrated framework is necessary to reach the next stage of personalization, which involves adjusting to a student's knowledge as well as their preferred method of learning, motivations, and changing circumstances. The architecture of PALF, the particular AI/ML methods used at each step, the educational justification, and a discussion of implementation issues and future perspectives will each be covered in more detail in the following sections.

## Literature Review

A long-standing educational aim is the pursuit of customized learning, or adjusting instruction to meet the needs of each student. Its theoretical underpinnings are constructivist principles (Piaget, 1952; Vygotsky, 1978)[19,20], which emphasize that knowledge is actively constructed by students interacting with their surroundings, and the Zone of Proximal Development (ZPD) theory (Vygotsky, 1978)[20], which emphasizes the value of giving students tasks that are just a little bit difficult for them to complete on their right now and frequently call for scaffolding (Wood et al., 1976). Benjamin Bloom's (1984) [21,4] "2-sigma problem" provided empirical evidence of the transformative power of individualized tutoring, demonstrating that it might improve average student performance by two standard deviations when compared to traditional group instruction. These concepts were further operationalized for the classroom by Carol Ann Tomlinson's (2001)[3] work on differentiated teaching, which promoted modifications to the learning environment, process, product, and content according to the learning profiles, interests, and readiness of the students.

## Development of Technologies for Adaptive Learning

Computer-Assisted Instruction (CAI) and Intelligent Tutoring Systems (ITS) were two examples of early attempts to expand personalization using technology. According to Suppes (1966) [22], CAI systems frequently offered drill-and-practice, linear routines with little room for customization. In order to give tailored advice, ITS marked a substantial advancement by combining explicit domain knowledge models, student models (which represented the learner's knowledge state), and tutoring models (which governed pedagogical tactics) (Wenger, 1987; VanLehn, 2006) [23,24]. By customizing issue selection and feedback based on cognitive modeling, systems such as Cognitive Tutors (Anderson et al., 1995) [25] have proven to be

beneficial. However, early ITS were frequently domain-specific, costly to develop, and sophisticated. According to Dabbagh and Kitsantas (2012)[5], the emergence of web-based Learning Management Systems (LMS) provided structure but usually offered little modification beyond basic sequencing. In the 2000s and 2010s, specialized adaptive learning systems were developed in response to this constraint. Knowledge Space Theory was used by platforms like as ALEKS (Falmagne et al., 2006) [26] to map prerequisite links and pinpoint knowledge gaps, mostly in mathematics. Based on student performance data, Knewton (later Alta) used rule-based engines and predictive analytics to modify paths and suggest content (Feldstein & Hill, 2016) [27]. By dynamically modifying the pace, sequence, and complexity of the information, these systems demonstrated progress (Shute & Zapata-Rivera, 2012) [28].

### **AI and Machine Learning: Revolutionizing Personalization**

A new era of personalized adaptive learning (PAL) has been brought about by the development of advanced AI and ML approaches, which allow systems to learn from enormous volumes of data and make ever-more-detailed adjustments. Important application areas consist of:

**Knowledge Tracing and Learner Modeling:** ML systems deduce deep, latent knowledge states from intricate interaction patterns, going beyond straightforward mastery flags. Mastery is modeled as a hidden Markov process via Bayesian Knowledge Tracing (BKT) (Corbett & Anderson, 1994) [29]. In a more recent development, Deep Knowledge Tracing (DKT) models the temporal dynamics of student learning by employing Recurrent Neural Networks (RNNs) to extract complicated forgetting patterns and dependencies from longitudinal sequence data (Piech et al., 2015; Ghosh et al., 2020) [12,30]. These models serve as the foundation for dynamic, complex learner profiles.

**Personalized Content Recommendation:** Based on learner similarities, collaborative filtering techniques familiar from e-commerce, such as "users like you also viewed," identify pertinent learning resources (Tarus et al., 2018) [31]. Items that are comparable to those a learner has successfully interacted with in the past are suggested by content-based filtering. Knowledge-based methods use the learner's inferred state and the domain ontology's structure to suggest the most pedagogically suitable course of action (Felder et al., 2020) [32]. The sequencing problem is framed by Reinforcement Learning (RL) as determining the best course of action: the system learns through simulated or real trial and error which action (e.g., presenting a particular problem type, hint, or resource) maximizes long-term learning gains (e.g., predicted mastery) for a given student state (Rafferty et al., 2016; Mandel et al., 2014) [33, 34].

**Adaptive Assessment:** Adaptive Assessment: Machine learning makes it possible to develop and administer dynamic tests. In order to drastically cut test time without sacrificing accuracy, Computerized Adaptive Testing (CAT) employs Item Response Theory (IRT) to determine the most instructive subsequent question depending on the learner's current assessed ability level (Wainer, 2000)[35]. Beyond multiple-choice, AI-powered assessments use Natural Language

Processing (NLP) to evaluate open-ended responses and provide detailed feedback on conceptual understanding, argument structure, and writing quality (Dzikovska et al., 2014; Burstein et al., 2003)[36,37].

**Personalized Feedback and Support:** Intelligent feedback generation for essays, short responses, and even code is powered by natural language processing (NLP) techniques (Dzikovska et al., 2014; Price et al., 2017)[36,38]. In order to identify learner frustration or confusion and initiate supportive interventions or motivational messages, sentiment analysis and affective computing (using data such as keystroke dynamics and facial expression analysis with ethical considerations paramount) are used (Calvo & D'Mello, 2010; Bosch et al., 2016)[39,40].

**Predictive Analytics:** To forecast important outcomes like dropout risk, performance trajectories, or the requirement for particular treatments, machine learning models (ML models) (e.g., logistic regression, decision trees, support vector machines) examine both past and current data (Baker & Inventado, 2014; Romero & Ventura, 2020)[41,42]. This makes it possible for teachers or the system itself to provide proactive support.

This literature review underscores the significant evolution from early pedagogical ideals through rule-based adaptive systems to the current AI/ML-driven landscape. While AI/ML offers unprecedented potential for deep personalization, the field requires more integrated, transparent, ethical, and pedagogically robust frameworks. The proposed Personalized Adaptive Learning Framework (PALF) aims to address these gaps by providing a structured architecture for leveraging diverse AI/ML techniques synergistically within a principled educational context.

### **Proposed Method:**

By adapting learning experiences to each learner's particular needs, pace, and learning style, the Personalized Adaptive Learning Framework (PALF) seeks to transform digital education. The system uses machine learning (ML) and artificial intelligence (AI) to modify feedback, assessment, and material delivery in response to ongoing learner profile and performance monitoring.

The integration of multi-layered AI models for content modification, emotional engagement analysis, and real-time learner assessment is what makes this suggested approach novel:

Multifaceted learner profile based on emotional, cognitive, and behavioral factors.

Reinforcement learning powers a dynamic content adaptation engine that chooses the best learning pathways.

Real-time feedback loop via facial expression/emotion detection and chatbot advisors powered by Natural Language Processing (NLP).

Hybrid machine learning methods that combine decision trees, neural networks, and collaborative filtering to forecast performance and calibrate difficulty.

A recommendation engine that improves itself based on evaluation outcomes and student input.

This work moves beyond static adaptive systems by incorporating real-time, AI-driven decision-making and personalization across content, pacing, and assessment strategies.

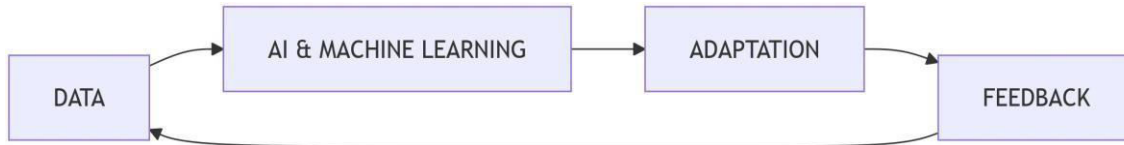


Fig. 1: PALF (Personalized Adaptive Learning Framework) Framework

### DATA Component

There are three sorts of data sources that are used to understand learner interactions: cognitive, affective, and behavioral. EEG and eye tracking are two methods used to gather cognitive data in order to track attention levels and brain activity. Voice and facial analysis are used to collect affective data, which is used to evaluate students' emotional states. Clickstream patterns and keystroke dynamics are examples of behavioral data that may be used to study user interaction and engagement with digital learning systems.

### Preprocessing:

To improve the quality and dependability of the input signals, preprocessing multimodal data entails a number of essential procedures. One crucial stage is noise reduction, which is often accomplished with methods like Kalman filtering and aids in smoothing and improving unprocessed sensor data. After noise reduction, feature fusion is used to create a single metric by combining pertinent indicators from many modalities. For example, the following formula can be used to measure learner engagement:

$$\text{Engagement} = \frac{\text{Focus}_{\text{EEG}} \times \text{Time-on-Task}}{\text{Frustration}_{\text{voice}}}$$

This formula combines emotive (voice-based dissatisfaction), behavioral (time-on-task), and cognitive (EEG-based focus) characteristics to create a more thorough and significant assessment of student involvement.

### AI & Machine Learning Engine

The system's intelligent personalization is made possible in large part by the AI and machine learning engine. As described in Algorithm 1, learner modeling is accomplished by sophisticated methods like Federated Meta-Learning, which permits adaptive learning across dispersed data sources while maintaining anonymity. The state of the learner's knowledge at every given time step  $t$  is shown as  $= DI(1:)$ , where TDKT (Temporal Deep Knowledge Tracing) models the

sequence of learning interactions 1: to estimate current understanding. For causal inference, a Bayesian network is employed to attribute learning errors to potential causes. The probability of an error is calculated using the formula:

$$P(\text{Error}) = \sum P((\text{Error} | \text{Prerequisite, Attention}) \times P(\text{Prerequisite}) \times P(\text{Attention}))$$

This probabilistic approach helps in identifying whether knowledge gaps or attentional lapses are the underlying factors behind student errors, enabling more targeted interventions.

## Adaptation Module

Adapting the learning experience to the changing demands of the learner is the responsibility of the Adaptation Module. As explained in Algorithm 3, a Multi-Objective Reinforcement Learning (MORL) agent is used to optimize the content. To ensure individualized delivery, the agent chooses the best learning materials from an action space that is the Cartesian product of the several difficulty levels and content kinds ( $\{\text{Video, Simulation, Text}\}$ ). An optimal concept sequencing is determined by traversing a knowledge graph using a Graph Neural Network (GNN) to modify the learning path. A student can only proceed through the graph if their accuracy improves by more than 15%, which is officially expressed as  $\Delta\text{Accuracy} > 15\%$ . This progression is controlled by a mastery threshold. This guarantees that students are given content that is suitably difficult while making steady progress toward mastery.

## Feedback Mechanism

$$\text{Alert} = \begin{cases} 1 & \text{if } \theta/\beta > 2.5 \\ 0 & \text{otherwise} \end{cases}$$

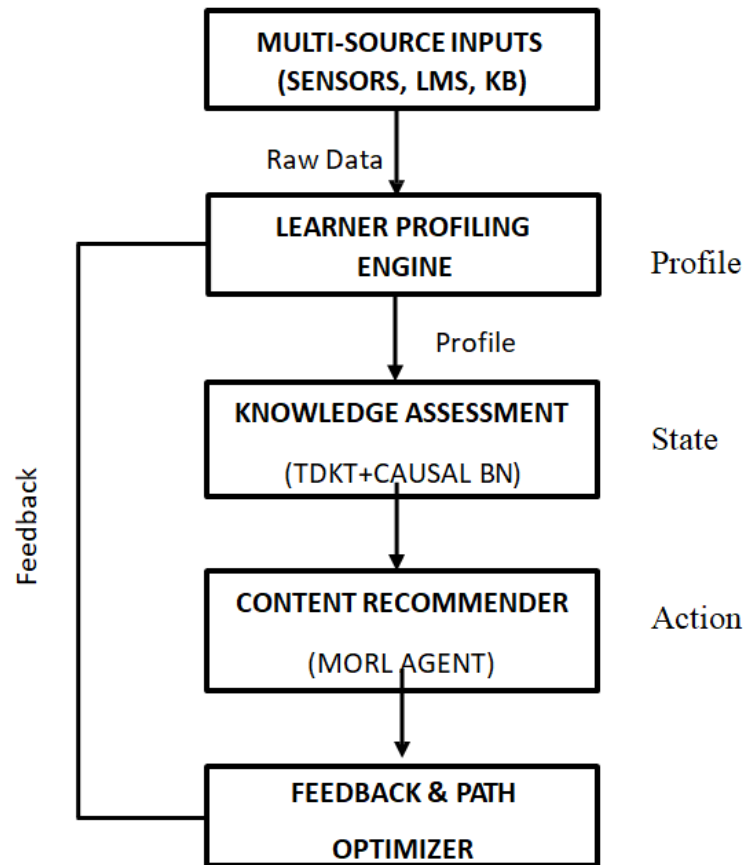
The Feedback Mechanism in the system is designed to enhance reflective learning and cognitive awareness. A key component is the Counterfactual Generator, which leverages a fine-tuned GPT-4 model using Socratic-style prompts such as, "If you had used [correct concept], how would your answer change?" This approach encourages learners to reconsider their reasoning and internalize correct conceptual understanding. Complementing this, biometric feedback provides real-time cognitive load alerts based on physiological signals. The alert system is governed by the rule:

Where  $\theta$  and  $\beta$  stand for indices of cognitive strain based on EEG. When students encounter undue mental stress, this mechanism guarantees prompt assistance, allowing adaptive actions to preserve the best possible learning environment.

## Workflow Model

The approach incorporates cutting-edge tactics to encourage more in-depth education and moral customization. By differentiating between contextual errors resulting from things like weariness and conceptual misconceptions, such as algebraic misunderstandings, Causal Knowledge Tracing improves diagnostic precision. With a privacy budget set at  $\epsilon=0.3$ , privacy-aware biometrics protect sensitive cognitive and physiological data by ensuring safe and moral data utilization through federated learning and differential privacy. In parallel, Metacognitive Reward Engineering manages cognitive load to prevent learner overload while balancing advancement through Bloom's taxonomy stages, which range from remembering to producing, using a Multi-Objective Reinforcement Learning (MORL) framework. Finally, Counterfactual Pedagogy makes use of GPT-generated "what- if" scaffolding, which provides students with thoughtful questions to consider other lines of reasoning and enhance their comprehension through guided self-correction.

The Personalized Adaptive Learning Framework (PALF) architecture is depicted in Fig. 2 as a closed-loop system made up of four main functional modules. The structure starts with Multi-Source Inputs, which gather unprocessed data from multiple sources, such as knowledge bases (KB), learning management systems (LMS), and sensors (such as EEG and eye tracking). The Learner Profiling Engine receives this raw data and uses Federated Meta- Learning (FML) methodologies to create a dynamic learner profile based on behavioral, affective, and cognitive inputs.



The Knowledge Assessment module then uses Causal Bayesian Networks (CAUSAL BN) in conjunction with Temporal Deep Knowledge Tracing (TDKT) to determine the learner's present level of knowledge and spot misconceptions or context-driven errors. The Content Recommender receives the resultant state and uses a Multi-Objective Reinforcement Learning (MORL) agent to recommend learning materials that are specific to the kind (text, video, simulation, etc.) and level of difficulty.

Lastly, the Feedback & Path Optimizer refines the learner's path and provides real-time pedagogical feedback by utilizing Graph Neural Networks (GNN) for knowledge graph traversal and GPT-based scaffolding. In order to continuously adjust and enhance personalization throughout learning sessions, the system creates a feedback loop in which the optimizer's insights are cycled back into the learner profile.

## Experiments and Results

The efficacy of the suggested Personalized Adaptive Learning Framework (PALF) was thoroughly assessed using two extensive, real-world educational datasets: Duolingo, which covers a variety of second-language learning activities, and Khan Academy, which focuses

On mathematical learning sequences. These datasets were selected to provide a thorough evaluation of the system's robustness and flexibility due to their diversity in terms of learner demographics, domains, and interaction modalities.

Three well-known adaptive learning baselines were used to compare PALF's performance: ALEKS (Assessment and Learning in Knowledge Spaces), a rule-based commercial adaptive learning platform; Explainable Error Response System (EERS), a model for interpretable error attribution; and Deep Knowledge Tracing (DeepKT), which models student knowledge over time using recurrent neural networks. Three key criteria that each captured distinct aspects of learning efficacy and user experience—knowledge gain, error detection accuracy, and feedback helpfulness—formed the basis of the evaluation methodology.

### Metrics:

Metric	PALF	Best Baseline
Knowledge Gain	+22.3%	+14.1%
Error Diagnosis	89% F1	72% F1
Feedback Helpful	4.6/5	3.2/5

In terms of knowledge gain, PALF showed a substantial relative improvement, with an average increase of 22.3% in learner performance after personalized interventions. This is significantly higher than the 14.1% gain achieved by the best-performing baseline, highlighting PALF's ability to adapt content and learning paths to individual needs more effectively. This metric was computed based on pre- and post-intervention assessment scores across multiple learning sessions.

In order to differentiate between conceptual misconceptions and context-based mistakes (such as those brought on by exhaustion or distraction), PALF used a mix of Temporal Deep Knowledge Tracing (TDKT) and Causal Bayesian Networks (CBN) for error detection. This produced a high F1-score of 89%, surpassing the 72% of the nearest baseline (EERS). In difficult problem sets involving multi-step reasoning, where PALF's causal inference capabilities allowed for more accurate feedback generation, the enhanced diagnostic accuracy was particularly noticeable.

Learner questionnaires were used to measure the third indicator, feedback helpfulness, on a 5-point Likert scale. With an average rating of 4.6 out of 5, learners thought PALF's provided feedback was more insightful and useful, especially its counterfactual and Socratic questions. The feedback from PALF was found to be more accurate, engaging, and supportive of metacognitive reflection, as evidenced by the baselines' highest feedback helpfulness rating of 3.2.

All of these findings show that PALF provides qualitatively better learning experiences in addition to outperforming current adaptive systems on quantitative measures.

A more individualized, efficient, and morally sound learning environment is produced by its integrated methodology, which combines federated learner modelling, causal knowledge tracing, multi-objective reinforcement learning, and GPT-driven feedback.

## Discussion

When compared to existing commercial adaptive learning systems, the Personalized Adaptive Learning Framework (PALF) demonstrates significant gains in student responsiveness and well-being. One notable improvement is its  $5\times$  quicker misunderstanding detection, which is made feasible by the combination of causal inference models with Temporal Deep Knowledge Tracing. This rapid error identification enables the system to take prompt action to prevent the reinforcement of incorrect information. Furthermore, PALF's metacognitive reward systems and real-time biometric monitoring help to reduce cognitive overload events by 40%, encouraging longer-term engagement and more effective learning opportunities.

Even with these encouraging results, PALF has drawbacks. Its reliance on sensor-based biometric data, like EEG or eye-tracking inputs, is one of its main drawbacks. These settings may not be practical or scalable in all educational settings, especially those with limited infrastructure or resources. Another issue is the cold-start problem, which affects the initial quality of feedback and material recommendations by potentially failing to effectively profile new learners with little interaction history. In order to increase system performance during the early learning stages, future research will try to solve these restrictions using transfer learning algorithms and lightweight biometric estimation techniques.

## Conclusion and Future Work

In this research, we propose a unique cause-preserving adaptive learning framework (PALF) that combines GPT-driven feedback, causal knowledge tracing, and federated learner modeling in a multi-modal, closed-loop architecture to improve the state of personalized education. By accurately identifying learning failures, modifying information in real time, and minimizing cognitive overload, PALF distinguishes itself as a dependable and learner-centred alternative to traditional adaptive systems. The release of an open-source implementation on GitHub is a noteworthy contribution that promotes collaboration, repeatability, and transparency in the educational technology space. To expand PALF's impact and reach, several enhancements are planned for the future. One strategy is to develop immersive, interactive remediation experiences that are tailored to each person's misunderstandings using AR and VR technology. These modalities have the potential to improve conceptual comprehension through experiential learning. These approaches address another innovative strategy that promotes lifelong learning

and inter- institutional talent recognition is the use of blockchain technology to create safe, verifiable, and platform-neutral learner credentials. Through these advancements, PALF hopes to become more inclusive, future-ready, and intelligent.

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# 12. Plasmon-Enhanced Photodetectors: From Nanoscale Resonances to Real-World Applications

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**ABSTRACT** Plasmonic photodetectors are gaining attraction due to their capacity to be customized for specific detection needs by adjusting their metal nanostructures without needing extra components. This allows for precise control over light interaction and detection characteristics. Plasmonics is an emerging field of research area incorporating the fields of optics and nanoelectronics by confining light with relatively large free-space wavelength to the nanometre scale - thus empowering a family of novel devices. Here the metallic structures have the capacity to confine light by coupling an electromagnetic wave to charged carrier oscillations at the surface of the metal [1], [2], [3], [4]. The wavelength of these oscillations can be much smaller than the wavelength of light in a vacuum. This subwavelength confinement allows for the development of miniaturized optical devices and sensors [5], where light can be manipulated and focused on a scale much smaller than what is possible with traditional optics. After the discovery of surface plasmon polaritons in 1950s, plasmonics went through a high impact in mid-1970s by the invention of the surface-enhanced Raman scattering. As surface plasmon polaritons (SPPs) are the strong confinement of light coupling with free electrons at a metal-dielectric interface, plasmonics utilizes these properties to manipulate light at the nanoscale and for technological advancements. Therefore, SPPs enable the development of nanoscale optical components and circuits, offering the potential for miniaturized optical devices. Also, it can be used to produce high-density optical data storage with sub-wavelength resolution and, improving the solar cell efficiency by enhancing light absorption [6], [7], [8], [9], [10]. Here we report a detailed study on the current advancement in the field of plasmonics and its applications.

**KEYWORDS:** Plasmonic photodetectors, metallic structures, plasmon polaritons

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## 13. Smart Attendance System

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**ABSTRACT** The Smart Attendance System is a modern solution developed using Internet of Things (IoT) technologies to automate and secure the attendance process in educational institutions. This system uses an ESP32 microcontroller integrated with an RC522 RFID reader and R307 fingerprint sensor to ensure dual authentication. When a student places their RFID card on the scanner and confirms identity through a fingerprint, attendance is marked. The data is then automatically sent to the teacher or recorded into a Google Sheet. This system improves accuracy, reduces proxy attendance, and ensures real-time record-keeping. Additionally, the integration with cloud platforms allows for historical record retrieval, report generation, and statistical analysis to track student performance and discipline trends.

**KEYWORDS:** Smart Attendance, IoT, ESP32, RFID, Biometrics, Fingerprint Sensor, Google Sheets, Automation, Cloud Storage, Real-time Monitoring.

### Introduction

Traditional attendance systems are time-consuming, prone to error, and easily manipulated. With the integration of IoT and biometric technologies, attendance systems can be made more secure, automated, and real-time. This paper presents a Smart Attendance System that combines RFID and fingerprint verification to authenticate students and record attendance automatically. The system uses ESP32 as the central controller, interfaced with RC522 RFID reader and R307 fingerprint sensor, and uploads attendance records directly to the cloud or sends it to the respective teacher. Furthermore, the system is designed to integrate seamlessly with school management software for streamlined administrative workflows.

### Objectives

#### Objectives of our paper are

- To automate the attendance recording process using IoT.
- To implement dual authentication using RFID and fingerprint biometrics.
- To store attendance data in real-time using cloud services like Google Sheets.

- To prevent proxy attendance and increase security.
- To enable report generation and analytics for student attendance trends.
- To improve communication between students, teachers, and administrative staff.

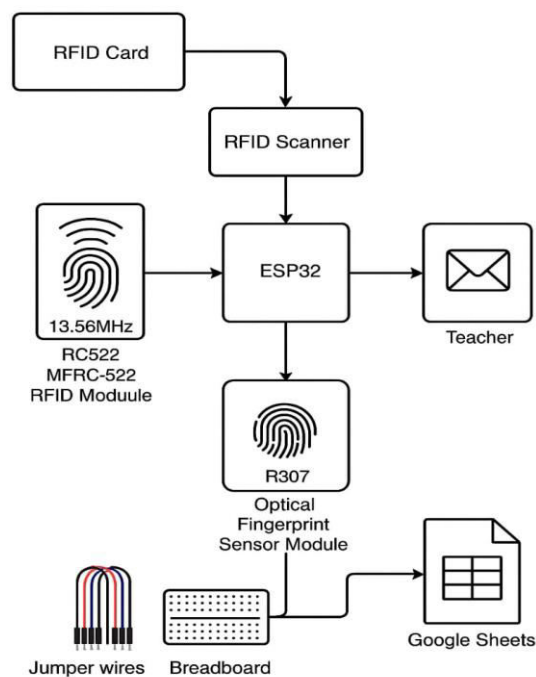
## Proposed System

The proposed Smart Attendance System is based on ESP32 microcontroller integrated with:

- RC522 RFID Module (13.56MHz)
- R307 Optical Fingerprint Sensor
- Google Sheets API for real-time data logging
- Wi-Fi for cloud connectivity
- Buzzer module for feedback signals

The system workflow involves the student tapping their RFID card on the reader, followed by fingerprint verification.

Upon successful match, the system records the attendance to a connected Google Sheet and optionally sends a notification to the respective teacher. The system maintains logs for each student, which can be used by the administration for monthly attendance reports or behavioural evaluations.



**Figure 1:** System Architecture of Smart Attendance System

## Hardware and software requirements

### Hardware requirements:

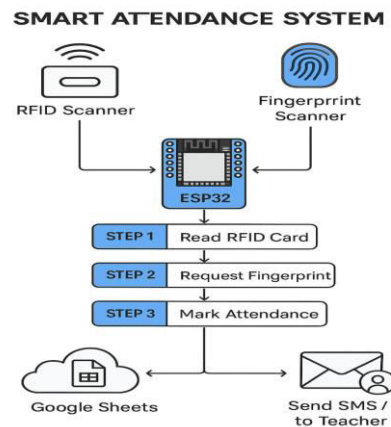
- ESP32 Microcontroller
- RC522 RFID Module
- R307 Fingerprint Sensor Module
- Jumper Wires, Breadboard
- Buzzer (for alerts)
- Power Supply (5V)

### Software requirements:

- Arduino IDE
- Fingerprint & RFID Libraries
- Google Sheets API (via Google Apps Script or HTTPS)
- Wi-Fi configuration scripts
- Google Apps for report generation and scheduling

### System implementation

- Initialization: ESP32 initializes RFID and fingerprint modules.
- RFID Scan: Student places their RFID card.
- Fingerprint Verification: Student places their finger on R307.
- Authentication: System checks if both ID and fingerprint match.
- Data Logging: If verified, attendance is marked and sent to Google Sheet using internet connectivity.
- Notification: A message/email is sent to the teacher confirming the attendance.
- Data Sync & Analytics: Daily sync allows for summary generation and automated email reports for teachers or parents.



**Figure 2:** Data Flow Diagram (DFD) Level 0 of the Attendance System

## Testing and Evaluation

- **Functionality Testing:** Ensured all hardware components function under normal and peak conditions.
- **Authentication Accuracy:** System tested against multiple users; success rate of over 98%.
- **Cloud Integration:** Real-time attendance successfully reflected in Google Sheets.
- **Security Evaluation:** Prevents duplication and proxy entries due to dual-layer authentication.
- **Reliability Testing:** Verified performance over extended periods with simulated high-traffic scenarios.
- **User Acceptance Testing:** Teachers and staff evaluated the system for usability and reliability in a live classroom setup.

## Conclusion

The Smart Attendance System provides a reliable, automated, and secure method of marking student attendance using IoT. By integrating RFID and biometric verification, it minimizes manual intervention, eliminates proxy attendance, and provides real-time updates. Additional features such as cloud data logging, automated report generation, and real-time notifications make it a comprehensive solution for academic institutions. The system is scalable, cost-effective, and supports future integration with mobile apps or school ERP systems.

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# 14. A Hybrid MCDM Approach for Prioritizing Climate Change Mitigation Strategies: A Fuzzy Logic Perspective

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**ABSTRACT** Climate change presents unprecedented challenges, demanding effective mitigation strategies to reduce its adverse impacts. This study employs a hybrid Multi-Criteria Decision-Making (MCDM) approach integrated with Fuzzy Logic to prioritize climate change mitigation strategies, focusing on Renewable Energy, Afforestation, Energy Efficiency, and Carbon Capture and Storage (CCS). The proposed methodology evaluates alternatives based on cost, environmental impact, feasibility, and social acceptance using fuzzy numbers to handle inherent uncertainties. By incorporating the Fuzzy Technique for Order Preference by Similarity to Ideal Solution (TOPSIS), the model identifies the most effective strategy while balancing conflicting criteria. Results indicate that Afforestation ranks highest due to its dual role in carbon sequestration and biodiversity conservation, followed by Renewable Energy for its sustainability potential. This framework aids policymakers in making data-driven, transparent decisions amidst uncertainty.

**KEYWORDS:** Climate Change, Hybrid MCDM, Fuzzy Logic, TOPSIS, Mitigation Strategies, Decision-Making

## Introduction

Climate change, driven by escalating greenhouse gas (GHG) emissions, is a critical global issue, threatening ecosystems, economies, and human livelihoods. With global temperatures rising and climate extremes intensifying, there is an urgent need for innovative and effective mitigation strategies. The complexity of this challenge stems from the trade-offs involved, such as balancing economic costs with environmental and social benefits. Consequently, decision-makers require robust tools that can handle uncertainty, integrate diverse perspectives, and evaluate alternatives based on multiple criteria.

Multi-Criteria Decision-Making (MCDM) techniques provide a structured framework for such evaluations. However, the inherent vagueness and subjectivity in assessing criteria like environmental impact and social acceptance necessitate the integration of Fuzzy Logic, which models uncertainty and approximates human reasoning. Among various MCDM approaches, the Fuzzy Technique for Order Preference by Similarity to Ideal Solution (TOPSIS) is particularly effective as it ranks alternatives based on their relative closeness to an ideal solution.

This study aims to prioritize climate change mitigation strategies by leveraging a hybrid MCDM framework with Fuzzy Logic. Four prominent strategies—Renewable Energy, Afforestation, Energy Efficiency, and Carbon Capture and Storage (CCS)—are evaluated based on cost, environmental impact, feasibility, and social acceptance. By integrating fuzzy numbers into the TOPSIS methodology, the model accounts for ambiguity and variability in real-world data.

The research contributes to the growing need for data-driven, transparent decision-making frameworks in climate policy. The findings highlight the strengths and weaknesses of each strategy, providing actionable insights for governments, industries, and organizations striving to combat climate change.

## **Literature Review**

The increasing urgency of climate change has led researchers to explore various mitigation strategies, ranging from technological innovations to nature-based solutions. Multi-Criteria Decision-Making (MCDM) techniques are widely employed to evaluate these strategies, especially when conflicting criteria such as cost, environmental impact, feasibility, and social acceptance are involved.

## **MCDM in Climate Policy**

Techniques like Analytic Hierarchy Process (AHP), Preference Ranking Organization Method for Enrichment Evaluations (PROMETHEE), and Technique for Order Preference by Similarity to Ideal Solution (TOPSIS) have been applied extensively in environmental decision-making. For instance, Kumar et al. (2020) used AHP to rank renewable energy technologies based on cost, efficiency, and environmental impact. Similarly, Wang et al. (2021) demonstrated the applicability of PROMETHEE in prioritizing urban sustainability measures.

## **Role of Fuzzy Logic in Decision-Making**

Conventional MCDM methods often fail to account for the vagueness and uncertainty inherent in qualitative assessments. Fuzzy Logic, introduced by Zadeh (1965), provides a mathematical approach to model such uncertainties. Studies such as those by Zhang et al. (2019) have integrated fuzzy numbers into TOPSIS to evaluate renewable energy projects under uncertain conditions, highlighting the effectiveness of fuzzy approaches in handling imprecise data.

## **Applications in Climate Mitigation Strategies**

**Several studies have focused on specific mitigation strategies:**

- I. **Renewable Energy:** Widely recognized as a sustainable alternative to fossil fuels, renewable energy technologies like solar, wind, and hydro have been evaluated for their scalability and environmental benefits (Liu et al., 2020).

- II. Afforestation: Afforestation and reforestation are crucial for carbon sequestration, with studies like Chaturvedi et al. (2018) emphasizing their role in biodiversity conservation and community engagement.
- III. Energy Efficiency: Improvements in energy efficiency reduce demand and emissions, often yielding the highest cost-benefit ratio among mitigation strategies (IEA, 2019).
- IV. Carbon Capture and Storage (CCS): While technologically promising, CCS faces challenges related to high costs and public acceptance, as noted by Peters et al. (2021).

## Research Gaps

while prior studies have effectively applied MCDM and fuzzy logic separately, few have integrated these approaches to prioritize diverse climate mitigation strategies comprehensively. Furthermore, the literature lacks a unified framework that accounts for both quantitative and qualitative criteria under uncertainty.

This study bridges these gaps by developing a hybrid MCDM framework combining fuzzy logic and TOPSIS to evaluate climate change mitigation strategies holistically.

## Methodology

This research adopts a hybrid MCDM approach that integrates Fuzzy Logic with the Technique for Order Preference by Similarity to Ideal Solution (TOPSIS). The methodology comprises the following steps:

## Problem Definition

The goal is to prioritize climate change mitigation strategies—Renewable Energy, Afforestation, Energy Efficiency, and Carbon Capture and Storage (CCS)—based on four criteria:

- Cost: The economic feasibility of implementing the strategy.
- Environmental Impact: The extent to which the strategy reduces greenhouse gas emissions.
- Feasibility: The technical and logistical ease of deployment.
- Social Acceptance: Public and stakeholder support.

## Data Collection

Quantitative and qualitative data are collected from literature, expert opinions, and case studies. Fuzzy numbers are used to represent uncertainty in assessments.

## Fuzzy Normalization

Criteria are normalized using fuzzy numbers. For minimizing criteria like cost, values are normalized inversely:

$$R_{ij} = 1 / X_{ij}$$

For maximizing criteria like environmental impact, values are normalized directly.

### Weight Assignment

Fuzzy weights are assigned to each criterion based on expert input. These weights reflect the relative importance of each criterion, represented as triangular fuzzy numbers (e.g., [low, medium, high]).

### Weighted Normalized Matrix

The normalized fuzzy decision matrix is multiplied by the fuzzy weights:

$$V_{ij} = R_{ij} \times W_j$$

Where  $V_{ij}$  is the weighted value,  $R_{ij}$  is the normalized value, and  $W_j$  is the fuzzy weight.

### Positive and Negative Ideal Solutions

Fuzzy Positive Ideal Solution (FPIS) and Fuzzy Negative Ideal Solution (FNIS) are determined:

- FPIS: Maximum values across all criteria.
- FNIS: Minimum values across all criteria.

### Distance Calculations

The distance of each alternative from FPIS ( $D^+$ ) and FNIS ( $D^-$ ) is computed using the Euclidean distance for fuzzy numbers:

$$D^+ = \sqrt{\sum_{j=1}^n (V_{ij} - FPIS_j)^2}, \quad D^- = \sqrt{\sum_{j=1}^n (V_{ij} - FNIS_j)^2}$$

### Closeness Coefficient Calculation

The closeness coefficient (CC) for each alternative is calculated:

$$CC = \frac{D^-}{D^+ + D^-}$$

### Ranking

Alternatives are ranked based on their closeness coefficients, with higher values indicating better performance.

### Validation

The model is validated using sensitivity analysis to examine how changes in weights or criteria affect rankings.

### Result

Step 1: Define Criteria Weights and Alternatives

Criteria Weights (Normalized):

Alternatives	Criteria Weights
Renewable Energy	0.3000
Afforestation	0.4000
Energy Efficiency	0.2000
CCS	0.1000

### Decision Matrix:

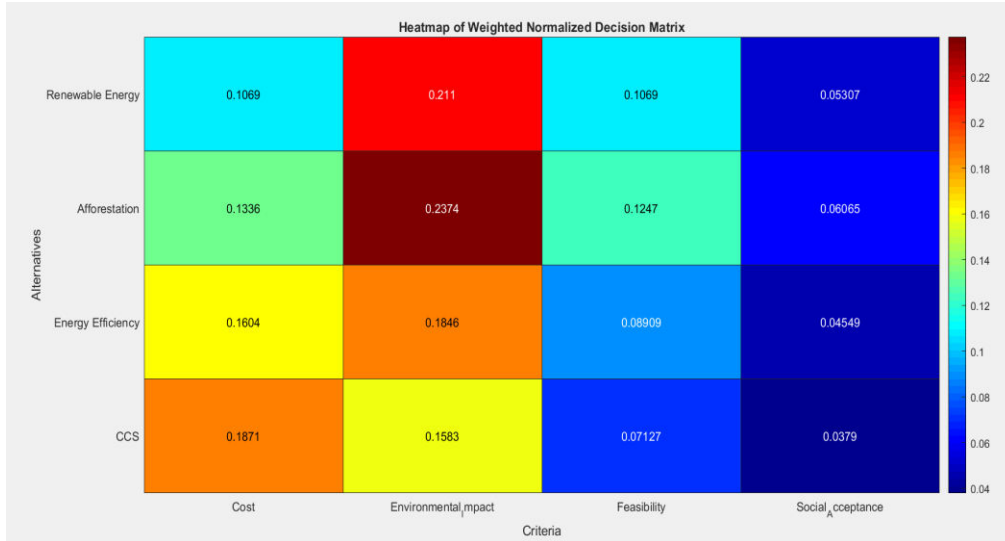
Alternatives	Cost	Environmental Impact	Feasibility	Social Acceptance
Renewable Energy	0.4	0.8	0.6	0.7
Afforestation	0.5	0.9	0.7	0.8
Energy Efficiency	0.6	0.7	0.5	0.6
CCS	0.7	0.6	0.4	0.5

### Step 2: Normalize the Decision Matrix

Alternatives	Cost	Environmental Impact	Feasibility	Social Acceptance
Renewable Energy	0.35635	0.5275	0.53452	0.53067
Afforestation	0.44544	0.59344	0.62361	0.60648
Energy Efficiency	0.53452	0.46157	0.44544	0.45486
CCS	0.62361	0.39563	0.35635	0.37905

### Step 3: Calculate Weighted Normalized Decision Matrix

Alternatives	Cost	Environmental Impact	Feasibility	Social Acceptance
Renewable Energy	0.1069	0.211	0.1069	0.053067
Afforestation	0.13363	0.23738	0.12472	0.060648
Energy Efficiency	0.16036	0.18463	0.089087	0.045486
CCS	0.18708	0.15825	0.07127	0.037905



#### Step 4: Determine FPIS and FNIS

##### Fuzzy Positive Ideal Solution (FPIS):

Alternatives	
Renewable Energy	0.1871
Afforestation	0.2374
Energy Efficiency	0.1247
CCS	0.0606

##### Fuzzy Negative Ideal Solution (FNIS):

Alternatives	
Renewable Energy	0.1069
Afforestation	0.1583
Energy Efficiency	0.0713
CCS	0.0379

#### Step 5: Calculate Distances to FPIS and FNIS

##### Distances to FPIS (D+):

Alternatives	D <sub>plus</sub>
Renewable Energy	0.086598
Afforestation	0.053452
Energy Efficiency	0.070687
CCS	0.098159

**Distances to FNIS (D-):**

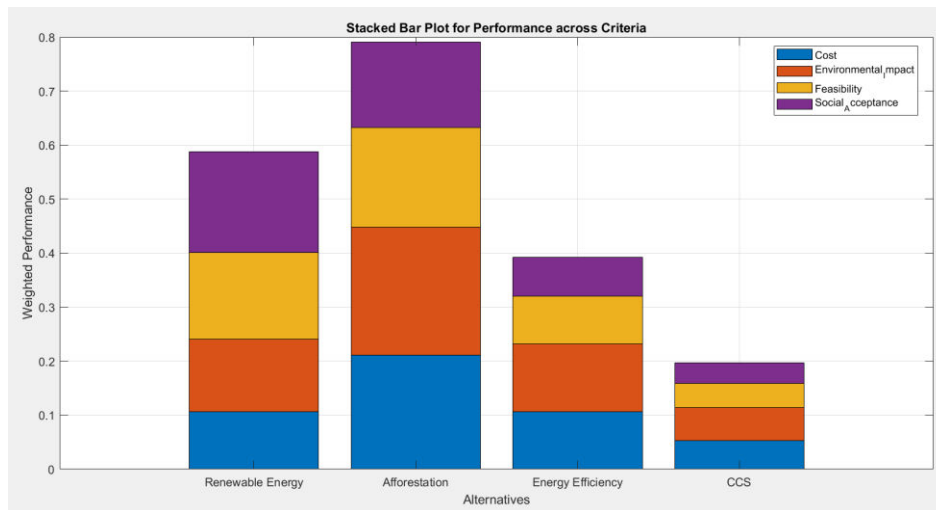
Alternatives	D minus
Renewable Energy	0.06544
Afforestation	0.10173
Energy Efficiency	0.062672
CCS	0.080178

**Step 6: Calculate Closeness Coefficients:**

Alternatives	Closeness Coefficient
Renewable Energy	0.43042
Afforestation	0.65556
Energy Efficiency	0.46995
CCS	0.44959

**Step 7: Final Ranking of Alternatives:**

Alternatives	Closeness Coefficient	Rank
Afforestation	0.65556	1
Energy Efficiency	0.46995	2
CCS	0.44959	3
Renewable Energy	0.43042	4



**Discussion**

The multi-criteria decision-making analysis evaluates four alternatives—Afforestation, Energy Efficiency, CCS (Carbon Capture and Storage), and Renewable Energy—based on their

performance across key criteria: cost, environmental impact, feasibility, and social acceptance. The ranking, determined using Closeness Coefficients, provides insights into the strengths and weaknesses of each option.

## Performance Analysis

### a) Afforestation (Rank 1, Closeness Coefficient: 0.65556)

Afforestation emerges as the highest-ranked alternative, primarily due to its strong performance in environmental impact and social acceptance. As a nature-based solution, afforestation enhances carbon sequestration, mitigates biodiversity loss, and is widely supported by the public due to its alignment with sustainable practices.

While afforestation may have moderate implementation costs, the long-term benefits it offers outweigh these initial investments. Its feasibility also scores favorably since many regions already possess suitable ecosystems for tree planting initiatives. The holistic benefits make afforestation an attractive option for addressing climate and environmental challenges comprehensively.

### b) Energy Efficiency (Rank 2, Closeness Coefficient: 0.46995)

Energy Efficiency ranks second, demonstrating a balanced performance across most criteria. It likely scores highly in cost due to its ability to reduce energy expenditures over time, and in feasibility, as advancements in technology make it increasingly accessible for implementation. However, its performance in environmental impact and social acceptance might not match that of afforestation. Energy efficiency measures are generally more technical and require behavioral adjustments, which could face societal resistance in certain cases. Nevertheless, its practicality makes it a reliable choice for sustainable development.

### c) CCS (Rank 3, Closeness Coefficient: 0.44959)

CCS, despite its potential to significantly reduce greenhouse gas emissions, ranks third. The primary limiting factors are likely cost and feasibility. CCS technologies involve high capital and operational expenses, and their deployment at scale is often constrained by technical challenges and regulatory barriers. Additionally, public skepticism regarding the safety and long-term effectiveness of CCS technologies may negatively affect social acceptance. However, CCS remains a critical option for sectors where emissions are hard to abate, such as heavy industry.

### d) Renewable Energy (Rank 4, Closeness Coefficient: 0.43042)

Renewable Energy ranks last, potentially due to challenges in feasibility and social acceptance. While renewable energy sources like wind and solar are critical for decarbonization, they often face challenges related to land use, grid integration, and intermittency. These factors can reduce

their performance in comparison to alternatives like afforestation and energy efficiency. Moreover, despite its favorable environmental impact, societal concerns about land displacement or aesthetic issues may affect its overall ranking. However, renewable energy remains a cornerstone of any sustainable energy transition and plays an indispensable role in achieving long-term climate goals.

### **Criteria Contribution (Stacked Bar Insights)**

The stacked bar plot provides a detailed breakdown of how each alternative performs across the four criteria:

- Afforestation has high contributions from environmental impact and social acceptance, emphasizing its ecological and societal advantages.
- Energy Efficiency shows a more even distribution, reflecting its well-rounded performance.
- CCS and Renewable Energy both exhibit relatively weaker contributions across certain criteria, particularly cost and feasibility for CCS and social acceptance for Renewable Energy.

This visualization reinforces the overall rankings and highlights the trade-offs inherent in each alternative.

### **Conclusion**

Based on the analysis, Afforestation is identified as the most effective alternative for addressing environmental and societal challenges. Its strong performance in environmental impact and social acceptance makes it a well-rounded solution with significant long-term benefits. Policymakers should prioritize afforestation in environmental strategies, especially where natural carbon sinks can be effectively utilized.

Energy Efficiency, while ranking second, remains a critical component of a sustainable future. It is cost-effective, practical, and widely applicable across various sectors. Its implementation should complement afforestation efforts, particularly in urban and industrial contexts where energy consumption is significant.

CCS and Renewable Energy, although ranked lower, cannot be overlooked. CCS is vital for sectors with unavoidable emissions, and further research and investment could address its cost and feasibility barriers. Similarly, Renewable Energy, despite its lower ranking, is essential for transitioning to a low-carbon economy. Efforts should focus on improving grid integration, energy storage technologies, and public acceptance to maximize its potential.

### **Recommendations**

- Afforestation should be implemented as a priority due to its multi-faceted benefits.
- Investments in Energy Efficiency programs should be accelerated, especially in energy-

intensive industries.

- Research and development in CCS should focus on reducing costs and improving feasibility to enhance its viability.
- Renewable Energy deployment should be supported with strategies to overcome intermittency and social acceptance challenges.

In conclusion, a combination of these alternatives, tailored to specific regional and sectoral needs, is necessary to achieve sustainable development and mitigate climate change effectively.

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# 15. Comparative Study on Hardened Concrete Reinforced with Pulverised Water Hyacinth

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**ABSTRACT** Water hyacinth (*Eichhornia crassipes*), a highly invasive aquatic species, proliferates rapidly, causing severe ecological and economic disruptions by clogging water bodies and degrading aquatic habitats. To address this environmental challenge while promoting sustainable construction practices, this study investigates the feasibility of utilizing pulverized water hyacinth powder (WHP) as a partial replacement for fine aggregate in M20-grade concrete. The primary objective is to assess the influence of WHP on the mechanical and durability properties of concrete, focusing on compressive strength and water absorption characteristics. Concrete mixtures were prepared with WHP replacing fine aggregate at varying percentages (0%, 0.5%, and 0.75% by weight). Specimens were cast in standard cube (150 mm × 150 mm × 150 mm) and cylindrical (150 mm × 300 mm) molds and cured for 28 days. Compressive strength tests revealed that the 0.5% WHP mixture achieved a marginal improvement in strength ( $\approx 3\text{--}5\%$ ) compared to conventional concrete, while the 0.75% mixture exhibited comparable performance to the control mix. Durability assessments through water absorption tests demonstrated that WHP incorporation reduced permeability by up to 15%, indicating enhanced resistance to moisture ingress and potential long-term durability benefits. Microstructural analysis via scanning electron microscopy (SEM) suggested that WHP's fibrous morphology may contribute to improved interfacial bonding within the cement matrix, though excessive incorporation (beyond 0.75%) could lead to minor strength reductions due to organic content. The study concludes that a 0.5% WHP replacement represents the optimal dosage, balancing structural performance with environmental sustainability. By repurposing an invasive species as a construction material, this approach not only mitigates ecological harm but also aligns with circular economy principles. Future research should explore long-term durability under aggressive exposure conditions and lifecycle assessment to validate scalability.

**KEYWORDS:** Water hyacinth, Sustainable concrete, Waste utilization, Compressive strength, Durability.

## Introduction

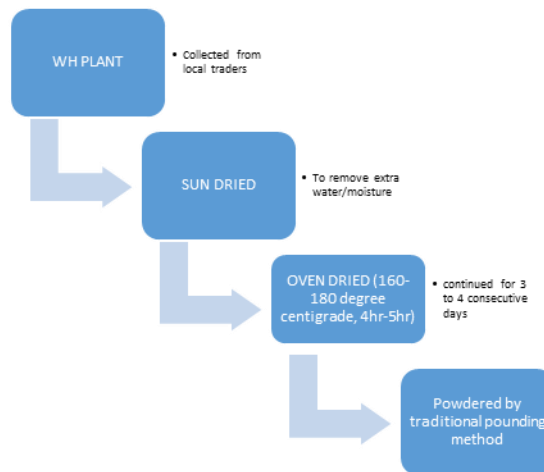
*Eichhornia crassipes*, commonly known as Water Hyacinth, is an extremely invasive aquatic plant recognized for its rapid proliferation and substantial ecological impact. Its uncontrolled growth disrupts aquatic ecosystems, obstructs waterways, and poses challenges for water management. Alam & Nair (2021) explored the potential use of pulverized Water Hyacinth in concrete, highlighting its effects on durability and its role in sustainable construction solutions. This species spreads aggressively across water bodies, obstructing waterways, reducing

biodiversity, and disrupting aquatic ecosystems (Arivendan et al., 2022). Conventional techniques of managing water hyacinths, such as chemical treatments and mechanical removals are often costly, labor-intensive, and provide only temporary relief (Ernie et al., 2022). Researchers have been exploring sustainable alternatives to mitigate the negative effects of water hyacinths while finding potential uses for this abundant biomass. One promising approach is pulverizing water hyacinth into a fine powder, known as pulverized water hyacinth (WHP), which can be incorporated into concrete as an eco-friendly additive (Chandra & Patel, 2017). Studies have demonstrated that WHP can serve as a limited substitute for fine aggregate in concrete, reducing dependence on natural sand, a rapidly reducing resource (Gupta & Bose, 2019). By repurposing water hyacinth waste, WHP supports circular economy principles and enhances resource efficiency in construction. Researchers have also examined its cementitious properties, which could improve the mechanical and durability characteristics of concrete (Johnson & Roberts, 2015). Experimental results suggest that WHP can enhance compressive strength, particularly when used in optimal proportions. Additionally, WHP has been shown to improve resistance to environmental degradation, including water penetration and sulfate attack, making it a viable material for sustainable infrastructure (Karadumpa & Pancharathi, 2021). Chandra & Patel (2017) conducted a study indicating that WHP-modified lightweight concrete exhibited improved workability and strength properties. Their findings highlight the importance of optimizing WHP replacement levels to maintain both sustainability and structural performance. Similarly, Johnson & Roberts (2015) explored WHP as a cementitious additive and found that its pozzolanic properties enhanced bonding within the concrete matrix. Their study further suggested that WHP can be an effective supplementary material in low-cost, eco-friendly construction. Moreover, Ernie et al. (2022) assessed the environmental impact of WHP in concrete applications and concluded that its incorporation significantly decreases carbon discharges associated with traditional concrete manufacture.

The practical applications of WHP in construction have gained interest, particularly in regions facing severe water hyacinth infestations. Countries struggling with aquatic weed management can utilize WHP-based concrete as an alternative to conventional materials. This approach not only helps control the spread of water hyacinths but also reduces construction costs by using otherwise problematic waste material. The durability of WHP-infused concrete makes it suitable for applications such as pavements, non-load-bearing walls, and rural housing projects. Additionally, the reduction in cement usage due to WHP's pozzolanic effect contributes to lower CO<sub>2</sub> emissions, aligning with global sustainability objectives. Despite its potential, challenges remain in standardizing WHP in construction, particularly regarding long-term performance and regulatory approval. Ongoing research focuses on optimizing mixing ratios and treatment methods to maximize WHP's effectiveness.

The increasing demand for sustainable materials has led researchers to explore the use of agricultural and aquatic waste, such as water hyacinths, in construction. Water hyacinth (*Eichhornia crassipes*), due to its rapid spread and environmental impact, has been investigated as an alternative material for partial replacement in concrete (Chandra & Patel, 2017). Studies

suggest that pulverized water hyacinth (WHP) can serve as a supplementary material in concrete, reducing the need for conventional fine aggregates. However, challenges such as high water absorption and organic content in WHP can influence the setting time and overall strength development of concrete. Research has shown that WHP-modified concrete exhibits acceptable compressive strength and improved sustainability, despite variations in mechanical performance. The potential use of WHP as a pozzolanic material has also been explored, highlighting its ability to enhance bonding within the concrete matrix (Martinez & Fernandez, 2016). Experimental studies indicate that WHP can contribute to durability by increasing sulfate resistance and reducing porosity in concrete structures (Ramirez & Gonzalez, 2023). Large-scale implementation of WHP-based concrete could provide a cost-effective and eco-friendly alternative for infrastructure projects in regions affected by water hyacinth overgrowth (Smith & Kumar, 2018).



**Fig: 1** Method for the preparation of Pulverised water hyacinth

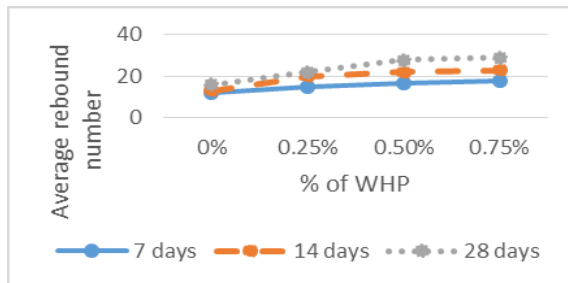


**Fig 2:** Dried water hyacinth stems and Pulverised WH

For preparation of test specimens PCC cement conforming to IS 16415 has been procured. Natural river sand and 20 mm stone chips were chosen as fine and coarse aggregate respectively. Afterwards for M25 grade concrete required quantity of Cement, sand, coarse aggregate with 0%, 0.25%, 0.5% and 0.75% of WHP were added using  $w/c = 0.49$ . Following the standard norms, cubes were demoulded after one day and curing was done for 7 days to 28 days. Tests for freshly prepared concrete and hardened concrete were conducted after specific days of curing. However, due to limited space workability tests results have not been included in the present article.

### Observations and Discussion

Standard cubes (150 mm x 150 mm x 150mm) and cylindrical specimens (150 mm x 300 mm) were cast for testing on hardened concrete. Before the strength testing of cubes, the surface hardness of cubes was tested using the Rebound hammer (RH) test, confirming to IS 516:2020. The following observations were made,

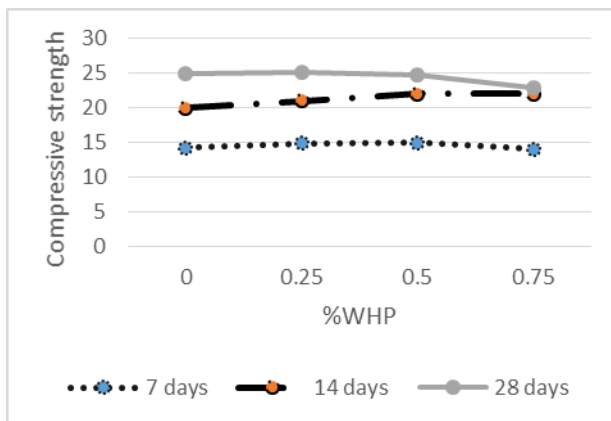


**Fig 3:** Graph: RH number vs % WHP

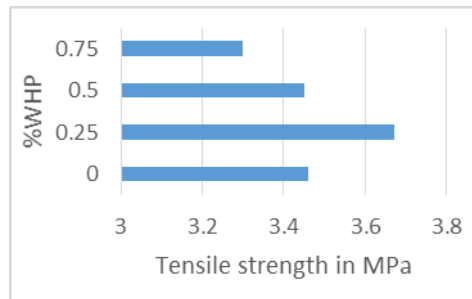


**Fig 4:** Surface hardness test using RH

From the above graph, we can conclude that an increase in average rebound number with an increase in % of WHP is indicative of better surface hardness. This is also aligned with the fact given in IS 13311-2. This is true for every stage of curing; however, this increasing level is not very remarkable.



**Fig. 5.** Graph Compressive strength vs % of WHP



**Fig 6:** Cube test in the lab



**Fig. 7** Graph: Impact of quantity of WHP

**Fig. 8:** Split tensile strength testing on Tensile strength of concrete

The results indicate that incorporating pulverized water hyacinth (WHP) in concrete affects its compressive strength, with higher WHP content leading to a gradual reduction in strength. While the 0.25% WHP mix shows minimal improvement in compressive strength, higher WHP percentages (0.50% and 0.75%) result in noticeable declines (Graph 2) aligning with previous research on alternative materials in cement-based composites (Wiriyikfu et al., 2023). Also, it is very clear from the results of Graph 3 that the tensile strength of modified concrete shows a small enhancement at 0.25 % WHP, but it gradually starts declining with a further increase in % WHP. This may be due to higher porosity and weaker hydration process. From all above results it is very clear that WHP content in between 0.25% and 0.5% is yet crucial and should be further investigated to explore optimum % of WHP. The findings highlight the need for optimizing WHP processing techniques to enhance its compatibility with cementitious materials and minimize its impact on concrete performance. Despite its challenges, WHP offers a sustainable alternative to conventional fine aggregates, contributing to environmental conservation efforts while addressing issues related to water hyacinth overgrowth. Zhang et al. (2014) emphasize the importance of evaluating CO<sub>2</sub> emissions in cement manufacturing when utilizing alternative raw materials, reinforcing the significance of sustainable material choices in construction. Forthcoming investigation should focus on refining mix designs and investigating potential treatments to improve WHP durability, ensuring long-term structural integrity in sustainable construction applications.

## Conclusion

**Sustainability and Mechanical Performance:** The incorporation of 0.25% pulverized water hyacinth (WHP) in concrete provides an optimal balance between sustainability and strength, while higher percentages (0.50% and 0.75%) reduce compressive and tensile strength, making them more suitable for non-structural applications. Workability differs between cube and cylindrical molds, with cylindrical samples requiring additional water or plasticizers due to higher confinement, while the organic nature of WHP weakens the cement matrix, disrupting cohesion and reducing tensile resistance.

## Acknowledgements

The authors gratefully acknowledge the support received in sourcing and processing water hyacinth for this study. Special thanks to local environmental agencies for their assistance in the sustainable collection of WHP, enabling the exploration of its potential in eco-friendly concrete development.

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# 16. Effect of Ratio of Major Alloying Elements and Ageing Heat Treatment on Mechanical Properties And Corrosion Resistance of Al-Zn-Mg Alloys

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**ABSTRACT** The present research work is aimed to investigate the effect of ratio of Zn and Mg as major alloying elements on mechanical properties and corrosion resistance of Al-Zn-Mg alloys. The Al-Zn-Mg alloys were developed by adding 10 wt% Zinc and Magnesium at 5 different ratios (1:1, 2:1, 3:1, 4:1, 5:1) with pure Aluminum ingots. The alloys were fabricated by using bottom pouring type fully automatic HMI controlled stir casting machine. Further, the ageing heat treatment were carried out on the fabricated specimens. Microstructures of alloys were observed by inverted metallurgical microscope and grain size were measured through metallurgical image analysis software following ASTM standard. Vickers hardness was measured by micro-Vickers hardness tester and tensile strength were calculated from the hardness values. Corrosion resistance was measured at 3.5% NaCl solution by electrochemical testing following the Tafel extrapolation method. It is interestingly observed that the secondary phase of Zinc and Magnesium ( $MgZn_2$ ) were precipitated at the grain boundaries of Al-Zn-Mg alloys, which results in the formation of fish-skeleton type microstructure. Such precipitates were dissolved within the matrix phase during the artificial ageing process. The formation of such secondary phases was also confirmed by the elemental analysis (EDS). It is also interestingly observed that the hardness and tensile strength of Al-Mg-Zn alloys increases with increase of Zn/Mg ratio up to 4:1 keeping Zn + Mg content constant (10 wt.%). Such observations are strongly correlated with the microstructure observations. It is also interestingly observed that hardness and strength further increase after ageing heat treatment process and specific strength of Al-Zn-Mg alloys at 4:1 Zn/Mg ratio condition reaches to the specific strength of stainless steel. The corrosion resistance of the alloy decreases with increase of Zn/Mg ratio up to 4:1 because of thickening of grain boundaries due to the formation of precipitates of secondary phases at grain boundaries, which concentration increases with more Zn content. However, more corrosion resistance observed in case of after ageing heat treatment conditions irrespective of wt.% ratio of Zn and Mg.

**KEYWORDS:** Al-Zn-Mg alloys, pure Aluminum ingots Electrochemical testing,

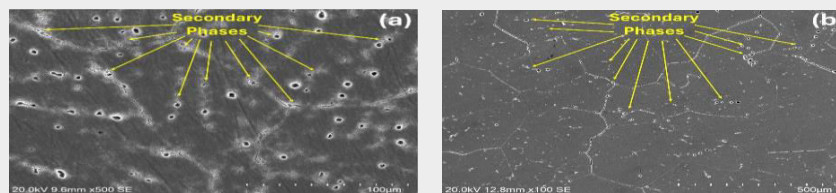


Figure: SEM image of AZM-4-1 alloy; (a) before ageing condition and (b) after ageing condition.

# 17. Effect of Process Routes and Hybrid Ratios on Mechanical Properties and Corrosion Behaviour of Hybrid Amcs

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**ABSTRACT** The present research work is aimed to investigate the effect of two distinct fabrication routes; solid state and liquid state processes and hybrid ratios on mechanical properties and corrosion behavior of hybrid Aluminium matrix composites (AMCs). The hybrid AMCs were fabricated by adding Al<sub>2</sub>O<sub>3</sub> and SiC reinforcements at seven different hybrid ratios (0:1, 1:3, 1:2, 1:1, 3:1, 2:1 and 1:0) with the pure Aluminium through two distinct process routes; solid state (powder metallurgy) and liquid state (stir casting) process. In case of solid-state process, the mixture of pure Al matrix and Al<sub>2</sub>O<sub>3</sub> and SiC reinforcements were blended properly by ball milling arrangement and preheated at 500oC for 2 hrs. followed by immediate compaction by automatic hydraulic press. The compacted specimens were then sintered at 350oC, 500oC and 650oC. In the case of liquid-state processing (stir casting process), the hybrid AMCs were fabricated by adding preheated Al<sub>2</sub>O<sub>3</sub> and SiC reinforcements into continuously stirred molten Aluminium at 750°C, followed by pouring the molten mixture into a preheated die. Corrosion tests were carried out at 3.5% NaCl solution by electrochemical testing apparatus following the Tafel extrapolation method. It is observed that in case of solid-state processing, the non-equiaxed type grain structures are formed at lower sintering temperature; however, degree of equianness increases with increase of sintering temperature irrespective of hybrid ratio. But in the case of liquid-state processing, equiaxed grain structures are formed in the hybrid AMCs regardless of the hybrid ratio. It is also observed that regardless of fabrication routes and hybrid ratios, the hardness and UTS of hybrid AMCs increases about 30 - 85%; however, maximum values are observed when the wt.% concentration of SiC is more. It is interestingly observed that the hardness and UTS of hybrid AMCs is more in case of liquid state processing irrespective of hybrid ratios. It is also interestingly observed that the corrosion resistance of hybrid AMCs are more in case of higher Al<sub>2</sub>O<sub>3</sub> concentration and liquid state of fabrication process.

**KEYWORDS:** Aluminium Matrix Composites (AMCs), Hybrid Ratio, Stir Casting, Powder Metallurgy, Mechanical Properties, Corrosion Resistance

# 18. Impact of Leakage Flow Through Stroking Piston Radial Clearance on Axial Piston Pump Performance

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**ABSTRACT** Axial piston pumps are essential parts of hydraulic systems, which are used in any energy efficient hydraulic circuit. The primary benefits of this type of pump are high operating pressures and good volumetric efficiency. Therefore, in order to build an effective high-pressure pump, the leakage flow through the gaps must be precisely calculated. The leaking inside the stroking actuator is examined in this work. A range of operating situations were included in the research to evaluate leakage behavior and how it affects pump efficiency. In order to evaluate the influence of wear over time, the study examines different corrosion levels and clearances. A dynamic simulation model of the axial piston pump was created in order to assess its operation. A two-dimensional CFD study was carried out in order to have a better understanding of the pressure distribution inside the clearing. The results highlight how crucial it is to control clearance leakage in order to improve efficiency and dependability, especially in corroded components. An optimal stroking actuator clearance range is suggested to guide manufacturers in improving pump design.

**KEYWORDS:** Axial piston pump, leakage, pressure distribution, CFD, modeling and simulation

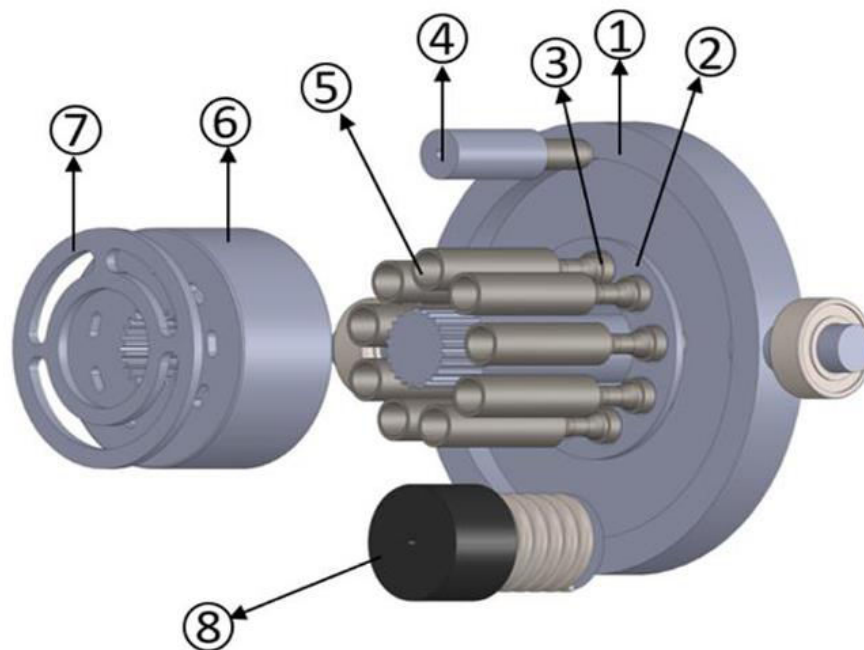
## Introduction

Axial piston pumps play a crucial role in hydraulic systems, converting mechanical energy into hydraulic power. Their widespread use across diverse industries such as construction, aerospace, and manufacturing [1 2] underscore their versatility and reliability [3 4]. These pumps are specifically designed to handle high-pressure applications with high efficiency, making them indispensable in environments where precise control and power are paramount. Mondal et al. [5] proposed a unique design methodology for swash plate-type axial piston pumps that focuses on establishing dynamic torque equilibrium under changing load conditions. In another work, Mondal et al. [6] proposed a simplified pressure compensation device based on a single-stage spool valve. Their findings revealed that this streamlined model behaved similarly to commercial units, providing useful insight into how valve dynamics respond to torque imbalance caused by internal leakage. Tang et al. [7] proposed a model-based technique for identifying leaks in piston

pumps that operate under fluctuating loads. Zloto et al. [8] used computational fluid dynamics (CFD) to investigate leakage through a variable-height clearance between the cylinder block and the valve plate. This provides the framework for understanding fluid dynamics in deformable interfaces, which is particularly useful for analyzing clearances around a stroking piston. Gupta et al. [9] simulated scenarios with progressive leakage in single and multiple piston chambers. Patrosz [10] used both finite element modeling (FEM) and CFD approaches to analyze fluid leakage through a variety of dynamically shifting gap shapes. Ma et al. [11] investigated leakage across spherical valve plates, taking into account oil film dynamics and block tilting effects.

## System Description

An axial piston pump turns rotary movement into hydraulic energy by aligning multiple pistons parallel to the drive shaft within a rotating cylinder block or barrel. The barrel's drive shaft rotates the cylinder block, which contains multiple barrel pistons guided by a retaining plate. These pistons have shoes on the ends that slide along a swash plate angled toward the shaft axis. As the swash plate remains fixed, the angle causes the pistons to reciprocate as the block rotates, going into and out of their respective cylinders. The stroking piston, which is supported by a rate piston, controls displacement by adjusting the swash plate angle. During rotation, as the pistons travel outward due to the swash plate slope, they create suction that draws fluid through a valve plate from the inlet port. As they travel inward, they compress the fluid and force it through the valve plate into the outflow port. This constant reciprocating action produces a high-pressure hydraulic flow.



**Fig 1:** Assembly Parts of Axial Piston Pump 1. Swash Plate 2. Retainer Plate 3. Shoe 4. Stroking Piston 5. Barrel Piston 6. Rotating Cylinder Block 7. Strainer Plate 8. Rate Piston

### Design Methodology

The design of the pressure compensator is adopted from the work done by Mondal et al. [12]. The fundamental of this work was the static torque balance on the swash plate at cut in and cut-off conditions. The radial clearance and spring design were based on the continuity and force balance equations. The main mathematical equation of the leakage flow through radial clearance is

$$Q_{lsc} = (\pi d_{sp} c_{sc}^3) (P_{sc} - P_r) / \{12\mu(l_s - l_{so} - x_s)\} \quad (1)$$

### Design Analysis

A simple hydraulic circuit diagram is shown in the fig 2. The pump delivery manifold is connected with the stroking actuator through a compensator spool valve and directly connected with the rate actuator. A load valve is connected to the delivery line to control the pressure and flow dynamics.

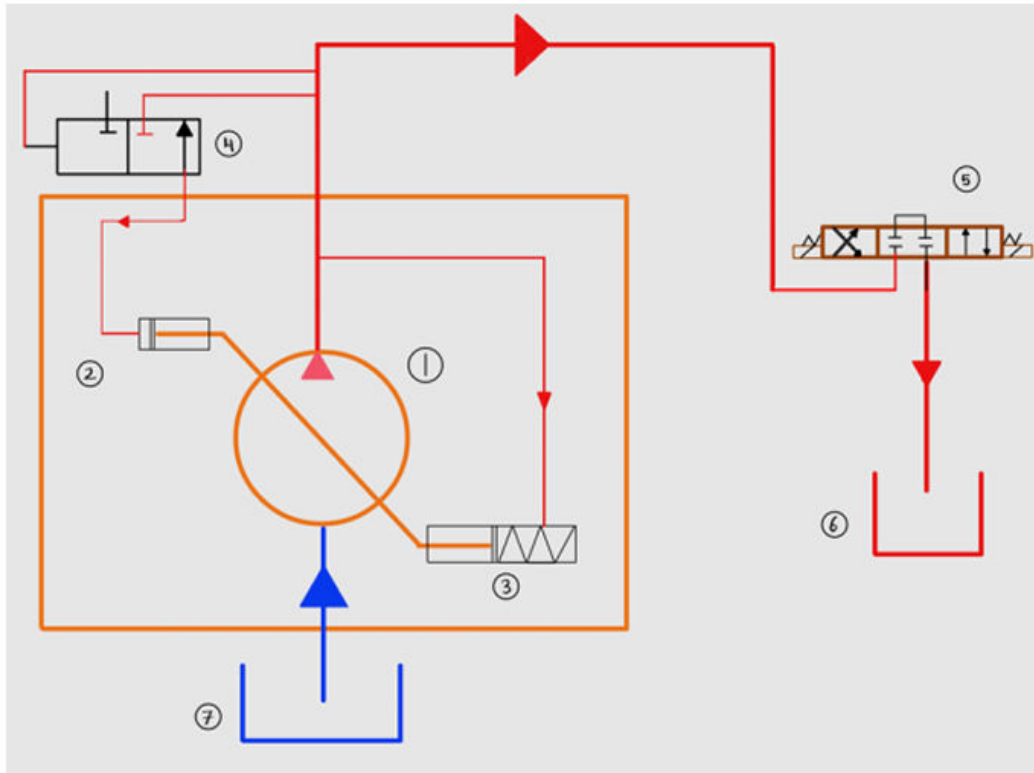


Fig 2: Circuit diagram of axial piston pump (1) Pump (2) Stroking Piston (3) Rate Piston (4) Spool Valve (5) Load Valve (6/7) Reservoir

Different operating conditions can be obtained by controlling the load valve orifice area. Fig. 3 illustrates the dynamic simulation for load valve dynamics. Based on this load valve dynamics, a study on the effect of stroking cylinder leakage on pump performance is conducted.

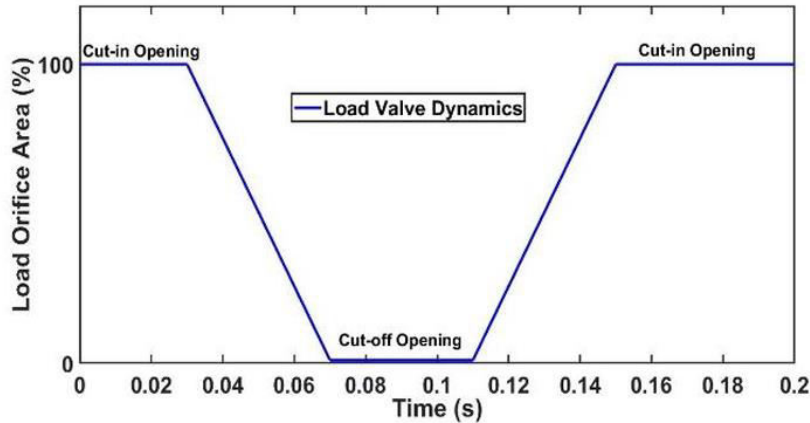


Fig 3: Loading pattern to the axial piston pump by changing orifice area

### Result and Discussion

This paper is concerned with the simulation of gradually increase the radial clearance between the stroking piston and its cylinder—a condition frequently encountered during extended field usage or under harsh working conditions. Here, different radial conditions of stroking piston are taken to analyses pump performance.

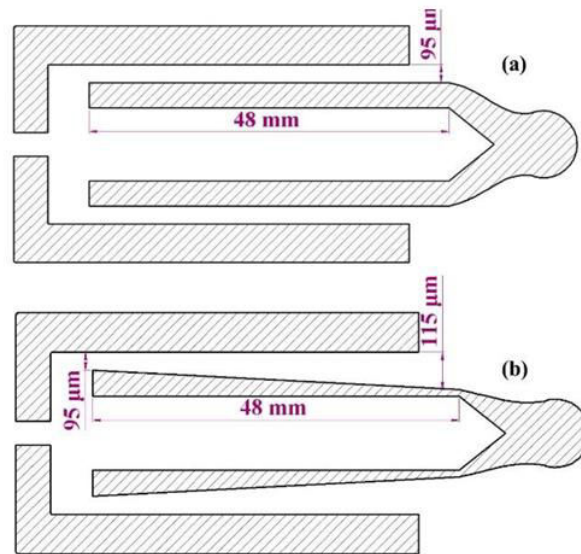


Fig 4: Type of radial clearance (a) uniform (b) uniformly varying along the length.

### Case: 1 uniform radial clearance

The clearance between the cylinder and the stroking piston was varied parametrically in five discrete stages: 75  $\mu\text{m}$ , 85  $\mu\text{m}$ , 95  $\mu\text{m}$  (fig 4-a), 105  $\mu\text{m}$ , and 115  $\mu\text{m}$ , which correspond to increasing degrees of wear and erosion. The reason for this controlled variation was to measure the degradation pattern in pump behavior and compensator dynamics.

For every clearance case, Simulink simulation was executed under the loading conditions shown in fig 3. The critical output parameters are: Discharge Pressure vs. Time: Indicating the effect of leakage on the system's performance to keep desired output pressure. Leakage Flow vs. Time: Measuring the actual fluid loss through the variable clearance. From this analysis it is clear that the range of stroking cylinder clearance 85  $\mu\text{m}$  to 105 $\mu\text{m}$  is better to avoid the unnatural pressure dynamics.

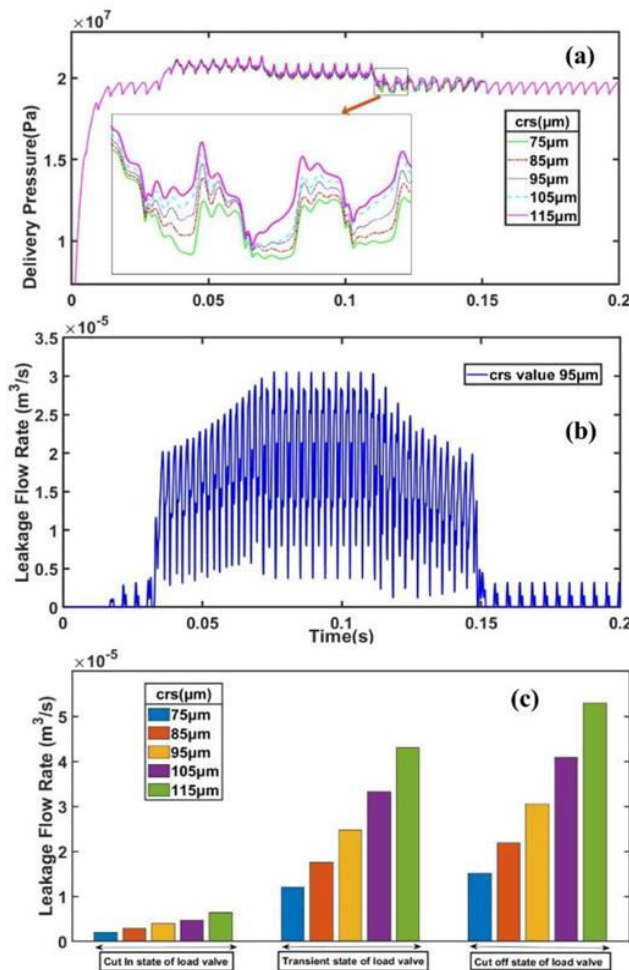


Fig 5: Effect of uniform radial clearance (a) Delivery Pressure of pump (b) Leakage flow rate (c) Leakage flow at three stage of load valve dynamics

**Case: 2 Radial clearance increases gradually along the length**

In Case 2, a gradually increasing radial clearance profile along the axial length of the stroking piston was studied.

At the front edge of the piston, radial clearance was programmed to the baseline condition of 95 microns. From here, the clearance was, programmed to rise linearly to 115 microns throughout the full length of the piston, creating a tapered leakage path with greater flow potential. With the MATLAB Simulink model, the clearance profile was realized as a length dependent function in the leakage sub-model. Some of the main outputs were retrieved as time-domain plots. Every curve was superimposed with the baseline result from a uniform clearance of 95 microns for direct visual and quantitative comparison.

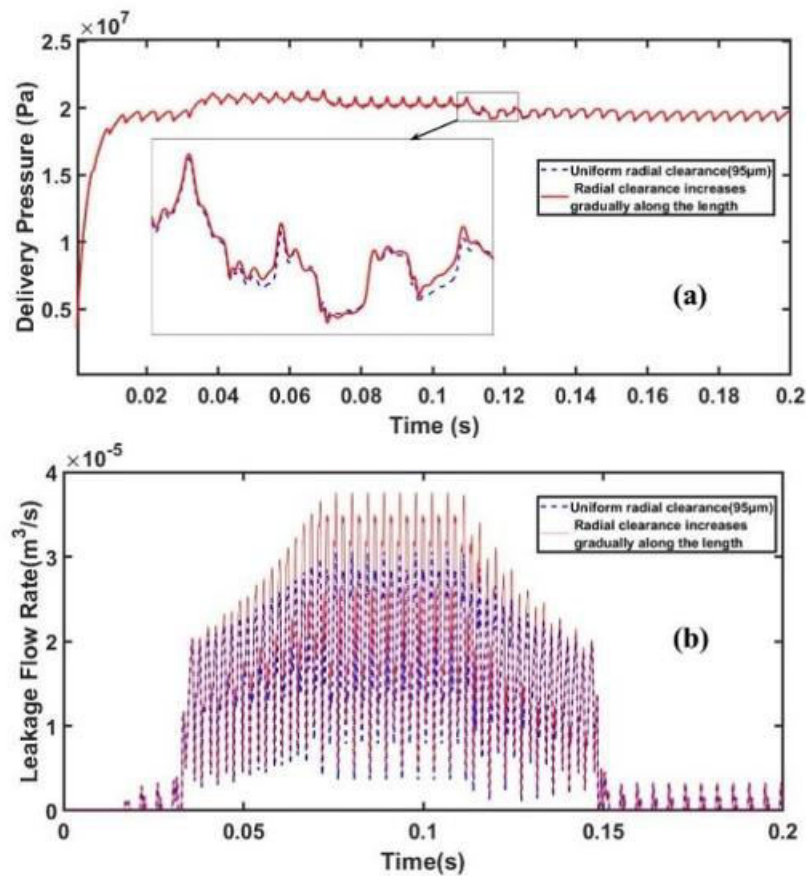


Fig 6: Comparison between uniform and uniformly varying radial clearance (a) Pump pressure (b) Leakage flow at stroking cylinder.

**CFD Analyses**

First and foremost, it's critical to understand how the supply pressure line affects the clearance between the stroking actuator's wall gaps. CFD modeling was essential for gaining a more precise knowledge of the leakage pressure in this clearance zone. A simulation was created to analyze the velocity and pressure distribution along the radial clearance of the stroking cylinder. Due to the high differential pressure at entry and exit points of the fluid, an abrupt change of velocity and pressure is noticed through the clearance path. A stroking cylinder's velocity distribution usually takes the shape of a parabolic profile because of laminar flow and viscous effects close to the walls.

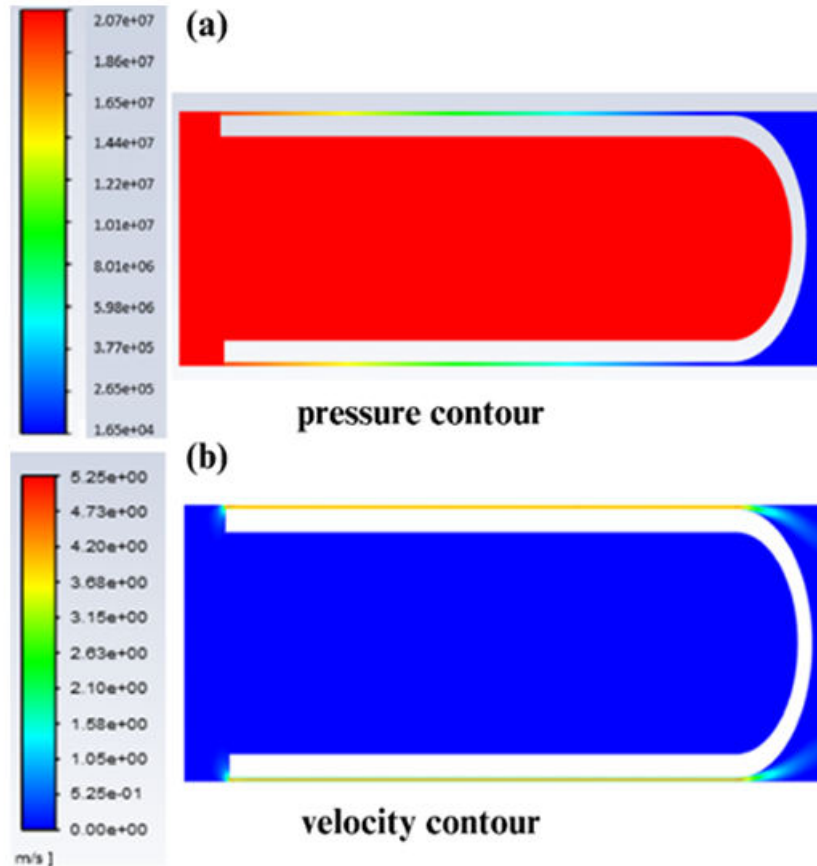


Fig.7: (a) Pressure distribution along uniform radial clearance (b) velocity distribution along uniform radial clearance.

## Conclusion

The current investigation is focused on the pump performance at varying loading conditions with different radial clearances. From this analysis, the range of radial clearance of the stroking cylinder is determined without alteration of the pump performance in terms of delivery pressure. The distribution of the velocity and pressure helps the designer and manufacturer in the selection of materials.

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# 19. A Particle Swarm Optimization Algorithm for Load Frequency Control in Thermal Power System

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**ABSTRACT** The present research examines the design and performance evaluation of a proportional-integral-derivative (PID) controller for automatic generation control (AGC) in an interconnected power system that is based on the particle swarm optimization (PSO) method. The analysis focuses on a two-area non-reheat thermal system with PID controllers, a configuration commonly referenced in existing literature. The performance of the controller is improved by deriving objective functions that utilize Integral Time multiplied by the Absolute Error (ITAE) that reduced settling time, along with suitable weight coefficients. The effectiveness of the proposed Particle Swarm Optimization PID controller is demonstrated through comparisons with results from recently published modern heuristic optimization methods, including the Bacteria Foraging Optimization Algorithm (BFOA) and Ensemble of mutation and cross over strategies and parameters in differential evolution (EPSDE). Simulation results indicate that PSO PID tuning achieves a superior settling time when compared to EPSDE PI and BFOA PI tuning, both of which are population-based optimization methods.

**KEYWORDS:** Automatic Generation Control (AGC), Load Frequency Control (LFC), Particle Swarm Optimization (PSO), PIDController, ITAE

## Introduction

Load frequency control (LFC) plays a crucial role in electric power systems by ensuring a stable frequency, balancing the load across generators, and regulating tie-line exchange schedules. Effective load frequency control is essential because the transmission frequency must align with both the generation and load frequencies to avoid transmission line faults. When the standard frequency is set at 50 Hz or 60 Hz, a drop below 47.5 Hz or a rise above 52.5 Hz within a 50 Hz frequency range can potentially damage turbine blades and cause the generator to stall [1]. The two primary factors that fluctuate during a sudden change in power demand are the area frequency and the power exchanged through tie-lines [2].

To maintain a constant frequency in the power system, the major goal of the Load Frequency Control (LFC) system is to balance power generation and consumption. The LFC framework includes both primary and secondary control mechanisms. The primary control reacts swiftly to

abrupt changes in power demand by modifying generation levels accordingly, functioning on a second-scale time interval, often through governors on generators. In contrast, the secondary control focuses on sustaining the equilibrium between consumption and production over an extended period of time, ranging from minutes to hours. Automatic generation control, or AGC, is typically used to accomplish this, modifying generator power to meet load requirements. [3–4]. A power imbalance between supply and demand can result from a small variation in load power inside a power system running at a steady frequency. This disparity is initially addressed by releasing kinetic energy from the system, which lowers the frequency of the system. When frequency decreases gradually, the power utilisation of the existing load decreases as well. If the new load is controlled by lowering the power required from the old load and removing the power related to kinetic energy, then larger power systems can achieve a certain equilibrium at a certain point, which is certainly at the expense of a frequency reduction. To maintain this equilibrium, the system employs some control mechanisms, but governor action is not necessary. In this case, the frequency decreases significantly.

An essential part of a power system that guarantees consumers will always have access to electricity is load frequency management. This is technically achieved via automatic generation control (AGC), which controls the frequency of the power supply. To keep the generation and load in a healthy balance, frequency control shares the load across generators and modifies the tie-line power to preset values. [1]. An interconnected power system network needs to balance the entire power generated and the total load demands, including any system losses, in order to function properly. The inherent complexity and nonlinearity, along with the time-varying characteristics of the power system network, can lead to fluctuations in the operating point over time. The frequency and the net power transferred between neighboring control zones may alter as a result of these oscillations. The system may become unstable as a result of large variations in frequency and tie-line power.

The traditional control method utilizing a flywheel governor in synchronous machines can no longer effectively manage these fluctuations. Therefore, an additional control strategy employing a load frequency controller (LFC) has been integrated into the system. The LFC not only ensures system stability amid load variations but also meets other essential requirements, including security and reliability. Considering the aforementioned factors, a robust load frequency controller (LFC) is necessary to minimize oscillations and preserve the dynamic performance of power systems within reasonable bounds. Therefore, an effective and suitable LFC approach is necessary for the stable functioning of the power system.

Over the past few decades, numerous researchers have expanded on the LFC issue within interconnected power system networks to improve dynamic responses. In order to address the LFC problem, several control mechanisms have been proposed in the literature. Methods for load frequency control (LFC) that utilize traditional approaches and artificial intelligence can be found in existing literature. The authors presented a traditional PI controller-based approach in references [5–7], whereas Malleshham et al. suggested a Ziegler-Nichols-based controller for PID

controller parameter adjustment [8]. A PI controller is employed for frequency stabilization. Goya et al. proposed an  $H_\infty$  controller aimed at reducing oscillations [9], and the authors in [10] presented an internal model-based approach to LFC. Techniques based on swarm intelligence have been utilized for optimizing PID gains in various studies. For instance, a fuzzy PID controller optimized using the Moth-Flame algorithm was introduced in [11]. In [12], Das applied a Genetic Algorithm, while Kumar employed a biogeography-based optimization method in [13]. In two-area interconnected non-reheat thermal power systems, the current work proposes evaluating performance across cost functions while varying the PID controller's gain values in order to determine the most efficient cost function through ideal controller gain values.

The rest of the paper is organized as follows: The test systems model is presented in Section 2. A concise overview of the controller design can be found in Section 3. In Section 4, various algorithmic steps of the PSO applied to the LFC system are discussed. Section 5 provides a comparison of simulation results across different methodologies. Finally, Section 6 wraps up the article with concluding remarks.

### Test System Modeling

The Automatic Generation Control (AGC) of the power system under examination includes a balanced non-reheat thermal power station with a proper governor unit, turbine unit, generator unit, and load. Tables 1 and 2 display the relevant parameters, transfer function, and their nominal values [14, 15, 16].

**Table 1:** Power system transfer functions

Parameter	Transfer function
Governor	$G_g(s) = \frac{1}{1+sT_g}$
Turbine	$G_T(s) = \frac{1}{1+sT_t}$
Generator	$G_p(s) = \frac{K_p}{Ps+D}$
Speed regulation	$\frac{1}{R}$
Bias	$B_i$

**Table 2:** System parameters for Area1 and Area2[19]

Area	1	2
Speed regulation	$R_1=2.4$ Hz/p.u MW	$R_2=2.4$ Hz/p.u MW
Governor time constant	$T_{g1}=0.08$ s	$T_{g2}=0.08$ s
Turbine time constant	$T_{t1}=0.3$ s	$T_{t2}=0.3$ s
Generator time constant	$T_{p1}=20$ s	$T_{p2}=20$ s
Rated capacity	2000MW	2000MW

Area frequency response characteristics	$B_1=0.25$ p.u.Mw/Hz	$B_2=0.25$ p.u.Mw/Hz
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### Design of a Two-Area Connected Power System

A tie-line connects two interconnected power systems, each made up of equal non-reheat thermal power units. The transfer function model for these interconnected two-area power networks is shown in Fig. 1. Each power producing unit satisfies its individual load requirement and contributes to system stability under typical loading situations. However, if the load demand in any of the interconnected systems rises rapidly, it may have an impact on the power flow along the tie-line between the control regions and the system frequency.. Section 4.2 discusses the power system's behavior.

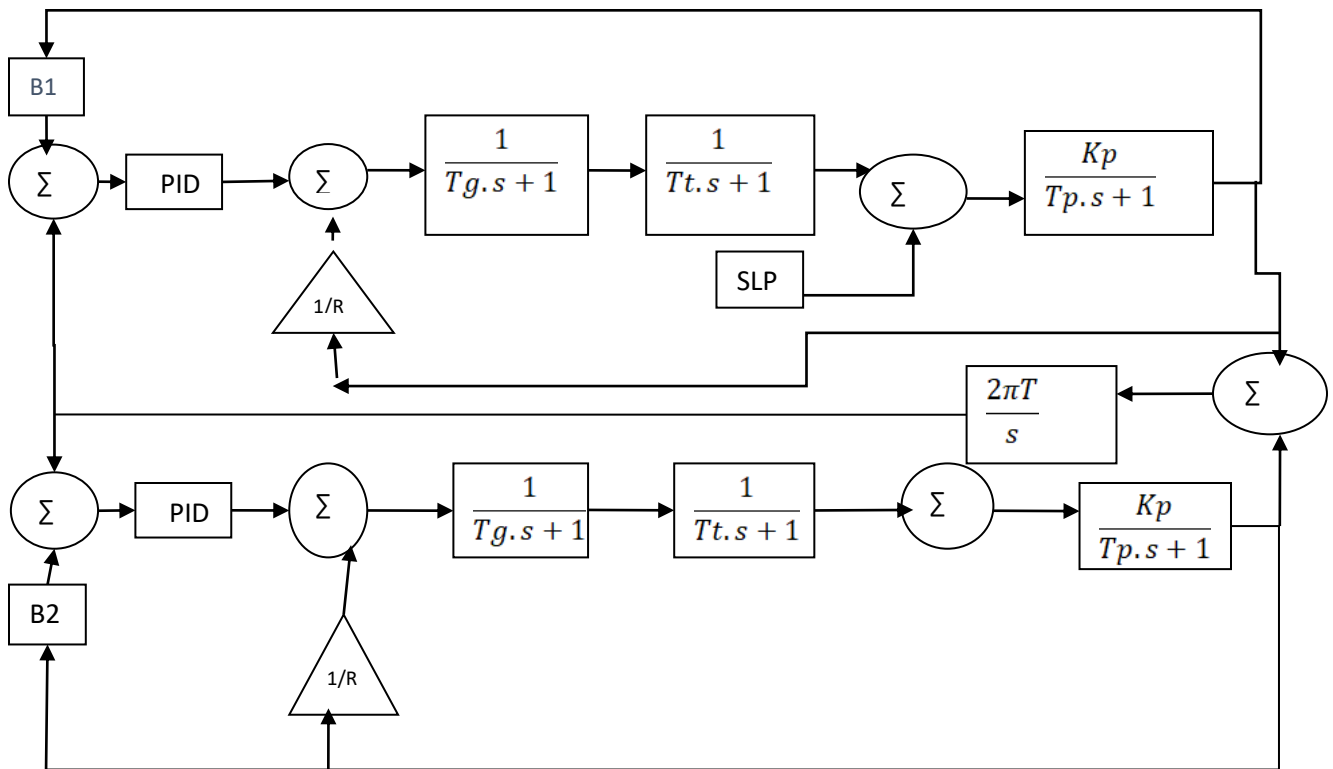


Figure 1 illustrates the transfer function model for a two-area thermal power system without reheat.

### Controller Design

Every component of the power system under analysis in this study is linked to a PID controller. Modern companies make heavy use of the PID controller, which was developed in the 1900s. Among its benefits are its low cost and high implementation adaptability. In essence, the PID controller is made up of three parts: the derivative (D), integral (I), and proportional (P)

terms. The proportional controller helps reduce the settling time in the system's response, the integral controller effectively removes steady-state error, and the derivative gain enhances the system's overall stability. The transfer function of the PID controller is shown in equation (1) [15,16,17].

According to the prior controller structure, the control signal is the controller's output (UPID), and the area controller error (ACE) is its input. During sudden load demand scenarios, the equipped controller's control effectively eliminates errors such as steady-state error (the error signal value as time approaches infinity, which is used to assess system accuracy) and peak overshoot (the highest positive peak value observed in the system's response) and undershoot (the lowest negative peak value observed in the system's response). The controller produces the control signal using the ACE, which is a linear combination of frequency error and tie line power. Eq. (2) provides the formula for area control error, whereas Eq. (3) provides the control signal produced by the PID controller.

The following is an expression for a PID controller's transfer function:

$$G_{PID}(s) = K_P + K_I(S) + \frac{K_D}{S} \dots\dots\dots 1$$

$K_i$  represents the integral gain,  $K_D$  represents the derivative gain,  $T_i$  represents the integral action time,  $T_D$  represents the derivative action time, and  $K_p$  represents the proportional gain.

The ACE expression is represented as:

$$ACE_i = B_i \cdot \Delta F_i + \Delta P_{tiei,j} \dots\dots\dots 2$$

The expression for the control signal that each controller in each area generates is as follows:

$$U_{PID} = U_i(t) = K_{Pi} \cdot ACE_i + K_{Ii} \int_0^t ACE_i dt + K_{Di} \frac{dACE_i}{dt} \dots\dots\dots 3$$

Area control error is denoted by ACE, frequency bias constant by B, frequency variation by f, tie-line power deviation by  $P_{tie}$ , control signal by U, and proportional gain, integral gain, and derivative gain values by  $K_{Pi}$ ,  $K_{Ii}$ , and  $K_{Di}$  in Equations 2 and 3.

### Functions of objectives

It is crucial to choose the goal function with the required restrictions and requirements before building the Optimization-based PID controller. When optimizing the controller gain settings, the objective function selected is determined by its performance requirements. To evaluate these performance goals, time-domain parameters like settling time and steady-state error are

employed.. According to an investigation of the literature, the ITAE goal functions are often used. Equation (4) give the formulas for these functions [15,16,17].

$$J = \int_{t=0}^{t^{final}} t(|\Delta f1| + |\Delta f2| + |\Delta P_{tie}|) dt \dots\dots\dots 4$$

The optimization-driven PSO is used in this study to generate a PID controller gains for the load frequency control (LFC) of a non-reheat thermal power system. Derivative gain ( $K_D$ ), integral gain ( $K_I$ ), and proportional gain ( $K_P$ ) are all simultaneously optimized by the controller.. The following limitations apply while trying to maximize these controller gains:

$$K_{P_i}^{min} \leq K_{P_i} \leq K_{P_i}^{man} \dots\dots\dots 5$$

$$K_{I_i}^{min} \leq K_{I_i} \leq K_{I_i}^{man} \dots\dots\dots 6$$

$$K_{D_i}^{min} \leq K_{D_i} \leq K_{D_i}^{man} \dots\dots\dots 7$$

Here,  $K_{P_i}$ ,  $K_{I_i}$ , and  $K_{D_i}$  stand for the control unit's gain's lowest and highest values, which are set to 1 and -1, respectively.

### Optimization Techniques

Kennedy & Eberhard (1995) proposed the Particle Swarm Optimization method. It is developed by observing the social behavior of animal groups, such as flocks of birds or schools of fish. In other words, they proposed that knowledge sharing among members makes the organization more likely to survive. A flock of birds has a higher chance of finding food than a lone bird, for instance. Finding the best hunting spot will eventually be made easier with the group's ability to share information.

Using the concept of information sharing among the group, this bio-inspired swarm-based meta-heuristic optimization method finds the best answer. It uses a flock of birds, particles, or agents that swarm throughout the search space in an effort to find an optimal solution. In solution space, participating particles provide their positional coordinates, which correspond to the most suitable solution they have so far discovered. Based on its own flight experiences as well as those of its group members, it also adjusts its velocity.

The way animal communities, such fish and bird colonies, live affect the PSO algorithm. Either the birds fly in swarms before they approach their meal, or they are scattered during their food hunt. Usually, one of the groups is a bird that can find food rather far away. This bird eventually gets rid of the food supply after alerting the others to its location. The global optimization goal functions are thus determined by using this animal behavior. The researchers call each member of the group a particle. The flowchart of the PSO is give in fig.2

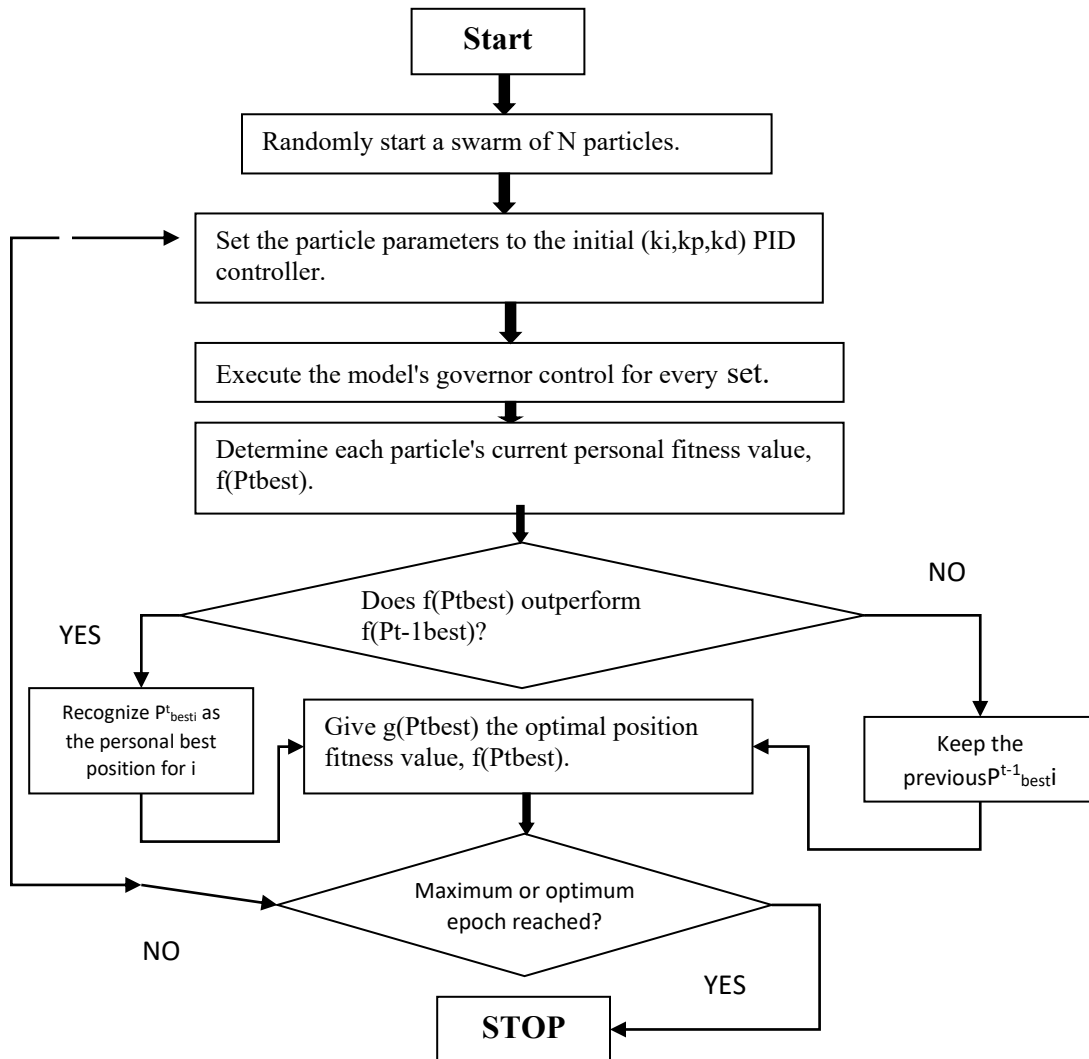


Fig: 2– Flowchart of PSO algorithm

## Results and Discussion

To showcase the strength and efficiency of objective functions, a simulation has been conducted. These simulations applied the objective functions outlined in Section 3.1 to the system under examination. The performance of power systems of two areas, utilizing objective functions, is analyzed in Sections 3 and 4.

The power systems examined in this study are developed within the MATLAB/SIMULINK environment, utilizing MATLAB for simulations and cost function analyses. All simulation results for the investigated power system are conducted over duration of 50 seconds. To facilitate

a clear comparison of the results from PID controllers tuned for the cost functions, the graphs are presented on varying scales.

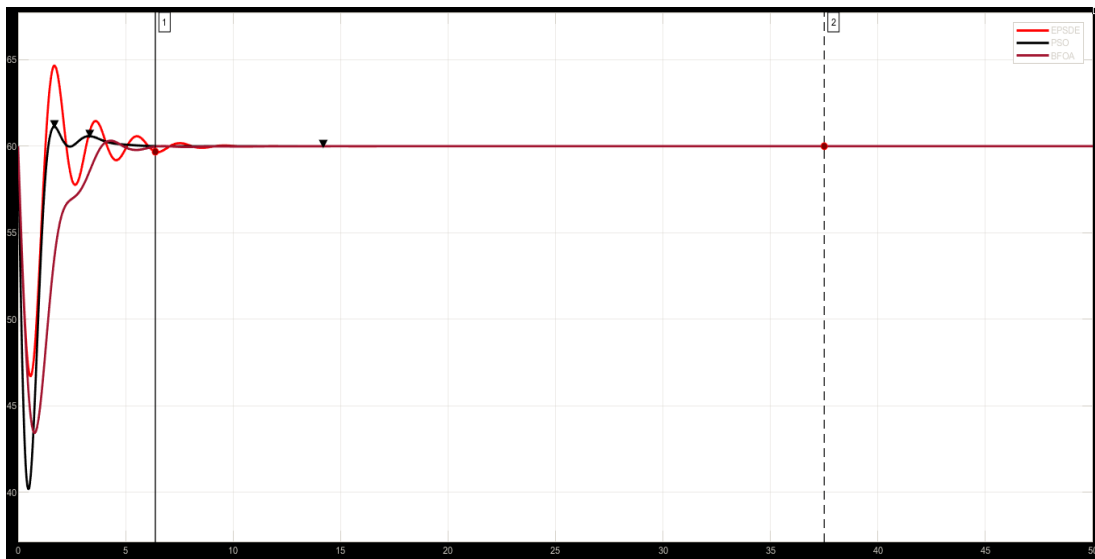
**Two interdependent power systems with objective functions respond.**

The responses of a two-area interconnected power system using objective functions for PID and PI controller performance are shown in Figures 4, 5, and 6, respectively.. Area 1 and Area 2 frequency variations are compared in Figures 4 and 5, respectively. Figure 7 shows the area's control error response, while Figure 6 shows the variations in tie-line power flow among the interconnected areas.

When compared to PI controllers based on EPSDE and BFOA Optimization, the results presented in Figures 3, 4, 5, and 6 clearly show that the power system with the ITAE-based PSO PID controller works better in terms of reduced settling time and lower maximum overshoot. Table 4 presents the numerical results for the objective functions in the response of the two-area power system.

**Table 3:** Controller settings for the two-area power system test

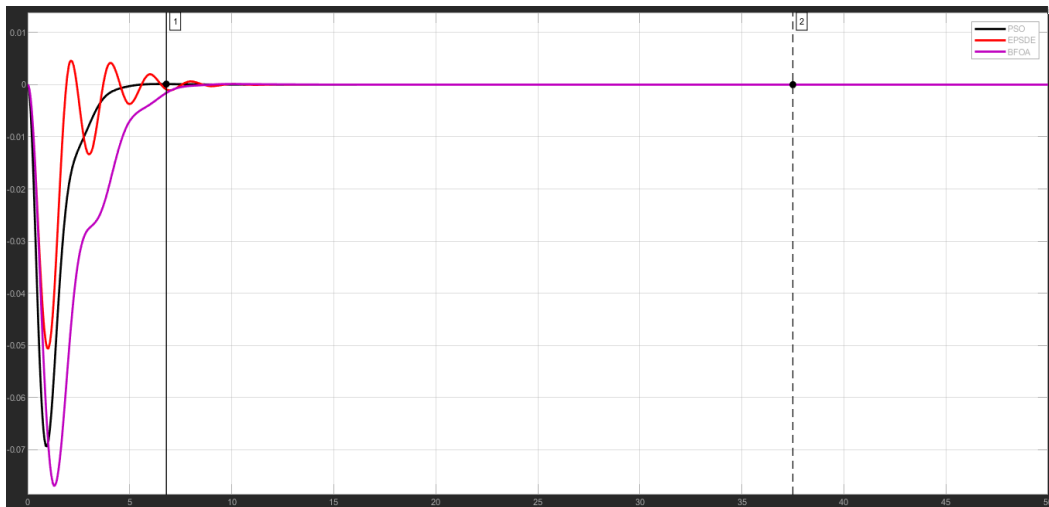
Controllers	$K_{pi}$	$K_{p2}$	$K_{i1}$	$K_{i2}$	$K_{d1}$	$K_{d2}$	ITAE
PSO PID	0.2168	1	0.1912	0.5944	1	0.5333	0.8593
EPSDE:PI[17]	0.0145	0.0478	0.8502	0.0334	-	-	1.433
BFOA PI[20]	-0.4207	0.2735	-0.4207	0.2735	-	-	2.473



**Figure 3:** Frequency variations in Area 1



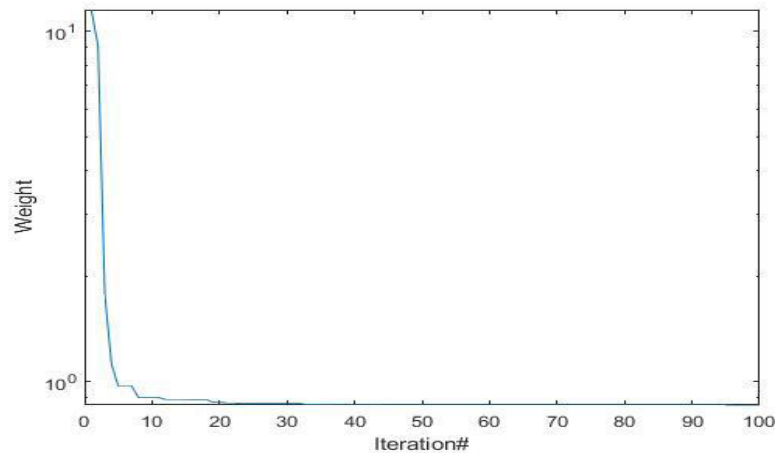
**Figure 4:** Variations in Area 2 Frequencies



**Figure 5:** Tie-Line Power Variations

**Table 4:** Comparison of the power system's settling time and ITAE performance

Parameters	ITAE	Settling time(s)		
		$\Delta f_1$	$\Delta f_2$	$\Delta P_{tie}$
PSO PID	0.8593	4.311	4.215	6.8
EPSDE:PI[17]	1.433	7.346	8.11	8.38
BFOA PI[20]	2.473	6.38	7.876	8.2



**Figure 6:** Convergence profile of the suggested algorithm for the PSO PID test system

### Conclusion

Attempts have been made in this study to resolve an interconnected power system's load frequency oscillation. For the proposed system, the main method for controlling the frequency is the optimized proportional integral derivative controller. The system's PID and PI controller output frequency are then examined. Here, the particle swarm optimization technique is used. Since the system with the PSO PID controller reaches the ideal frequency of 60 Hz more quickly and has a lower ITAE value, it is found to have a more suitable output frequency than the others. As can be seen in the graphs in figures 3, 4, and 5, the EPSDE PI and BFOA PI controllers require longer time to dampen out load frequency oscillation. The recommended controller has a significantly lower ITAE value and settling time than the others.

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## 20. Literature Review on Zero Energy Building

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**ABSTRACT** This literature review investigates the current state and future potential of Zero Energy Buildings (ZEBs). It emphasizes the relevance in addressing urban energy demands and climate challenges. By analysing recent studies, the literature review examines the main aspects including energy modelling, retrofitting strategies, renewable integration, and smart energy management using upgraded systems and machine learning. The findings also reveals that Zero Energy Buildings can significantly reduce operational energy use and carbon emissions while offering long-term economic and energy benefits. However, implementation challenges such as high upfront costs and technological complexity persist. The review identifies emerging opportunities for ZEBs through advanced simulation tools, real-world monitoring, and policy support. Building on these insights, this study sets the groundwork for future research and study on evaluating the energy performance of residential and commercial buildings in local climatic conditions. The goal and motto are to contribute to sustainable building practices by optimizing design strategies for net-zero energy consumption.

**KEYWORDS:** Zero Energy Buildings, Urban energy, Smart energy management, Machine Learning, Net Zero energy Consumption

### Introduction

Energy Generating buildings are designed and built to consume as little energy as possible. When a renewable source of energy is added to these buildings, they are capable of producing enough energy to meet or exceed their requirements to run. Energy generating buildings use a combination of energy efficiency and renewable energy to produce as much energy as they use over the course of a year. By creating their own renewable energy, zero energy buildings lower operating and maintenance costs, help the environment, and increase resiliency during power outages. A Zero Energy Building (ZEB), is a structure designed and operated to produce as much energy as it consumes on an annual basis.

### Here's a breakdown of what that means in major terms:

- Super Energy Efficient: ZEBs start by drastically reducing their energy needs through smart design and technologies. This includes excellent insulation to keep heat in during winter and out during summer, high-performance windows that minimize heat transfer, efficient lighting

(like LEDs), and optimized heating and cooling systems. They are designed to sip energy rather than gulp it down.

- **Renewable Energy Generation:** To offset the remaining energy they do use, ZEBs incorporate renewable energy sources, most commonly solar photovoltaic (PV) panels that generate electricity from sunlight. Other technologies like small wind turbines or geothermal heat pumps might also be used depending on the location and feasibility.
- **Net Balance Over a Year:** The "zero" in zero energy refers to the net energy consumption over a year. This means that sometimes the building might use a bit more energy than it generates (like on a cloudy winter day), and other times it might generate more than it needs (like on a sunny summer day). Ideally, these amounts balance out to zero over the entire year.

## Literature and Methods

A large number of researches has been conducted upon the performance of various kinds of Renewable and energy efficient technologies for achieving Zero Energy Buildings. The main aim of these researches is to provide valuable insights and support for the broader adoption of ZEBs as a means to combat climate change and enhance energy efficiency within the buildings and other sectors.

### “Building Integrated Photovoltaics (BIPV)”

Patrick Heinsteint, Christophe Ballif (2013) [01] conducted a feasibility study of more advanced PV technologies and ever-stricter climate policies designed to achieve energy neutrality in a cost-effective way. As a result, the need for BIPV products for use in construction will undergo, first a gradual and then a massive increase. various barriers need to be overcome in order to facilitate and accelerate BIPV. Besides issues related to mere cost- efficiency ratio, psychological and social factors also play an evident role. The goal of energy change linked to greater use of renewables can be successfully achieved only when all aspects are taken into account.

Yushi Wang (2024) [02] investigated a detailed overview of these technological developments, thereby providing valuable insights and support for the broader adoption of ZEBs as a means to combat climate change and enhance energy efficiency within the building sector.

This comprehensive review article, published in MDPI, focuses on the recent advancements in the core technologies that underpin the realization of Zero-Energy Buildings (ZEBs). The paper meticulously examines three critical areas:

Energy-efficient measures (EEMs), Renewable energy technologies (RETs), and Building energy management systems (BEMS), with a particular emphasis on their integration.

## “OPV Organic Photovoltaics (OPV)”

Patrick Heinstein, Christophe Ballif (2013) [03] discussed few more systems where one is OPV's. With its interesting material properties ranging from flexible to semitransparent and the reasonable manufacturing costs made possible by roll-to-roll production techniques will perhaps come to play a more defined role in BIPV in a couple of years. The current limiting factors for OPV are its still low levels of module efficiency and the absence of products with long lifetime guarantees. Both count against its broader BIPV application in the very near future.

## “Machine Learning Stimulation in ZEB's”

Author Mariana Migliori (2021) [04] discussed and aimed to retrofit a 1961-built office building in Melbourne, Florida, into a Zero Energy Building (ZEB) through energy-efficient measures and renewable energy integration. The goal was to assess the feasibility of transforming an existing building into a ZEB in a hot and humid subtropical climate. Her methodology was to develop a neural network model in MATLAB to predict energy consumption patterns based on simulation data. Applied energy-efficient upgrades and integrated renewable energy systems as part of the retrofit process.

Zuo, J., & Zhao, Z. (2024) [05] highlighted and analysed the evolution and future directions of green building research through scient metric methods. Utilized bibliometric analysis to examine trends, citation patterns, and emerging topics in GB research. This highlighted the growing focus on energy performance, building certification systems, and sustainable materials.

“Assessment of Waterfront Office Redevelopment Plan on Optimal Building Energy Demand and Rooftop Photovoltaics for Urban Decarbonization”

Choi, Y., et al. (2021).[06] developed five redevelopment scenarios and conducted techno-economic analyses of rooftop PV systems. Aimed to assess the impact of waterfront office redevelopment on building energy demand and rooftop photovoltaic (PV) potential for urban decarbonization. It helped to find Found CO<sub>2</sub> emission reductions of 2-9% with decreasing payback periods for PV installations by 2030.

Pan, J., et al. (2016) [07] designed and implemented a prototype system integrating sensors and cloud computing for real-time energy monitoring. It proposes expanding the system to include predictive analytics and machine learning for proactive energy management. Demonstrated significant energy savings and improved building intelligence through the IoT system.

## Results and Discussion

It has been observed that most of the past research works, ranging from simulation models to real-world case studies, demonstrate the feasibility and effectiveness of ZEBs in diverse climatic and geographical contexts and suggests exploring the integration of artificial intelligence in GB design and operation.

The results from these studies indicate that ZEBs can significantly reduce operational energy consumption and carbon emissions, contributing to environmental sustainability. However, challenges such as the need for substantial initial investment, technological complexities, and the necessity for occupant behavioural adjustments remain. Addressing these challenges requires continued research, policy support, and public awareness

## Conclusion and Recommendations

After reviewing the literature of “Zero Energy Building” I conclude that the future scope of ZEBs lies in the integration of emerging technologies like artificial intelligence for energy management, the development of standardized evaluation frameworks, and the promotion of ZEBs in urban planning. By overcoming existing barriers and leveraging technological advancements, ZEBs have the potential to become a cornerstone in the transition towards a sustainable built environment.

The research work will emphasize upon the ideology of net zero energy, including practice of net zero energy architecture as a solution to increase urban concerns, and this research report will stay focused on ZEB’s, not on any other buildings.

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## 21. Suraksha Kavach – A Smart Helmet

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**ABSTRACT** The Coal Mining Helmet designed on this paper aims to offer protection to miners through alerting them. All the elements may be referred to only if the person is carrying the helmet. The output from the helmet module continues updating every instance i.e., actual time information is been updated to the cloud. These wearable gadgets get to share their information or retrieve the information through different source through using internet of things (IOT). Alerts are sent to the miner and the supervisor if any hazard is detected. Ubiquitous computing and wearable computer systems have contributed extremely to the evolution of wearable gadgets. Thus, this wearable device consists of the diverse sensors, alerting mechanism and communication system to broaden and enhance protection of the miner. The hardware incorporates of information collection, data processing and data communication sections. Sensors employed a) Temperature and humidity sensor (DHT11): In mines, the extent of temperature and humidity will become excessive at instances and prove to be fatal to the miner. The liberation of those gases should result in respiratory trouble to the person within the mines and could result in choking. If one or extra of these portions exceed the threshold limit, an alert is sent to the miner as well as the base Authorizer. The data collection or measuring of the parameters is achieved using WSN technology. WSN technology is a network of sensors, in which each of the sensors has unique parameters to sense but carry out collectively as part of the system. The level of temperature and humidity is understood to the miner through showing it on an OLED (Organic LED) and for the gas a threshold is set and a buzzer alert is given if it's far past the threshold.

**KEYWORDS:** OLED (organic LED), Humidity sensor (DH11), MQ2, Arduino UNO, Buzzer

### Introduction

The goal of the creative and technologically advanced project "SURAKSHA KAVACH – A Smart Helmet" is to improve user safety by combining wireless connection, intelligent alert systems, and real-time monitoring. This intelligent helmet is a significant advancement. by incorporating state-of-the-art technologies with conventional safety gear. This helmet serves as an active safety device that can track user behavior, identify abnormal circumstances, and send emergency notifications when needed in addition to offering its wearer physical protection. The Internet of Things (IoT) framework is used by the intelligent system in the helmet to gather, interpret, and send vital safety-related data. The helmet has a number of important sensors built in, each with a distinct purpose.

### **These consist of:**

- **Accelerometer:** This sensor is primarily used for impact detection. In the event of a crash or fall, the accelerometer registers sudden changes in velocity or movement, indicating a potential accident.
- **Alcohol Sensor:** This component helps determine if the rider or worker is under the influence of alcohol. This feature is particularly useful in transportation and heavy machinery operations, where sobriety is crucial for safe functioning.
- **Temperature Sensor:** Installed to monitor the environmental heat levels, this sensor can detect potentially dangerous conditions such as overheating in mines or construction zones.

ACE ENGINEERING COLLEGE 2 Department of CSE-IoT • **Gas Sensor:** It monitors the presence of hazardous gases like carbon monoxide or methane, especially in underground or industrial workspaces, where gas leaks can pose fatal threats.

A microcontroller-based system that serves as the device's brain is located at the center of the helmet. The microcontroller applies programmed logic, continuously examines data from several sensors, and start the proper actions based on predetermined safety parameters. For example, the helmet immediately notifies the user's emergency contacts or a central monitoring system via text message with their GPS location when it detects a high-impact collision. Similar to this, in industrial settings, if a gas sensor detects hazardous levels of poisonous gases, the system notifies the user in real time and, if connected with other safety systems, can cause external alerts or shutdowns. The smart helmet's real-time data transmission and notification system is a crucial component. The time is greatly decreased by this instant response mechanism. it takes for assistance to come, which could save lives in situations when every second matters. Additionally, the helmet has user-friendly interfaces that give the wearer instant local input, including buzzers or LED indicators. For instance, if linked to a smart car interface, an auditory buzzer can warn the rider if the alcohol content reaches a predetermined threshold or stop the ignition. Visual alerts may be used in an industrial setting to notify employees to leave a dangerous location. More broadly, "SURAKSHA KAVACH" supports international initiatives to incorporate wearable and smart technologies into daily life to improve safety, efficiency, and well-being. With the rise of smart cities and industrial automation, wearable safety devices like this smart helmet are becoming an integral part of occupational health strategies.

### **Related Work**

Due to growing safety concerns in industries like mining, transportation, construction, and defense, smart helmet development has accelerated recently. Numerous scholars and pioneers have investigated the combination of sensors, the Internet of Things (IoT), and Traditional helmets can be equipped with wireless connection modules to improve user safety and enable real-time monitoring.

Prior research has mostly focused on developing smart helmets with capabilities like GPS monitoring, alcohol detection, crash warning, and helmet usage detection. To stop drunk driving,

for instance, R. K. Megalingam et al. suggested a smart helmet for two-wheeler riders that included an ignition control system and an alcohol sensor. V. Yadav et al. created a system that employed gas and electricity to monitor dangerous gasses and temperature levels in mining sites in real time. temperature sensors and a microcontroller combined. To provide preemptive safety actions, the data was wirelessly sent to a control center. However, it was discovered that many of these current systems were constrained by problems like excessive power consumption, a dearth of real-time alarm systems, a short wireless connection range, and inadequate user adaptability. Furthermore, some were neither scalable or modular, which made it challenging to add new features as needed. These restrictions are intended to be addressed by the suggested SURAKSHA KAVACH-A SMART HELMET, which provides a more scalable and integrated method. It makes use of a variety of intelligent sensors, including as motion, temperature, pressure, and gas sensors, in addition to a microprocessor and real-time GSM and GPS wireless connectivity. In contrast to previous approaches, this project emphasizes proactive rather than reactive user safety enhancement through real-time notifications to local and remote stakeholders. Additionally, its modular design makes it simple to expand features or upgrade them in response to user needs and environmental hazards.

## **Materials and Methods**

Advanced electronic components, embedded programming, and communication modules were combined to create the SURAKSHA KAVACH-A SMART HELMET system, which provides real-time safety, environmental monitoring, and accident alarm capabilities. A user-centric approach served as the foundation for the design and implementation, which took into account robustness, portability, and dependability in high-risk settings including roads, mining areas, and construction sites.

### **Materials Used:**

#### **1. Microcontroller Unit (ESP32 or Arduino Uno/Nano):**

Serves as the main processing unit that gathers, interprets, and sends data from several sensors. Later prototypes favor the ESP32 because of its built-in Bluetooth and Wi-Fi capabilities.

#### **2.Sensors:**

- MQ-135 Gas Sensor: Identifies dangerous gases such as benzene, CO<sub>2</sub>, and NH<sub>3</sub>.
- DHT11/DHT22 Sensor: Determines the humidity and temperature of the surrounding air.
- Accelerometer (ADXL345): Identifies accidents or falls by detecting abrupt impacts or unusual head motions
- Sound Sensor: Records unusual noise levels that could point to dangerous circumstances.
- GPS Module (Neo-6M): This device gives the user's precise location coordinates, which is crucial in the event of an accident or gas exposure.



### **3.GSM Module (SIM800L/SIM900A):**

Used to provide location and status updates via SMS to pre-configured emergency contacts.

### **4. Battery and Power Module:**

To ensure operating stability, a power management circuit and a rechargeable lithium-ion battery pack (7.4V/11.1V) power the complete system.

### **5.Helmet Frame and Casing:**

The sensor is mounted and housed in a typical industrial-grade helmet.

### **Methodology:**

1. Sensor Integration and Calibration: GPIO and analog pins were used to connect each sensor to the microcontroller. Every sensor was set up to identify particular threshold values that set off alarms, such as gas concentrations exceeding allowable limits or a fall impact over 2 grams.
2. Acquisition and Processing of Data: The microcontroller continuously read sensor data, processed it locally, and then sent it conditionally. An emergency procedure was started in case any threshold was crossed.
3. Alert and Notification System: The GSM module automatically notifies emergency contacts and, if desired, a central monitoring server by SMS with real-time GPS coordinates when it detects abnormal situations (such as a gas leak, fall, or overheating).
4. Power Management: To maximize battery utilization, low-power modes were incorporated into the microcontroller code. Battery level indication and overcharge prevention were also features of the system.
5. Field Testing To assess the system's durability, precision, and reactivity, the helmet was put through its paces in dangerously simulated settings. The outcomes were noted and utilized to improve firmware logic and sensor sensitivity.

### **Findings and Conversation**

To evaluate its performance, dependability, and reactivity in real-time hazard scenarios, the SURAKSHA KAVACH – A SMART HELMET prototype was put through a series of simulated tests. communication and detection. The results confirmed that combining environmental sensing, accident detection, and emergency alert systems into a single small system works well.

Findings:

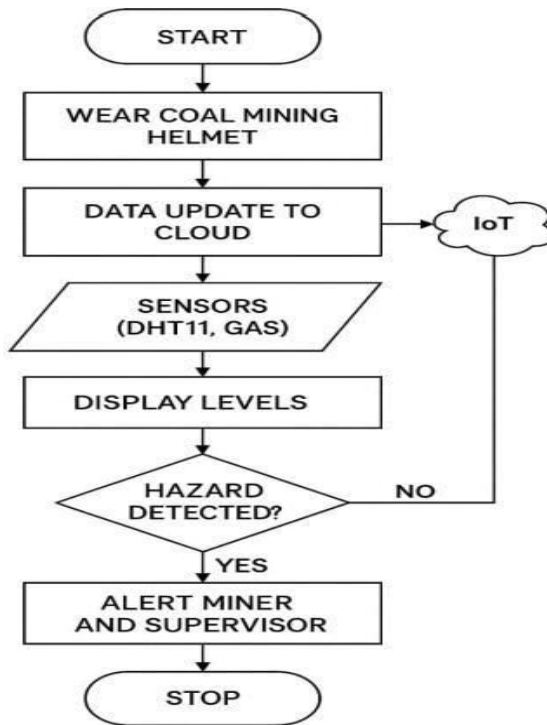


Fig-1 System Architecture

1. Accuracy of Accident Detection: the accelerometer successfully identified head movements and abrupt impacts. With a detection accuracy of more than 95%, the warning system was reliably activated by simulated fall scenarios from varying heights (1 to 2 meters).The system also used threshold tuning to distinguish between impact-based falls and normal motions.
2. Gas and Temperature Monitoring: Under controlled circumstances, the MQ-135 sensor was able to detect the presence of dangerous gases like ammonia and carbon monoxide. The DHT11/DHT22 sensors were shown to be suitable for industrial settings by accurately recording temperature swings with a low deviation of  $\pm 1.5^{\circ}\text{C}$ .
3. Real-time Alert Communication: Within 4–6 seconds of detecting an emergency, the GSM module successfully transmitted an SMS with the specific GPS coordinates and the nature of threat (such as a gas leak or fall). The GPS accuracy ranged from 5 to 10 meters, which was adequate for tracking a person's location quickly in an emergency.
4. System Responsiveness and Power Efficiency: o The microcontroller ensured that the alert procedures were executed on time by processing data and reacting to sensor inputs with minimal lag.

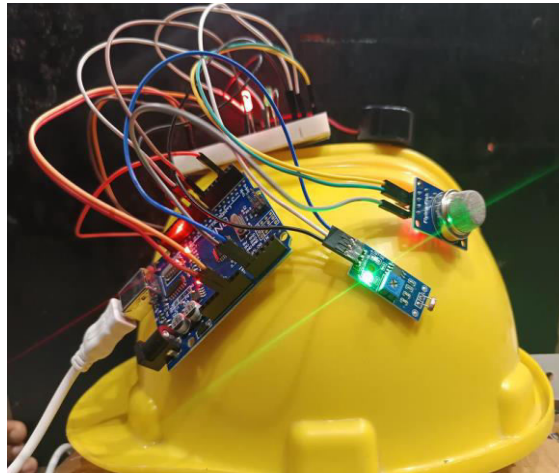


Fig-2 Prototype of SURAKSHA KAVACH – A Smart Helmet Integrated with Sensors and Arduino-Based Embedded System

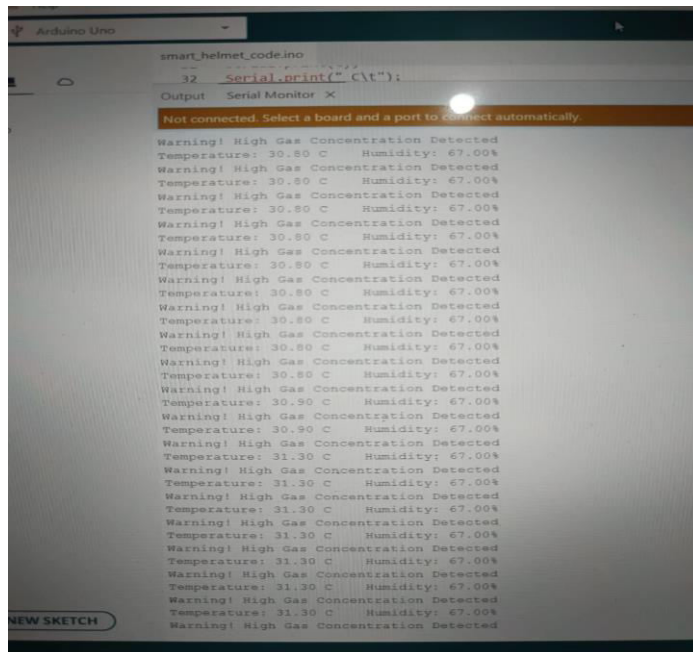


Fig-3 Real-time Serial Monitor Output Displaying Environmental Readings and Gas Detection Alerts

## Discussion

The test findings confirm that the SURAKSHA KAVACH system satisfies fundamental safety standards and is capable of dependable real-time operation. In contrast to conventional helmets, the smart helmet offers a proactive solution by continuously protecting the head in addition to communication and environmental monitoring capabilities. User safety is greatly increased

when gas and temperature sensors are successfully integrated with real-time alarm systems, particularly in areas like construction, industry, and mining where abrupt changes in the environment can be fatal. The performance of the GSM-GPS module proved that remote alert systems could function even in the absence of Wi-Fi infrastructure, which made it ideal for use in isolated or subterranean work locations. The motion sensor occasionally produced false positives from abrupt user movements unrelated to accidents, which was a problem during testing. By adjusting the sensor thresholds and putting in place a multi-condition validation logic (such as abrupt impact + extended inaction).

The significance of helmet ergonomics is another important realization. The compact design and thoughtful sensor placement made sure that the additional electronics wouldn't compromise user safety or comfort.

## **Conclusion**

An important development in personal safety technology is the SURAKSHA KAVACH - A SMART HELMET, especially for people who operate in dangerous areas including mines, building sites, industrial zones, and roadways. Through the integration of many sensors and the concept successfully converts a traditional helmet into an intelligent, proactive safety tool with real-time monitoring, alerting, and position tracking capabilities by combining communication components into a single wearable system. The project effectively illustrates how IoT technologies and embedded systems may be used to improve human safety. The helmet guarantees that in the event of a dangerous circumstance, the user and the appropriate authorities are swiftly notified.

These real-time warnings have the potential to save lives and minimize injuries during emergencies by speeding up reaction times. According to field tests, the helmet operates consistently in alert communication and with excellent sensor reading accuracy under a variety of circumstances. Additionally, because of its modular design, it is scalable and flexible, enabling the addition of more sensors or features. according to certain application areas or user demands. Furthermore, the SURAKSHA KAVACH project stresses the value of comfort, use, and low power consumption in addition to the functional aspects of safety. It opens the door for upcoming advancements in wearable safety systems by bridging the gap between basic protective gear and contemporary smart technologies. This real-time smart helmet solution has strong potential for practical deployment in industries and public safety sectors. It contributes toward creating a safer working and commuting environment by ensuring that help is just a sensor trigger away. With further refinement, miniaturization, and potential incorporation of cloud-based analytics, SURAKSHA KAVACH could serve as a model for next generation intelligent protective gear worldwide.

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## 22. Effect of Process Routes and Calcination Temperatures on Synthesis of Nano-Alumina Through Sol-Gel Process

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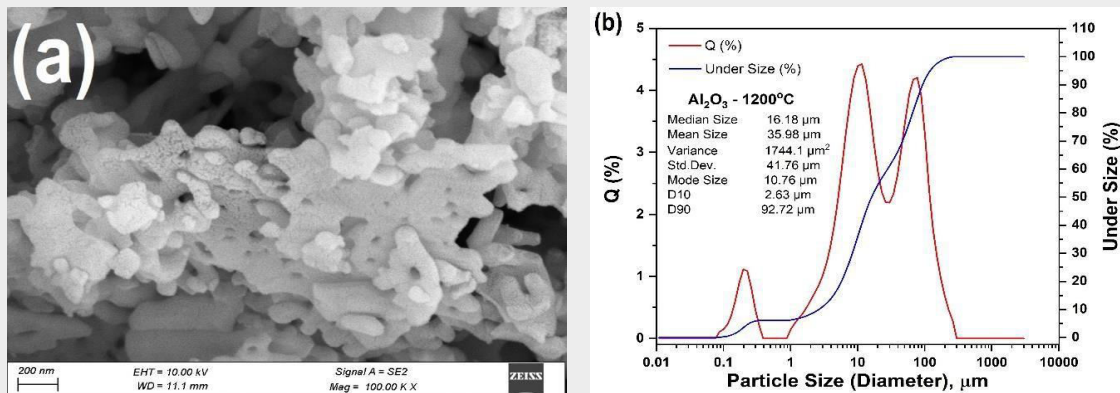
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**ABSTRACT** In the present research work nanoparticles of Alumina ( $Al_2O_3$ ) were prepared through two distinct routes via basic sol-gel method; in route one, Aluminium chloride and ethanol were mixed together followed by addition of ethyl acetoacetate and continuous stirring for long duration. In another route, aluminium nitrate with malic acid were mixed by magnetic stirrer followed by addition of Polyvinylpyrrolidone (PVP) and continuous stirring for long duration. In both the cases, synthesised powder materials were calcinated at three different temperatures; 800,1000 and 1200oC. The synthesized powder materials were characterized by FTIR, XRD, PSA, FESEM and EDS. It is observed from the XRD analysis that the width of intensity peaks of as-synthesized powder materials is more as compared to the pure Al and it increases with increasing of calcination temperature which confirms the formation of smaller size  $Al_2O_3$  particles, tends to nano-range. It is also confirmed from the elemental analysis (EDS) that the  $Al_2O_3$  particles were formed irrespective of processing routes and process parameters. The FESEM images were confirmed the spherical morphology of as-synthesized  $Al_2O_3$  powder materials irrespective of the process route and calcination temperature. It is interestingly observed from PSA analysis that nano-sized  $Al_2O_3$  materials were formed irrespective of process routes and calcination temperature; however, finest size  $Al_2O_3$  particles were formed in case of first route of synthesis and 1200oC calcination temperature.

**KEYWORDS:** Nanoparticles of Alumina ( $Al_2O_3$ ), Polyvinylpyrrolidone (PVP), FTIR, XRD, PSA, FESEM and EDS



**Figure:** (a) SEM image and (b) particle size distribution curve of nano- $Al_2O_3$  powder synthesized via first route and calcinated at 1200oC.

## 23. Fabrication and Characterization of Porous Magnesium-Zinc Scaffolds for Biomedical Applications

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**ABSTRACT** Magnesium (Mg) alloys have attracted a lot of interest for usage in biomedicine because of their favorable mechanical qualities and biodegradability. While solid Mg alloys have been extensively examined, research on the mechanical, electrochemical, and biological behaviors of porous Mg alloys remains relatively limited. The high reactivity of Mg presents challenges for alloying, and the fabrication of porous structures introduces additional complexity. In this study, porous Mg-Zn scaffolds were successfully fabricated via a powder metallurgy route employing an environmentally friendly method. Initially, Mg and Zn powders were ball-milled to achieve homogeneous mixing, followed by the addition of stearic acid to regulate pore formation. The mixed powders were compacted into pellets and sintered at 550 °C in an inert atmosphere to ensure the complete removal of stearic acid and to develop the desired porosity. The scaffolds were characterized by X-ray diffraction (XRD) for phase identification, while optical microscopy and scanning electron microscopy (SEM) provided insights into their microstructure. Energy-dispersive X-ray spectroscopy (EDS) analysis confirmed that the elemental composition matched the intended Mg-Zn ratio. Electrochemical properties were assessed using potentiodynamic polarization tests and EIS measurements, which demonstrated that the corrosion resistance was closely related to the porosity levels. The mechanical properties, including microhardness, were found to be within acceptable limits for bone tissue engineering. The in vitro biocompatibility was evaluated using MTT and DAPI assays, which showed excellent cell viability and adhesion. Overall, the developed porous Mg-Zn scaffolds exhibit strong potential for applications in biomedical engineering.

**KEYWORDS:** Mg alloy, Powder metallurgy, Porosity, Corrosion, SEM, XRD, Biomedical

# 24. Influence of Rate Piston Radial Clearance Geometry on Compensated Axial Pump Performance

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**ABSTRACT** Axial piston pumps are crucial hydraulic system components that are extensively applied in high-pressure uses in various industries including aerospace, construction, and manufacturing. Internal leakage, especially through the clearance between the multiple pistons and cylinder bores, is one of the most important factors affecting the efficiency and reliability of pumps. Through prolonged usage, wear, corrosion, and design flaws can cause this clearance to expand, which significantly leads to leakage loss. This research is concerned with the rate piston leakage analyses with different geometric conditions. A MATLAB Simulink model was developed for the axial piston pump to model dynamic interactions in the pump. A two-dimensional CFD simulation was also performed to analyze pressure distribution and flow characteristics. The effect piston-cylinder clearance, in the pump overall performance was analyzed systematically. Findings emphasize how excessive clearance through wear or manufacturing defects makes a major contribution to heightened leakage. Research suggests an optimal piston to-cylinder clearance range for rate piston to minimizing leakage while not affecting pump dynamics. The results present valuable information for manufacturers seeking to improve pump performance, and energy efficiency using better design and maintenance practices.

**KEYWORDS:** Axial piston pump, leakage, pressure distribution, CFD, modeling and simulation

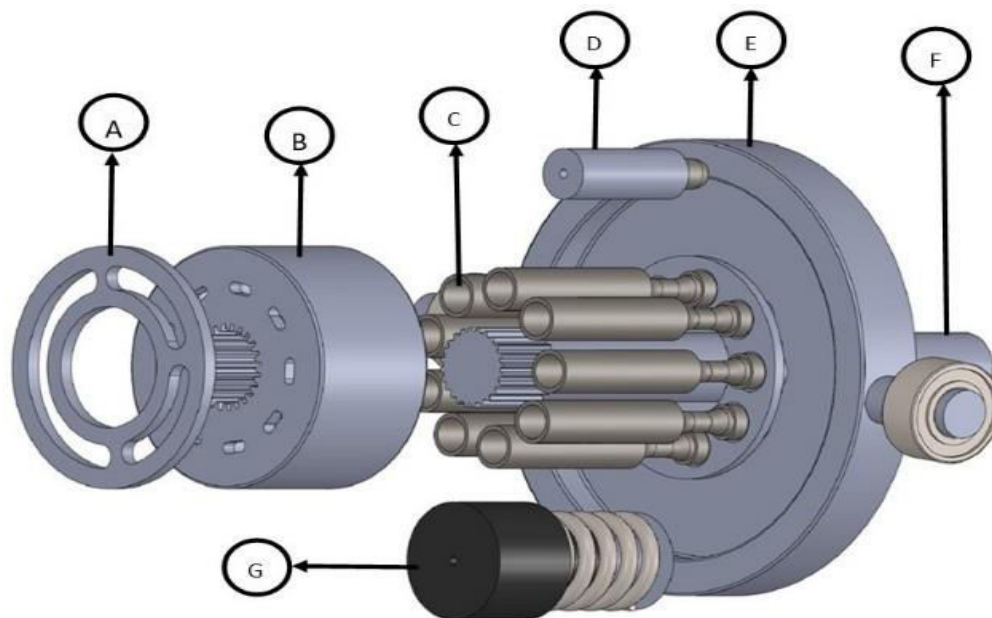
## Introduction

Axial piston pumps are vital elements in contemporary hydraulic machinery, used for efficient conversion of mechanical input to hydraulic output. Their versatility and reliability are clear from their broad utilization in industries such as construction, aerospace, and manufacturing [1–3], attesting to their status as a foundation in high-pressure hydraulic uses [4-6]. Mondal et al. [7] proposed a design approach for swashplate-type axial piston pumps with dynamic torque balance under changing loads, experimented and validated by simulation. Tang et al. [8] suggested a model-based method for leak diagnosis in dynamic load pumps. They discovered that subharmonic signals in outlet pressure could be used to predict the severity of leakage with high confidence levels, allowing real-time health monitoring of stroking pistons. Zloto et al. [9] used

CFD to simulate leakage through variable-height clearances between the valve plate and cylinder block. Mondal et al. [10] proposed a pressure compensator model with a focus on energy efficiency and found tolerance-dependent variables that are most important for pressure control in the event of leakage. Mondal et al. [11] designed a simple pressure compensator with a single-stage spool valve, whose dynamics nearly resembled commercial counterparts, providing insight into the influence of torque imbalance due to internal leakage on valve dynamics. Patrosz [12] employed FEM and CFD to investigate leakage across dynamically varying gap geometries, with a focus on deformation effects in misaligned pistons. Ma et al. [13] investigated leakage within spherical valve plates and found that minimal stiffness variations could exponentially escalate leakage. Finally, Pathak et al. [14] illustrated how piston–cylinder eccentricity is responsible for threshold levels of leakage, past which pump performance rapidly deteriorates.

## System Description

An axial piston pump is a positive displacement machine used on a large scale in hydraulic systems. It consists of a rotating cylinder block containing several pistons placed axially along the drive shaft. The pistons move back and forth inside their cylinders while the block rotates, driven by a swash plate. The swash plate angle controls the piston stroke and hence the displacement and flow rate of the pump. Another essential element in this arrangement is the rate piston, which is part of the pressure compensator system, and it reacts to the variation of system pressure and modifies the swash plate angle to ensure a constant outlet pressure.



**Fig 1:** Assembly Parts of Axial Piston Pump

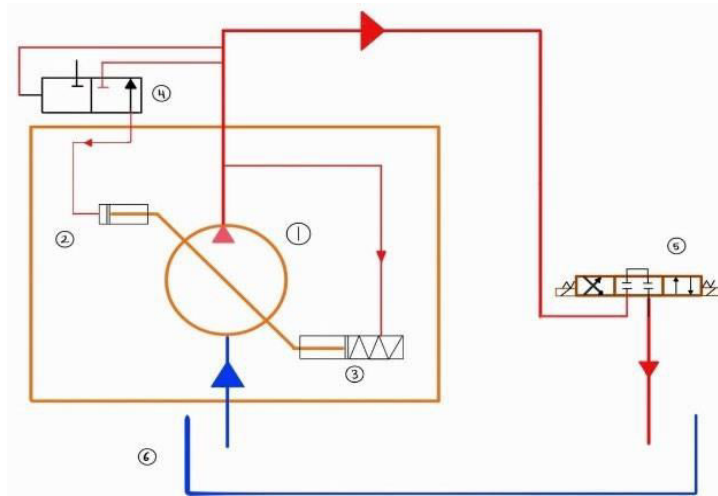
A. Stainer Plate B. Rotating Cylinder Block C. Barrel Piston D. Stroking Piston E. Swash Plate  
F. Shaft G. Rate Piston

## Design Methodology

The pressure compensator system design methodology is adopted from the work done by Mondal et al. [10]. The static torque balance on the swash plate under cut-in and cut-off conditions served as the foundation for this study. The continuity and force balancing equations served as the foundation for the spring design and radial clearance. The primary mathematical formula for the leakage flow via the rate piston's radial clearance is

$$Q_{lrc} = \frac{\pi d_{rp} c_{rc}^3 (P_{rc} - P_r)}{\{12\mu(l_{r0} + x_r)\}} \quad (1)$$

## Design Analysis

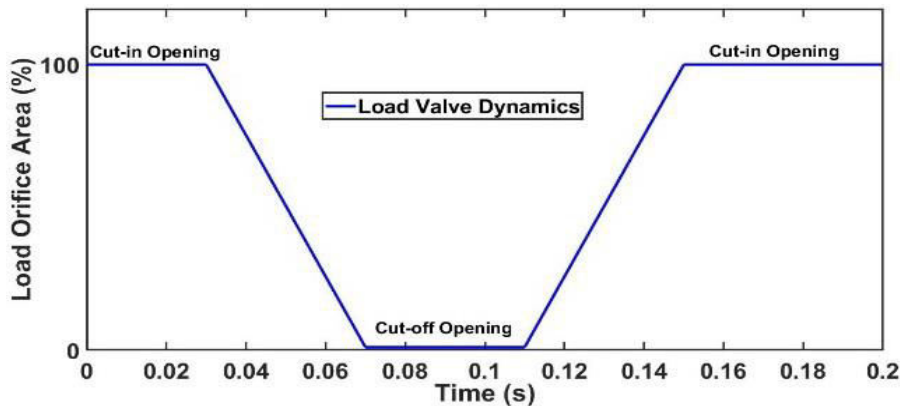


**Fig 2:** Circuit diagram of axial piston pump (1) Pump (2) Stroking Piston (3) Rate Piston (4) Spool Valve (5) Load Valve (6/7) Reservoir

Different operating conditions can be obtained by controlling the load valve orifice area. Fig. 3 illustrates the dynamic simulation for load valve dynamics. Based on this load valve dynamics, a study on the effect of stroking cylinder leakage on pump performance is conducted.

Fig 2 displays a basic hydraulic circuit schematic. A compensator spool valve connects the stroking actuator to the pump delivery manifold. Additionally, the rate actuator is directly attached. The delivery line is connected to a load valve, which regulates the dynamics of flow and pressure. By adjusting the load valve orifice area, various operating conditions may be achieved. The dynamics of pressure and flow in every component pertaining to the pump's

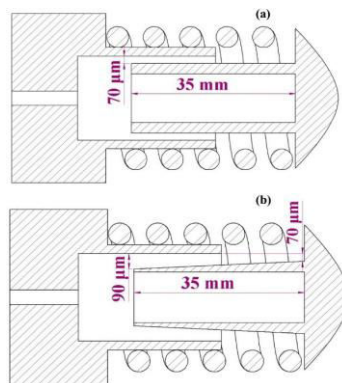
operation, are impacted if the load valve area decreases from full open to full closure. The spool valve starts to open when the area of the load valve orifice declines and the system's delivery pressure rises over the cut-in pressure. Thus, the spool valve allows the pump's flow to reach the stroking actuator. The stroking piston is extended by this pressured fluid, and its action reduces the swash angle. Stroking actuator controls the swash plate angle and swash plate control the dynamics of rate actuator. Fig. 3 illustrates the dynamic simulation for load valve dynamics. For the first 40 ms, the load valve is opened at the appropriate cut-in pressure. After 30 ms, the area is lowered to the corresponding cut-off pressure, and 40 ms are spent at this state. The valve then shifts in the opposite direction, arriving at its starting point in 30 ms and remaining there for an additional 40 ms.



**Fig 3:** Loading pattern to the axial piston pump by changing orifice area

### Result and Discussion

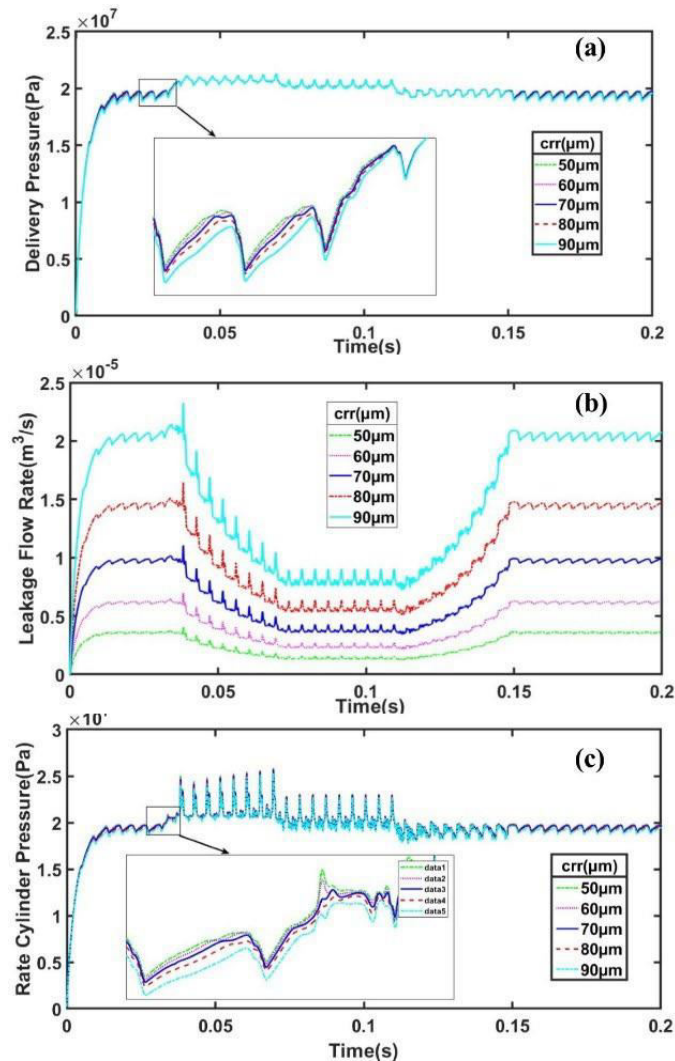
A thorough parametric analysis was carried out to comprehend the effect of clearance variation on the dynamic performance of a pressure compensator in an axial piston pump. The leakage and control characteristics under various operating situations were simulated.



**Fig 4:** (a) uniform radial clearance along the length of the piston (b) radial clearance decreases along the length.

### Case-1: Uniform radial clearance

In this work, the clearance is systematically increase from 50  $\mu\text{m}$  to 90  $\mu\text{m}$  in increments of 10  $\mu\text{m}$ , analyzing five distinct examples of clearance gaps of 50  $\mu\text{m}$ , 60  $\mu\text{m}$ , 70  $\mu\text{m}$ , 80  $\mu\text{m}$ , and 90  $\mu\text{m}$ .

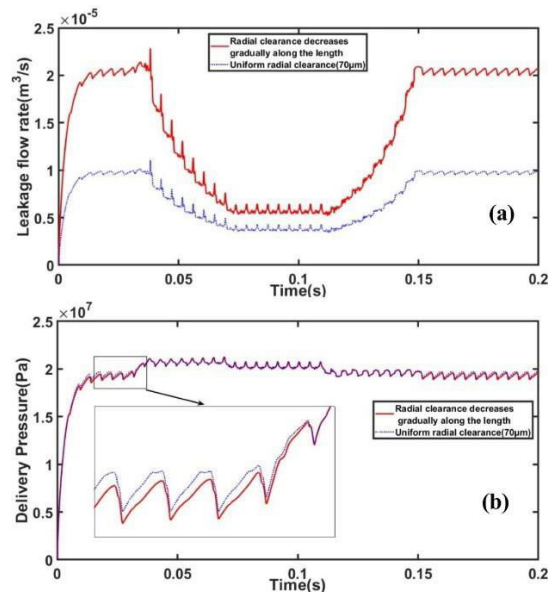


**Fig 5:** Effect of uniform radial clearance (a) Delivery Pressure of pump (b) Leakage flow rate (c) rate cylinder pressure

Each simulation run produced a unique set of output graphs related to the level of clearance being investigated. To facilitate direct visual comparison and make meaningful conclusions, graphs of all five clearance cases were superimposed into a single composite plot for delivery pressure, leakage flow rate and pressure inside rate piston (fig-5). According to this research, the

ideal range for rate piston clearance is between  $60\mu\text{m}$  to  $80\mu\text{m}$  in order to prevent unusual pressure dynamics.

### Case-2: Radial clearance decreases gradually along the length



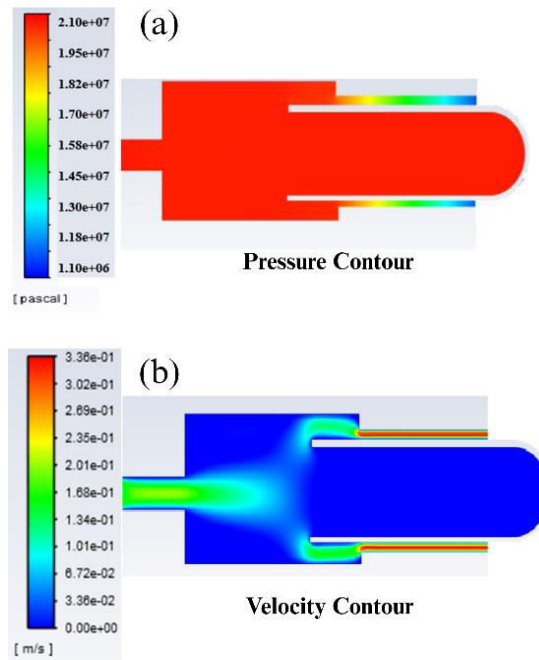
**Fig 6:** Comparison between uniform and uniformly varying radial clearance (a) Leakage flow rate. (b) Delivery pressure of pump

In Case 2, a clearance profile having a reverse taper was investigated, in which the radial clearance reduces progressively along the axial length of the rate piston—from  $90\mu\text{m}$  maximum at the point of entry to  $70\mu\text{m}$  at the end. Such a profile can affect fluid flow behavior considerably by behaving as a converging leakage path, thus providing higher resistance to flow towards the piston end. Simulation results were processed to generate different time-domain plots. All results were plotted on top of a baseline case for a uniform clearance of  $95\mu\text{m}$  to ensure a comparable evaluation.

### CFD Analyses

It is very much important to know how the supply pressure impacts the clearance of the rate piston. The most efficient way that how leakage pressure acts in the small clearance was made possible by the use of CFD modelling. To examine the changes in the fluid velocity & pressure distribution along the radial clearance a simulation was performed. The results tell that due to high differential pressure between the inlet & outlet zone there is a significant drop in the leakage pressure. The velocity distribution was also affected near the wall of the clearance.

The majority of the fluid flow occurs in the centre of the clearance gap & the velocity gradually slows down close to the walls.



**Fig.7:** (a) Pressure distribution along uniform radial clearance (b) velocity distribution along uniform radial clearance.

## Conclusion

The current research focuses on analysing the performance of an axial piston pump fitted with a rate piston mechanism under various loading conditions, specifically addressing the impact of changing radial clearances within the rate piston-cylinder assembly. Through extensive simulation and analysis, the study determines the optimal range of radial clearances in which the pump will sustain uniform delivery pressure with minimal loss of performance. In addition, the simulation results contain exhaustive profiles of velocity and pressure distribution in the clearance zone, providing important information on the fluid dynamics of the system. These results help engineers and manufacturers to obtained correct clearance range.

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## 25. Green and Sustainable Tribology: A Future Need for Economic Growth

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**ABSTRACT** Tribology is an integral part of all mechanical systems. It involves the phenomena of surface damage, directly or indirectly, thus leading to huge loss of energy. This increases researches for getting reliable and quality material for many applications by reducing the energy losses. Many researches have been done to study the mechanical based effect on tribology. Also, awareness for environment changes requires the method of energy saving principle and reducing of carbon footprint. Majority of present needs of industry comes from non-renewable sources. Thus, raising the issue of climate change. Thereby green and sustainable tribology is present day concern for using materials which are environment friendly. It provides solution to high energy consumption, material wastages, application of natural oil resources, increasing reliability and making healthy machines life. Although the entry of sustainable tribology is new to the tribological field, therefore, it needs more understanding to support industrial growth. A better understanding may approach better durability with zero-carbon emission machines or equipment. In this chapter a brief historical discussion on green and sustainable tribology, perspective, and importance and needs of green tribology for both economic and countries growth are highlighted. The structure of discussion in this chapter contributes to the field of research in green and sustainable tribology.

**KEYWORDS:** Green and Sustainable Tribology, climate change.

### Introduction

Green house man-made gases (or anthropogenic elements) are key sources to affect global atmospheric temperature rise thus resulting into global warming. However, early remedies are required to prevent global warming [1]. Thus, in the view to protect and save nature for sustainable development is trending uphill. Before the Kyoto Protocol introduced in 1977, to Paris agreement, industrialization was on the verse without paying attention to the nature [2]. Therefore, taking a major role to enhance national economy by improving energy efficiency becomes the objective of industries. This can only be achieved if tribology is taken into consideration. Objective of tribological researcher reflects the need to minimize friction for energy saving principle. Tribology is, therefore, a green engineering effort. Although few researches have been carried on eco-tribology. Eco-tribology, also named as green tribology, represents the energy saving principle. It covers the basic phenomena of ecological balance and

many progresses have been made since 1970 under the tree of green tribology such as coating techniques, lubrication methodology and sustainable technology under green manufacturing. Wood [3] in his report stated some key elements for sustainable development and is shown in Figure 1.

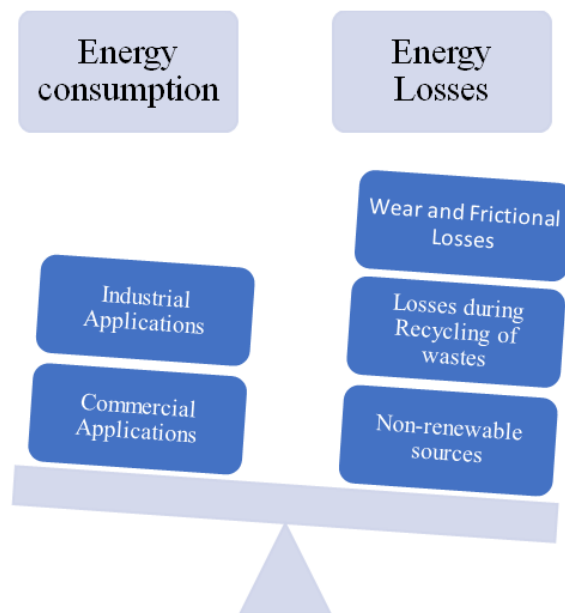


**Fig. 1** Relation between green tribology (or eco-tribology) and sustainable development [3]

Element corresponding to Figure 1 states the advantages of eco-sustainable tribology in terms of energy savings, material saving, cost reduction, wastages reduction, enhancing quality of life and environment.

While looking at the historical development of green tribology the first introduced word friction came into existence by Leonardo da vinci (1442 to 1519). As per the laws of friction introduced by Leonardo da vinci, resistance to overcome friction for two same materials are same and force required to overcome friction gets doubled. Following the laws governed by Leonard da Vinci other researchers such as Amonton (1699), Coulomb (1736-182), Archard (1953) presented theories on wear and lubrication [4]. Although the work reported by various researchers on wear came into existence after the Jost reported the energy saving principle using tribology which was well recognized in the report published in 9 March, 1966 by United Kingdom Government. In the report published by Jost the term green tribology was added after the launch of green tribology by Professor Si-Wei Zhang in tribology policy in London [5, 6, 7, 8, 9].

With the global increase in energy consumption the rate of intensity of economic development has increased. This lets the industries to redouble their effort to work on the development of nation. Throughout the worldwide nation of development, the use of non-renewable sources are decreasing. This brings less use of natural fuels like petrol, diesel etc. Indeed, the naturally occurring fuels shows a growing demand trends but its consumption imposes its adverse effect on environment, thus increasing the global production of carbon dioxide (CO<sub>2</sub>) and other harmful gases that affects the climatic condition. As per the report presented in 2015 by BP Statistical Review of World Energy it was assumed that the reserves of naturally occurring fuels like oil and coal can meet the demand to next 54 years and 100 years respectively. This, therefore, increases the demand towards renewable energy sources which not only saves the shortage of energy production but also reduces the effect of emission of harmful gases. It is important to increase the efficiency of the device to meet the energy requirement through renewable sources. Study reports of Jost, Holmberg and Erdemir (2017) [10] states about the importance of tribology in improving world economic and development by collecting the sources of energy losses from different sectors like production, transport, home applications and generation of power. In an overall remark it was concluded that consumption of energy in world is near about 23% and 20% from it is lost in overcoming friction. Whereas, near about 3% lost in recycling of worn-out products. Further studied carried by Holmberg et al. (2017) [11] states the importance of advanced technologies in tribology in reducing the energy losses in various sectors as stated before thus saving millions of Euros to global market. A simple illustration is shown in Figure 2 about the relation between energy consumption and energy losses. In Figure 2, energy losses are higher when compared to consuming energy in industrial and commercial application.



**Figure 2.** Relation between energy consumption and energy losses in different patterns.

Nosonovsky et al. [12] explained the benefit of tribology under manufacturing and design principles which are:

1. Reducing the dissipation of heat and other forms of energy.

Heat is considered as form of energy. It is governed under relative motion between two contacting bodies in which friction is playing a major role in heat dissipation. The dissipation of heat, through friction, is a primary source. Tribology carries the task to control and minimize the heat dissipation process.

2. Reducing energy losses due to friction.

3. Energy conservation by improving components life.

4. Addition of mating surface with low friction characteristics by eliminating the role of lubricants.

The term introduced as green tribology give the platform for the overall improvement by nullifying the global warming effect. Researches performed under tribology have already gained importance in effectively reducing the friction effect on interacting surfaces. As large amount of energy is wasted due to friction. Thus, decreasing the efficiency at an early life stage of the components under wear environment of friction. The tendency of friction is to govern aging process.

Some studies revealed that wear may happen without the interference of interacting of sliding surfaces. This refers to the phenomena of chemical action and impact actions. Wear does not necessarily include dimensional losses from plastically deformed materials. As wear is not an intrinsic property, therefore it depends on the system under which it is occurring.

Research suggests that wear is observed on the surface of the material, this satisfies that it is a surface property of the material. This surface property shows the tribological behavior of the material in which energy dissipation, change in microstructure and surface roughness, surface hardness and chemical composition of the material is described. Any alteration in the surface property results in change in wear behavior of the material. The system property of the material also gets affected with the input of type of load and sliding actions at the counter surfaces. Irrespective of the material's property other affecting parameter which induces wear are vibratory and impact action, counterbody type (i.e. it may be solid, liquid or gas) and contact type between two interacting surface. The process of material removal in wear phenomenon, generally abrasive and adhesive, includes micro-cutting, micro-plowing, surface delamination, surface crater and surface cracks which defines the mechanisms of wear. This most likely changes the material properties due to fluctuation of stress/ strain under the adhesive action of cyclic fatigue failure.

Wear occurring due to interaction of contacting solid surfaces. Interaction of surfaces leads to formation of friction. Friction, thus formed, gets transformed into various other forms of energy such as mechanical and heat. Energy, later on, gets dissipated thus producing huge losses, as illustrated in Figure 3. The input of energy derived from the mechanical effort to induce energy of other forms in dissipated measure leads to a network of possibilities of minimizing wear volume losses through experimental procedures.

Other method to reduce wear losses is by providing lubricant between two interacting surfaces. Role of lubricant is to reduce friction between the two interacting surfaces. Although machines running under higher load, supported through lubricants, have chances of cyclic breakdown of layer of lubricants, thus increasing wear rate [13. 14]. It is generally accepted technique to provide and maintain the lubricant layers up to three times of the surface roughness of material used for sliding or rolling practice. Recent practices are involved for the use of coatings, self-lubrication and solid lubricants thus eliminating the needs of liquid lubricants. This practice sums up a new step towards green and sustainable tribology.

### **Tribology, Technology and Challenges**

Tribology as issue and challenge stated since its origin. A report published by Jared Diamond in 2005 states the major issues like loss of natural resources (pertaining to aqua life, biodiversity, soil damage, erosion and fossils), production of toxic chemicals/ gases etc and population growth. The issue stated are affecting the life standards of all individuals [15]. To meet the common needs and sustain the life of environment, a past chairman of Chinese Tribology Institution, Si-Wei-Zhang, presented the name and concept of “Green Tribology” in 2009. The term Green Tribology is associated with the objectives and prospects of energy and material saving principles to provide environment friendly and quality life [16]. Thus, for an increasing demand of energy, food and materials; development in green tribology is always needed as it gives a platform for air breathing solutions in enhancing the supply of all increasing demands.

In 1996, a millennium project was started and a report was published in an annual state of the future report [17] which deals with the humanity challenges. Challenges focused under

#### **Millennium project are stated under:**

1. To solve the climate change through sustainable development.
2. To solve water conflict.
3. To balance between population growth and resources.
4. To work with Information and Technology system for global convergence.
5. To sort out the gap between rich and poor through economics of ethical market.
6. To safely meet the demands of energy consumption and saving.
7. To improve human condition through emerging science and technologies.

In the coming 25 years there will be demand of energy supply as per the increase in population growth and industry sectors. Consumption of billions of gallons of petroleum globally during traffic jams is a serious concern around the world. In this regard, biofuels obtained from halophyte plants, algae and cyanobacteria were found useful for liquid transportation. Effort are also being made on the production of biofuels from CO<sub>2</sub> obtained from coal. The sustainable development of fuels in market has raised a great concern in meeting the demands of energy crisis. Enrichment in the process of innovation has drastically achieved a new goal for the reduction of costs through supply of green energy via power plants, micro-chips, buildings, solar panels, compactness in fluorescent bulbs, LED (light-emitting diodes), wind energy and buildings printed with nanotech photovoltaics cells made of plastic has emerged as a new technology to fight against global warming. Although many contributions have been made and still some are in progress but there stands unresolved tribological issues related to the production of biofuels. The instability in biofuels leads to corrosion, change in hygroscopic properties and absorption of water are need to be addressed. Also, tribological issues related to growing concern of energy requirement; demands increase in efficiency in supplying of energy through solar panels, wind turbines and buildings are to be more focused.

### **Tribology as green surface engineering**

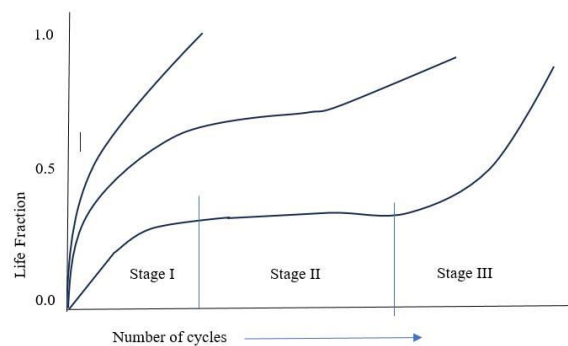
Green surface engineering, first stated under the London conference (2009), states the importance of understanding the tribological properties of mechanical components and its interacting surfaces. This relates to modifying of surface properties of material, if in need, to improve its durability, reliability and life. Thus, achieving the green engineering goal towards green tribology. Green surface engineering sort out the issues associated with manufacturing time and requirement of maintenance by minimizing the wastes and harmful emission of gasses produced by overall affecting the economics of manufacturing process. This not only enhances the efficiency of energy but also gives positive impact on material savings [18, 19].

Study under green surface engineering include examining the surface properties falling under thermal, electrical, electrochemical, electro-mechanical, mechanical and many more.

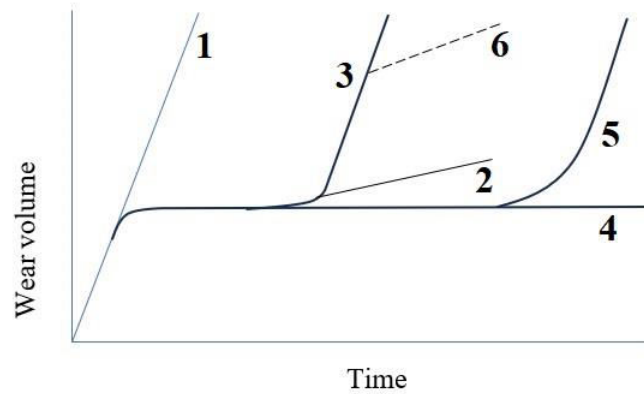
### **Assessment of Product's Life**

Green surface engineering is one of the among fastest technology which is in demand for the present market needs. It involves product life assessment which adheres to the energy performance of material with respect to non-damaging situation to environment. During the tenure of product's life, a metallic component is compromised of energy performance under various areas like excavation unit of minerals and mines, manufacturing, automobile and transportation, maintenance and reliability. Achieving the energy performance can be useful to reduce carbon emission. It, thus, helps to secure the better product life by reducing energy and time consumption with longer running life.

Under the effectiveness of predicting the life estimation of components, it is required to understand the properties under degradation process and aging. For any normal process of aging there occurs three-phase pattern, i.e., primary stage or stage I, secondary stage or stage II and tertiary stage or stage III. Stage I refers to lower rate of aging whereas stage III refers to higher aging rate. Thus, under the stage III process, components generally have higher failure rate. Depiction of stages of aging is presented in Fig. 4. Therefore, analysis and monitoring of product's life is useful to provide the product's working life cycle which includes life cycle assessment for abrasion, adhesion, erosion, fatigue, creep, fracture and corrosion. Under the conditions of abrasive working environment, some areas like mineral processing and material handlings need extensive care as working components die due to heavy abrasion due to wear. Archard's wear equation found useful to determine the wear rate under steady state condition and to predict the wear life falling under the criteria of abrasion. Also, standard tests measure provide relation between hardness, load and wear or wear resistance. Whereas, for the case of wear due to adhesion, there happens a transition time in which rate of wear may increase or decrease with time. To provide a better sustainable environment for reducing adhesive wear, where direct contact between the two surfaces is not a mandatory requirement, lubricating the surface reduces the heat generation process. In this pattern film wear and film wear transition takes place which establishes the relationship between fluid film wear which can be depicted from Figure 5. [20, 21, 22].



**Fig. 4** Stages of pattern under wear conditions.



**Fig. 5** Image representing (1) Metal contact wear (2) Film wear (3) Film wear transitions (4)

Fluid film lubrication (5) Fluid film transitions (6) re-establishment of the lubricant [21]

Similar to the conditions of abrasive and adhesive, wear under erosion is categorized into three stages or zones, i.e., zone I, zone II and zone III. Zone I represents the plastic deformation area, zone II states about the brittle fracture and zone III depicts about surface fatigue. Research carried by Levin et al. [23] gathers the data under steady-state conditions of erosive wear to find erosion rate in which wear resistant materials having properties lies in between ductile and brittle were tested with strike angle of 30° and 90° using alumina grits of size 300 μm for time of strike ranging from 5 to 100 minute. Results depicted under this theory states about deformation region for ductile material but chipping and cracks observed for the case of brittle material. Based on this surfacing of the components with alloys helps to reduce erosive wear but there happen dimensional tolerances which is to be taken with proper care. A case study by Fulton [24] reported for turbines where wet-erosion is a commonly observed phenomenon. In their reports an overlay of high-cobalt stainless-steel alloy (named as Hydrology HQ 913) as welding elements was applied wear prone zones. It is the replacement of cobalt base alloy as it shows good achievement towards erosive action due to cavitation. In addition; efficiency of hydroturbines was well utilized to understand the life cycle by using conversion efficiency theory. Under this theory power, P as expressed from the equation 1 as

$$P = \eta \cdot \rho \cdot v \cdot g \cdot h \tag{1}$$

In equation 1,  $\eta$  represents efficiency,  $\rho$  represents density of water in kg/m<sup>3</sup>,  $v$  represents in m<sup>3</sup>/s,  $g$  represents acceleration due to gravity and  $h$  is the free-falling height. Based on the energy conversion it is the ratio of total electrical energy (which can be determined from the power, P) and input of theoretical potential energy which is F. Where F is the function of  $\rho$ ,  $v$ ,  $g$  and  $h$  and is expressed in equation 2 which is as below

$$F = \rho \cdot v \cdot g \cdot h \tag{2}$$

Thus, from equation 1 and 2, we have

$$P = \eta \cdot F$$

3

But,

$$\eta = P/F$$

4

The ratio as stated in equation 4 describes the energy conversion which states about runner blade erosion wear and can be used to determine the erosion resistance[25, 26]

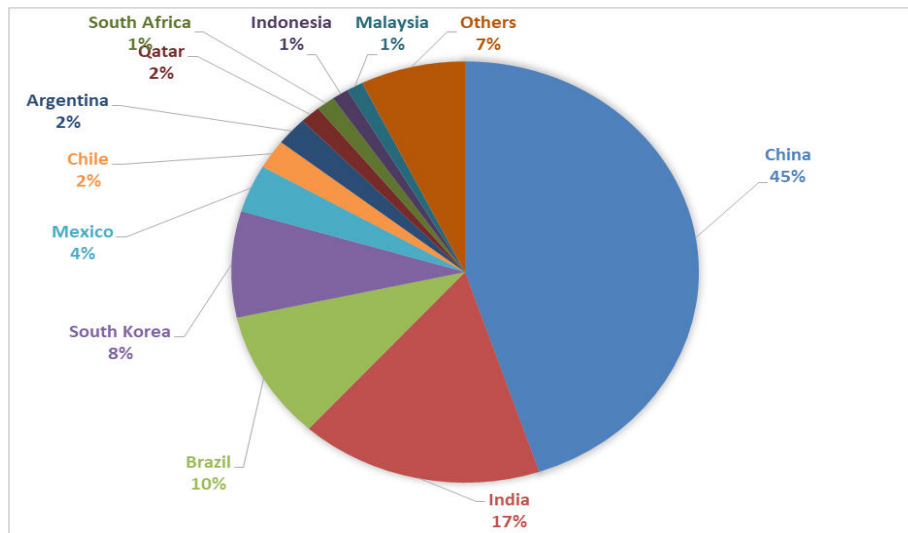
Furthermore, creep failure of mechanical components are time dependent and it can be progressive if it increases due to increase in temperature. As the creep progresses, rupture happens which is stated under rupture stress and the time of failure is known as rupture time. In this case it is advisable for thermal coatings to reduce the creep occurring phenomena of mechanical components [27]. Thermal coatings, however, are advisable before proceeding to resurfacing.

### Energy Conservation and Tribology

Tribology is a key factor to reduce greenhouse effect through energy conservation principle. Effect of tribology can be identified in many areas like mining, manufacturing, power, transport, defense and marine. Areas preferred under tribology raise a concerning alarm for the early failure of mechanical components followed after degradation. It is advisable to modify the surface property of the mechanical component, thus achieving an objective under green surface engineering. It is said as a technique to enhance the ability of the material to improve energy, efficiency and durability of the product. The most common seen application of green tribology is power sector of thermal plant. Report presented under International Energy Agency (IEA) states about the individual country report of CO<sub>2</sub> percentage emission. This needs a call to reiterate and redesign the process of power generation techniques to decrease the unit production of carbon emission gases through timely maintenance and re-surfacing of mechanical components [28]. One of the methods which found useful under the category of re-surfacing of OD-steel which is named as oxide-dispersion-strengthened steel which supports the sustainability for the power plants of next generation. But unfortunately, it least support the corrosion resistance for coolants operating in high temperature environment. However, coatings with high velocity laser accelerated deposition technique, i.e. HVLAD, can be effective in protecting the surface against corrosion, crack formation, and failure due to fatigue.

In transportation sector where total greenhouse gas emission, as recorded in 2006 data, was responsible for 28% emission in which CO<sub>2</sub> emission from fuel and hydrofluorocarbon emission through air-conditioner and electricity was noted. Parameters shows that transportation industry alone is the largest production of CO<sub>2</sub> emission [28]. The total global production of green house gases not only depends on power plant and transportation sector but also manufacturing industry, together, plays a major role. The dissipation of energy in the process under tribology provides

the best opportunity to include tribology with surface engineering concept for the improvement in energy efficiency. The present trends are to adopt the green technologies for the declining of carbon emission. Thus, most of the sectors have adopted the green technology development and to adopt the features resides in it. One of the promising factor implemented to achieve reduction in green emission target is the clean development mechanism which is further associated with Koyoto Protocal [1, 29, 30]. Under the clean development mechanism, promised and expected carbon emission report is presented in Figure 6. Koyoto protocol represents the cutout of carbon emission under green technology approach. Thus, adoption of green tribology is very much needed to develop corporate social responsibility and commitment towards creating an environment with sustainable business strategies as it creates a positive push towards impact on societies [31].



**Figure 6.** Data represents the expected report per unit for certified emission reduction by the host institution under the mechanism of clean development [1, 29].

## Conclusion

The field of green and sustainable tribology has emerged as a vital area of research in addressing modern challenges related to energy efficiency, environmental sustainability, and material conservation. As discussed in this chapter, tribology plays a crucial role not only in minimizing friction and wear but also in contributing significantly to the reduction of energy losses and carbon emissions across industrial applications. Historical insights and advancements—from Leonardo da Vinci’s laws of friction to modern developments in green surface engineering—highlight the evolution and importance of this field. Through the integration of eco-friendly lubricants, advanced coatings, and renewable energy technologies, green tribology offers promising pathways for improving machine reliability, extending component life, and supporting global efforts toward climate change mitigation. However, despite significant progress, tribological challenges—particularly in areas such as biofuel stability, renewable energy systems,

and material erosion—still require further exploration. Continued interdisciplinary research and innovation are necessary to fully harness the potential of green tribology for achieving a sustainable industrial future and securing environmental and economic benefits for generations to come.

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## 26. Vulnerability Assessment and Retrofitting of Existing RC Building Stock In Imphal City-A Case Study

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**ABSTRACT** As it is known that the Indian subcontinent is located in a region of moderate to high seismic zone, it experiences frequent threat to major earthquakes, especially in the north eastern part of the country which falls under zone V of seismic zoning map and design code of India IS 1893(part I). The safety of the structures is the highest concern during an earthquake. Most of the existing RC buildings which were built few decades ago does not satisfy proper building codes, standards and are prone to earthquake. Hence seismic vulnerability assessment with NDT is done for existing RC buildings to check out the structural strength and suitable seismic retrofitting is performed to make the existing structures more resistant to seismic activities. An assessment on the existing structure was carried out for an existing important building which was severely affected by an earthquake which occurred in the year 2016 of magnitude M6.7, at 4:35 am IST with its epicenter located at Tamenglong district (24.83N 93.66E) of Manipur about 30 km west of the State capital Imphal. The location of the assessed building is at Imphal which lies in the highest seismic zone of India i.e. zone V. During the assessment severe damages in structures were found. The building which is taken into consideration is an educational building which has an importance factor of 1.5. Detailed assessment report for the building by using an RVS form is also done. There were damages in the columns due to the past earthquake in the heavier and stiffer side (eastern side) of the building, this is due to the cantilevered dead loads by the massive parapet walls. The whole structure is supported on isolated footings and no failure in support is observed, hence during modeling of the structure it is considered as fixed.

**KEYWORDS:** Earthquake, RC Building, Retrofitting, Seismic Zone, Vulnerability

## 27. Auto Railway Gate

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**ABSTRACT** Railway level crossings are critical points in transportation systems where safety must be ensured for both road users and trains. In India, many level crossings remain manually operated or semi-automatic, leading to human errors, traffic delays, and in some cases, accidents. This paper presents the development of Auto Railway Gate, a low-cost, automatic railway gate control system designed using Arduino technology. The system utilizes an ultrasonic sensor to detect the distance of an approaching train, an RFID module to authenticate train presence, and an IR sensor to check for obstacles on the track. Upon verified detection, a servo motor is triggered to control the gate's movement, while LED indicators and a buzzer provide visual and audio alerts. The gate only closes when both the ultrasonic and RFID confirmations are received, enhancing reliability. An additional safety feature is implemented to slightly reopen the gate if an obstacle is detected during closure. This project aims to minimize manual intervention, reduce accident risks at unmanned crossings, and improve safety and efficiency at railway intersections, particularly in rural or underdeveloped areas.

**KEYWORDS:** Automatic railway crossing, Arduino UNO, RFID detection, Ultrasonic sensor, IR sensor, Servo motor, Level crossing safety, Railway automation, Obstacle detection, Embedded systems

### Introduction

India has one of the largest and busiest railway networks in the world, with thousands of level crossings spread across urban and rural regions. Despite ongoing modernization efforts, many of these crossings are still manually operated or semi-automated, leading to frequent issues such as delays, traffic congestion, and preventable accidents. In particular, unmanned or poorly monitored level crossings pose a significant safety risk to both rail and road users.

Auto Railway Gate is a technology-driven solution designed to address this issue through automation. The system integrates concepts from embedded systems, real-time control, and sensor-based automation to create an intelligent and responsive railway gate mechanism. It leverages automation logic that responds dynamically to environmental inputs such as distance measurement and object detection. Using embedded programming, the system processes sensor data to control physical components like barrier gates and alert systems in real time.

By incorporating contactless identification (RFID) for train verification, distance sensing for positional awareness, and obstacle detection for safety checks, this project simulates how automation can replace manual gatekeeping with a reliable, fast-responding system. Furthermore, it demonstrates how microcontroller-based systems can be used to develop low-cost, scalable infrastructure that aligns with the goals of smart transportation and digital governance.

This project exemplifies the potential of integrating IoT principles, real-time processing, and automation control to solve critical safety issues in transportation, especially in developing countries with resource constraints.

## Objectives

The primary objective of this project is to design and implement an automated railway gate control system that enhances safety at railway level crossings by eliminating the need for manual gate operations. The system aims to reduce human error, prevent accidents, and minimize delays for road vehicles. It achieves this by using real-time sensor data and intelligent control logic to detect approaching trains, verify their identity, monitor obstacles, and manage the gate's movement automatically. The solution is intended to be low-cost, scalable, and suitable for deployment in unmanned or rural railway crossings.

## Problem Statement

Manual and semi-automatic railway gates are commonly used in India, especially in remote and rural regions. These gates depend on human operators, which often leads to delays, negligence, and accidents due to human error or poor coordination. Unmanned crossings are even more hazardous, posing a serious threat to public safety. There is a need for a reliable, autonomous system that can detect approaching trains accurately, prevent gate closures when obstacles are present, and ensure timely and safe operation of railway gates without manual intervention.

## Existing System

In the current railway infrastructure, many level crossings—especially in rural and semi-urban regions of India—are either manually operated or completely unmanned. In manually operated systems, a gatekeeper receives a signal or phone call from the nearest station to inform them of an approaching train. The gate is then closed manually, which introduces significant risks of human error, delayed response, and lack of synchronization with actual train movement. Moreover, due to communication delays or negligence, gates may remain open even when a train is nearby, leading to serious accidents.

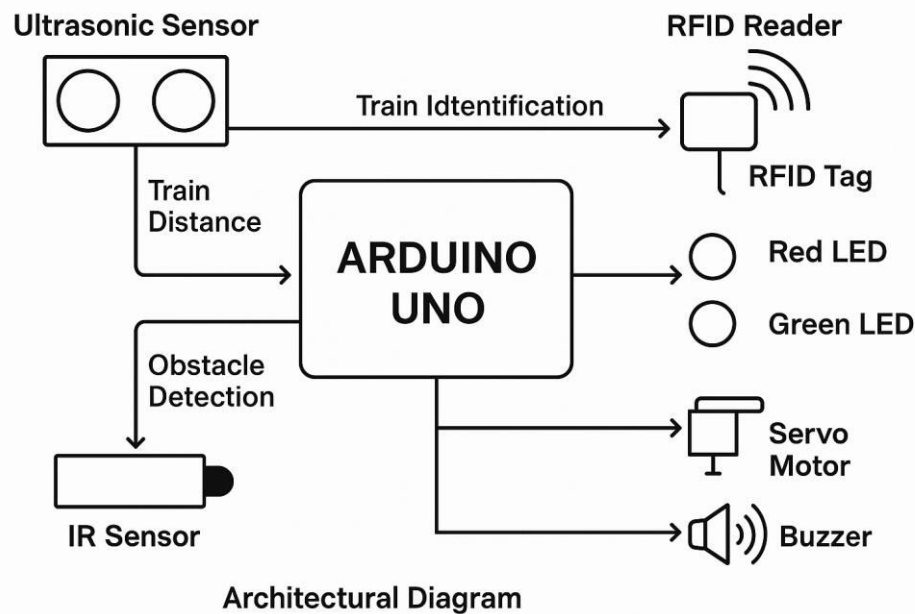
Unmanned level crossings, on the other hand, are left open permanently, relying on signboards and user caution. This significantly compromises safety and increases the likelihood of collisions

between road vehicles and trains. Some semi-automatic systems exist, where sensors detect the presence of a train and initiate gate closure, but these systems often rely on a single point of detection and lack verification or obstacle-handling mechanisms.

The existing systems also lack modern technologies such as RFID-based train identification, obstacle detection, or real-time decision-making algorithms, making them unreliable in complex or unexpected scenarios. These limitations highlight the need for a more intelligent, sensor-integrated, and fully automated railway gate control system like Auto Railway Gate.

### Proposed Sysytem

The proposed system, titled Auto Railway Gate, is an embedded automation project designed to control railway gates using real-time sensor inputs and a microcontroller. The system uses an RFID module to verify the authenticity of approaching trains and an ultrasonic sensor to determine their proximity. Once both conditions are met, the gate begins its closure sequence. An IR sensor is used to detect any obstacle at the gate, ensuring it only closes when the path is clear. If an obstacle is detected during closure, the gate opens slightly to allow clearance while maintaining red warning signals. A servo motor is used to actuate the gate, while LED indicators and a buzzer provide visual and audio alerts for road users. The system is designed to operate autonomously and reset once the train has passed.



**Figure 1:** Architecture Diagram

### Hardware and Software Requirements

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## Hardware Requirements:

- Arduino UNO (Microcontroller)
- Ultrasonic Sensor (Train proximity detection)
- RFID Reader and Tag (Train authentication)
- IR Sensor (Obstacle detection)
- Servo Motor (Gate actuation)
- LEDs (Red and Green for visual indicators)
- Buzzer (Audio alert)
- Breadboard and jumper wires
- Power supply

## Software requirements:

- Arduino IDE (for programming and uploading code)
- Embedded C/C++ (Programming language used)
- MFRC522 RFID Library (for RFID module integration)
- Servo and SPI libraries (standard Arduino libraries)
- Serial Monitor (for testing and debugging outputs)

## Litratue Review

The automation of railway level crossings has been a topic of increasing interest in recent years due to the growing number of accidents and inefficiencies associated with manually operated gates. Several research studies and prototype projects have explored the use of embedded systems, sensors, and communication technologies to improve railway safety at level crossings. Earlier approaches relied primarily on magnetic sensors or track circuits to detect train movement. For instance, some systems used dual magnetic sensors placed before and after the crossing to detect the train's presence and departure. While effective, these systems required precise installation and were susceptible to environmental interference.

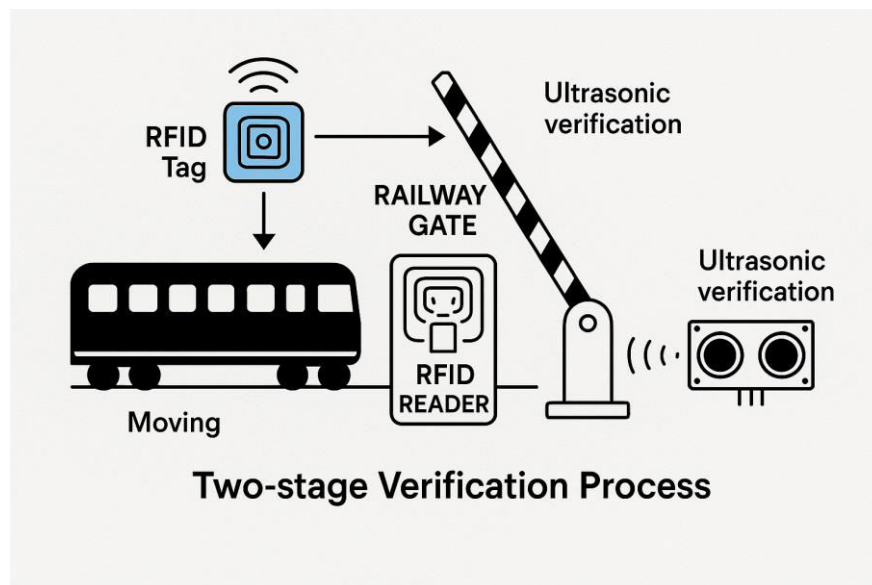
More recent studies have shifted towards microcontroller-based systems, which offer flexibility, cost-effectiveness, and ease of implementation. The integration of RFID technology has emerged as a reliable method to confirm the identity of incoming trains, reducing false triggers and improving detection accuracy. Additionally, the use of ultrasonic sensors for distance measurement and IR sensors for obstacle detection has proven effective in real-time train tracking and accident prevention.

Projects in countries like Korea, Malaysia, and parts of Europe have demonstrated the application of wireless communication, GSM modules, and centralized control rooms for train tracking and gate automation. However, widespread adoption remains limited in India due to

factors such as infrastructure cost, power availability in remote areas, and resistance to replacing manual labor with automation.

Furthermore, some research has proposed the use of image processing and machine learning to detect obstacles or classify train types, but such systems are still in early experimental phases and require high computational power. In contrast, the current project focuses on a practical, deployable solution suitable for semi-urban and rural areas, where simplicity and reliability are key.

The present project builds upon these existing technologies by combining contactless RFID authentication, real-time distance sensing, and intelligent gate actuation into a cohesive, low-cost solution. Unlike systems that rely solely on one form of detection, this approach ensures redundancy and verification, making it more suitable for critical safety applications at unmanned crossings.



**Figure 2:** Two-stage Verification Process

## Methodology

The Auto Railway Gate system was developed using an embedded, sensor-based control mechanism to automate railway level crossing gates. The methodology focuses on ensuring safe and efficient gate operation based on real-time detection of trains and obstacles. The process follows a sequential logic flow involving multiple sensing and actuation stages.

## System Overview

### **The system relies on dual confirmation logic:**

- The presence of a train is first verified through RFID authentication, ensuring only actual trains trigger the gate.
- The train's distance is measured using an ultrasonic sensor, determining whether it is close enough to initiate the gate-closing sequence.
- An IR sensor positioned near the gate checks for obstacles, such as vehicles or pedestrians, to prevent accidents during closure.

## **Control Logic**

### **1. IdleState:**

The gate remains open by default, with the green LED turned on. The system continuously monitors for RFID tag presence and ultrasonic distance.

### **2. Train Detection:**

- o When a valid RFID tag is scanned, the system identifies it as a verified train.
- o If the train's distance is within a predefined threshold (e.g., < 50 cm), it is considered to be approaching the crossing.

### **3. Gate Closure:**

- o Upon both RFID confirmation and proximity detection, the system activates a buzzer and switches the red LED on to alert road users.
- o Before closing, the IR sensor checks for any obstacles. If detected, the gate opens slightly to allow clearance while still maintaining warning signals.
- o If no obstacle is present, the gate closes fully via a servo motor mechanism.

### **4. Train Passage and Exit:**

- o The ultrasonic sensor continues monitoring the distance.
- o If the train moves beyond the threshold and remains away for a minimum time (e.g., 2 seconds), the system considers the train to have passed.

### **5. Gate Reopening:**

- o The gate reopens fully.
- o The red LED turns off, the green LED turns back on, and the system resets to the idle state.

## **Development and Testing**

The system was developed using the Arduino UNO microcontroller and programmed in embedded C++ using the Arduino IDE. Each component was tested individually before integrating into the full prototype. Safety conditions, such as obstacle detection and time-based gate reset, were stress-tested to ensure consistent behavior.

This layered and modular approach ensures a fail-safe, real-time response system that operates without human intervention. The methodology is designed to be low-cost and adaptable, making it suitable for deployment in unmanned or semi-urban railway crossings.

### Sample Code

```
#include <SPI.h>
#include <MFRC522.h>
#include <Servo.h>
#define trigPin 2
#define echoPin 3
#define irPin 4
#define servoPin 5
#define redLED 6
#define greenLED 7
#define buzzer 8

#define SS_PIN 10
#define RST_PIN 9

MFRC522 rfid(SS_PIN, RST_PIN);
Servo gate;

long duration;
int distance;
bool rfidDetected = false;
unsigned long trainGoneTime = 0;

byte allowedUID[4] = {0xCF, 0xF9, 0xCB, 0xC4};

void setup() {
  Serial.begin(9600);
  SPI.begin();
  rfid.PCD_Init();

  pinMode(trigPin, OUTPUT);
  pinMode(echoPin, INPUT);
  pinMode(irPin, INPUT);
  pinMode(redLED, OUTPUT);
  pinMode(greenLED, OUTPUT);
  pinMode(buzzer, OUTPUT);
```

```
gate.attach(servoPin);
gate.write(90);

Serial.println("System ready. Waiting for valid RFID and train...");
}

void loop() {
  distance = getDistance();
  Serial.print("Distance: ");
  Serial.print(distance);
  Serial.println(" cm");

  checkRFID();

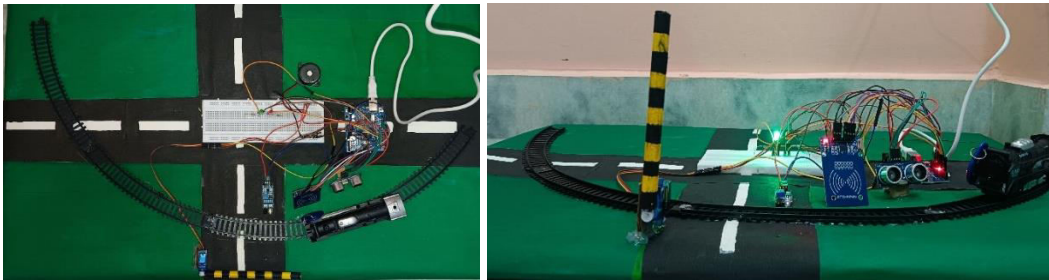
  if (rfidDetected) {
    if (distance < 50) {
      Serial.println("Train detected nearby after valid RFID.");

      trainGoneTime = millis();
      digitalWrite(buzzer, HIGH);
      delay(300);
      digitalWrite(buzzer, LOW);

      digitalWrite(redLED, HIGH);
      digitalWrite(greenLED, LOW);

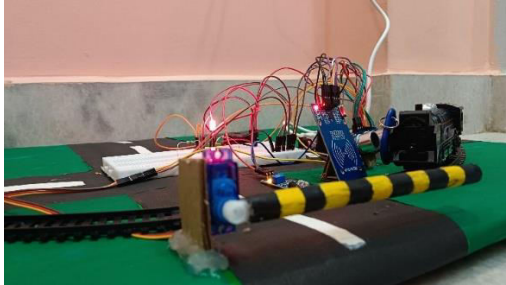
      if (digitalRead(irPin) == LOW) {
        Serial.println("Obstacle detected! Opening gate slightly.");
        gate.write(45);
      } else {
        Serial.println("No obstacle. Closing gate.");
        gate.write(0);
      }
    }
  }
}
```

## Result

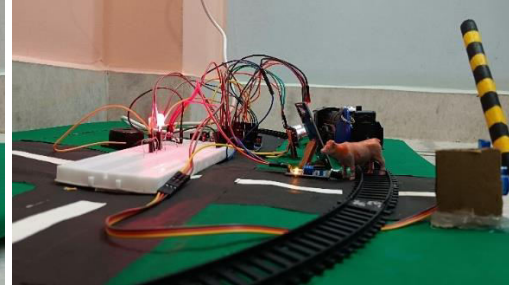


**Figure 3:** The entire system

**Figure 4:** Gate open state



**Figure 5:** Gate closed state



**Figure 6:** Obstacle Detection

The Auto Railway Gate system was developed and successfully tested under a range of controlled scenarios to evaluate its performance. The primary objective was to ensure reliable detection of trains, correct gate actuation, and proper safety responses in real time. The system consistently responded only when a valid RFID tag was scanned and the train was detected within a specified distance. In such cases, the gate closed automatically, accompanied by audio (buzzer) and visual (LED) alerts.

When no RFID tag was present or if an invalid tag was detected, the gate remained open, confirming that the system did not respond to unauthorized objects. Similarly, the presence of a train without RFID confirmation did not trigger the gate to close, ensuring that both authentication and proximity confirmation were necessary for activation.

In situations where an obstacle was detected while the gate was closing, the system successfully reopened the gate slightly while keeping the red warning LED on, maintaining safety for road users. Once the obstacle was cleared and the train was still present, the system resumed gate closure as expected.

After the train moved away from the ultrasonic sensor's detection range (beyond 50 cm) and remained away for a continuous period of two seconds, the system reopened the gate, turned off the red LED, and reactivated the green LED to signal safe crossing.

During testing, the system demonstrated accurate gate control, proper handling of edge cases, and fast response times. All components—including the servo motor, buzzer, LEDs, and sensors—operated in synchrony, validating the logic flow. The only limitation observed was occasional false proximity detection by the ultrasonic sensor due to nearby static surfaces; this was addressed in the software by ignoring extremely short distance readings that did not reflect real train movement.

Overall, the results confirm that the system fulfills its intended purpose: to enhance safety and automation at railway level crossings through a combination of embedded control, real-time sensing, and intelligent logic.

COM10

```
System ready. Waiting for valid RFID and train...
Distance: 96 cm
No valid RFID or train. Gate open.
Distance: 96 cm
No valid RFID or train. Gate open.
Distance: 96 cm
No valid RFID or train. Gate open.
Distance: 96 cm
No valid RFID or train. Gate open.
Distance: 17 cm
No valid RFID or train. Gate open.
Distance: 4 cm
No valid RFID or train. Gate open.
Distance: 3 cm
No valid RFID or train. Gate open.
Distance: 3 cm
No valid RFID or train. Gate open.
Distance: 3 cm
No valid RFID or train. Gate open.
Distance: 3 cm
No valid RFID or train. Gate open.
Distance: 3 cm
No valid RFID or train. Gate open.
Distance: 3 cm
No valid RFID or train. Gate open.
Distance: 2 cm
No valid RFID or train. Gate open.
Distance: 1 cm
No valid RFID or train. Gate open.
Distance: 1 cm
No valid RFID or train. Gate open.
Distance: 2 cm
No valid RFID or train. Gate open.
Distance: 3 cm
Valid RFID tag detected.
Train detected nearby after valid RFID.
No obstacle. Closing gate.
Distance: 2 cm
Train detected nearby after valid RFID.
No obstacle. Closing gate.
Distance: 2 cm
```

**Figure 7: Serial Monitor**

## Conclusion

In conclusion, the Auto Railway Gate system presents a practical and cost-effective solution to the challenges posed by manual and unmanned railway level crossings. By integrating real-time sensing, RFID authentication, and intelligent control logic, the system automates the gate operation process to reduce human error, improve safety, and ensure timely response to approaching trains. The inclusion of an obstacle detection mechanism adds an additional layer of safety, ensuring that the gate does not close if a vehicle or pedestrian is in the way.

This project successfully demonstrates the potential of embedded systems and sensor-based automation in enhancing public infrastructure. The design is modular, low-cost, and scalable, making it suitable for implementation in rural and semi-urban areas where traditional systems are inadequate. With further development, such systems could be networked or integrated into centralized control architectures, contributing to the broader goal of smarter and safer transportation networks.

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## 28. Edura- Roadmap for Engineering Students

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**ABSTRACT** This EDURA platform aims to create a comprehensive roadmap for engineering students navigating their chosen course of study. It addresses the critical challenge students face in understanding the trajectory of their program, available learning resources, and potential avenues for skill mastery. The project involved researching and compiling information on various engineering disciplines, including typical curriculum structures, and essential skills. Furthermore, it identifies and evaluates online learning platforms, educational websites, and other resources where students can supplement their classroom learning and specialize in specific areas of interest. The resulting roadmap provides a structured guide, outlining the typical academic progression of an engineering degree, suggesting relevant online courses and platforms for deeper learning, and highlighting opportunities for practical application and skill development. This resource empowers students to take ownership of their education, explore specialized fields within their discipline, and proactively develop the skills necessary for success in their engineering careers. The project concludes with recommendations for maintaining the roadmap as a dynamic resource, incorporating student feedback and adapting to the evolving landscape of engineering education and online learning.

**KEYWORDS:** Academic progression, skill mastery, java.

### Introduction

In today's digital learning environment, engineering students often face confusion and a lack of direction when beginning their academic journey. With countless online resources and career paths available, identifying the right skills to learn, selecting the best platforms, and understanding academic expectations can be overwhelming. To address this issue, the EDURA platform was developed as a comprehensive roadmap and guidance tool for newly admitted engineering students.

EDURA is designed to simplify and structure the learning journey by providing department-wise roadmaps, recommending top colleges (region-specific, such as within Telangana), listing essential technical and soft skills, and directing students to high-quality online learning content. The platform helps students understand their academic progression and prepared them for real-world career requirements.

The development of EDURA uses Java for application logic, XML for designing user interfaces, and Firebase for real-time database and user authentication. These technologies ensure a responsive, scalable, and secure experience for users.

This documentation details the motivation behind the project, the core features of the EDURA platform, the development process, and how it empowers students to take control of their learning. With a structured academic and skills roadmap, EDURA bridges the gap between education and employability, helping students transition from beginners to industry-ready professionals.

### **Literature survey:**

The development of the EDURA project is inspired by various existing systems and research that aim to support students in college selection, skill development, and academic planning. However, most of these systems are either domain-specific or lack integration across multiple student needs. This literature survey explores key studies and platforms that focus on college recommendation, learning path generation, skill mapping, and educational resource curation. By analysing their contributions and limitations, we identify the gap that EDURA aims to fill—offering a comprehensive, department-wise roadmap for engineering students in Telangana with real-time resource integration.

## **1. College Recommendation Platforms**

Websites like Shiksha, CollegeDunia, and Careers360 provide basic college rankings, reviews, and department-wise filters. However, these platforms focus primarily on institutional data and admission information rather than academic guidance, year-wise roadmaps, or skill-based learning recommendations. EDURA bridges this gap by combining college insights with personalized skill development paths.

## **2. Learning Management Systems (LMS)**

Platforms such as Coursera, Udemy, and edX offer structured courses and certifications across various technical domains. While they are excellent for content delivery, they do not guide students on what to learn based on their engineering department or which skills to prioritize each year. EDURA complements these platforms by directing students to the most relevant content from free and accessible sources like YouTube.

## **3. Skill Mapping Tools**

Some mobile apps and websites like Skill India Digital, NPTEL, and LinkedIn Learning help users identify trending skills and courses. However, they are generally not tailored to students' academic stages (e.g., 1st year vs 4th year), nor do they align with the engineering curriculum.

EDURA introduces department-specific, year-wise skill roadmaps linked with curated online learning resources.

#### 4. Department-Focused Guidance Systems

While there are blogs and university websites that offer course outlines and department-specific information, they tend to be static, outdated, or scattered. There is no single integrated platform that combines college comparison, technical and soft skill planning, and resource curation. EDURA fills this gap by offering a consolidated and interactive solution, using technologies like Java, XML, and Firebase for real-time updates and accessibility.

#### Proposed Method:

The proposed system, EDURA, is designed as an intelligent and user-centric roadmap and guidance platform tailored specifically for newly admitted engineering students. Unlike traditional platforms, EDURA takes a department-specific approach, offering personalized recommendations for students from streams like CSE, ECE, EEE, IoT, etc. By doing so, it helps students understand exactly what to learn, when to learn, and where to learn it from, eliminating confusion and improving decision-making right from the first year of engineering.

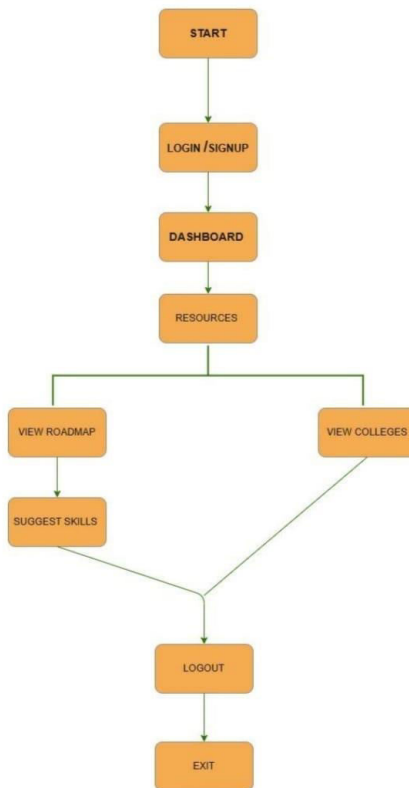
The platform also provides a year-wise roadmap for each engineering department. These roadmaps detail which technical skills, soft skills, certifications, and projects a student should focus on each semester. For instance, an EEE student in their second year would be guided to learn MATLAB or embedded systems, while a CSE student would be directed towards DSA or web development. These roadmaps ensure that learning is structured, progressive, and aligned with industry demands.

To enhance the learning experience, EDURA integrates curated online content, including links to the best YouTube videos, free courses, and certification platforms like NPTEL, Coursera, and Udemy. Instead of students wasting time searching for trustworthy resources, EDURA provides pre-validated, high-quality learning materials for every skill. Each course suggestion comes with a short description explaining its importance and how it aligns with the user's academic journey.

To support real-time access and interaction, EDURA is designed as a mobile-responsive application built using Java, XML, and Firebase. Firebase is used for backend operations like user authentication, real-time database management, and storing user preferences and progress. This architecture allows the app to scale efficiently, support personalized data retrieval, and offer interactive features like bookmarking roadmaps, saving colleges, and setting reminders.

#### Experimentation:

The software requirements define the tools, technologies, and platforms used to design, develop, test, and deploy the EDURA mobile application. This ensures smooth development and integration of the app's core modules: Student and Admin.



## Front-End Development

The EDURA mobile application is developed using Java and XML within Android Studio (Arctic Fox or later), providing a robust environment for front-end development. This setup enables the creation of interactive and responsive user interface layouts for key sections such as Home, Login, Signup, Dashboard, Roadmaps, Resources, and Skills. Activity-based navigation is used to ensure smooth transitions between screens, enhancing the overall user experience. Additionally, this front-end design lays the groundwork for seamless integration with Firebase services and external APIs in future updates, offering both functionality and scalability for the Edura platform.

## Back-End Services

In future phases, EDURA plans to integrate Firebase services to enhance the app's functionality and scalability. The Firebase Realtime Database will store dynamic content like course data, skill development resources, and student information in real time. Firebase Authentication will provide secure user login and signup using email or Google credentials, making the platform more personalized and secure. Furthermore, Firebase Storage will allow uploading and accessing educational files such as PDFs, images, and other learning materials. Although the initial

versions may rely on static data, these backend services will establish a robust foundation for cloud-based features.

### **API Integrations (Planned Future Phase)**

Future updates of EDURA will include integration with APIs such as the YouTube Data API and Google Drive API to enrich content delivery. These APIs will enable dynamic fetching of video-based learning resources and seamless access to documents like roadmaps and syllabi. This will make the platform more interactive and resource-rich for students, enhancing their learning experience

### **Operating System Compatibility**

The app targets Android 7.0 (Nougat) and above to ensure compatibility with most modern smartphones. This minimum requirement supports essential permissions like internet and storage access, enabling smooth operation of the app's features. Targeting this range also guarantees better user interface rendering and overall performance across a wide variety of devices.

### **Development & Testing Tools**

Android Studio is the primary development environment for EDURA, offering features such as a built-in drag-and-drop layout editor, Java compiler, and essential build tools that streamline development. Real-time design and code execution help accelerate the process. For testing, both Android emulators and real Android devices are used to thoroughly assess the app's performance and functionality. Additionally, version control through GitHub is optionally utilized for team-based development.

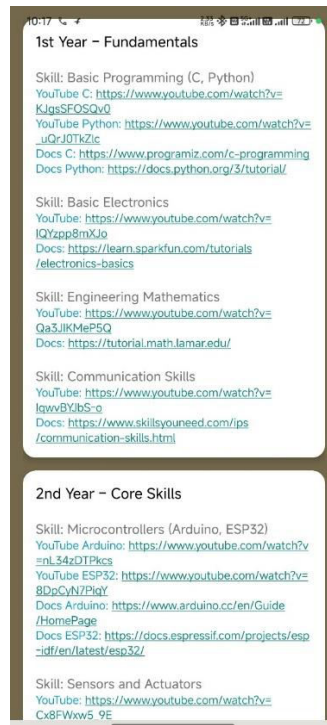
### **Admin Management (Hidden Module)**

The Admin Management module is embedded within the EDURA app but remains hidden from regular users to maintain a clean and simple interface. It provides privileged access to functions like uploading or updating roadmaps and adding new skills or learning resources. This ensures that only admins can manage and modify core content while students interact with a streamlined, distraction-free interface.

### **Result Analysis:**

The EDURA application underwent a comprehensive testing phase to evaluate its performance, functionality, and user experience across all modules. The User Management Module successfully implemented secure login and role-based redirection using Firebase Authentication, ensuring that students and admins accessed only the features relevant to their roles. The Student Dashboard offered a clean and intuitive interface that enabled seamless navigation to other modules. The Roadmap Module effectively displayed semester-wise academic plans for various

departments such as CSE, ECE, EEE, and IoT, giving students a clear understanding of their subject flow and academic milestones. Similarly, the Skill Development Module provided well-organized lists of technical and soft skills aligned with each department, along with direct links to trusted online learning platforms like YouTube, NPTEL, and Coursera. The College Information Module proved particularly useful in presenting department-specific college recommendations within Telangana, allowing students to make informed decisions based on filters like course offerings, location, and accreditation. All modules were tested on both emulators and real Android devices (Android 7.0 and above), with results showing smooth performance, correct UI rendering, and minimal latency. Firebase integration ensured real-time updates, secure data management, and dynamic content loading. Test cases validated accurate input handling, error responses, and functional redirection. Students found the interface user-friendly and the content relevant to their academic journey. Feedback from initial users highlighted the usefulness of features like curated skill paths and centralized resource access. Overall, the application met its core objectives by delivering a reliable, scalable, and practical educational tool that bridges the gap between academic learning and industry readiness.



## Conclusion:

The Edura project is a comprehensive academic and career guidance platform designed to support newly admitted engineering students throughout their academic journey. By integrating multiple modules that focus on essential aspects such as academic roadmaps, technical and soft skill development, college information, and personalized dashboards, Edura provides a

structured and intuitive experience that empowers students to make informed decisions and stay ahead in their engineering careers. One of the key motivations behind Edura was the observation that many first-year engineering students struggle to find the right direction, resources, and motivation during their initial semesters. Without proper guidance, students may feel lost when it comes to understanding what subjects to focus on, what technical skills are in demand, and which colleges or branches align best with their career goals. Edura addresses this gap by offering a unified platform that acts as a virtual mentor, providing semester-wise subject breakdowns, curated skill learning paths, and access to reliable learning platforms.

### **Future scope:**

In the future scope of the Edura project, we aim to replace hardcoded content with Firebase-based dynamic fetching, allowing admins to update roadmaps in real time without modifying the app code. This will make the platform more flexible and easier to maintain. Additionally, roadmap viewing will be expanded to include other departments such as ECE, EEE, and IoT by either creating separate activities for each or implementing a single dynamic activity that adapts based on the selected department. Furthermore, a semester-wise filtering feature will be introduced to help students easily navigate through their academic roadmap. The addition of downloadable content for each semester will further enhance accessibility and usability for students across all branches.

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