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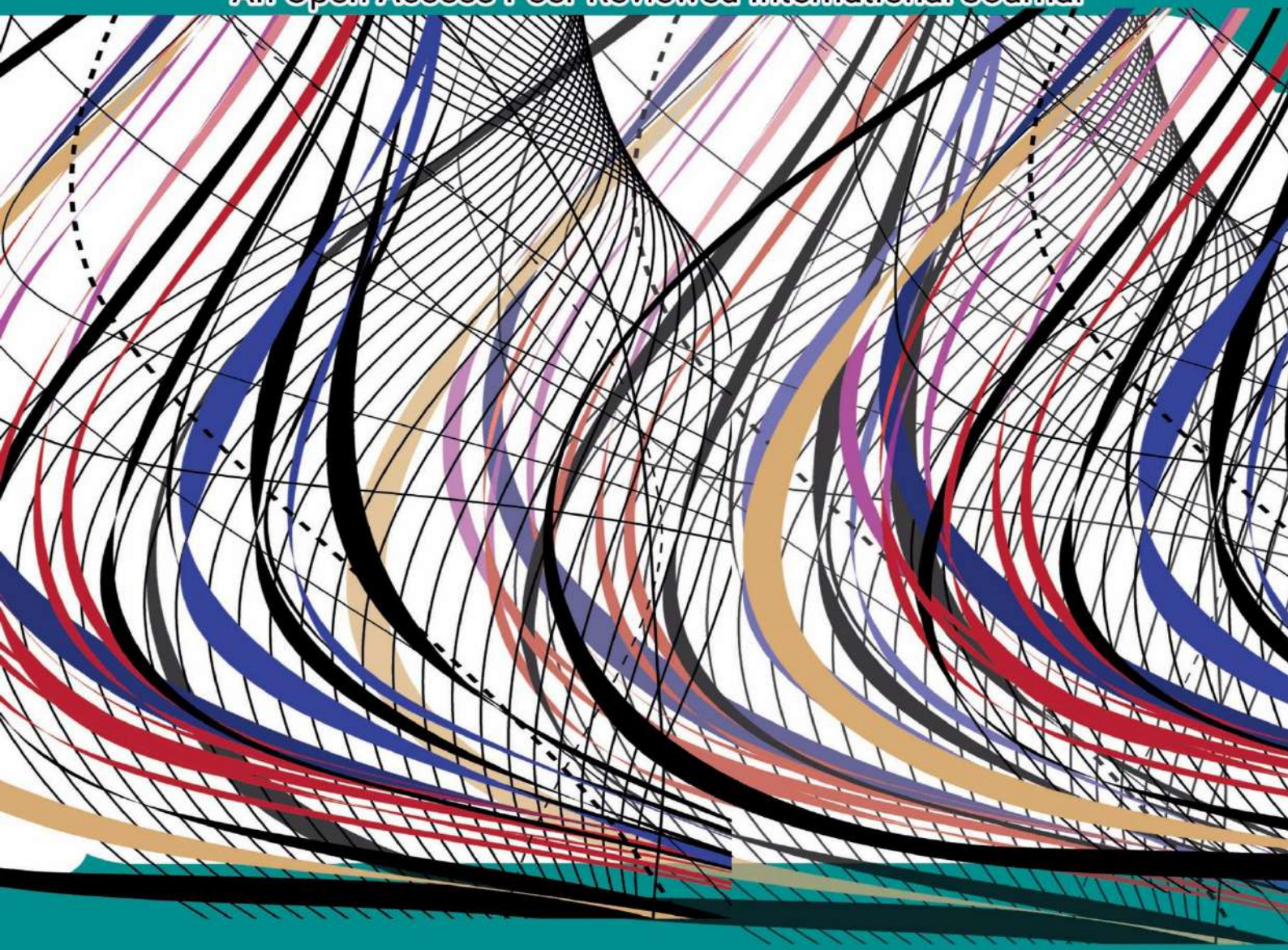

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Based on the MATLAB Simulation of Peanut Nest-Hole Wheel-Type Planting Machinery's Seeding Performance

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Abstract *— Using the nest-wheel seeding device as the research object, a MATLAB-based simulation model for seeding performance was built with the goal of improving the operational efficiency and seeding accuracy of peanut hill-drop planting machinery. This model focused on the motion characteristics of the key components of the seeding device and the rules of interaction between seed groups. In order to simulate and analyze the seed hole occupancy rate, missed seeding rate, and reseeding rate during the seeding process, various operating speeds (20–60 r/min) and hole spacing parameters were set by combining the physical characteristics of peanut seeds (thousand-seed weight, geometric dimensions, and friction coefficient). With the highest seed hole occupancy rate of 93.61% and the lowest missed seeding rate and reseeding rate dropping to 1.74% and 3.79%, respectively, the results demonstrated that the seeding performance was within the ideal range when the nest wheel speed was set at 30 to 40 r/min and the hole spacing was set at 150 mm. This simulation model offers a theoretical foundation for the structural optimization of peanut hill-drop planting equipment and can accurately forecast seeding performance.*

Keywords *—* ***Peanut seeder, Seeding Performance, MATLAB/Simulink, Kinematic Simulation, Nest-Wheel Seed Metering Device***

I. INTRODUCTION

Peanut, as an important oil crop in China, its planting process is directly influenced by the quality of hole sowing, which in turn affects yield and resource utilization. Traditional hole sowing machinery relies on physical testing for seeding performance optimization, which is time-consuming, costly, and difficult to adjust parameters. With the development of computer simulation technology, multibody dynamics simulation has become an important means for predicting the performance and optimizing the structure of agricultural machinery.[1-4]

Currently, scholars both domestically and internationally have conducted research on crop seeding simulation: Zhang Ningning et al. simulated and experimented on the seeding performance of a roller-type hole seeder based on EDEM; Li Jian et al.[3,5,6-8] established a corn seeding device model based on ADAMS and analyzed the impact of rotational speed on seeding stability; foreign scholar Smith used the Discrete Element Method (DEM) to simulate the movement trajectory of soybeans within the seeding device;[2,4,9,10] Eudulino Da Costa and Arzu Yazgi optimized the cubic form mathematical model of peanut seeding quality index using the Central Composite Design (CCD) method; Xiang Zhang and Loc Vu-Quoc simulated the flow of

legumes in a channel using an improved tangential force-displacement model based on DEM.

MATLAB, as a multi-domain simulation platform, utilizes its Simulink module to facilitate dynamic modeling and motion simulation of mechanical systems. The Simulink module is capable of constructing multi-parameter coupled performance analysis models, providing technical support for the "visualization" and "parameterization" research of the seeding process. This paper takes the nest-wheel peanut seeding device as the research subject, constructs a seeding system simulation model using MATLAB, and simulates the seeding performance under different working conditions, aiming to provide an efficient and low-cost research method for the design optimization of peanut hole sowing machinery.

II. MATHEMATICAL FORMULAS AND DESCRIPTIONS

The collision dynamics of seed discrete elements and the nest wheel's kinematics are the two main modules that comprise the fundamental mathematical formulas. These are the particular key formulas: It is used to describe the rotation of the eye-catching wheel and the entrainment movement of the seeds with the wheel body, which is the foundation of simulation. The relationship between the angular velocity and linear velocity of the nest-eye wheel.

$$V = \omega \cdot R \tag{1}$$

where V is linear velocity of the outer circle of the nest wheel (m/s), determining the seeding rhythm, *ω*is angular velocity of the eye-nest wheel (rad/s), converted from the rotational speed of the transmission system (ω=2πn/60, n represents the rotational speed r/min), and *R* is outer radius of the eyelet wheel (m). The seed makes circular motion within the nest hole along with the wheel body, and its tangential velocity component is:

$$V_t = \omega \cdot r \tag{2}$$

where $V_n = 0$ is the normal relative velocity in circular motion, which is only affected by centrifugal force, and r is the distance between the centroid of the seed and the wheel center, or the radius of the nest hole. The wheel body's linear velocity and the time difference between seed discharge determine the seed spacing, also known as hole spacing:

$$L = V \cdot \Delta t \tag{3}$$

where Δt is the time interval between two adjacent seeds being ejected from the seed hole, and L is the seed spacing (m). The equilibrium between centrifugal and frictional forces on the nest hole wall determines whether the seeds are flung out of the hole as

$$F_c = m \cdot \omega^2 \cdot r \tag{4}$$

the maximum force of static friction as

$$F_f = f \cdot F_N \tag{5}$$

where f represents the friction coefficient and F_N denotes the normal pressure exerted by the nest wall on the seed. When $F_c > F_f$, the seed detaches from the seed hole and completes the seeding process. Used to determine key metrics like the rate of missing and reseeded seeds and to confirm the efficacy of simulation

$$P_1 = N_1/N_t \times 100\% \tag{6}$$

where N_t is the total number of holes and N_l is the number of missed holes.

$$P_r = N_r/N_s \times 100\% \tag{7}$$

where the total number of seeds actually released is N_s, while the number of rebroadcast seeds (the total number of seeds released from a single nest hole ≥ 2) is N_r. A fundamental performance measure for seed metering, the seed filling rate shows the percentage of seeds that were effectively filled during the wheel's revolution.

$$P_c = N_c/N_t \times 100\% \tag{8}$$

where P_c represents Seed filling rate (outcome stated as a percentage, with values ranging from 0 to 100%), N_c represents the number of successfully seeded holes (determined in simulation as the total number of holes where "at least one seed is placed in a single hole"), and N_t represents the hole-drilling wheel's total number of holes (the known parameter of the fixed number of holes made for the seeder). For instance, the seed filling rate P_c = 48/50 ×100% = 96% if the pocket wheel has 50 pockets in total and 48 of those pockets are filled with seeds following simulation. The degree of consistency between the "number of seeds per hole" that are actually discharged and the "design target seed count per

hole"—which is typically "1-2 seeds per hole" for peanut hole sowing, with specific target values established by agronomic requirements—is reflected in the qualified rate of seed count per hole.

$$P_q = N_q/N_e \times 100\% \quad (9)$$

where P_q represents qualification rate of cavity particle count (result expressed as a percentage, ranging from 0 to 100%), N_q represents qualified hole count (in simulation, the total number of holes whose "actual hole count falls within the 'target hole count range'" is counted. For example, when the target is 2-3 holes, holes with an actual count of 2 or 3 are both counted as qualified), and N_e represents actual effective seeding hole count (in simulation, it refers to the "number of holes successfully filled with seeds", which is the total number of holes after excluding missed holes, and equals to the number of successfully filled holes Nc, as one filled hole corresponds to one seeding hole). For instance, the pass rate P_q = 38/48×100% ≈ 79.2% if the goal number of seeds in each hole is 1-2 and there are 48 effective seeding holes overall after simulation, of which 38 holes contain 1 or 2 seeds.

As the prerequisite factors for determining the pass rate, the typical aims for peanut sowing are one seed per hole and two to three seeds per hole.

III. CONSTRUCTION OF SEED METERING SYSTEM SIMULATION MODEL

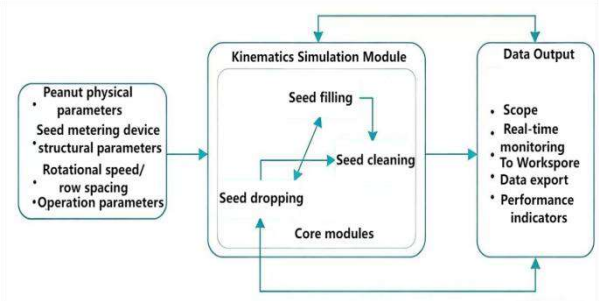

Fig.1: MATLAB Simulink Seed Metering Simulation Schematic Table

The MATLAB Simulink seeding simulation schematic diagram in Figure 1 allows us to build the appropriate system simulation model and preliminary deduce the following transfer function. The seed metering system is essentially a coupled system of "mechanical motion + seed particle motion". After simplification, it can be regarded as a dynamic system with "rotating speed of the seeding wheel" as the input and "actual number of seeds in the hole" as the output. The transfer function is as follows:

The input quantity *R(s)* is the nest-eye wheel's angular velocity command signal (unit: rad/s), which represents the seeder's forward speed and the hole spacing. matching relationship, which is

$$\omega = V/r \cdot n \quad (10)$$

where V is the forward speed, r is the eye-nesting wheel's radius, and n is the number of eye nests. A discrete value, the output C(s) is the actual number of seeds sown in a single hole; however, during modeling, it can be approximated as a continuous dynamic quantity. Both "mechanical transmission delay" and "seed filling probability" are impacted by the seed metering wheel's rotating speed during the seed metering operation. Ignoring high-frequency interference, the first-order linear transfer function is as follows:

$$G(s) = C(s)/R(s) = K \cdot e^{-\tau s/(Ts+1)} \quad (11)$$

where K is Gain coefficient (physical meaning: the rate of change in average seed count per unit angular velocity change, determined by structural parameters such as nest volume and seed size), τis delay time (physical meaning: the time difference from the moment the auger wheel receives the speed command to the moment it completes the seed filling-discharging process, which is related to mechanical inertia and seed flow speed), T is Time constant (physical significance: system response speed, related to the rotational inertia of the nest wheel and the friction coefficient between the seed and the nest wall), and $e^{-\tau s}$ is Pure delay element (due to the sequential process of "speed input → mechanical rotation → seed filling → discharge" in seed metering, there is a non-negligible time delay).

The relevant simulation model of the peanut burrow wheel seed metering device based on MATLAB/Simulink. The model is shown in Figure 2 and 3 below:

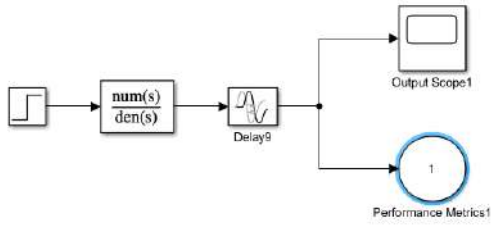

Fig.2: Simulation structure diagram of peanut nest-hole wheel seed meter based on MATLAB/Simulink

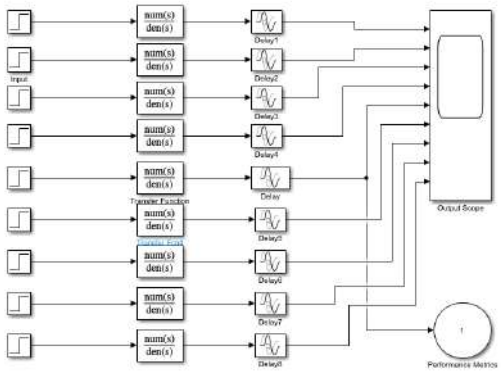

Fig.3: Simulation model of peanut nest wheel seed meter based on MATLAB/Simulink

IV. DETERMINATION OF SIMULATION OBJECT AND PHYSICAL PARAMETERS

The experiment selected the main cultivar "Luhua 11" grown in North China. Each group was tested three times and the average value was taken. The testing method referred to the "General Principles for the Measurement of Physical Properties of Agricultural Materials". The results are shown in Table 1.

Based on the existing 2BHF-2 peanut hill drop planter, the core structural parameters of the seed metering device are determined to ensure consistency between the simulation model and the actual machine model. The parameters are shown in Table 2.

Table 1: Physical parameters related to peanut seeds

Physical characteristic parameters	**thousand grain weight**	**geometric dimensions (length × width × height)**	**seed-steel friction coefficient**	**seed-seed friction coefficient**	**elastic recovery coefficient**
Numerical value	225±6 g	6.8±0.3 mm×5.4±0.2 mm×4.9±0.2 mm	0.33±0.02	0.46±0.03	0.69±0.04
Determination method	Weighing with an electronic balance (accuracy 0.01 g)	Measured with a vernier caliper (accuracy 0.02 mm)	Inclined plane method (adjust the inclination to allow the seed to slide down at a constant speed)	Inclination method (measurement of inclination angle when seed pile slides down at a constant speed)	Falling ball method (seed falls from a height of 50 mm onto a steel plate)

Table 2: Structural parameters of the nest-eye wheel seed metering device

structural components	**nest eye wheel**	**nest eye wheel**	**nest eye wheel**	**nest eye wheel**	**seed tube**	**seed tube**
parameter name	diameter	number of holes	aperture diameter	thickness	inner diameter	inclination
numerical value	125 mm	12	8.2 mm	16 mm	10 mm	45°

To simplify simulation calculations, reduce modeling complexity, and ensure the consistency of simulation accuracy with actual conditions, the following model assumptions are proposed:

Assumption 1：Seed geometry assumption: Peanut seeds are regarded as regular ellipsoids, ignoring minor surface protrusions and textures. Their geometric dimensions are taken as the average values measured in experiments (6.8 mm × 5.4 mm × 4.9 mm), with an error controlled within ±0.3 mm;

Assumption 2：Assumption on seed physical properties: During the seeding process, the seeds are not damaged or deformed, and their physical properties (mass, friction coefficient, elastic recovery coefficient) remain stable and do not change with environmental temperature and humidity;

Assumption 3：Mechanical motion assumption: The eye-nesting wheel rotates at a constant speed, ignoring the speed fluctuations of the power system (fluctuation amplitude ≤ ±1 r/min), and the coaxiality error between the eye-nesting wheel and the transmission system is ≤0.1 mm;

Assumption 4：The simulation environment is at room temperature (25℃) and standard atmospheric pressure, ignoring the influence of air resistance on seed movement (the influence of air resistance on peanut seeds is ≤1%, which can be neglected);

Assumption 5：Assumption for seed cleaning process: The gap between the seed cleaning brush and the nest wheel is uniform (0.5 mm), the seed cleaning force is consistent, and no excess seeds remain in the nest.

V. SIMULATION DATA AND RESULTS

During simulation, the seed picker may encounter phenomena such as single seed picking, double seed picking, and missed seeds. The ability of the seed picker to pick single seeds is a key factor for the seed metering device to achieve precise sowing. The simulation of the seed picker picking single seeds is an important aspect to consider.

Key indicators for the adaptability of peanut seeds to seed meter parameters. Utilizing the single-factor variable method, simulations were conducted on peanut seeds under varying seed meter parameters and operating speeds. The number of missed seeds, reseeded seeds, and single-seed counts during seed metering were statistically analyzed for each simulation. The operating speeds of the hole seeder were set to 20 r/min, 25 r/min, 30 r/min, 35 r/min, 40 r/min, 45 r/min, and 50 r/min for simulation, the comparison chart of simulation results is shown in Figure 4 below; the statistical results are presented in Table 3 below.

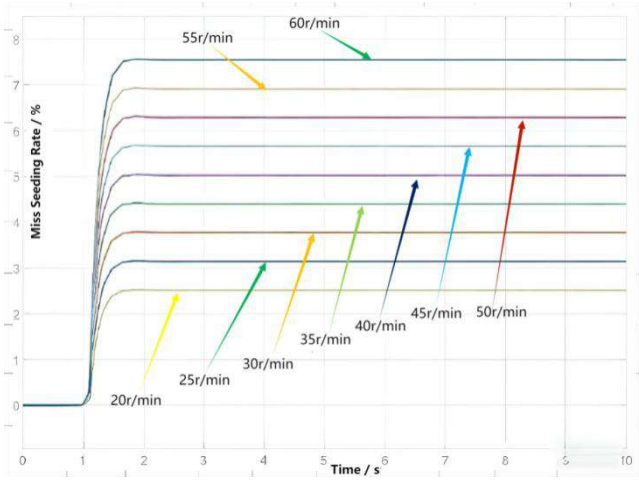

Fig.4: Comparison of simulation results of peanut seed leakage index under different rotational speeds of the nest-wheel type seeder

Table 3: Statistical Table of Simulation Result Data

Operating speed(r×min-1)	Qualification Index(%)	Replay Index(%)	Missed Broadcast Index(%)
20	**92.47**	**4.97**	**2.56**
25	**92.83**	**4.04**	**3.13**
30	**93.15**	**3.06**	**3.79**
35	**93.61**	**2.01**	**4.38**
40	**93.23**	**1.74**	**5.03**
45	**91.71**	**2.58**	**5.71**
50	**89.96**	**3.77**	**6.27**
55	**88.75**	**4.31**	**6.94**
60	**87.30**	**5.17**	**7.53**

From Table 3 and Figure 4, it can be seen that the qualified rate of cavity grain number exhibits a trend of "first increasing and then decreasing" with changes in rotational speed: At rotational speeds of 20-35 r/min, the pass rate increased from 92.47% to 93.61%,

representing a 1.14% increase. The reason is that at low rotational speeds, the seeds stay in the seeding holes for a longer period of time (0.5 s at 20 r/min and 0.286 s at 35 r/min). This allows for sufficient seed filling and effective cleaning of excess seeds by the seed cleaning brush, thus gradually improving the pass rate; At rotational speeds of 35-60 r/min, the pass rate decreased from 93.61% to 87.30%, a decrease of 6.31%. The reason is that at high rotational speeds, the centrifugal force of the seed metering wheel increases (the centrifugal force at 60 r/min is 2.9 times that at 35 r/min), reducing the residence time of seeds in the seed metering wheel, leading to insufficient seed filling. At the same time, seeds are easily thrown out of the seed metering wheel too early, resulting in an increase in the number of unqualified holes.

The rate of missed sowing shows a "continuously rising" trend as the rotational speed changes: At rotational speeds ranging from 20 to 60 r/min, the seed leakage rate increased from 2.56% to 7.53%, representing a 4.97% increase. The reason is that as the rotational speed increases, the centrifugal force of the seed metering wheel also increases. The adhesive force (provided by friction) of the seeds within the seed metering holes is insufficient to resist the centrifugal force, leading to the premature detachment of seeds from the holes. These seeds are thrown out before completing the seed filling process, resulting in an increase in the number of missed seeding holes; Low rotational speed (20-30 r/min): The rate of seed leakage increases slowly, rising from 2.56% to 3.79%, with an increase of 1.23%. The reason is that at low rotational speeds, the centrifugal force is relatively small, allowing seeds to remain stably in the seeding holes, resulting in fewer instances of seed leakage; High rotational speed (40-60 r/min): The rate of seed leakage increases rapidly, rising from 5.03% to 7.53%, an increase of 2.50%. The reason is that at high rotational speeds, the centrifugal force increases sharply, disrupting the balance between seed adhesion and centrifugal force, leading to a significant increase in seed leakage.

The replay rate exhibits a trend of "first decreasing and then increasing" as the rotation speed varies: At rotational speeds of 20-40 r/min, the reseeding rate decreased from 4.97% to 1.74%, representing a decrease of 3.23%. The reason is that at low rotational speeds, seeds spend a longer time in the hole, which is prone to multiple seeds entering the hole simultaneously, leading to reseeding. As the rotational speed increases, the residence time decreases, and the probability of multiple seeds entering the hole simultaneously decreases, resulting in a decrease in the reseeding rate; At a rotational speed of 40-60 r/min, the reseeding rate increased from 1.74% to 5.17%, representing a 3.43% increase. The reason is that at high rotational speeds, the centrifugal force of the seed-collecting wheel increases, and the movement speed of seeds within the seed-collecting wheel accelerates. This makes seeds more prone to bounce back into the seed-collecting wheel after collision, leading to an increase in the number of seeds within a single seed-collecting wheel and a subsequent rise in the reseeding rate.

There is a certain degree of error between the simulation results and the actual planting conditions, and the error is relatively small, but there are still some deviations. The main reasons can be summarized into four categories:

1. Simplified error of seed characteristics

The simulation abstracts peanut seeds as regular ellipsoids, ignoring the tiny protrusions, textures, and individual size differences on the actual seed surface (with an error of ±0.3mm). This leads to deviations in the calculation of the contact area and friction coefficient between the seeds and the hole wall. Specifically, the friction coefficient of the actual rough surface is 5%-8% higher than the simulated set value, directly affecting the simulation of seed adhesion during seed filling, resulting in prediction deviations in seed filling rate and seed leakage rate.

2. Idealization error of mechanical motion

The simulation assumes that the cradle wheel rotates at a constant speed, without considering the speed fluctuation (±1-2r/min) and coaxiality error (≤0.1mm) of the actual transmission system. Speed fluctuation can lead to instability in the time interval of seed discharge, while coaxiality error can cause a relative positional deviation between the cradle and the seeds. Together, these factors may result in a simulated value of the qualified rate of seed quantity per hole that is 2%-3% higher than the actual value.

3. Environment and process ignore errors

The simulation did not account for air resistance (with an impact on peanut seed movement of ≤1%), slight changes in temperature and humidity on seed physical properties (friction coefficient, elastic recovery coefficient), and also simplified the seed cleaning process - assuming that the seed cleaning brush has uniform gaps (0.5mm), but in reality, wear and tear of the seed cleaning brush can lead to local gaps increasing to 0.8mm, leaving residual seeds, which may cause the simulated value of the reseeding rate to be 4%-5% lower than the actual value.

4. Parameter measurement accuracy error

The physical characteristics of seeds (thousand-seed weight, friction coefficient) are determined through sampling tests, with a measurement error of ±3%. The machining accuracy deviation (±0.1mm) of the seed metering device structural parameters (hole depth, seed guide tube inclination) can also accumulate in the simulation results, potentially leading to deviations of ≤2.5% in some indicators (such as seed filling rate).

VI. CONCLUSION

This study focuses on the nest-eye wheel-type peanut seeder, constructs a simulation model for seeding performance using the MATLAB/Simulink platform, and combines the physical characteristics of "Luhua 11" peanut seeds with the structural parameters of the 2BHF-2 type hole seeder. By analyzing the impact of rotational speed on seeding performance using the single-factor variable method, the following core conclusions are drawn:

The constructed model simplifies the seed metering system into a first-order linear dynamic system, with the angular velocity of the nest wheel as the input and the actual number of seeds in the holes as the output. By coupling kinematic formulas with discrete element collision dynamics formulas, it can accurately simulate the entire process of seed filling, cleaning, and dropping. The model can quantitatively output core indicators such as the pass rate of seeds in the holes, the missed seed rate, and the reseed rate, which are consistent with the actual seed metering logic, providing a reliable tool for predicting seed metering performance.

When the rotational speed is within the range of 20~40r/min, the qualified rate of seed cavity count shows an overall upward trend with increasing rotational speed, the seed leakage rate first decreases and then increases, and the reseeding rate continues to decline. When the rotational speed exceeds 40r/min, the qualified rate significantly declines, and both the seed leakage rate and the reseeding rate rapidly increase. This is because at low rotational speeds, the seeds are fully filled but prone to reseeding, while at high rotational speeds, the centrifugal force is too strong, causing the seeds to prematurely detach from the nest, leading to insufficient seed filling and resulting in seed leakage.

Based on comprehensive performance indicators, the seeding performance reaches its optimal when the rotational speed of the nest wheel is between 30 and 40 r/min and the hole spacing is set at 150 mm. Within this range, the qualified rate of seed count per hole reaches a maximum of 93.61%, while the rates of missed sowing and double sowing are minimized to 1.74% and 3.79% respectively, meeting the agronomic requirement of "1-2 seeds per hole" for peanut hole sowing. This provides a direct basis for parameter adjustment in actual production operations.

Compared to traditional physical experiments, the simulation method based on MATLAB can quickly achieve iterative analysis of parameters under multiple working conditions, significantly shortening the research cycle and reducing experimental costs. This model can be further applied to the optimization design of structural parameters such as the size of the hole in the nest wheel and the inclination of the seed guiding tube, providing theoretical support for improving the performance and structural design of peanut hole sowing machinery.

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Research on Recovery under Pruning Degeneration Using LoRA Technology

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***Abstract*—** *In several fields, Convolutional Neural Networks (CNNs) have demonstrated impressive progress in recent years. However, its adoption on devices with limited resources is limited by its enormous model scale and high computational requirements. Neural network pruning in particular has become one of the most important methods for resolving this problem. The choice of importance criteria has a significant impact on pruning's effectiveness. Without systematic comparisons of numerous criteria under the same pruning ratio, the majority of the research to far has been on the proposal of single criteria or comparisons under non-strict control. Furthermore, trimming frequently results in performance loss that must be fixed through fine-tuning. The advent of parameter-efficient fine-tuning algorithms like LoRA offers a fresh approach to addressing the high computational cost of conventional global fine-tuning. It is still unknown how they work together with various pruning criteria. This is accomplished by conducting controlled experiments on the CIFAR-10 dataset to evaluate the performance of three widely used pruning criteria: L_1-Norm pruning, SNIP pruning, and Taylor pruning, at pruning ratios ranging from 30% to 60%. LoRA is being methodically incorporated into the pruning recovery stage for the first time, demonstrating that it is a versatile and successful fine-tuning method that might significantly lessen the performance loss caused by trimming. Furthermore, in order to support the deployment of effective neural networks, this research offers empirical evidence for choosing suitable pruning and fine-tuning procedures for actual application objectives as seeking compression rate or accuracy.*

***Keywords*— L_1-Norm Pruning, SNIP Pruning, Taylor Pruning, LoRA, Model Sparsity.**

I. INTRODUCTION

Since the advent of artificial intelligence, Convolutional Neural Networks (CNNs) have achieved remarkable accomplishments across numerous domains. However, their substantial model size and computational demands significantly hinder deployment on resource-constrained devices. To address this challenge, model compression techniques, particularly neural network pruning, have emerged as key tools for reducing model scale and enhancing inference efficiency [1-3].

As a mainstream model compression technique, the core idea of pruning is to remove redundant parameters in the network while preserving model performance as much as possible. Based on whether the original network structure is retained after pruning, it can be categorized into unstructured pruning and structured pruning. Early pioneering work, such as the Optimal Brain Surgeon proposed by Hassibi and Stork, laid the foundation for unstructured pruning based on the Hessian matrix [4]. However, unstructured pruning requires specialized hardware to achieve acceleration. Consequently, structured pruning, which directly reduces the number of channels or filters and thereby enables acceleration on general-purpose hardware, has become a key research focus in recent years [5, 6]. Structured pruning methods are widely applied in

both CNNs and LLMs [7].

In unstructured pruning, how to define parameter importance is crucial to its effectiveness [8-11]. Different importance criteria have led to the formation of various pruning approaches. Among them, the most intuitive are norm-based criteria, such as using the L_1-Norm of filter weights to measure their importance [5]. This method is computationally efficient and requires no additional data, making it widely used as a baseline. However, its main limitation is that it is a static estimation that fails to account for the actual contribution of parameters during training dynamics. To assess parameter importance more accurately, gradient-based criteria were proposed. The first-order Taylor expansion criterion introduced by Molchanov was a milestone work [12]. This criterion uses the product of the gradient of the loss function with respect to the weight and the weight itself to approximate its importance, positing that parameters with less impact on the loss function are less important. By incorporating training dynamics, this method theoretically better identifies redundant parameters [13]. Han et al. have also demonstrated that unstructured pruning can effectively compress model networks and reduce model size [14]. To further reduce computational overhead, connection sensitivity-based criteria enable pruning early in the training phase, with Lee's proposed Single-shot Network Pruning (SNIP) criterion being a prominent example [15]. SNIP measures the sensitivity of each weight by calculating the magnitude of the gradient of the loss function with respect to it and prunes low-sensitivity connections in a single step before training begins. This method offers high efficiency, but its "preemptive" pruning strategy has also sparked discussions regarding its robustness.

The core of unstructured pruning lies in identifying and removing redundant parameters in the network, and its effectiveness highly depends on the adopted importance criterion. Although criteria such as L_1-Norm, Taylor, and SNIP have been widely proposed and applied, existing research often focuses on the promotion of a single criterion or makes comparisons under different experimental settings. There is a lack of systematic comparison and in-depth analysis of the model sparsity patterns, compression efficiency, and final performance resulting from these criteria under strictly controlled conditions with identical pruning ratios. Furthermore, pruning inevitably leads to model performance degradation, making efficient performance recovery crucial. Due to the high computational cost of traditional global fine-tuning, recently emerged Parameter Efficient Fine-Tuning (PEFT) techniques, particularly Low-Rank Adaptation (LoRA) proposed by Hu et al., offer a new direction to address this issue [16]. Although significant progress has been made in the aforementioned research, most works focus on proposing or improving a single criterion. There is insufficient research conducting systematic and fair comparisons of different importance criteria under strictly controlled conditions with the same target pruning ratio [17]. Additionally, the synergistic effects of employing emerging PEFT techniques like LoRA as a standard recovery method after pruning, in conjunction with different pruning criteria, remain underexplored [18-20].

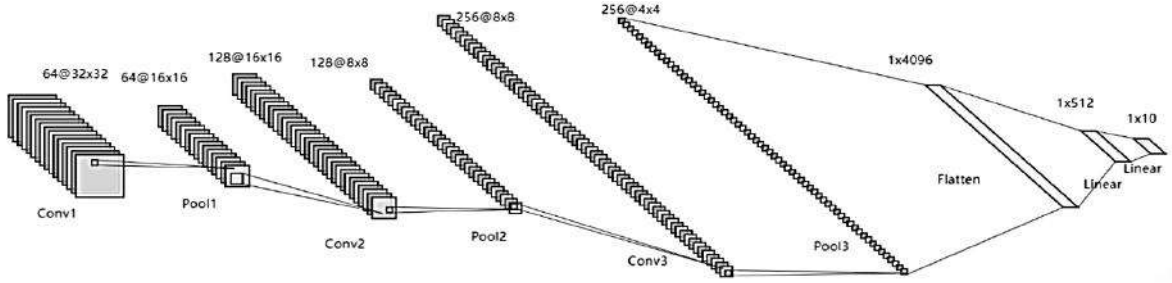

Fig.1. CNN Model Architecture (LeNet Style)

To address these research gaps, this paper designs a controlled experiment on the CIFAR-10 dataset to systematically evaluate the pruning effects of three mainstream importance criteria—L_1-Norm, Taylor, and SNIP—on CNN models at target pruning ratios ranging from 30% to 60%. This paper comprehensively assesses the post-pruning model accuracy retention and places particular emphasis on analyzing the effectiveness of LoRA fine-tuning as an efficient recovery method.

II. MODEL ARCHITECTURE

This paper employs an improved Convolutional Neural Network (Improved CNN) as the benchmark model, with its architecture inspired by the visual geometry group (VGG) network. The model consists of three convolutional blocks, each sequentially composed of a convolutional layer (Conv2d), a batch normalization layer (BatchNorm2d), a ReLU activation function, and a max-pooling layer (MaxPool2d). The output channel numbers for the three convolutional layers are 64, 128, and 256, respectively, with all convolutional kernels having a size of 3x3. Following the final pooling layer, the feature maps are flattened and fed into two fully connected layers (Linear), with a Dropout layer (dropout rate of 0.5) incorporated in between to prevent overfitting. The final output of the model is 10-dimensional, corresponding to the 10 classes of CIFAR-10. The model was first trained on the training set for 60 epochs using the Adam optimizer (learning rate 0.001, weight decay set to 1e-4) and a step learning rate scheduler (StepLR), ultimately achieving a test accuracy of 86.78%. This model serves as the baseline for all subsequent pruning experiments. The architecture of the convolutional neural network model is illustrated in Figure 1, where part of the depth is omitted due to the large number of layers.

The experiments utilized the CIFAR-10 dataset, which consists of 60,000 32x32 color images across 10 categories, with 50,000 images for training and 10,000 for testing. This study adopted a standard data preprocessing and augmentation pipeline to enhance model generalization. For the training set, preprocessing included random horizontal flipping and random cropping (with padding=4), followed by converting pixel values to tensors and normalization (with mean and standard deviation both set to 0.5). The data was loaded via PyTorch's DataLoader, with the batch size set to 128 for both training and testing.

III. PRUNING METHODS WITH PEFT

3.1 Pruning Methods

This paper implements three mainstream structured pruning methods on the pre-trained model and compares them across various target pruning ratios ranging from 30% to 60%. All pruning is performed on the weight parameters.

(1) L_1-Norm Pruning

L_1-Norm Pruning uses the L_1-Norm of the weights as the importance criterion. Its core idea is that a weight with a smaller absolute value is less important. The importance score $I_{L_1}(W_i)$ is defined as:

$$I_{L_1}(W_i) = |W_i| \quad (1)$$

Here, W_i represents the i-th weight in a given layer, meaning the importance score of each weight W_i is its absolute value. The approach adopted in this paper is as follows: for each layer, the L_1-Norm of its weight matrix is calculated, and the specified proportion of weights with the smallest norm values are removed. The specific implementation utilizes PyTorch's built-in torch.nn.utils.prune.l1_unstructured function, followed by prune.remove to permanently eliminate the pruned weights.

(2) Taylor Importance Pruning

The Taylor importance pruning method determines the significance of a weight by evaluating its impact on the loss function. If removing a weight leads to a substantial increase in the loss, the weight is considered highly important; conversely, if its removal results in negligible change or even a decrease in the loss, it is deemed unimportant. The specific importance score $I_{\text{Taylor}}(W_i)$ can be approximated by the absolute value of the product of the weight and its gradient:

$$I_{\text{Taylor}}(W_i) = \left|W_i \cdot \nabla_{W_i} L\right| \quad (2)$$

Here, $\nabla_{W_i} L$ represents the gradient of the loss function with respect to the weight. To achieve a stable estimation, this paper performs forward and backward propagation on the first 10 batches of the training set and accumulates the importance scores of each weight. Therefore, Equation (2) can be rewritten as:

$$I_{\text{Taylor}}^{(\text{cumulative})}(W_i) = \sum_{k=1}^{M} \left|W_i \cdot \nabla_{W_i} L^{(k)}\right| \quad (3)$$

where $\nabla_{W_i} L^{(k)}$ represents the gradient of the loss function with respect to the weight during the k-th pruning round, and M denotes the set of all weights in a given layer. Subsequently, based on the global importance scores, the specified proportion of weights with the lowest scores is removed.

(3) SNIP Pruning

SNIP pruning is a single-shot pruning algorithm based on connection sensitivity, which can be performed before training begins. First, forward and backward propagation are executed on a batch of data, and the absolute value of the gradient for each weight is calculated as its sensitivity score:

$$I_{\text{SNIP}}(W_i) = |g_i \odot W_i| \approx |g_i w_i| \quad (4)$$

Among them, $g_i \triangleq \frac{\partial L}{\partial W_i}$ represents the gradient of the loss function with respect to the weight, and $\odot$ denotes the element-wise multiplication between two vectors. Subsequently, a global sensitivity threshold is calculated, and all weights with sensitivity below this threshold are removed. For convolutional layers, their sensitivity scores can be averaged by the output channels. It is worth noting that while the mathematical formulation of SNIP pruning appears very similar to that of Taylor pruning—and indeed, Taylor's method serves as the theoretical foundation for SNIP—the key distinction adopted in this work is that SNIP performs pruning in a single step before training begins, whereas Taylor pruning calculates gradients and importance scores using the current model at each pruning iteration.

3.2 Parameter-Efficient Fine-Tuning

To address the prevalent issue of performance degradation following model pruning, this study departs from the traditional global fine-tuning approach—which is parameter-inefficient and prone to overfitting—and instead adopts the LoRA technique from the Parameter-Efficient Fine-Tuning (PEFT) paradigm for performance recovery [7]. The core concept of LoRA originates from the observation that the weight update matrices of large models, when adapted to downstream tasks, exhibit an intrinsic low-rank property.

Building on this insight, an improved CNN integrated with LoRA modules is designed. This design freezes all original parameters of the pruned network to preserve acquired knowledge, while only injecting trainable LoRA layers in parallel alongside the fully connected layers. These adaptation layers approximate the incremental update ΔW of the original weights through the product of two small matrices B*A. This strategy allows the model to optimize only a minimal number of newly added parameters during fine-tuning, thereby efficiently guiding the model to adapt to new tasks while significantly reducing computational and storage costs.The hyperparameters for LoRA are set as follows: rank = 8, scaling factor (alpha) = 16.0. Only these newly added parameters were trained for 10 epochs using the Adam optimizer with a learning rate of 0.001.

IV. EXPERIMENTAL RESULTS

This paper presents the effects of different pruning methods, including L_1-Norm, Taylor, and SNIP, on model performance, compression efficiency, and fine-tuning recovery under various pruning ratios. All experiments are based on the CIFAR-10 dataset and the Improved CNN model described in Section 2, and the following evaluation metrics are adopted to comprehensively assess the effectiveness of different pruning methods:

(1) Top-1 Accuracy (%): The classification accuracy of the model on the test set, serving as the core metric for evaluating performance retention.

(2) Pruning Ratio (%): The targeted proportion of weights to be removed, used as a controlled variable in the experiments.

(3) Accuracy Drop (%): The difference in accuracy between the pruned model and the original model, measuring the destructiveness of pruning.

(4) LoRA Improvement (%): The difference in accuracy after LoRA fine-tuning compared to the accuracy right after pruning, evaluating the effectiveness of recovery.

All experiments were implemented using the PyTorch framework and executed on a single NVIDIA GPU to ensure environmental consistency. The original unpruned Improved CNN model used in this study achieved an accuracy of 86.78% on the test set, serving as the baseline for all comparisons. The model size is 9.45 MB, and this performance will be used as the benchmark for evaluating the accuracy degradation caused by all pruning methods and the subsequent recovery effects.

4.1 The Impact of Pruning Ratio on Accuracy

Following the methodology proposed in this paper, the performance of the models after pruning and before fine-tuning was evaluated to directly assess the destructiveness of each pruning method. The experimental results are presented in Table 1. An initial observation reveals that the three pruning methods differ in their ability to preserve performance, which can be analyzed across different pruning ratios:

(1) Low Target Pruning Ratios (30%-40%):

At low target pruning ratios, the SNIP method demonstrated the best performance, maintaining the highest accuracy rates of 86.61% and 86.07%, which are nearly equivalent to the original model's 86.78%. The Taylor method ranked second, achieving a respectable 81.72% at a 30% pruning ratio but dropping significantly to 68.34% at 40%. In contrast, the L_1-Norm method performed the poorest, with accuracy already declining markedly to 65.17% and 60.64% even at these low pruning ratios.

(2) High Target Pruning Ratios (50%-60%):

When the target pruning ratio was set at 60%, the accuracy of the models pruned by all three pruning methods was less than 40%. The models obtained using Taylor and SNIP pruning methods even had an accuracy of less than 20%. Therefore, this experiment considers that a target pruning ratio of 60% is too high, significantly damaging the underlying structure of the original model. Under a target pruning ratio of 50%, the models pruned by Taylor and L_1-Norm methods had accuracies of less than 50%, suggesting that a 50% target pruning ratio is still too high for these two methods. However, the model obtained using the SNIP pruning method was able to maintain an accuracy of 70.42%, significantly better than the other two methods. Combined with subsequent fine-tuning operations, the model's accuracy can be further improved. Therefore, this experiment shows that a target pruning ratio of 50% is still a meaningful pruning ratio for the SNIP method. Both the Taylor and L_1-Norm methods experienced sharp performance degradation at high pruning ratios. Particularly at the 60% pruning ratio, the accuracy of both Taylor and SNIP dropped to approximately 16%.

Table 1. Accuracy of Three Pruned Models under Different Target Pruning Ratios

Pruning Ratio	L1-Norm	Taylor	SNIP
30%	0.6517	0.8172	0.8661
40%	0.6084	0.6834	0.8607
50%	0.4995	0.4540	0.7042
60%	0.3922	0.1654	0.1617

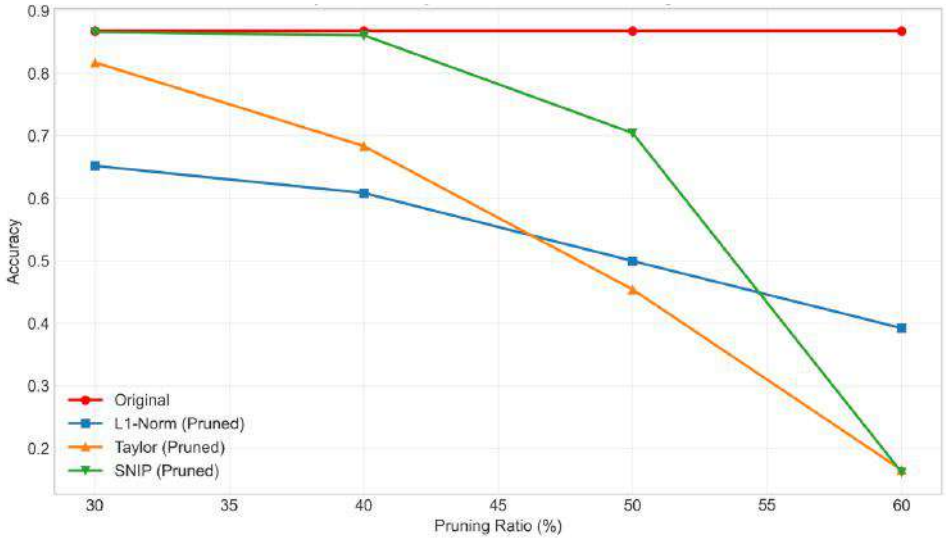

Fig.2. Accuracy vs. Pruning Ratio for Different Pruning Methods

Plotting the data from Table 1 into the line chart of Figure 2 clearly reveals the extent and pattern of impact that different pruning methods have on model performance. The chart shows that as the target pruning ratio increases from 30% to 60%, the accuracy of all pruning methods exhibits a declining trend. It is noteworthy that the three pruning methods—L_1-Norm, Taylor, and SNIP—

demonstrate distinct degradation characteristics across different pruning intervals: at low target pruning ratios, the performance decline of each method is relatively gradual, with minor differences between them; however, when reaching high target pruning ratios, the rate of accuracy drop accelerates significantly, and the performance gap between different methods widens progressively, reflecting the varying capabilities of each pruning criterion in identifying and preserving critical network connections. Particularly notable is that at the high target pruning ratio of 60%, the accuracy of all methods drops to a low level, a phenomenon that highlights the damage caused by excessive pruning to the model's representational capacity, while also emphasizing the necessity and urgency of employing PEFT methods like LoRA for performance recovery under such extreme sparsity conditions.

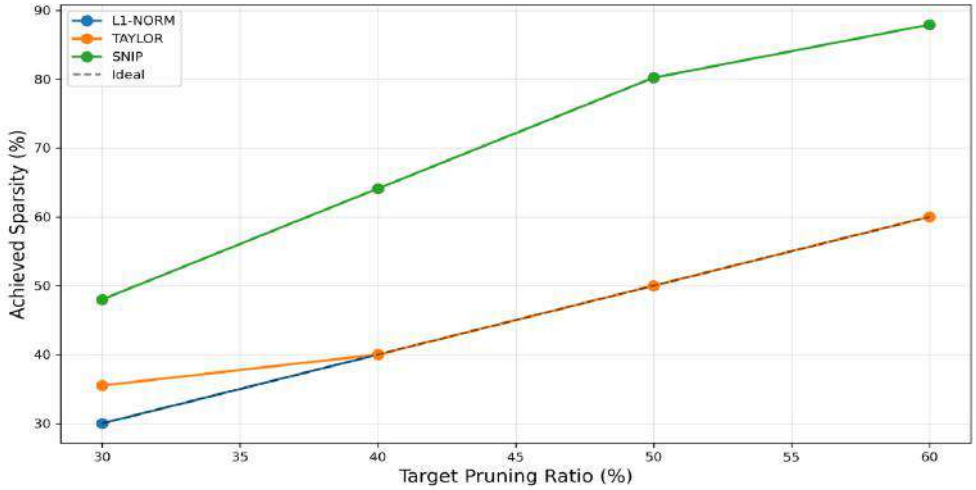

Fig.3. Achieved Sparsity vs. Target Pruning Ratio

The actual sparsity ratios of the pruned models obtained through the three pruning methods are shown in Figure 3. By comparing the actual sparsity levels achieved by different pruning methods under different target pruning rates, this figure provides profound insights into the core performance and control precision of each pruning algorithm. The ideal diagonal line in the figure represents the target sparsity, while the proximity of the three curves (L_1-Norm, Taylor, and SNIP) to this ideal line visually reflects the precision and reliability of each method. Through systematic analysis of the deviation patterns of these curves across different pruning intervals, it can be evaluated whether each method exhibits systematic biases—such as a tendency toward conservative under-pruning or aggressive over-pruning. This quantitative assessment of pruning precision is crucial. It can be observed that the L_1-Norm method achieves actual sparsity that perfectly matches the target sparsity, indicating that this method "follows instructions precisely." The Taylor method shows a slightly higher actual sparsity than the target at the 30% pruning ratio, while matching the target at other ratios, suggesting it possesses a certain level of intelligent judgment but overall still completes the task as required. In contrast, the SNIP method is the most aggressive: when it identifies a large number of redundant weights, it prunes quite boldly. Consequently, at every target pruning ratio, the actual sparsity of SNIP-pruned models significantly exceeds the target sparsity.

4.2 Performance Recovery via LoRA Fine-Tuning

According to the methodology proposed in this paper, the performance of the models after pruning and after fine-tuning was evaluated. These results are presentedalongside the performance of the models after pruning but before fine-tuning in Table 2. The table clearly demonstrates the effectiveness of LoRA fine-tuning, which produced significant performance recovery for all pruning methods and across all pruning ratios, with the sole exception of SNIP at the 60% target pruning ratio. This improvement is visually evident in Figure 4.

Table 2. Accuracy of Three Pruning Methods Combined with LoRA Fine-Tuning under Different Target Pruning Ratios

Pruning Ratio	L1-Norm	L1-Norm + LoRA	Taylor	Taylor + LoRA	SNIP	SNIP + LoRA
30%	0.6517	0.8346	0.8172	0.8579	0.8661	0.8670
40%	0.6084	0.8105	0.6834	0.8418	0.8607	0.8629
50%	0.4995	0.7938	0.4540	0.8230	0.7042	0.8496
60%	0.3922	0.7622	0.1654	0.7583	0.1617	0.1917

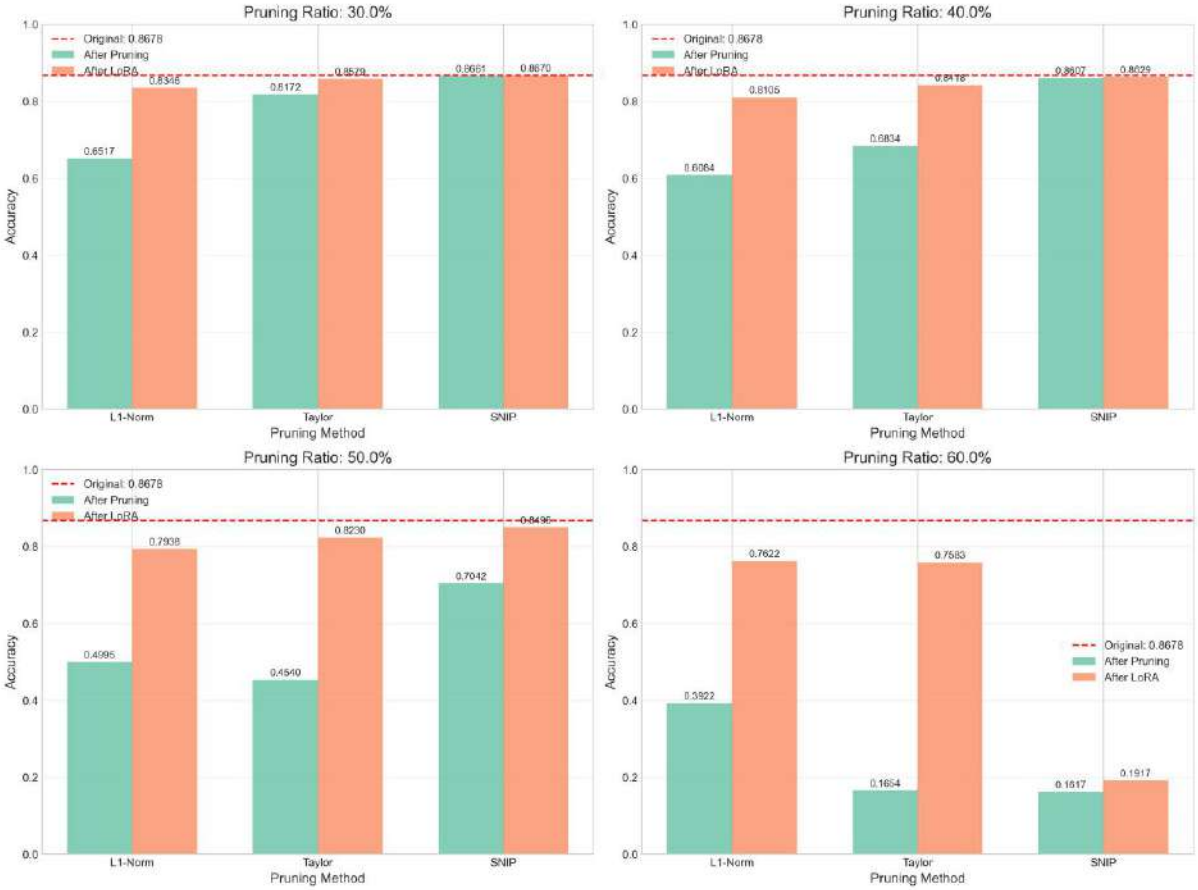

Fig.4. Pruning Methods Comparison at Different Pruning Rations

The experimental data reveal the synergistic effects between different pruning methods and LoRA. For highly destructive pruning methods like L_1-Norm and Taylor, LoRA acts as a "lifesaver." In the case of L_1-Norm + LoRA, even at the 60% target pruning ratio where the post-pruning accuracy plummets to 39.22%, LoRA is able to restore it to 76.22%, representing an improvement of 37 percentage points. For Taylor + LoRA, the most substantial recovery is observed at the 60% pruning ratio with an impressive 59.29% increase. This indicates that although Taylor pruning removes a significant number of weights, it effectively preserves the network's "skeleton" or "potential," enabling LoRA to efficiently reconstruct functionality on this foundation and demonstrating the strongest recovery capability.On the other hand, for pruning methods like SNIP that already maintain good performance, LoRA serves as "icing on the cake." At target pruning ratios of 30%–50%, SNIP alone maintains accuracy between 86.61% and 70.42%, leaving limited room for LoRA to bring improvements ranging from only 0.09% to 14.54%. Nevertheless, the final accuracy achieved by SNIP + LoRA is the highest among all combinations. However, at the 60% target pruning ratio, SNIP's accuracy drops drastically and can no longer be recovered through LoRA fine-tuning. This trend after fine-tuning is visually captured in Figure 5.

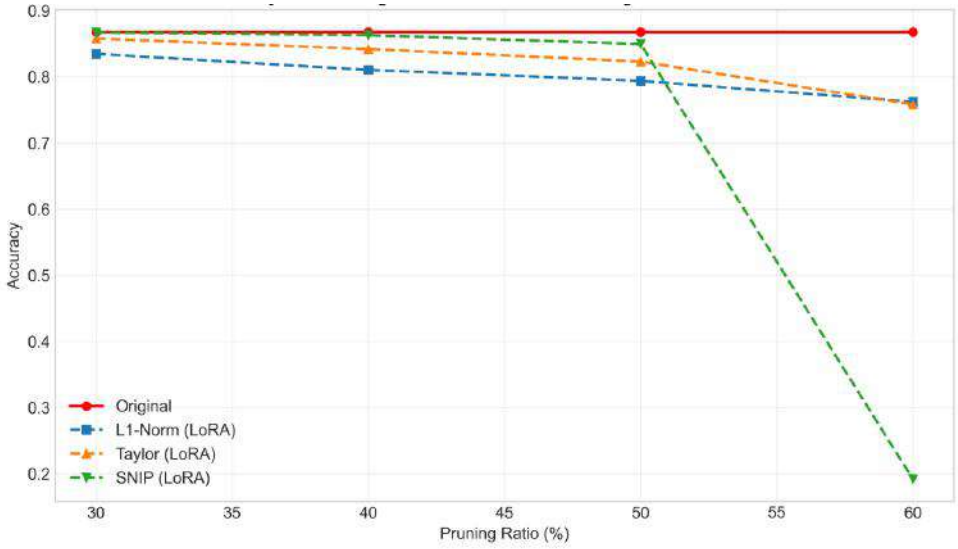

Fig.5. Accuracy vs. Pruning Ratio for Different Pruning Methods with LoRA

4.3 Discussion

The pruning effects of different importance criteria are directly determined by their underlying theoretical assumptions and computational approaches. The SNIP criterion demonstrates excellent performance retention at target pruning ratios of 30%-50%, which can be attributed to its foundation in connection sensitivity. By calculating gradient magnitudes through a single forward-backward pass during the model initialization phase, SNIP identifies weights with the least impact on the loss function. This "one-shot global pruning" strategy tends to remove a substantial number of redundant connections, resulting in actual sparsity that often significantly exceeds the target value, reflecting its strong compression aggressiveness. However, this aggressive approach may excessively remove structurally critical weights in the network at the high target pruning ratio of 60%, damaging the model's skeleton and consequently making subsequent fine-tuning ineffective for performance recovery. This finding aligns with Lee's emphasis on SNIP's efficiency and one-shot pruning advantage, while our experiments also reveal its potential risks under high sparsity demands, thereby supplementing the original research's insufficient discussion of extreme compression scenarios.

The Taylor importance criterion, when combined with LoRA fine-tuning, shows the strongest recovery capability at the 50% target pruning ratio. This is because the Taylor criterion dynamically evaluates parameter importance through the interaction between weights and their gradients, reflecting the actual contribution of parameters during the training process. This gradient-based evaluation enables better discrimination between important and unimportant weights, thereby preserving the functional skeleton of the model after pruning, while enhancing the accuracy of importance estimation through the incorporation of gradient information. Our experimental results further indicate that the Taylor method can achieve effective reconstruction through LoRA even at higher target pruning ratios, suggesting that the retained weight structure contains substantial representational potential.

Although L_1-Norm pruning is simple in criterion and computationally efficient, its sole reliance on weight magnitude while ignoring training dynamics leads to the poorest performance across all pruning ratios. Nevertheless, L_1-Norm pruning combined with LoRA still achieves considerable recovery at the high target pruning ratio of 60%, indicating that while its pruning approach is "blind," it does not destroy the most fundamental network structure. That is, norm-based methods, though imprecise, can still serve as stable compression baselines. Based on the presentation of experimental data, the summarized characteristics of the three pruning methods discussed above are systematically compared and described in Table 3.

Table 3. Comparative Summary of Characteristics of the Three Pruning Methods

Pruning Method	L_1-Norm	Taylor	SNIP
Characteristics	Precise Executor	Mild Over-achiever	Aggressive Over-executor
Performance	The L_1-Norm method precisely achieved the target sparsity across all pruning ratios	It slightly exceeded the target sparsity by 5.5% at the 30% pruning ratio, but accurately met the target at other ratios	It significantly exceeded the target sparsity, with the deviation magnitude increasing as the target ratio rose
Rationale	L_1-Norm pruning, based on simple weight magnitude ranking, can remove weights strictly according to the specified ratio	The Taylor importance criterion, being gradient-based, may identify a larger proportion of "less important" weights in certain layers	SNIP employs a global sensitivity threshold, exhibiting a tendency to remove more connections deemed unimportant
Advantages	It provides predictable and controllable compression outcomes	It demonstrates a certain degree of intelligent adaptive capability	It achieves the highest accuracy rates at target pruning ratios of 30%-50%

V. CONCLUSION

Through systematic comparative experiments, this study reveals the distinct performance of three mainstream pruning criteria—L_1-Norm, Taylor, and SNIP—under identical target pruning ratios, and validates the effectiveness of LoRA fine-tuning in restoring model performance after pruning.

In terms of strategy selection, the optimal choice depends on the target pruning ratio. At low target pruning ratios (30%-40%), the recommended strategy is SNIP + LoRA, as it can almost fully restore the original model performance, representing the solution with minimal accuracy loss. At high target pruning ratios, if the target is 50%, the recommended strategies are Taylor + LoRA or SNIP + LoRA. The former combination demonstrates remarkable recovery effectiveness, while the latter achieves the highest accuracy. However, if the target pruning ratio is 60%, the recommended strategies become Taylor + LoRA or L_1-Norm + LoRA, as they can still restore accuracy to over 75%, demonstrating stronger robustness. In contrast, SNIP appears to damage the most fundamental structure of the model under extremely high pruning ratios, making it impossible for LoRA to effectively recover its accuracy.

In summary, the conclusions of this study both support and supplement existing research. It has been successfully obtained a performance comparison of the three pruning methods—L_1-Norm, Taylor, and SNIP—across target pruning ratios of 30% to 60%, and introduced LoRA fine-tuning into the pruning recovery phase. This demonstrates that LoRA, as a universal and efficient recovery method, can significantly mitigate the performance loss caused by different pruning techniques, providing important insights for future research. The final selection of a pruning strategy should be based on practical application requirements. SNIP + LoRA and Taylor + LoRA are superior at target pruning ratios of 30%-50%. At a target pruning ratio of 60%, although the accuracy of SNIP + LoRA cannot be salvaged, the accuracy of L_1-Norm + LoRA and Taylor + LoRA can still be restored to a trustworthy range through LoRA fine-tuning.

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Analysis of Wesleyan University-Philippines (WU-P) Electronics Engineers Licensure Examinations (2021-2023): Basis for a Proposed Test Bank

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Abstract *— "Analysis of WUP Electronics Engineers Licensure Examinations (2021-2023): Basis for a Proposed Test Bank" is a descriptive study that examines the performance of WUP Electronics Engineering (EE) examinees in four significant subjects, which are Communications Engineering, General Engineering & Applied Sciences, Electronics Engineering, and Engineering Mathematics. With an average mark of 58.8%, well short of the 75% pass requirement, and just 12 out of 80 passing, the figures show that engineering mathematics is the toughest subject. Also, with just 12 passing and an average mark of 63.8%, Electronics Engineering showed a low pass rate. Communications Engineering recorded 21 passes, against 14 pass candidates for General Engineering & Applied Sciences. The overall challenge of the licensing examinations was indicated by the absence of top scores of 95% or higher in any subject among the examinees. The researchers recommend enhancing the curriculum in Electronics Engineering, offering special support for Engineering Mathematics, and implementing practice exams and mock tests to identify areas of weakness and sharpen test-taking skills to enhance student performance. To create a good learning environment, study groups that encourage peer-to-peer collaboration are also recommended. The development of a large test bank that provides personalized practice materials specific to exam structures is at the core of these concepts, with the end goal of improving student preparedness and passing rates.*

Keywords *— **Communications Engineering, Electronics Engineering, General Engineering, Licensure Examination, Mathematics, Wesleyan University-Philippines***

I. INTRODUCTION

The licensure examination is a crucial milestone for engineering students, especially those enrolled in the Electronics Engineering program at Wesleyan University Philippines (WUP). It serves as a formal assessment that certifies whether graduates possess the necessary knowledge, skills, and competencies required to practice professionally. Beyond individual success, passing this test improves the school's standing and guarantees that its graduates fulfill industry requirements, which advances the engineering profession and advances national development (Alam & Forhad, 2022).

For WUP Electronics Engineering students, the licensure exam represents both a challenge and an opportunity. It demands a comprehensive understanding of core engineering principles and the ability to apply theoretical knowledge to practical problems. Successfully navigating this exam opens doors to professional licensure, which is essential for career progression, eligibility for higher positions, and participation in specialized engineering projects. It

also instills confidence and credibility, affirming that the graduate is equipped to uphold safety, innovation, and ethical standards in their work. (Hu, Mao, Fu, Wu, & Zhou, 2023).

Given the significance of the licensure examination, it is imperative for educational institutions like WUP to continuously enhance their academic programs and support systems. This involves embracing novel instructional approaches, revising curricula to meet new industry needs, and equipping students with sufficient resources like review materials, practice examinations, and mentoring. Focusing on critical thinking, problem-solving, and experiential learning can more adequately equip students to contend with the demanding character of the exam and the professional challenges they will encounter in the future (Mangiduyos & Subia, 2021).

In addition, creating an environment of collaboration and inspiration is crucial in assisting students with resilience and confidence development. Providing peer study groups, offering individualized review sessions, and incorporating real-world engineering applications within courses can enhance learning and facilitate exam preparedness (Zhang, Morphew & Stelzer, 2023). With the prioritization of these strategies, Wesleyan University Philippines can equip its Electronics Engineering students to perform well in their licensure examinations and become capable, confident professionals who can contribute valuable services to the field of engineering.

An action that would practically augment the support of WUP Electronics Engineering students on licensure exam preparation is the creation and application of a complete test bank. The test bank will be comprised of a variety of practice questions as well as sample exams on all of the pertinent subjects, formulated to resemble the format and level of difficulty of the real licensure exam. Through consistent interaction with these resources, students can determine their strengths and weaknesses, get accustomed to exam trends, and sharpen their time management and test-taking skills. Moreover, the test bank may also be utilized as an effective tool for educators to customize their teaching strategies and give precise feedback, eventually enhancing the efficacy of exam preparation and passing rates (Harrell, Subramaniam, Long, Thompson, & Pope, 2023).

II. METHODOLOGY

This research study utilized documentary analysis. According to Grant (2022), "documentary analysis is research which involves documents as the data". Licensure examination results from 2021-2023 of the Bachelor of Electronics Engineering of Wesleyan University Philippines were analyzed and explored in this study. A total of 80 examination takers were included in this study. Their examination results were analyzed and discussed in this study. This research was conducted during the second semester of school year 2024-2025.

III. RESULTS AND DISCUSSION

Electronics Engineers Licensure Examination- October 2021, April 2022, October 2022, & April 2023

Table 1. Overall Performance in Engineering Mathematics of 80 Examinees from October 2021 to April 2023

Percentage Scores	Engineering Mathematics
25 to 34	7
35 to 44	4
45 to 54	17
55 to 64	25
65 to 74	15
75 to 84	12
85 to 94	0
95 and above	0
Total Examinees (N)	80
Mean Percentage Score	58.8
Mean Passing Percentage	75
Lowest Score	27
Highest Score	84

Table 1 shows the overall results in Engineering Mathematics of 80 Electronics Engineering takers from the examination in October 2021 to April 2023.

The table shows the scores of 80 students on an Engineering Mathematics test. The majority of students had a score of between 55% and 64%, and fewer students scored very high or very low. The

mean score was 58.8%, which is lower than the pass mark of 75%. The lowest score was 27%, and the highest score was 84%. This indicates a large number of students failed the test, and no one scored in the upper ranges. It indicates that the students felt that the test was difficult and might need extra attention in order to develop their math skills (Kukreti & Broering, 2019). The findings indicate that a considerable number of students are struggling with attaining the required competency in engineering mathematics, which could negatively affect their general academic growth and confidence in the subject. There is a requirement for increased instructional assistance, i.e., increased tutoring, revised pedagogical approaches, or further material to be studied, since the average mark is far from the passing mark, and no student achieved high scores. In an effort to assist students in developing their mathematics base, improving performance, and increasing their chances of success in their engineering degrees, these deficiencies need to be addressed.

Table 2. Overall Performance in Electronics Engineering of 80 Examinees from October 2021 to April 2023

Percentage Scores	Electronics Engineering
25 to 34	0
35 to 44	4
45 to 54	13
55 to 64	20
65 to 74	31
75 to 84	12
85 to 94	0
95 and above	0
Total Examinees (N)	80
Mean Percentage Score	63.8
Mean Passing Percentage	75
Lowest Score	38
Highest Score	82

Table 2 exhibits the overall results in Electronics Engineering of 80 Electronics Engineering takers from the examination in October 2021 to April 2023.

Most Electronics Engineering examinees scored between 55 and 74 percent, with 31 out of 80 getting 65–74 percent and 20 getting 55–64 percent. Very few scored above 75 percent (only 12 people), and nobody scored higher than 84 percent. At the lower end, only 4 people scored between 35–44 percent, and nobody scored below 35 percent.

The average score was 63.8 percent, which is below the passing mark of 75 percent. The lowest score was 38, and the highest was 82. This means most students did not pass, and only a small number came close to or above the passing score. The results suggest that many students need more support or preparation to meet the passing standard.

These findings imply that the majority of Electronics Engineering examinees are struggling to meet the required passing standard, as most scored below 75 percent. This highlights a need for improved teaching strategies or additional support to help more students achieve passing scores (Nurdianingsih, 2021).

Table 3. Overall Performance in General Engineering & Applied Sciences of 80 Examinees from October 2021 to April 2023

Percentage Scores	General Engineering & Applied Sciences
25 to 34	0
35 to 44	10
45 to 54	15
55 to 64	18
65 to 74	22
75 to 84	14
85 to 94	1
95 and above	0
Total Examinees (N)	80
Mean Percentage Score	61
Mean Passing Percentage	75
Lowest Score	35
Highest Score	87

Table 3 presents the overall results in General Engineering and Applied Sciences of 80 Electronics Engineering takers from the examination in October 2021 to April 2023.

Fewer students in General Engineering & Applied Sciences scored higher than 75 percent, while the majority of the 80 students in the course received scores between 55 and 74 percent. Only one student received extremely high scores (between 85 and 94 percent), while other students received lower scores (between 35 and 54 percent).

The minimum passing mark was 75 percent, and the mean score was 61 percent. This means that most of the students failed and need special help to improve their understanding and performance in this area. These findings suggest that most students are struggling to achieve the passing mark in General Engineering & Applied Sciences. It lays emphasis on the need for enhanced teaching approaches and additional support in order for students to move forward with their knowledge and pass the course (Arashpour et al.,2023).

Table 4. Overall Performance in Communications Engineering & Applied Sciences of 80 Examinees from October 2021 to April 2023

Percentage Scores	Communications Engineering & Applied Sciences
25 to 34	2
35 to 44	9
45 to 54	11
55 to 64	16
65 to 74	19
75 to 84	21
85 to 94	2
95 and above	0
Total Examinees (N)	80
Mean Percentage Score	63.4
Mean Passing Percentage	75
Lowest Score	31
Highest Score	87

Table 4 displays the overall results in Communications Engineering and Applied Sciences of 80 Electronics Engineering takers from the examination in October 2021 to April 2023.

Most of the 80 students in Communications Engineering & Applied Sciences did pretty well, with scores between 55 and 84 percent. A smaller number scored below 55, and only a few scored very high over 85 percent. The average score was 63.4%, which is lower than the 75% needed to pass. This means that a lot of students didn't pass and needed extra help to understand the material better and do better in this class.

These results show that a lot of students know the basics of Communications Engineering, but a lot of them are not meeting the passing standard. This shows that more help and specific teaching methods are needed to help more students do well in this subject (Thompson & Copeland, 2020).

Table 5. Summary Table of Electronics Engineers Licensure Examination- October 2021, April 2022, October 2022 & April 2023

Percentage Scores	Engineering Mathematics	Electronics Engineering	General Engineering & Applied Sciences	Communications Engineering
25 to 34	7	0	0	2
35 to 44	4	4	10	9
45 to 54	17	13	15	11
55 to 64	25	20	18	16
65 to 74	15	31	22	19

75 to 84	12	12	14	21
85 to 94	0	0	1	2
95 and above	0	0	0	0
Total Examinees (N)	80	80	80	80
Mean Percentage Score	58.8	63.8	61.0	63.4
Mean Passing Percentage	75	75	75	75
Lowest Score	27	38	35	31
Highest Score	84	82	87	87

The table illustrates that the engineering mathematics subject is the most difficult among the four subjects taken by EE examiners, indicating that just 12 out of 80 candidates achieved a passing grade, with scores varying from 27 to 84. This particular subject is very difficult for WUP EE takers, as indicated by a mean passing rate of 58.8%, which is much lower than the 75% passing threshold. Likewise, Electronics Engineering has also 12 passers like the Engineering Mathematics area, although it is considered easier, with passing score rates of 63.8%; however, it is still below the required 75%.

Only 14 candidates were successful in the field of General Engineering & Applied Sciences, but Communications Engineering had a considerably higher number of successful candidates, with 21 individuals passing. Nevertheless, the lack of any students who achieved the highest grades of 95 and above highlights the overall difficulty of the examination across disciplines for WUP EE students.

Based on these findings, WUP must provide additional support and resources to students struggling with engineering mathematics, such as intensive and targeted study sessions, particularly allocating more time and resources to mastering difficult subjects, aiming to improve their success rate in this challenging subject. Furthermore, there should be a concerted effort to enhance the curriculum and teaching methods in Electronics engineering to bridge the gap between the current passing rate and the required threshold of 75%. Additionally, utilizing practice exams and mock tests can help simulate the exam environment, identify areas of weakness, and refine test-taking strategies. Lastly, collaborating with peers in study groups can foster a supportive learning environment (Vauras et al, 2003).

IV. CONCLUSIONS AND RECOMMENDATIONS

The following conclusions and recommendations are derived from the findings of the study:

1. With a mean score of 58.8%, well below the 75% passing threshold, and only 12 out of 80 candidates passing, engineering mathematics is the most difficult subject for WUP EE examinees.
2. With only 12 passing candidates and an average score of 63.8%, Electronics Engineering is still below the required passing rate even though it is thought to be easier than Engineering Mathematics.
3. Although there were 14 successful applicants in General Engineering & Applied Sciences and 21 in Communications Engineering, no student received a top score of 95 or higher in any subject, underscoring the exams' general difficulty.
4. In order to overcome these obstacles, WUP should give students who are having trouble with Engineering Mathematics extra help through focused, intense study sessions and devote more funds to challenging courses in order to increase success rates.
5. To help students reach the 75% passing requirement, the Electronics Engineering

curriculum and teaching strategies need to be improved.

6. Students can discover their areas of weakness and enhance their test-taking abilities by using practice exams and mock tests.
7. Study groups that promote peer collaboration can establish a nurturing learning atmosphere that promotes greater comprehension.
8. Lastly, it is advised that a thorough test bank be created in order to give students a wealth of practice materials that are specific to the exam format, enabling them to better prepare and perform better overall.

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Internal Job Satisfaction of WUP MBA Alumni Employed in the Banking and Lending Sectors

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Abstract *— This research explored the Internal Job Satisfaction of 50 WUP MBA Alumni Employed in the banking and lending sectors. The study discovered that respondents have moderate levels of job satisfaction with role alignment and relationships with superiors, but high levels of internal job satisfaction with regard to career advancement, working environment, and working relationships. The employees' work contributes to the success of the company. They feel that their supervisors continuously trust them to do quality work without feeling the need to closely monitor their daily tasks, and they desire to do work that is in line with the company's missions. Employees are also enthusiastic in their relationships with others, and the organization educates them about the risks and hazards of the workplace. Finally, this research presents human resource implications and recommendations for further research in this field.*

Keywords *— **Alumni, banking sector, internal job satisfaction, lending sector, Master in Business Administration.***

I. INTRODUCTION

Employee's job satisfaction is the level of happiness or contentment that an employee feels for his/her job and is an essential part of any business organization (Kalogiannidis, 2020).

Sharma and Goel (2012) presented methods for the improvement of job satisfaction. In improving job skills, self-control and motivation were vital to achieve a goal. One can start to attain small goals before moving on to larger objectives. Support from co-workers in the advancement of skills can help the employee overcome the challenge and achieve job satisfaction.

A job turns to become boring as the employees' abilities are used routinely and do not match with work responsibilities. Job satisfaction can be improved to overcome boredom in the workplace by breaking the monotony. Cross-training can be done for the performance of different activities. Employees can be inspired too, to enhance the level of job satisfaction.

The article of Mizne (2017) described proven ways to boost the job satisfaction of employees. At the top of the list of factors contributory to job satisfaction and employee engagement were relationship with immediate supervisors and communication between management and employees.

The level of job satisfaction of employees in the banking sector was measured in the study of Rahman et al. (2017), based on the context of socio-demographic variables. Analysis of Variance and T-test estimated the level of satisfaction using indicators of welfare facilities, salary, bonus facilities, colleagues working relationships, view to officers, leadership styles, increment method of allocation, job security, work schedules, evaluation process, performance appraisal, which revealed higher level of job satisfaction on employees.

The job satisfaction of employees is critical to organizational survival (Latif et al., 2015), which makes the fact that employees are increasingly productive during their work hours when they are

relatively satisfied with their jobs of paramount importance to the success of organizations.

Any institution must study employee job satisfaction, as it directly benefits both the organization and its workforce. This research specifically aims to assess the job satisfaction of WUP alumni in their current workplaces. The findings will serve as baseline data to help institutions create better working environments for their graduates, ultimately enabling organizations to support and treat their employees more effectively.

This study sought to determine the internal job satisfaction of 50 WUP MBA Alumni working in Banking and Lending Institutions. Specifically, it determined their satisfaction as to career advancements, role alignment, and relationship with superiors, working environment, and working relationships.

II. METHODOLOGY

This research employed a descriptive research method, utilizing a questionnaire to collect the needed information from the respondents (Garcia & Subia, 2019). Aggarwal (2008), as cited by Salaria (2012), defines descriptive research as the systematic collection of information on existing conditions or situations, to describe and interpret them. This study involved collecting data from 50 Master in Business Administration Alumni of Wesleyan University-Philippines' Graduate School. The 50 respondents were chosen purposively using the following inclusion criteria: MBA graduate of WUP, at least three years working, and employee in the lending or banking sector. Means and weighted means were the statistical tools utilized in the study. The study was conducted during the second semester of the academic year of 2024-2025.

III. RESULTS AND DISCUSSION

Level of Job Satisfaction of the Respondents based on:

1. Career Advancement;

Table 1 presents the level of job satisfaction of the respondents in terms of their career advancement.

Table 1. Career Advancement

Career Advancement	Employees (n=50)	Verbal Description
1. The employee has opportunities for his/her career growth.	3.24	Moderate Level
2. The employees' work contributes to the success of the company.	3.68	High Level
3. The employee is well-prepared in any task we ask him/her.	3.48	High Level
4. The employee's work consistently causes his/her to develop his/her talents and abilities.	3.46	High Level
5.The employee regularly meets the task commitments in terms of deadlines to have quality work.	3.42	High Level
Overall Weighted Mean	3.46	High Level

Legend: 1.00 to 1.74 Not Satisfied; 1.75 to 2.49 Low Level; 2.50 to 3.24 Moderate Level; 3.25 to 4.00 High Level

Career advancement posted an Overall weighted mean of 3.46, verbally interpreted as high level of satisfaction. "The employees' work contributes to the success of the company" ranked the highest with a weighted mean of 3.68. The lowest ranked is the item "The employee has opportunities for his/her career growth" at 3.24.

The findings show that employees are generally satisfied with their career advancement. They feel that their work plays an important role in the company's success, which contributes to their positive outlook. However, there is some concern about limited opportunities for career growth, suggesting that while employees are happy with their current roles, they may be looking for clearer paths to advancement within the organization (Auriol, Misu & Freeman, 2013).

2. Role Alignment;

Table 2 shows the level of job satisfaction of the respondents in terms of their role alignment.

Table 2. Role Alignment

Role Alignment	Employees (n=50)	Verbal Description
1. The employee feels physically tired because of unrelated workload.	2.21	Low Level
2. The employee is having a hard time concentrating at work because of other workload that is not part of his/her job.	2.06	Low Level
3. The employee wants to do work that is aligned with the missions of the company.	3.55	High Level
4. The workload often prevents the employee from doing his/her work well.	2.18	Low Level
5. The employee is satisfied with his/her current job responsibilities.	3.25	High Level
Overall Weighted Mean	2.65	Moderate Level

Legend: 1.00 to 1.74; Not Satisfied; 1.75 to 2.49 Low Level; 2.50 to 3.24 Moderate Level; 3.25 to 4.00 High level

In terms of Role Alignment, the overall weighted mean for employees is 2.65, verbally interpreted as a moderate level of job satisfaction. The highest item rating is "The employee wants to do work that is aligned with the missions of the company" with a weighted mean of 3.55, while the lowest is "The employee is having a hard time concentrating at work because of other workload that is not part of his/her job" with a weighted mean of 2.06.

The findings suggest that employees have a moderate level of satisfaction when it comes to role alignment. They show a strong desire to engage in work that supports the company's mission, indicating a sense of purpose. However, difficulties in focusing due to tasks outside their main responsibilities may be affecting their overall job satisfaction. This implies a need for better task alignment and workload management to help employees stay focused and motivated in their roles (Coco, Dale & Keller, 2018).

3. Relationship with Superiors;

Table 3 shows the job satisfaction of the respondents in terms of their relationship with their superiors.

Table 3. Relationship with Superiors

Relationship with Superiors	Employees (n=50)	Verbal Description
1.My superiors treat employees with respect.	3.27	High Level
2.My superiors manifest good leadership in leading the team.	3.04	Moderate Level
3. My superiors appear to be honest with employees.	3.03	Moderate Level
4.My superior constantly trusts me to do good work without feeling a need to closely monitor my daily task.	3.44	High Level
5. My superiors give me useful feedback on my job performance.	3.12	Moderate Level
Overall Weighted Mean	3.18	Moderate Level

Legend: 1.00 to 1.74; Not Satisfied; 1.75 to 2.49 Low Level; 2.50 to 3.24 Moderate Level; 3.25 to 4.00 High level

In terms of relationship with superiors, the employees have an overall weighted mean of 3.18 (moderate level). The highest item for employees is "My superior constantly trusts me to do good work without feeling a need to closely monitor my daily task", with a weighted mean of 3.44 (HIGH LEVEL).

The lowest in terms of weighted mean is "My superiors appear to be honest with employees" (WM = 3.03) and is verbally described as a moderate level of satisfaction.

The findings indicate that employees generally have a positive relationship with their superiors, showing a high level of satisfaction. They feel trusted to perform their tasks without being closely monitored, which can boost confidence and morale. However, there is still room for improvement, as some employees feel only moderately satisfied in this area. This suggests the need for consistent communication and trust-building efforts to strengthen relationships between employees and their supervisors (Tang, et al. 2020).

4. Working Environment;

Table 4. Working Environment

Working Environment	Employees (n=50)	Verbal Description
1. The company is a safe place to work.	3.29	High Level
2. The company makes the employees aware of the risk and hazards of the work environment.	3.45	High Level
3. The employee is comfortable in his/her working area.	3.31	High Level
4. The working environment gives meaning in the employee's career growth.	3.16	Moderate Level
5. There is flexibility in employees' work environment.	3.14	Moderate Level
Overall Weighted Mean	3.27	High Level

Legend: 1.00 to 1.74; Not Satisfied; 1.75 to 2.49 Low Level; 2.50 to 3.24 Moderate Level; 3.25 to 4.00 High level

For the working environment, the overall weighted mean of employees is 3.27 and is verbally described as a high level of satisfaction. Highest item ranking is "The company makes the employees aware of the risk and hazards of the work environment" with a weighted mean of 3.45. The lowest item is "There is flexibility in employees' work environment with a weighted mean of 3.14" and verbally described as a moderate level of satisfaction.

Rantaen (2013) suggests that "the best possible working environment was to consider all the tangible and physical objects that should support workers' well-being. Physical elements have a great role in sustainability and the overall working environment. If there are problems in that element, it can cause dissatisfaction, different health problems, and a decrease in productivity".

5. Working Relationship

Table 5. Working Relationship

Working Relationship	Employees (n=50)	Verbal Description
1.The employee tends more towards being outgoing or more reserved.	3.60	High Level
2.The employee is enthusiastic in his/her relations with others.	3.63	High Level
3. The employee has been described as high-spirited by others.	3.22	Moderate Level
4.The employee likes to be in control in relationships.	3.41	High Level
5. The employee works towards co-operative relationships with others.	3.52	High Level
Overall Weighted Mean	3.48	High Level

Legend: 1.00 to 1.74; Not Satisfied; 1.75 to 2.49 Low Level; 2.50 to 3.24 Moderate Level; 3.25 to 4.00 High level

In terms of working relationship, employees garnered an overall weighted mean of 3.48, with a verbal interpretation of high level. For individual items, the highest ranked item is "The employee is enthusiastic in his/her relations with others" with a weighted mean of 3.63, while the lowest in terms of weighted mean is "The employee has been described as high spirited by others" (WM =3.22) and verbally described as moderate level.

The results imply that when employees work towards co-operative relationships with others, when they are enthusiastic about his/her relationship with others, and when they have been described as high-spirited, there is a very high level of job satisfaction. This brings forth the importance of a good working relationship in the performance of their jobs.

People are more productive if the working relationship is ideal. A good relationships, especially in the working environment, can make people more productive (Pozen & Downey, 2019).

IV. CONCLUSIONS

The levels of internal job satisfaction of the respondents as to their career advancement, working environment, and working relationships are at high levels, while moderate satisfaction for role alignment and relationship with superiors. The employees' work contributes to the success of the company. They want to do work that is aligned with the missions of the company, and they believe that their superiors constantly trust them to do good work without feeling the need to closely monitor their daily task. Additionally, the company makes the employees aware of the risk and hazards of the work environment, and the employees are enthusiastic in his/her relations with others.

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The Lived Experiences of HMO Individual Cardholders on Healthcare Coverage and Services

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Abstract *— This qualitative study explored the lived experiences of Health Maintenance Organization (HMO) individual cardholders regarding the adequacy, accessibility, and inclusivity of their healthcare coverage and services. Using a phenomenological research design, ten participants were interviewed to capture their perceptions and experiences in availing HMO benefits. Findings revealed recurring challenges such as long waiting times, delayed billing and approval processes, and limited availability of accredited healthcare providers. These administrative inefficiencies often resulted in inconvenience, out-of-pocket payments, and decreased satisfaction. Despite these issues, participants expressed generally positive perceptions toward HMO plans, highlighting their affordability, practicality, and financial protection during emergencies. Many recognized improvements in accessibility through digitalized approval systems and more responsive service channels. Overall, the study concludes that while gaps remain in coverage inclusivity and benefit awareness, HMO membership continues to serve as a valuable complement to PhilHealth by providing financial security and promoting greater access to private healthcare services.*

Keywords *— **Health Maintenance Organization, Healthcare Coverage, Accessibility***

I. INTRODUCTION

Healthcare has long been recognized as a cornerstone of human development, directly influencing life expectancy, productivity, and overall quality of life. Around the world, societies face the challenge of balancing the demand for accessible medical services with the rising costs of treatment, hospitalization, and preventive care. In both developed and developing countries, financial constraints remain one of the most significant barriers to healthcare utilization, often forcing individuals to postpone or forego necessary treatment. As a response, health financing mechanisms such as government insurance schemes, private health insurance, and Health Maintenance Organizations (HMOs) have emerged to bridge the gap between medical needs and financial capacity. These systems aim not only to reduce the economic burden of healthcare but also to promote proactive health-seeking behaviors by making medical services more affordable and accessible. Among these, HMOs have gained increasing attention due to the structured approach to healthcare delivery, emphasizing preventive care, cost efficiency, and partnerships with accredited healthcare providers. Consequently, understanding the impact, benefits, and limitations of HMOs becomes essential in evaluating the role of HMOs in the healthcare system and in addressing persistent challenges of accessibility and affordability.

Globally, health systems continue to grapple with the dual challenge of providing equitable access to care while managing escalating healthcare costs. In many developed countries, universal health coverage

has reduced out-of-pocket expenditures, but gaps remain, particularly in addressing preventive and long-term care needs. In most developed European countries, the government funds the public healthcare programs through taxes and social insurance contributions. This system provides universal healthcare coverage through low-cost access to care. However, this requires contributing about 5 to 15 percent of an individual's monthly income. While this system ensures access to essential care, it can lead to longer waiting time and limited provider options as public hospitals can only accredit HMO companies approved by the government. In contrast, developing countries often struggle with underfunded public health systems, making private health insurance and HMOs vital alternatives (World Health Organization, 2021). Studies have shown that HMOs play a significant role in enhancing access to healthcare by pooling risks and offering cost-effective service packages (Freundt & Bortoluzzo, 2022). For instance, in the United States, HMOs have been widely adopted to manage healthcare utilization through provider networks, preventive care, and negotiated service costs, helping patients reduce financial exposure (Sarkodie, 2021). Similarly, countries in Europe and Asia have experimented with mixed financing models, combining public insurance with private health plans, to improve efficiency and widen access. Despite their benefits, debates persist regarding the affordability, inclusivity, and long-term sustainability of HMOs, underscoring the importance of contextualized studies that explore their effectiveness in different national settings.

In the Philippine context, access to affordable and quality healthcare continues to be a significant challenge. The country faces a limited hospital capacity, uneven distribution of medical resources, and significant out-of-pocket expenses that prevent many Filipinos from seeking timely health care (Bautista et al., 2023). As of December 2022, the Philippines had fewer than 1,300 hospitals, of which only 403 were government-owned. With a population of over 115 million in 2024, this translates into an overwhelming strain on public health facilities. Although the Philippine Health Insurance Corporation (PhilHealth) was established to provide financial protection and universal healthcare coverage, its benefits are often insufficient to cover the full cost of medical services, leaving patients with substantial out-of-pocket payments. Aside from PhilHealth benefits, Republic Act No. 11223, or the Universal Health Care (UHC) Act, was enacted in 2019 to provide all Filipinos access to quality health care and financial protection from health-related expenses. The law includes the automatic enrollment of all citizens into the National Health Insurance Program (NHIP), addressing the long-standing disparities in healthcare by expanding beyond those who could afford premiums or employer-sponsored plans. It strengthens the healthcare delivery network by integrating local health systems and ensuring that essential services are available at the primary care level (Lam et al., 2020). Despite having PhilHealth and UHC, individuals still resort to availing prepaid HMOs from private institutions to somehow lessen the unexpected medical expenses.

Additionally, this gap has fueled the steady growth of the HMO industry in the country, as individuals and employers seek more comprehensive healthcare coverage. Depending on the policy, HMOs provide access to accredited hospitals and clinics, cover doctors' professional fees, laboratory services, and hospitalization expenses, and even extend coverage to dependents. Corporate HMOs are often offered by companies as part of employee benefits, while individual or family plans cater to self-employed workers and those without employer-sponsored coverage. More affordable alternatives, such as prepaid health cards, provide short-term or limited coverage but remain attractive to lower-income households. Despite these options, challenges in awareness, affordability, and accessibility hinder the full potential of HMOs. Many Filipinos still view them as an unnecessary expense, prioritizing immediate household needs over long-term health security.

Beyond financial protection, HMOs also shape how individuals perceive and engage with healthcare. Policyholders often develop stronger habits of preventive care, such as regular check-ups and early detection of diseases, which ultimately reduce long-term medical costs and improve overall health outcomes. At the same time, the availability of accredited providers increases confidence in healthcare services, encouraging individuals to seek

medical attention earlier rather than later. Nevertheless, disparities remain, as not all Filipinos can equally access these benefits, raising questions about the inclusivity and effectiveness of HMOs in improving national health outcomes. Moreover, this study seeks to explore the lived experiences of individual HMO cardholders in the Philippines, focusing on how they perceive healthcare coverage and services under their plans. By examining their perspectives, the research aims to shed light on whether HMOs truly ease financial burdens and improve health-seeking behavior or whether gaps in coverage and accessibility limit their effectiveness. This investigation is particularly relevant in shaping discussions on the role of HMOs as a supplement to PhilHealth and as a key player in the broader Philippine healthcare system.

Research Question

1. What are the lived experiences of HMO individual cardholders in relation to healthcare coverage and services?

Interview Guide Questions

1.1 What challenges do HMO individual cardholders encounter in availing healthcare services?

1.2 What are the perceptions of HMO individual cardholders regarding the adequacy and inclusivity of their coverage?

1.3 What are the experiences of availing the HMO services and coverage?
1.4 What impact does HMO have on its unexpected or out-of-pocket healthcare expenses?

1.5 What are the differences in the experiences of having an HMO plan compared to the experiences with the public healthcare system (PhilHealth)?

2. How do HMO individual cardholders cope with the challenges and demands associated with their healthcare coverage?

Interview Guide Questions

2.1 How do these challenges affect the healthcare-seeking behavior of HMO individual cardholders?
2.2 How do these perceptions influence the healthcare utilization patterns of HMO individual cardholders?

2.3 How do these experiences affect the way HMO cardholders use their HMO coverage?

2.4 How do HMO cardholders perceive the affordability of their plans compared to the coverage and benefits received?

2.5 How do these experiences affect their perception of having an HMO aside from PhilHealth?
3. Based on the emerging themes from the study, what practical outputs can be proposed to improve the healthcare coverage and services of HMOs in the Philippines?

II. RELATED LITERATURE

Lived Experiences of HMO Individual Cardholders

Health maintenance organizations (HMOs) and similar managed-care insurance arrangements continue to shape how people access, pay for, and experience healthcare services. A large-scale systematic review analyzed worldwide data on the key determinants of patient satisfaction and experience across various healthcare and insurance settings. According to Ferreira et al. (2023), patient experience is determined by three interdependent dimensions: the quality of clinical care, the nature of provider–patient communication, and system-level factors including efficiency of scheduling, waiting times, and claims management. The authors suggest that patient experience is influenced by three interrelated dimensions: the standard of clinical care, the quality of communication between providers and patients, and organizational factors such as scheduling efficiency, waiting time, and claims processing.

Furthermore, studies examining HMO participation in social health insurance partnerships, such as Nigeria's National Health Insurance Scheme (NHIS) HMO model, reveal that while enrollees often benefit from the financial protection of prepaid coverage, they also encounter administrative challenges, including delays, restricted provider options, and perceived disparities between insured and private-pay patients. These issues influence both trust in the system and the everyday meaning of being covered. Mixed-method research further indicates that enrollees' perceptions of service quality and their lived experiences are largely determined by how effectively HMOs and healthcare facilities

manage referrals, waiting times, and claims or authorization procedures. This suggests that the design of the system and the operational behavior of facilities play a crucial role in shaping cardholders' practical experiences with insurance coverage (Mkperedem et al., 2023; Ngabea & Durotoluwa, 2024).

In addition, a Philippine study conducted among multi-specialty clinic patients examined how HMO membership influenced healthcare-seeking behaviors before and during the COVID-19 pandemic. Bautista et al. (2023) found that HMO cardholders generally increased their use of outpatient services when accessible and perceived their coverage as a motivating factor for seeking timely medical attention, thereby minimizing cost-related delays. However, the study also revealed challenges such as appointment backlogs, tighter authorization procedures, and uncertainty about coverage policies, which shaped mixed experiences of reassurance from financial protection and frustration due to administrative burdens. Overall, the study highlights the dual character of Filipino HMO cardholders' lived experiences: financial relief from healthcare expenses, coupled with stress arising from procedural complexities in accessing care.

Research focused on developing and validating patient-experience measurement tools in the Philippines underscores the necessity of culturally grounded frameworks when examining lived experiences. Filipino-centered models highlight the significance of interpersonal respect, communication in the local language, and smooth administrative interactions as key components of patients' perceptions of care. Consequently, studies validating Filipino-specific instruments and national patient experience initiatives emphasize that understanding the lived experience of HMO cardholders in the Philippines requires contextually adapted measures that assess not only clinical quality but also administrative navigation, provider respect, and clarity of coverage – elements that shape everyday meaning for cardholders. (Doroteo et al., 2020; Judan-Ruiz et al., 2020).

Challenges HMO Individual Cardholder's Encounter

Health Maintenance Organizations (HMOs) were originally designed to provide affordable and accessible health care through prepaid systems and managed care structures. However, research has shown that HMO members often experience significant challenges related to access, affordability, and satisfaction. Frazier et al. (2022) examined the financial barriers experienced by HMO enrollees and concluded that high out-of-pocket expenses continue to be a major obstacle to utilization, especially for low-income individuals. In addition, administrative barriers, such as pre-authorizations and extensive documentation requirements, also hinder timely service delivery.

Moreover, Faiz et al. (2024) found that prior authorization procedures frequently delay diagnostic tests and specialist consultations, negatively affecting continuity of care. Similarly, Frazier et al. (2022) emphasized that financial barriers, including co-payments, package limits, and out-of-network charges, discourage individuals from seeking necessary treatment, even when insured. Additionally, studies in the United States and Europe have shown that HMO members tend to report lower satisfaction levels compared with those under fee-for-service models.

In the Philippine context, a qualitative study by De Guzman and Santos (2022) explored the experiences of Filipino HMO cardholders regarding healthcare accessibility. Participants reported long waiting times, confusion about accredited facilities, and limited communication from their HMO providers. Similarly, Reyes (2021) conducted a survey on satisfaction among HMO users in Metro Manila and found that 68 % of respondents were dissatisfied with reimbursement processes and claim response times. These findings reinforce the conclusion that administrative hurdles and lack of transparency significantly affect cardholders' healthcare experiences.

The Health Maintenance Organization industry is recognized as an important component of private health financing. The Insurance Commission (2023) notes that most HMO memberships are employer-based, with limited uptake among

individual cardholders due to high premiums and narrow benefit coverage. According to the Oxford Business Group (2022), individual HMO plans are typically more expensive and provide fewer accredited hospitals compared to corporate group plans, making them less accessible to average Filipinos. Also, the Philippine Competition Commission (2023) further observed that the local HMO market faces regulatory and competition challenges, which contribute to higher costs and limited consumer options. Additionally, local news reports highlight real-world experiences of individual cardholders who encounter difficulties in claim processing, delayed approvals, and hospitals refusing HMO cards due to unsettled reimbursements (Philippine Daily Inquirer, 2023).

HMO Individual Cardholder Coping Mechanisms

Health Maintenance Organizations (HMOs) and other forms of private health insurance (PHI) are intended to reduce out-of-pocket (OOP) payments and improve access to care. However, empirical evidence from multiple settings shows that enrollment in PHI or HMO plans does not always eliminate financial hardship: many insured households still experience substantial OOP spending and resort to coping mechanisms such as borrowing, using savings, selling assets, delaying care, or substituting cheaper/alternative treatments. These coping responses are critical indicators of underinsurance (coverage exists but is insufficient) and are important to measure when evaluating effective financial protection (Park, 2024).

To mention, a recent study of household out-of-pocket expenditures for non-communicable diseases reported common coping actions: seeking alternative or cheaper treatments (61.0%), borrowing money (39.5%), and using savings (29.0%), illustrating how households–including those with some form of insurance–manage recurring cost burdens from chronic conditions (Magana et al., 2025). National health accounts confirm that household OOP remains a major share of health financing, which sustains conditions that prompt coping strategies (PSA, 2024). Policy analyses and the Health Care Financing Strategy (DOH, 2023) identify OOP reduction as a target and document benefit gaps that leave households vulnerable (DOH, 2024).

Furthermore, research shows that the extent of financial protection provided by Health Maintenance Organizations (HMOs) and private health insurance (PHI) depends more on the depth of coverage than on insurance enrollment itself. Limited benefit packages—such as those that exclude outpatient medicines or impose restrictions on diagnostic services—often leave members underinsured and exposed to substantial out-of-pocket (OOP) payments (Park, 2024). This vulnerability is particularly evident among individuals with chronic conditions, as non-communicable disease (NCD) patients face recurring health expenses that typically fall outside standard HMO coverage, leading to repeated coping behaviors such as borrowing or using personal savings (Magana et al., 2025). While supplementary PHI can reduce some inpatient expenditures, existing studies show mixed evidence on its ability to mitigate overall household debt or prevent financial distress, suggesting that insurance alone may not guarantee economic security (Park, 2024).

Emerging Themes from the Interview

One common theme that has been identified in the interview is the improvement of the network of HMO providers with the accredited hospitals and medical professionals. It was mentioned by all respondents that they have experienced delays in the process, especially with the approval of their Letter of Authority, and the limited accredited medical professionals in the area. As stated by an article of Fair Health Consumer, HMO providers negotiate the price of medical services with certain doctors, hospitals, labs, and other providers. These providers are in the plans' "network". Many insurers offer plans with "narrow" networks because these plans have lower premiums, but as a trade-off, your choice of providers is limited. Plans must meet certain regulations, such as having enough network providers in different specialties and throughout the geographic area. There must be enough providers to deliver the benefits the plan promises its members. An HMO plan holder must consider a wider network if a family member or the plan holder anticipates needing a lot of medical services.

Another theme present is the sense of security in having HMO coverage, especially in the Philippines, since the public health care system is

seen as inadequate. Having an HMO in the Philippines provides a sense of security by offering financial protection against medical expenses, making quality healthcare more accessible, and providing peace of mind during illnesses or accidents. It allows members to seek necessary medical attention, such as check-ups, emergency care, and procedures, without having to worry about large out-of-pocket costs, preventing potential financial crises from health emergencies.

Financial protection and peace of mind, as it mitigates financial stress. An HMO plan helps cover costs for medical expenses, preventing the holder from having to rely on savings or loans for treatment. This gives the holder the peace of mind knowing that a financial safety net is in place for unexpected health events, accidents, or illnesses. It also reduces out-of-pocket spending as it can eliminate the need for an upfront hospital deposit for admissions to accredited hospitals and cover a significant portion of your medical bills. Although there are instances where the HMO holder pays for excluded services or procedures, the coverage provides greater financial protection.

Given both the advantages and disadvantages of having an HMO coverage, respondents are unanimous in recommending securing an HMO plan as the advantages outweigh the disadvantages based on their experiences.

III. METHODOLOGY

This study will employ a phenomenological research design, which will seek to explore and understand individuals' lived experiences regarding a specific phenomenon. As mentioned by Creswell and Poth 2023, in adopting a phenomenological design, the researcher seeks to uncover the essence of participants' lived experiences of a phenomenon and to describe how the phenomenon is understood from the perspective of those who have experienced it. It will aim to uncover how participants perceive and make sense of their experiences, emphasizing their personal meanings and interpretations. In this research, the phenomenological approach will be deemed appropriate because it will allow for an in-depth exploration of the challenges that HMO individual cardholders will encounter in availing healthcare services. Through this design, the study will seek to capture the essence of these experiences by analyzing participants' narratives and identifying recurring themes that will reflect their shared realities.

The study will be conducted in the Philippines, particularly in Metro Manila, where Health Maintenance Organization (HMO) services are actively utilized. The geography of the study is within two of the three major islands in the Philippine archipelago. The majority of the respondents are from Luzon, mostly in the major cities of Metro Manila, as this is where the capital of the country is and is considered to be the center of commerce in the Philippines. One respondent is in the province of Quezon. A respondent is residing in Bohol, which is in the Visayas, but also works in Metro Manila. The Philippines is an archipelagic area, which greatly affects the connectivity of the provinces or regions. This plays an important factor in the study as the location of the hospitals or medical facilities affects the services needed.

The area hosts a high concentration of multi-specialty clinics, private hospitals, and healthcare facilities accredited by leading HMOs. The chosen locales reflect regions with diverse socioeconomic backgrounds, enabling the researcher to capture a range of experiences among HMO individual cardholders. The Philippines serves as an appropriate setting for this study because it represents a mixed healthcare system where both public health insurance (PhilHealth) and private HMOs play significant roles in providing healthcare access. The geographical coverage allows for an understanding of how regional differences in healthcare infrastructure, provider availability, and administrative practices influence cardholders' lived experiences with their HMO coverage.

The participants of this study consist of individual HMO cardholders who are currently enrolled in private Health Maintenance Organizations (HMOs) in the Philippines. All respondents are working individuals within the range of 20-45 years of age. Most with dependents or beneficiaries provide for a wider experience in utilization of the HMO coverages. We have a total of ten (10) respondents from the major Philippine islands, Luzon and Visayas. Nine (9) respondents are

from Luzon, and one (1) is from the Visayas. The diversity in the age and location provides diverse experiences in the utilization of the HMO coverages. The respondents are also enrolled in various HMO providers, giving different perspectives on services.

This study will use a purposeful sampling design, selecting participants who can provide in-depth and relevant perspectives on the lived experience of HMO cardholders. Purposeful sampling is appropriate for qualitative research as it enables the researchers to concentrate on participants or cases that provide the most relevant and detailed information. Ahmad & Wilkins (2025) emphasize that purposive sampling should align with the study's aims, methodology, and the characteristics of the phenomenon being investigated, to ensure credibility, transferability, and rigour. Participants will be recruited through purposive outreach. A brief explanation of the study's purpose, confidentiality assurances, and voluntary participation terms will be provided prior to obtaining informed consent. This recruitment strategy ensures that participants have firsthand experience with HMO systems, allowing the study to gather meaningful insights into their lived experiences.

This study will employ thematic analysis as the main qualitative tool to interpret participants' responses. As defined by Reyes (2021), thematic analysis involves identifying, analyzing, and reporting patterns or themes within qualitative data, allowing for both detailed description and interpretation. Primary data will be collected through semi-structured interviews using predetermined open-ended questions to encourage participants to share their experiences as HMO individual cardholders. The researcher will ensure a comfortable interview environment and transcribe all responses verbatim. The interview questions, responses, and observations will be organized in a table format to aid systematic analysis. Data cleaning will follow to correct errors, remove irrelevant content, and ensure accuracy and reliability. Finally, data coding and theming will be conducted by grouping significant statements into categories and overarching themes that capture the participants' lived experiences. This process will enable the researcher to interpret and present the core meanings of the participants' shared realities, aligning with the phenomenological approach.

The researcher will ensure that all ethical standards in conducting qualitative research will be strictly observed throughout the study. Prior to data collection, participants will be informed about the purpose of the research, the procedures involved, and their right to withdraw at any time without penalty. Confidentiality will be maintained by keeping all personal information and responses private and accessible only to the researcher. To uphold anonymity, participants' real names and identifying details will be replaced with pseudonyms in transcripts and reports. The study will also adhere to the provisions of the Data Privacy Act of 2012 (Republic Act No. 10173), ensuring that all data collected will be securely stored, encrypted, and used solely for academic purposes. Informed consent will be obtained from all participants before interviews are conducted.

IV. RESULTS AND DISCUSSION

The experiences of HMO cardholders vary depending on how each individual perceives and utilizes their health maintenance coverage. This chapter presents the results and discussions derived from the participants' narratives, supported by relevant data collected through interviews and analysis. The findings reveal the realities, challenges, and benefits encountered by HMO cardholders as they access and maximize their plan's services and coverages.

The discussion focuses on key aspects such as accessibility, coverage and benefits, service satisfaction, provider performance, and affordability of HMO plans. Each theme captures the participants' lived experiences, reflecting both the positive outcomes and difficulties they face in navigating the healthcare system. These findings are examined in relation to existing literature and theoretical frameworks, highlighting points of convergence and divergence with previous studies. By integrating the participants' insights with scholarly perspectives, this chapter aims to provide a deeper understanding of how HMO systems shape the healthcare experiences of individual members. Ultimately, the analysis seeks to identify areas for improvement that can enhance

service delivery, promote patient satisfaction, and strengthen the overall effectiveness of HMO programs in the Philippine healthcare context.

1. The lived experiences of HMO individual cardholders in relation to healthcare coverage and services

1.1 Challenges do HMO individual cardholders encounter in availing healthcare services

Table 1.1 Systemic Barriers to Efficient Access to HMO Healthcare Services

Participants	Responses	Sub-ordinate Themes
HMO Cardholder 1	*"Delays in approval of billing because sometimes we go to a hospital and the check-up is not long however the approval of billing takes 2-3 hours, that's inconvenient, at the same time the limited accredited hospitals especially if you reside in the province."*	Limited Accredited Healthcare Facilities and Providers; Delays in Billing and Approval Processing
HMO Cardholder 2	*"Yung matagal ma-approve pag inapply mo yung HMO kasi minsan inuuna yung bigating HMO provider, inuuna bago yung aking HMO."*	Delays in Billing and Approval Processing
HMO Cardholder 3	*"I think personally my HMO provide good coverage interestingly enough my coverage is different from my dependents so one of the challenges we have, they have more limited option in terms of hospitals and clinics that is available to them which are accredited by the HMO. The main challenge is looking for the best and nearest hospital in our area so that means we have to look for a hospital or clinic that would suit our needs and that's a bit more convenient."*	Limited Accredited Healthcare Facilities and Providers
HMO Cardholder 4	*"Long waiting hours at long approval time kapag wala kang LOA. Nare-resolve naman sya dahil may application si PhilCare na pwede kang mag-generate ng LOA. Minsan kahit may LOA ka na, kung pumunta ka sa oras o araw na maraming pasyente, maghihintay ka pa rin nang matagal bago ma-accommodate."*	Delays in Billing and Approval Processing
HMO Cardholder 5	*"Sa Quezon Province, kaunti lang yung accredited po na clinic so nahirapan kaming i-avail yung benepisyo. Meron namang malapit sa Lucena, kailangan lang magbiyahe."*	Limited Accredited Healthcare Facilities and Providers
HMO Cardholder 6	*"First-hand, nung hindi ako aware sa mga process, parang ang tagal niya. Kasi pag pinapasa ako dun sa mga clinic or diagnostic centers sa hospital, it takes 1-2 hours bago ma-approve. So maghihintay kami doon. Pero nung later on, pwede naman pala yung pre-approval, so tumatawag muna ako dun sa clinic, and then kapagka-credited nila yung HMO card, medyo nagiging mas madali*	Delays in Billing and Approval Processing

	yung process niya.1-2 hours talaga [waiting time] nung mga unang year na inavail ko yung HMO card."	
HMO Cardholder 7	*"Kadalasan na na-experience is matagal yung approval, depende rin sa medical facilities kung saan kami pupunta, tapos hindi pala pwede yung HMO. Pero yung time in approving yung main challenge."*	Delays in Billing and Approval Processing
HMO Cardholder 8	*"1st is finding a nearby doctor that is partnered or accredited with PhilCare. For example, in Chinese General Hospital, there's only 1 PhilCare accredited doctor so we have to go to Manila Medical since there's more accredited doctors there. 2nd is it takes time for the approval for check-ups. You have to get the HMO approval before proceeding with the laboratories requested by the doctor."*	Limited Accredited Healthcare Facilities and Providers; Delays in Billing and Approval Processing
HMO Cardholder 10	*"For outpatient care, it's difficult to schedule. Back in IntelliCare, green forms needed to be filled out aside from going to satellite clinics instead of hospitals, but for Maxicare, you can call and schedule, but the availability will be the challenge, and location of the accredited doctor/clinic, especially from where I live, but the availability is the main challenge."*	Limited Accredited Healthcare Facilities and Providers

The most frequently reported challenges among HMO cardholders include delays in billing and approval processing, as well as limited availability of accredited healthcare facilities. Participants commonly described experiencing long waiting periods for billing approvals before they could proceed with consultations or medical procedures. These administrative inefficiencies disrupt the smooth delivery of healthcare services and often lead to patient dissatisfaction. Consistent with these findings, Montemayor et al. (2025) observed that such procedural delays and restricted provider networks are key factors discouraging private health insurance utilization in the Philippines, as the perceived inconvenience diminishes the overall value of HMO membership.

Participants revealed that while HMOs provide convenience and financial protection, disparities remain in coverage between principal members and their dependents, reflecting inconsistencies in benefit design that lead to uneven healthcare affordability. Fragmented coverage structures in private health plans result in unequal access to services, limiting the broader goal of financial equity. Nonetheless, many participants noted that HMO processes have improved through digital tools such as mobile applications and the PhilCare LOA generator, which streamline approvals and reduce waiting times. According to Reyes (2021), technology-driven systems in healthcare financing not only enhance efficiency but also help reduce administrative barriers, thereby supporting affordability and improving the overall HMO experience.

1.2 The perceptions of HMO individual cardholders regarding the adequacy and inclusivity of their coverage.

Table 1.2 Perceived Adequacy and Limitations of HMO Coverage

Participants	Responses	Sub-ordinate Themes
HMO	*"No (it doesn't cover the*	Perceived

Cardholder 1	*medical bills) it's just a small help but if you encounter, for example you're sick, you stayed long in the hospital, the bill is piling up even it (the coverage) is 95,000, it's very less, knowing how the hospital charges the patients here so yes, it can help for check-ups, usually we use it for check-ups but it it's a severe disease, no you can't count on it"*	Insufficiency of Coverage for Serious or Prolonged Illnesses
HMO Cardholder 2	*"May times na inclusive naman sya, pero may iba na kailangan mo muna ng approval kung included sya sa package ng HMO, may mga ganon na scenario"*	Conditional or Selective Inclusivity of Services
HMO Cardholder 3	*"Well, it really differs from myself and my family members. To me, I thinks it's adequate, I think we have a good maximum coverage but with my dependents, with the limited hospitalization, in terms of benefits I think there's still some improvements that can be made. I think for me, one of the issues is the limited dental benefits, medical-wise it's enough."*	Conditional or Selective Inclusivity of Services; Disparity Between Member and Dependent Coverage
HMO Cardholder 4	*"Yes, dahil 16,000 lang binabayaran ko pero ang consultation ngayon ay 1,000 na. Laboratory ay 2,000 to 4,000. Na-u-utilize ko ang coverage ko na worth 80,000 lalo na nung na-hospitalize ako."*	Positive Perception of Affordability and Practical Benefits
HMO Cardholder 5	*"Sa kung iisipin ko sir, sa 14,000 na kada taon na binabayaran ko, sa sarili ko, tapos sa magulang ko din, tapos meron siyang 105,000 na medical coverage, ang iisipin mo sir, maganda naman talaga na meron pa ding health card, gawa ng saan ka kukuha eh magkano ho ang check-up ngayon, kung private 800 to 1200 ang check up pa lang. So maganda pa rin talaga na meron silang ginaganyan na offer. Kasi kung wala ka ding health card ang laki din talaga ng epekto lalo na kung sa akin magkano lang naman sahod ko sa isang buwan, so kung magkasakit yung magulang ko sir, or kahit magpa-check up, nawawala ko sa budget kung wala akong health card. Kaya kahit medyo hirap akong magbayad, sinisigurado ko na meron silang health card para kapag kailangan nila, wala na akong iniisip na gastos."*	Positive Perception of Affordability and Practical Benefits
HMO Cardholder 6	*"Naco-cover naman [yung kailangan ko] and yung inclusion ng HMO is enough parang, para ma-secure yung annual health natin."*	Positive Perception of Affordability and Practical Benefits
HMO Cardholder	*"Sa tingin ko, sa binabayaran ko, adequate*	Positive Perception

7	*naman, kasi compared naman dun sa mga magiging health issues mo, malaking bagay yung may HMO, even if depende sa sitwasyon mo."*	of Affordability and Practical Benefits
HMO Cardholder 9	*"Sapat naman ang benefits na covered ng HMO ko kaya lagi ko pa rin syang binabayaran. Marami syang accredited hospitals at maraming services na nagagamit ko."*	Positive Perception of Affordability and Practical Benefits
HMO Cardholder 10	*"I think it's sufficient, it just needs to update with time, since for example, if you have a severe illness, you can easily consume your coverage within a week of being confined, so even being covered by your HMO, you still have to pay out of pocket. But other than that, for just regular checkups, it's adequate, but medical costs in the Philippines can be expensive for more serious cases."*	Perceived Insufficiency of Coverage for Serious or Prolonged Illnesses

Despite concerns about coverage limitations, many participants conveyed a positive perception of their HMO plans, particularly highlighting their affordability and practicality for everyday healthcare needs. Respondents appreciated that their HMO membership reduced the financial burden of routine medical expenses such as consultations, laboratory tests, and basic treatments. This perception of affordability stemmed from the ability to access healthcare services without the need for large, upfront payments, a feature that provided a sense of financial security and convenience. Participants also valued the "cashless" feature of accredited facilities, where payments were handled directly between providers and the HMO, minimizing out-of-pocket costs and administrative stress during medical visits.

These findings are consistent with the conclusions of Ferreira, Lopes, and Rivera (2023), who found that patient satisfaction in managed healthcare systems is strongly influenced by perceived convenience, cost savings, and ease of service access. Dans, De Leon, and Villaverde (2024) likewise observed that while HMO coverage in the Philippines may not fully eliminate catastrophic spending, it effectively reduces the routine healthcare expenses that are most commonly incurred by working individuals and families.

1.3 The experiences of availing the HMO services and coverage

Table 1.3 Varied Experiences and Evolving Accessibility in Availing HMO Services

Participants	Responses	Sub-ordinate Themes
HMO Cardholder 1	*"That's it, it takes long to get approved. The cashier says "No approval yet" so you just keep on waiting and waiting for 3-4 hours and it should not be that way because the health card should be there for emergencies. Actually I experienced this, you go for emergency check-up and it took 3-4 hours to get the approval"*	Long Waiting Time and Slow Approval Process
HMO Cardholder 2	*"There are times na okay naman sya gamitin depends on the hospital, sa ibang hospital the Philcare is not accredited, dun sa mga nauna kong puntahan na hospitals so I need to find another hospital na kayang i-cover yung mga pangangailangan ko kasi kunware may*	Variability of Service Experience Depending on Hospital Accreditation

	mga kailangan tests na hindi pala covered dun sa package ko so mag-aadd ako, magbabayad ako."	
HMO Cardholder 3	*"Well, it has gotten better compared to before. Before to get an approval we have to line up for an hour or so but now online portals and SMS are much easier to get an approval."*	Improvement in HMO System and Service Accessibility
HMO Cardholder 4	*"Nakaka-avail ako ng annual physical examination, check-ups kapag may sakit ako, asawa ko, o anak ko. Kapag may emergency, nagagamit ko ang hospitalization coverage at kung may operation man na gagawin, nacocover din sya ng HMO ko."*	Positive Experience of Utilizing Coverage and Benefits
HMO Cardholder 5	*"Okay naman, sir. Yun lang, kailangan lang talaga itanong muna sa hospital kung itong aking health card ay, ay mac-cover kung anuman yung kailangan kong ipagawa sa ospital. Ang, sa like, kung may diperensya ba kung nag-cash ka or nag-health card ka, wala din namang difference sa service. Yun lang talaga, kailangan mo ipa-check kung accredited para masiguradong hindi ka talaga magbabayad at maaavail mo siya. Pero*	Variability of Service Experience Depending on Hospital Accreditation; Positive Experience of Utilizing Coverage and Benefits
	sa diperensya sa pagpapa-ospital, parang pareho lang naman, so mas nakabuti pa kung meron kang health card, no? Para at least hindi kayo nag-aalala ng babayaran mo. Parang kasi yun yung purpose niya."	
HMO Cardholder 6	*"Naging madali na yung process namin dahil yung HR dun sa company namin, is kukuha muna ng pre-approval, so susulat muna yung HR namin sa Philcare, and kapag may letter of approval na, effective siya for 1 month, so anytime within that 1 month pwede kaming mag-conduct ng aming Annual Physical Exam."*	Improvement in HMO System and Service Accessibility
HMO Cardholder 7	*"Mostly naman, smooth naman yung transaction and approval, most of the time naman mabilis silang mag-approve, although may instances na matagal, kumporme na lang sa kung ano yung pinapagawa or kung saan ako pumunta na accredited yung HMO. So far so good naman."*	Long Waiting Time and Slow Approval Process; Variability of Service Experience Depending on Hospital Accreditation
HMO Cardholder 8	*"In the Philippines, having an HMO is a benefit because you don't have to pay for emergency expenses.*	Improvement in HMO System and Service Accessibility;

	I'm confident to go to the emergency room when I'm not feeling well because I know I have an HMO that can pay my hospital expenses. I can also do annual check-ups to know my health status. You can also access accredited hospitals and doctors online so it's more convenient. There's a lot of services available in my HMO, you just have to know your coverage."	Positive Experience of Utilizing Coverage and Benefits
HMO Cardholder 9	*"Nagagamit ko yung annual medical check up. Mas mabilis at madali sakin i-avail to nang walang binabayaran dahil sa HMO ko. Mabilis rin yung process dahil may HMO ako."*	Improvement in HMO System and Service Accessibility; Positive Experience of Utilizing Coverage and Benefits
HMO Cardholder 10	*"The most recent times I've used my HMO were for my psychiatric health, and then an emergency case where my child was bitten by an unvaccinated dog. For the psychiatrist, it wasn't so convenient because he was pretty far, but it was pretty convenient for my son, since we just had to go to the emergency room, and the wait wasn't that long."*	Positive Experience of Utilizing Coverage and Benefits

The participants described varied yet generally improving experiences in accessing their HMO services. Several noted persistent issues such as long waiting times and slow approval processes, particularly during hospital admissions or requests for specialized procedures. Others observed that their experiences often depended on hospital accreditation, with accredited facilities providing faster, smoother transactions, while non-accredited ones required more paperwork or higher out-of-pocket costs. Despite these challenges, many participants recognized noticeable improvements in HMO systems and service accessibility, including the shift to online approval systems, digital membership verification, and more responsive customer service channels. These developments were perceived as signs of progress in the efficiency and modernization of healthcare access through HMOs.

Furthermore, the study found a growing positive experience in utilizing coverage and benefits, especially for routine consultations and laboratory services. Respondents expressed appreciation for the convenience, affordability, and reduced financial burden that HMO membership provides. These results are consistent with Ferreira, Lopes, and Rivera (2023), who emphasized that system efficiency and service accessibility significantly influence members' satisfaction with managed care. Similarly, Dans, De Leon, and Villaverde (2024) highlighted that while systemic delays and accreditation disparities persist, improvements in digital processing and benefit delivery enhance patients' perception of care accessibility. Overall, the findings indicate that although operational challenges remain, HMOs are gradually evolving toward more accessible and user-centered healthcare systems, fostering a more positive experience among individual cardholders.

1.4 Impact of HMO Coverage on Out-of-Pocket Healthcare Expenses

Table 1.4 Financial Implications and Coverage Limitations of HMO Plans

Participants	Responses	Sub-ordinate Themes
HMO Cardholder 1	*"Yes (used money from pocket). If you maximized the coverage, for example, you have a 300,000 bill, so it's like comparing*	Inadequate Coverage Leading to Significant Out-of-

	HMO to PhilHealth, very minimal, not that impactful."	Pocket Payments
HMO Cardholder 2	*"Yung kunwari kailangan mo ng medical certificate, kailangan mong bayaran out of pocket kasi di kasama ng coverage, though nakakita ka ng doctor na accredited yung kailangan mong documents kailangan mong bayaran kasi di sya kasama, out of pocket yun tapos minsan din yung mga intense na tests so hindi na siya kasama sa coverage so kailangan kong mag out of pocket para magawa yung service o yung health care na kailangan ko"*	Exclusion of Certain Services and Procedures from Coverage
HMO Cardholder 3	*"Based on my experience, as long as it's within the maximum amount per illness, then there's really minimal out-of-pocket expense. Thankfully, we haven't really had illnesses or hospitalization where we had to shell out a big sum of money. But for instance, we have to get a medical certificate, we have to pay an extra P200 for the documents, but other than that, the out-of-pocket is minimal."*	Exclusion of Certain Services and Procedures from Coverage; Minimal Out-of-Pocket Expenses for Minor Services
HMO Cardholder 4	*"It lessens my out-of-pocket expenses because aside from my HMO, I also have a Philhealth, so almost wala na akong nilalabas na pera."*	Minimal Out-of-Pocket Expenses for Minor Services
HMO Cardholder 5	*"Kasi katulad nung tatay ko, nagpa-opera siya sa bato, eh umabot ng 200,000 yung bill niya. Eh 105,000 lang yung coverage. So kailangan pa rin talaga naming maglabas ng pera. Kasi hindi nailalabas yung tatay ko kung hindi bayad."*	Inadequate Coverage Leading to Significant Out-of-Pocket Payments
HMO Cardholder 6	*"Meron naman, kasi around 2024, nagpa-checkup ako sa urologist, and may mga ni-request siya na ipa-test sakin. Hindi pa ako aware at that time sa coverage ng HMO, so nagkamali ako siguro ng sagot doon sa Philcare, so ang sagot ni Philcare is hindi siya covered nung HMO, so naglabas ako roughly ng mga 5000 pesos for the test. So may mga tanong sagot pala doon sa mga tinatanong nila para pumasok siya doon sa inclusion nung HMO."*	Exclusion of Certain Services and Procedures from Coverage; Lack of Awareness of Coverage Inclusions Causes Unnecessary Expenses
HMO Cardholder 7	*"May mga times naman na napilitan akong magbayad kasi hindi covered, pero usually, hindi naman siya ganun kalaki. Usually, mga paraphernalia lang na hindi covered ng HMO, pero nothing major."*	Exclusion of Certain Services and Procedures from Coverage; Minimal Out-of-Pocket Expenses for Minor Services

HMO Cardholder 8	*"I only pay for the consultation fee of a sub-specialist doctor because my HMO doesn't cover that."*	Exclusion of Certain Services and Procedures from Coverage
HMO Cardholder 9	*"Meron akong naging out-of-pocket pero maliit lang katulad ng doctor's fee. May ibang doctor naman na accredited ng HMO pero konti lang sila."*	Exclusion of Certain Services and Procedures from Coverage; Minimal Out-of-Pocket Expenses for Minor Services
HMO Cardholder 10	*"The experiences I've had where I had to pay out of pocket were not necessarily for myself, but for my brother when he got sick and got hospitalized repeatedly, so he had consumed all his contributions, so we had to pay with our own money for his own medical expenses. So even if people are covered by HMOs, it doesn't last with a serious illness."*	Inadequate Coverage Leading to Significant Out-of-Pocket Payments

Coverage limitations and out-of-pocket expenses remain common challenges experienced by HMO individual cardholders when availing healthcare services. Although most participants acknowledged that HMO membership helps reduce overall medical costs, many still encounter unexpected personal expenses due to limited benefit coverage and service exclusions. This reveals a clear gap between members' expectations of financial protection and the actual extent of their HMO benefits.

Participants shared that certain medical services, such as the issuance of medical certificates, laboratory tests, and specialist consultations, are often excluded from HMO coverage. Others mentioned that once they reach their maximum coverage limit, they are required to shoulder the remaining medical expenses personally. Despite these limitations, respondents still recognized the value of having an HMO, as it significantly lessens their financial burden, especially when benefits are used alongside PhilHealth coverage.

These findings are consistent with Estacio Jr. et al. (2020), who noted that while HMOs improve healthcare affordability, many Filipinos continue to experience financial strain due to limited benefit packages. Similarly, Montemayor et al. (2025) emphasized that a lack of awareness regarding plan inclusions and benefit limits often results in unnecessary out-of-pocket spending among policyholders. Moreover, the World Health Organization (2020) reported that inadequate health financing protection remains a major obstacle to achieving universal health coverage in developing countries such as the Philippines. Hence, even with the presence of HMOs, individuals remain financially vulnerable when faced with serious illnesses or high-cost treatments, underscoring the need for broader coverage and clearer benefit communication.

1.5 Comparison of Experiences Between HMO and Public Healthcare System (PhilHealth)

Table 1.5 Enhanced Healthcare Accessibility, Financial Security, and Overall Satisfaction through HMO Coverage

Participants	Responses	Sub-ordinate Themes
HMO Cardholder 1	*"It does help, aside from the PhilHealth, if you have a health card, it will lessen your bill even if it will not cover all, plus the PhilHealth itself. So, if you have an operation, you have 95,000 if you have a health card, so for that you don't have to shell out that much*	Greater Financial Coverage and Reduced Out-of-Pocket Expenses with HMO

	cash."	
HMO Cardholder 2	*"Malaki yung kaibahan nila kasi kunware yung sa HMO magpapa-approve ka, maa-aprubahan naman you just to wait more time para ma-serve yung kailangan mo. Sa Philhealth naman kasi meron certain na sakit na ico-cover nila, hindi abot dun magdadagdag ka pa rin so mas okay na rin yung may HMO kaysa ang aasahan mo lang ay Philhealth"*	Greater Financial Coverage and Reduced Out-of-Pocket Expenses with HMO; Faster and Easier Access to Healthcare Services under HMO; Perception of PhilHealth as Limited or Supplementary Support
HMO Cardholder 3	*"Much different because well it's more of like my perception, Philhealth is more like a supplementary medical coverage, ultimately they can't cover anything that your regular HMO would provide so that means as someone who has a lot of dependents, we rely on HMO coverage then whatever very minimal benefit we could get from Philhealth, we regarded that as just a bonus but as far as I know Philhealth covers very minimal amount in terms of hospitalization."*	Greater Financial Coverage and Reduced Out-of-Pocket Expenses with HMO; Perception of PhilHealth as Limited or Supplementary Support
HMO Cardholder 4	*"We have better access to big and private hospitals compared to Philhealth, which is limited to public hospitals ang coverage. Also, sa doctors, mas maraming accredited sa HMO kesa sa PhilHealth. Mas malaki rin ang monetary coverage ng HMO kesa sa PhilHealth."*	Broader Access to Private and Accredited Healthcare Facilities; Perception of PhilHealth as Limited or Supplementary Support
HMO Cardholder 5	*"Iba pa din ho talaga kapag may HMO ka, kasi katulad niyan kung may 105,000 ka na coverage, hindi naman yan covered ho ng Philhealth. Ang alam ko nga ho, parang less 20,000 lang ang cover niyan? Tapos ho, at least kahit papaano, kung gusto makapunta ka sa private na hospital, at accredited naman yung health card mo, pupwede ka ho doon. Hindi mo kailangang pumila sa mga public hospital, kung aasahan mo lang yung Philhealth. Though nakakatulong naman ho yung Philhealth makabawas ng bills, pero, iba pa rin ho kung mayroon kang HMO, kahit papaano, bibigyan ka niyan ng kapanatagan."*	Greater Financial Coverage and Reduced Out-of-Pocket Expenses with HMO; Broader Access to Private and Accredited Healthcare Facilities; Perception of PhilHealth as Limited or Supplementary Support; Enhanced Peace of Mind and Sense of Security with HMO
HMO Cardholder 6	*"Yung sa Philhealth kasi, yung coverage niya lang is sa hospitalization, so kailangan muna ma-*	Faster and Easier Access to Healthcare Services under

	confine ka muna bago mo magamit yung Philhealth. Hindi nau-utilize yung Philhealth, outside of that, even if maliit lang yung contribution, hindi ko nakikita na easy access siya sa healthcare system, unlike yung HMO health card kapag accredited yung doctor or yung diagnostic center, ambilis ng process, so malaki ang difference, and mas easy access yung HMO."	HMO; Perception of PhilHealth as Limited or Supplementary Support		
HMO Cardholder 7	*"Malaki yung difference in terms of kung ano yung kayang i-cover ng HMO against Philhealth. Ang pakakaintindi ko, may specific value lang na nilaan ng gobyerno sa specific disease, so yung sa HMO, is for more financial security when seeking medical attention. So mas malaki yung peace of mind sa HMO, since yung Philhealth is maliit lang, and mas malaking chance na mag out of pocket."*	Greater Financial Coverage and Reduced Out-of-Pocket Expenses with HMO; Perception of PhilHealth as Limited or Supplementary Support; Enhanced Peace of Mind and Sense of Security with HMO	HMO Cardholder 9	*"Nung wala pa akong HMO at nagrerely ako sa PhilHealth, ang haba ng pila sa government hospitals. Mura sya pero ang hassle i-avail ang mga services. Pero sa HMO, convenient dahil halos private ang accredited hospitals nila, malinis, maganda ang facilities, at mabilis ang services. Reliable rin ang mga results from these hospitals."*	Broader Access to Private and Accredited Healthcare Facilities; Faster and Easier Access to Healthcare Services under HMO; Enhanced Peace of Mind and Sense of Security with HMO
HMO Cardholder 8	*"Nagagamit ko ang HMO sa emergency check-up o confinement unlike sa PhilHealth na sinasabi ng hospital na hindi applicable ang PhilHealth sa*	Greater Financial Coverage and Reduced Out-of-Pocket Expenses with HMO; Faster	HMO Cardholder 10	*"So we do have a law about supposedly, the Universal Health Care, where everything's free, but everything is free for certain government hospitals only, and usually it's not well-equipped, even if there are good doctors, so having a good HMO will give access to*	Greater Financial Coverage and Reduced Out-of-Pocket Expenses with HMO; Broader Access to Private and Accredited Healthcare Facilities

better medical services in the country, so having an HMO that has good coverage, and that you can rely on, gives better peace of mind."

The findings indicate that HMO coverage offers greater financial protection, faster access to healthcare services, and a wider range of accredited facilities compared to PhilHealth, particularly in private hospitals and clinics. Participants acknowledged that while PhilHealth provides valuable assistance, it remains limited and supplementary, emphasizing the advantage of HMOs in delivering convenience, reliability, and overall satisfaction.

HMO members reported broader coverage and quicker service approvals, with significant reductions in medical expenses, especially when combined with PhilHealth benefits. In contrast, PhilHealth was perceived as providing only partial or disease-specific support, often restricted to public hospitals. Respondents also expressed that HMOs give them peace of mind and a stronger sense of security, as access to quality private healthcare fosters both financial and emotional stability.

These findings support Sales et al. (2020), who found that private insurance enhances access to quality healthcare and minimizes treatment delays. Similarly, Montemayor et al. (2025) noted that PhilHealth's limited coverage drives individuals to seek private alternatives. The World Health Organization (2025) likewise observed that inadequate public healthcare systems in developing nations push citizens toward private insurance. Overall, participants' preference for HMOs reflects a practical response to the limitations of public health insurance, underscoring the need for more integrated and equitable healthcare systems in the Philippines.

2. HMO individual cardholders coping strategies with the challenges and demands associated with their healthcare coverage

2.1 Effects of HMO-Related Challenges on Healthcare-Seeking Behavior

Table 2.1 Behavioral and Psychological Responses to HMO System Challenges

Participants	Responses	Sub-ordinate Themes
HMO Cardholder 1	*"It really has an effect, especially if my parents reside in the province. Sometimes they have to go to Manila to avail the HMO, or else if it's really an emergency, they can't use it because the nearby hospital is not accredited, they have to pay cash from their pockets."*	Delayed or Avoided Healthcare Due to Accessibility and Approval Barriers
HMO Cardholder 2	*"Nahihirapan silang i-please yung mga gustong iapply yung HMO, mas kampante sila sa nauna nilang HMO kasi iyong mga ni-lobby nilang HMO may feedback na ganoon yung nangyayari so yun yung nagiging epekto."*	Distrust and reluctance to switch due to negative HMO feedback
HMO Cardholder 3	*"It adds another layer or step, for instance, for emergencies. Instead of going straight to the nearest hospital we have, we still need to check first if they're accredited. So behavior-wise, we have to do a bit of research on which one and go straight to that hospital."*	Delayed or Avoided Healthcare Due to Accessibility and Approval Barriers; Adaptation and Coping Behavior in Navigating HMO Processes
HMO	*"Kailangan lang ng*	Adaptation

Cardholder 4	*mahabang pasensya sa pag-a-avail ng services na covered ng card since mas mura ko syang nakukuha dahil sa HMO at wala na akong out-of-pocket expenses."*	and Coping Behavior in Navigating HMO Processes		*pa siya, kung nagb-benefit pa ako dun sa binabayaran ko, or yung from my own pocket na lang. So yun yung nakita ko na challenges dito. Yung mental health, nakakadagdag siya ng isipin, nakakadagdag siya ng stress, lalo na kapag may sakit ka na, and then you want to go home, ma-checkup ka na kaagad, so kailangan muna maghintay ka for approval."*	
HMO Cardholder 5	*"Siguro ang marerequest ko lang, lalo na kapag sa mga probinsya, lawakan nila yung accredited hospitals. Kasi katulad ng mga magulang ko, may edad na. Nahirapan na sila pumunta sa malayo para lang ma-avail yung health card na kinuha ko para sa kanila. So nakakaapekto siya kasi imbis na mabigyan ka ng kaginhawaan, dahil iniisip mo na covered ka, eh kung limitado naman yung hospitals sa probinsya na accredited sila, so medyo nakakalungkot yung ganun. Inconvenient."*	Delayed or Avoided Healthcare Due to Accessibility and Approval Barriers	HMO Cardholder 7	*"Mas maganda kung mas mabilis na ma-approve, mas mabilis na matatapos, di na maghihintay nang matagal, and kung mas malawak sana yung network ng accredited hospitals ng HMO."*	Adaptation and Coping Behavior in Navigating HMO Processes
HMO Cardholder 6	*"In the beginning, ang parang nakikita ko ang naapektuhan, yung mental health. Kasi, you are ill, may sakit ka na nga, and then nagbayad kami, nagbayad ako, and then pag-kukuha ako ng service parang ang tagal magbigay. So kung minsan nagdadalawang isip na ako kung itutuloy ko*	Increased Stress and Mental Strain from System Inefficiencies	HMO Cardholder 8	*"Sometimes you have to set a schedule or delay the consultation because you need to wait for the approval and fall in line at the hospital. It takes a few more days to avail the HMO services depending on the doctor's schedule/availability. And sometimes you get better already before you can avail their services."*	Delayed or Avoided Healthcare Due to Accessibility and Approval Barriers
			HMO	*"Kahit na parang*	Continued

Cardholder 9	*dagdag bayarin ang HMO, pilit ko syang binabayaran kasi importante na may security ka kapag may emergencies. Priority ko pa rin bayaran ang HMO ko."*	Reliance on HMO Despite Inconveniences
HMO Cardholder 10	*"For emergency cases, it is pretty convenient since we can just go directly, but the only problem in the ER, is the time for approval, but for outpatient care, it can be discouraging, especially being told that there are limited slots, and the locations aren't convenient, which can also lead to delaying your needed care which can develop into a worse condition."*	Delayed or Avoided Healthcare Due to Accessibility and Approval Barriers

According to the interview responses, they reveal the recurring challenges among individual HMO cardholders, particularly concerning delayed approvals, limited accredited networks, and the resulting difficulty in accessing timely healthcare services. Many participants shared that they often have to wait for authorization or travel considerable distances to accredited hospitals, which discourages them from seeking care promptly. A few respondents also described the emotional toll of navigating these administrative barriers, such as feelings of stress and frustration when seeking medical attention. Most of the experiences of the participants highlight a gap between formal insurance coverage and the actual ease of service utilization.

These findings align with earlier literature emphasizing that insurance enrollment alone does not ensure financial or service protection. Park (2024) argues that it is the depth of benefits—rather than mere coverage—that determines the extent of protection against out-of-pocket expenses. In the Philippine context, many HMO plans exclude outpatient diagnostics or medications, leaving members financially vulnerable despite being insured. This pattern of underinsurance has also been observed in studies of low- and middle-income countries, where limited benefit depth and narrow provider networks diminish the practical value of coverage (Lasco et al., 2025).

The recurring issue of network limitations described by respondents resonates with international research on network adequacy, which shows that restricted provider lists and pre-authorization requirements often delay or deter care. Such administrative hurdles have been linked to poorer patient experiences, delayed treatment, and higher long-term healthcare costs (American Medical Association, 2023). Moreover, participants' accounts of adjusting their behaviour—such as researching accredited hospitals or delaying appointments until approvals are secured—reflect adaptive coping mechanisms noted in prior studies on health-seeking behaviour under constrained insurance conditions. Overall, the lived experiences of HMO individual cardholders highlight that the effectiveness of private health insurance depends not only on coverage existence but also on its operational design and responsiveness. Addressing administrative and network barriers is essential to making HMO membership genuinely protective and responsive to members' healthcare needs.

2.2 The influence of Perceptions on Healthcare Utilization Among HMO Individual Cardholders

Table 2.2 Perceptions Shaping Health-Seeking Motivation and Utilization Behavior of HMO Cardholders

Participants	Responses	Sub-ordinate Themes
HMO Cardholder 1	*"Even if you do have a health card, you don't feel secure; there's always this fear that the money you saved will go to the hospital, especially for severe sickness. The health card will not really give you security because of the coverage, it's not that big.* *It's not giving them the*	Reduced Confidence and Hesitation in Utilizing HMO Services; Utilization Affected by Financial Limitations

	confidence that if you have a health card, you feel secure, you don't feel that way. Is it the health card? Or is it the logo that, if you have a health card, you feel secure. It's good that you have a health card because it can help with things like check-ups, minimal check-ups from a doctor, but I don't think it's really that big of a help, especially if you're just paying the minimum."	Beyond Coverage	Cardholder 4	*ka ng HMO lalo na sa mga emergency situations. Kahit sa mamahaling ospital ka maconfine, basta covered sya ng HMO mo, wala kang magiging isipin sa babayaran."*	Reinforcement of Utilization During Emergencies and Practical Needs
HMO Cardholder 2	*"Sometimes nagkakaroon ng doubt kung covered ba siya, kailangan mo pang tanungin, research ka if covered ng HMO. Tanong muna bago gamitin yung HMO."*	Reduced Confidence and Hesitation in Utilizing HMO Services; Increased Awareness and Proactive Information-Seeking Behavior	HMO Cardholder 5	*"So maganda pa rin talaga na meron silang ginaganyan na offer. Kasi kung wala ka ding health card ang laki din talaga ng epekto lalo na kung sa akin magkano lang naman sahod ko sa isang buwan, so kung magkasakit yung magulang ko sir, or kahit magpa-check up, nawawala ko sa budget kung wala akong health card. Kaya kahit medyo hirap akong magbayad, sinisigurado ko na meron silang health card para kapag kailangan nila, wala na akong iniisip na gastos."*	Positive Reinforcement of Utilization During Emergencies and Practical Needs; Greater Willingness to Maintain and Maximize HMO Membership
HMO Cardholder 3	*"It's really for us knowing what accredited hospital and the coverage, in terms of behavior, it's not something that we could make a decision on, we have to do research, we have to call the Maxicare support hotline, so it is not as straightforward or convenient as we would like."*	Reduced Confidence and Hesitation in Utilizing HMO Services; Increased Awareness and Proactive Information-Seeking Behavior	HMO Cardholder 6	*"In the beginning, mahirap siya gamitin, kasi hindi kami aware sa paggamit nun, pero once na inaral ko na yung process, madali lang pala. Kelangan lang aware dun sa systems nila, sa protocol, and nakita ko naman na smooth yung operations, so mas nagagamit ko na."*	Increased Awareness and Proactive Information-Seeking Behavior
HMO	*"Importante na magkaroon*	Positive	HMO Cardholder 7	*"Nam-maximize ko naman yung coverage, like kapag may emergencies, nagagamit ko naman, or sa dental, since binabayaran ko naman, mina-maximize*	Positive Reinforcement of Utilization During Emergencies and

	ko na din."	Practical Needs; Greater Willingness to Maintain and Maximize HMO Membership	to Maintain and Maximize HMO Membership
HMO Cardholder 8	*"I have to wait for the availability of funds to avail medical services that's not covered by my HMO."*	Utilization Affected by Financial Limitations Beyond Coverage	
HMO Cardholder 9	*"Priority ko pa rin syang bayaran for emergency purposes."*	Positive Reinforcement of Utilization During Emergencies and Practical Needs; Greater Willingness to Maintain and Maximize HMO Membership	
HMO Cardholder 10	*"You want to have that peace of mind that if ever you need it, that it's there, and that you can actually avail of the services, hassle-free, and the convenience is a big thing, even if you don't need to use it yet."*	Positive Reinforcement of Utilization During Emergencies and Practical Needs; Greater Willingness	

The responses of the participants reveal two dominant behavioral patterns in relation to their use of health maintenance coverage: hesitation and reduced confidence in utilization, and positive reinforcement of membership during emergencies and practical needs. Several expressed doubt or uncertainty about whether specific services or hospitals were covered by their plans, which often led them to delaying the utilization of it until they confirmed eligibility or till they researched accredited providers. Others described the initial difficulty of understanding HMO procedures, which improved only after learning the system through personal experience. Conversely, many participants emphasized that having an HMO was vital during emergencies, providing reassurance and financial relief when hospitalization occurred. These patterns illustrate how perceived coverage clarity, convenience, and emergency utility shape members' engagement with their health insurance.

In addition, studies have shown that policyholders often underuse their health insurance because of confusion over coverage terms and limited awareness of accredited facilities (Lasco et al., 2022). Park (2024) similarly argues that insufficient benefit depth and poor communication of coverage details lead to "underinsurance," where insured individuals remain financially exposed and hesitant to seek care. Such uncertainty can translate into delayed treatment or unnecessary out-of-pocket spending, as reflected in participants who expressed the need to "research first" before using their HMO.

Furthermore, the emergence of proactive information-seeking behavior—such as calling hotlines or studying approval protocols—demonstrates adaptive coping. Participants who became familiar with the process reported smoother utilization and greater satisfaction. This supports findings that literacy and engagement with health

insurance systems can mitigate the negative effects of administrative barriers (Savin, 2025).

Taken together, these findings portray a dual reality: while HMOs in the Philippines provide valued financial protection, their effectiveness is tempered by informational and operational challenges. Members' confidence and utilization depend heavily on how transparent and user-friendly the system is, as well as on whether coverage extends meaningfully to everyday and preventive care—not just hospitalization. Addressing these gaps through simplified communication, wider accredited networks, and member education programs could strengthen both trust and effective use of HMO services.

2.3 Effects of Previous Experiences on the Utilization Behavior of HMO Cardholders

Table 2.3 Experiential Influences on Trust, Adaptation, and Continued Utilization of HMO Coverage

Participants	Responses	Sub-ordinate Themes
HMO Cardholder 1	*"Sometimes you think that even the coverage is 95,000, last time my bill was 8,000, and I still felt stressed because I kept on waiting for the approval, so it doesn't give me confidence. So I have this perception that if you use a health card, be prepared to get your whole day wasted waiting for their approval, not a good reputation, I guess."*	Reduced Confidence and Frustration Due to Delays in Approval Process
HMO Cardholder 2	*"Yes, nagkakaroon ng epekto yun dun sa paggamit namin gawa nang gusto mong gamitin o kaya i-avail yung ganoong service nung HMO kailangan mo munang maghanap ng hospital or doctor na accredited ng mismong HMO provider so ayun yung nagiging epekto so tumatagal yung process, tumatagal yung paghahanap mo kasi di katulad nung iba na madaling hanapan ng accredited."*	Difficulty in Accessing Accredited Hospitals and Providers
HMO Cardholder 3	*"Same thing, it's really about learning about the coverage cause it's not like we know what hospitals or the coverage, from there making the decision to where to go, which doctor is the best."*	Development of Proactive and Informed Health-Seeking Behavior
HMO Cardholder 4	*"Good experience sya dahil may access ka sa private hospital and clinics at nasasave ka ng HMO sa out-of-pocket expenses."*	Increased Trust and Willingness to Continue Using HMO
HMO Cardholder 5	*"Nakakaapekto siya kasi halimbawa, kung paano kung emergency, tapos yung malapit na hospital sa bahay mo, like, sa amin, sa Quezon Province, medyo malayo pa kami sa Lucena. So yung malapit na ospital. Paano yun, so, minsan, eto pa yung na-experience ko, matagal sumagot yung health card provider para mag-confirm. So nakakaapekto siya, na imbis na mabilis ang pagpapa-ospital mo, mapapatagal. Ang alam ko nga sir, sa ibang bansa eh, lalo na kung magpapa-ospital ka, and*	Reduced Confidence and Frustration Due to Delays in Approval Process; Difficulty in Accessing Accredited Hospitals and Providers

	emergency, hindi na kailangan hanapan ng health card. Dine-diretso ka na sa ospital, at saka na lang yan. Saka na nila hinahanap kapag yung na-attendan na yung needs mo."	
HMO Cardholder 6	*"Kapag may kaagad akong nararamdaman, bukod pa dun sa APE, tinitignan ko na kaagad kung merong doctor na accredit na malapit sa amin, so hindi ako naghe-hesitate na magpa-check up kaagad."*	Development of Proactive and Informed Health-Seeking Behavior
HMO Cardholder 7	*"For the past 11 years, yes, gusto kong ipagpatuloy yung paggamit ko ng HMO, based on my experiences."*	Increased Trust and Willingness to Continue Using HMO
HMO Cardholder 8	*"I have the peace of mind that if anything happens to me, I can avail medical services under my HMO policy."*	Increased Trust and Willingness to Continue Using HMO
HMO Cardholder 9	*"Convenient magkaroon ng HMO dahil napapadali yung pag-avail ng services at wala akong binabayaran dahil covered sya ng HMO plan ko."*	Increased Trust and Willingness to Continue Using HMO
HMO Cardholder 10	*"If you want to avoid inconveniences/long wait, paying upfront with money is much faster compared to the long waiting time for approval, even just for minor injuries."*	Reduced Confidence and Frustration Due to Delays in Approval Process

The responses highlight three main patterns in HMO utilization: frustration with approval delays, difficulty accessing accredited providers, and growing trust among experienced members. Many participants described long waiting times for approval and the inconvenience of finding accredited hospitals, especially in provincial areas, which weakened their confidence in HMO services. Others, however, expressed satisfaction after successful claims, emphasizing the convenience and financial security HMOs provide.

These findings reflect the persistent issue of administrative barriers in insurance systems. Prior-authorization delays and complex procedures have been shown to reduce patient satisfaction and deter care-seeking (American Medical Association, 2024; Savin, 2025). The geographic difficulty of locating accredited facilities further supports research on network inadequacy and spatial inequity in healthcare access (Lasco et al., 2022; Park, 2024).

Despite these challenges, several participants reported improved experiences once familiar with HMO procedures, demonstrating that information and literacy can mitigate frustration and foster trust. Similar results were noted by Quimbo et al. (2008), who found that awareness of benefits enhances effective insurance use. Overall, these accounts reveal that while HMOs offer valued financial protection, their impact is limited by administrative inefficiencies and network constraints. Streamlining approval processes and expanding accredited providers could strengthen both confidence and accessibility among members.

2.4 Perceptions of Affordability and Value of HMO Plans Relative to Coverage and Benefits

Table 2.4 Perceived Cost–Benefit Relationship and Satisfaction with HMO Coverage

Participants	Responses	Sub-ordinate Themes
HMO Cardholder 1	*"It has ups and downs. If you want to go to the hospital for a check-up,*	Perceived Balance and Value-for-

	you don't have to worry. If you feel sick, you don't have to worry about the money because you have a health card, so you can go anywhere, even if you don't have cash. (The 95,000 coverage) it helps for the check-ups, but not for major."	Money in HMO Plans; Dissatisfaction Due to Limited Coverage for Major or Severe Illnesses
HMO Cardholder 2	*"There are times na okay, di naman totally hindi pero kadalasan nakukulangan ka dun sa kailangan na benepisyo versus dun sa binabayaran mo so hindi ka rin ganoon ka-satisfied, dun yung nagkakaroon ng iniisip na baka magpalit na lang kasi kulang yung kailangan mong benefits."*	Dissatisfaction Due to Limited Coverage for Major or Severe Illnesses; Perceived Inequity Between Premium Cost and Benefit Limitations
HMO Cardholder 3	*"I think long-term it's better to have HMO on hand rather than to pay everything upfront, but of course we still have to pay 18,000-20,000 a year. It's something that would give you peace of mind if something happens like an emergency. Ultimately, it's still an affordable investment."*	Perceived Balance and Value-for-Money in HMO Plans; Cost-Justified Peace of Mind and Financial Protection
HMO Cardholder 4	*"Yes, affordable sya dahil 16k lang binabayaran ko pero ang coverage ng HMO ko ay 80k."*	Perceived Balance and Value-for-Money in HMO Plans; Cost-Justified Peace of Mind and Financial Protection
		and Financial Protection
HMO Cardholder 5	*"Hindi ho [sufficient yung premium na binabayaran] sir. Kapag meron kang major operation parang wala ding silbi yung health card. Nakakatulong lang siya like pang check-up check-up, pero kung meron kang kailangan major na operasyon, malaki pa din [ang nailalabas]. Alam niyo naman po ang mga ospital dito, pagpasok mo pa lang, pera, pera pera, so mababa talaga siya? Mukha lang siyang malaki kung wala kang sakit. Pero kapag may sakit ka, barya lang. Parang ganun ho."*	Dissatisfaction Due to Limited Coverage for Major or Severe Illnesses; Perceived Inequity Between Premium Cost and Benefit Limitations
HMO Cardholder 6	*"Sa tingin ko po, win-win situation po sa akin on my side, kung meron po akong health care provider based sa binabayaran ko annually."*	Perceived Balance and Value-for-Money in HMO Plans
HMO Cardholder 7	*"I think may value naman, maayos naman yung benefits na nakukuha ko based dun sa binabayaran ko. Most of the time naman kasi, mabilis yung approval and maayos yung services."*	Perceived Balance and Value-for-Money in HMO Plans; Cost-Justified Peace of Mind and Financial Protection
HMO	*"Yes, because as a*	Perceived

Cardholder 8	*bread-winner, I cannot afford unexpected expenses, although I have savings. I can provide my dependents' medical consultations under my HMO without shelling out money."*	Balance and Value-for-Money in HMO Plans; Cost-Justified Peace of Mind and Financial Protection
HMO Cardholder 9	*"Yes, very helpful magkaroon ng HMO dahil kung iko-compute mo ang expenses ng annual check-up, emergency, at dental, sulit ang binibayad ko sa HMO."*	Perceived Balance and Value-for-Money in HMO Plans; Cost-Justified Peace of Mind and Financial Protection
HMO Cardholder 10	*"Yes, I think my premium provides additional value, because comparing other coverage premiums compared to private ones with bigger premiums, the ones with bigger premiums provide the services I need."*	Perceived Balance and Value-for-Money in HMO Plans; Perceived Inequity Between Premium Cost and Benefit Limitations

Based on the responses provided by the participants, they have felt that the premium they are paying for their HMO coverage gives them an added value for their money. With their experience in using their HMO coverage, they have perceived the balance and value for money in HMO plans. The annual premium offsets the expenses that are incurred when they are hospitalized or require other medical services. Despite this, there are still whose insights show the contrary. There is still a perception that the premium being paid is not not equitable as compared to the benefits being offered. There is a perceived inequity between premium cost and benefit limitations.

This perception is aligned with an article reissued in 2025 by the Public Medicine of the National Library of Medicine: Impact of HMO ownership on Management Processes and utilization outcomes by M. Ahern and C. Molinari stated that national managed care organization-owned HMOs are less likely to use provider capitalization, out-of-pocket payments for hospital use, catastrophic case managements, and hospital risk sharing to lessen use of the national funds.

2.5 Perceptions of the Importance and Advantages of Having an HMO in Addition to PhilHealth

Table 2.5 Perceived Value and Complementary Role of HMO in Strengthening Healthcare Security Beyond PhilHealth

Participants	Responses	Sub-ordinate Themes
HMO Cardholder 1	*"I do recommend having HMO. That's why I pay for my parents'."*	HMO as a Source of Financial Security and Peace of Mind; Endorsement and Recommendation of HMO to Others
HMO Cardholder 2	*"Mas okay kung mayroon kang HMO kasi minsan di covered ng Philhealth pero covered ng HMO, pero minsan covered ng Philhealth pero hindi covered ng HMO, yung ang kagandahan ng mayroong HMO at saka mayroon ka ring Philhealth."*	Recognition of HMO as Essential and Complementary to PhilHealth
HMO Cardholder 3	*"Absolutely (recommend HMO), I think it's a necessity especially with the*	HMO as a Source of Financial Security and Peace of Mind; Endorsement

	hospitalization being quite expensive especially in the Philippines even you have to pay a premium ultimately having HMO not only give you peace of mind but some sort of financial flexibility as well."	and Recommendation of HMO to Others		*benepisyo."*	
HMO Cardholder 4	*"Yes, maganda na mayroon kang HMO dahil madalas ng hospital at clinics tumatanggap ng HMO. Makakapag-avail ka rin ng services katulad ng check-ups, laboratory nang walang binabayaran."*	Positive Perception of HMO's Wider Coverage and Accessibility	HMO Cardholder 6	*"Even though mandatory yung Philhealth, and minimal lang yung amount, so if ever na later, mahospital tayo, with the help of Philhealth and HMO, magtutulong din sila. We are more on security and insurance, kaysa pagdating ng panahon na mahospitalize tayo, kung wala tayong nitong mga healthcare na ito, medyo struggle pa tayo, pero once lang ma-ospital yung member, doon lang magagamit yung Philhealth."*	Recognition of HMO as Essential and Complementary to PhilHealth; HMO as a Source of Financial Security and Peace of Mind
HMO Cardholder 5	*"Oho. Kasi katulad nga nung nabanggit ko, iba pa din na mayroon kang HMO aside sa Philhealth, kasi mas nagagamit actually yung HMO kaysa sa Philhealth. Hindi ko pa ho nasubok gamit ang Philhealth, eh. Parang hindi ko alam kung paano. Ang naaalala ko lang po is yung sa lola ko, binawasan yung total bill niya ng Philhealth. Parang 18k ata yun, pero iba pa rin talaga kapag may HMO ka. Mas may*	Recognition of HMO as Essential and Complementary to PhilHealth; Positive Perception of HMO's Wider Coverage and Accessibility	HMO Cardholder 7	*"Mas malaking bagay na magkaroon ng HMO compared to Philhealth, kasi kahit papaano may certain amount na malaki kung may HMO ka, compared sa Philhealth, na for certain diseases lang. So mas maganda na may HMO ka aside sa Philhealth."*	Recognition of HMO as Essential and Complementary to PhilHealth
			HMO Cardholder 8	*"Yes, it's very important to have an HMO because Philhealth coverage is limited compared to my HMO plan.*	Positive Perception of HMO's Wider Coverage and Accessibility

	You can easily avail medical services with an HMO compared to PhilHealth services. Like sa mental health services, sa PhilHealth hindi sya covered pero sa HMO, included sya sa coverage."		*services needed, but with an HMO, when you need one, regardless of reason, it can help save money."*
HMO Cardholder 9	*"Sulit yung pagkakaroon ng HMO dahil marami kang pagpipilian na hospitals na less hassle. Challenging lang magbayad ng HMO pero I encourage everyone to get one for emergency purposes, convenience, peace of mind. Maganda rin ang services at benefits ng HMO kesa sa PhilHealth."*	HMO as a Source of Financial Security and Peace of Mind; Positive Perception of HMO's Wider Coverage and Accessibility; Endorsement and Recommendation of HMO to Others	
HMO Cardholder 10	*"Yes, I recommend it, because Philhealth does not cover it all. I believe it only covers 30 or 40% of your total medical bills? And I'm not even sure if it covers the professional fee. With only Philhealth, you'll still have to pay a big chunk out of pocket, depending on your medical*	Recognition of HMO as Essential and Complementary to PhilHealth; HMO as a Source of Financial Security and Peace of Mind; Endorsement and Recommendation of HMO to Others	

All respondents who have experienced utilizing their HMO coverage have unanimously recommended securing an HMO coverage, not only for themselves, but also for their beneficiaries. Their experiences has provided them an insight that the security of having an HMO coverage (despite its flaws in their system) still gives the financial security that they may need when a medical emergency arises. HMO is seen as a source of financial security and peace of mind. It reduces the financial risk that the insured is exposed to especially when you look at it in the local setting wherein a universal healthcare system (Philhealth) is not yet fully established as compared to the other universal healthcare system in other parts of the world. There is the recognition of HMO as essential and complementary to Philhealth. For all respondents, they have unanimously provided recommendation of HMO to others because of the benefits it provides as compared to the annual premium it costs.

This positive perception is aligned with an article in reissued in 2025 by the Public Medicine of the National Library of Medicine : Growth of HMOs challenges traditional health care by Atkinson S. stating that Health Maintenance organizations (HMOs) - a method of prepaid delivery health care delivery guaranteeing all medical care for a fixed annual premium - are growing rapidly and presenting traditional medical institutions with increased competition. Hospitals in response are accrediting these HMO companies for them to retain a percentage of the patient population, as less HMO accreditations means less incoming patients for these traditional medical institutions.

Proposed Action Plan to Address the Challenges Encountered by HMO Individual Cardholder

Key Results Area	Objectives	Strategies / Activity	Persons Involved	Resources	Estimated Budget	Time Frame	Success Indicator
EFFICIENT AND FASTER APPROVAL AND BILLING PROCESSES	To reduce processing time for billing and approvals	Implement a digitalized billing and approval system with automated verification and real-time tracking	HMO management, IT department, partner hospitals	Computers, software systems, training materials, internet connection	₱150,000	6 months	Reduced waiting time; improved transaction efficiency
WIDER AND MORE ACCESSIBLE ACCREDITED HEALTHCARE NETWORK	To expand the number of accredited hospitals and clinics, especially in underserved areas	Establish partnerships and accreditation agreements with additional healthcare providers nationwide	HMO network coordinators, hospital administrators, regional representatives	Communication tools, contracts, marketing materials	₱50,000	4 months	20% increase in accredited facilities; improved service coverage
TRANSPARENT AND RESPONSIVE HMO SERVICE SYSTEM	To enhance communication and transparency in procedures and reimbursements	Develop an online member portal and 24/7 customer hotline for tracking claims and inquiries	HMO management, customer service team, IT support	Website and hotline setup, training sessions	₱80,000	3 months	Higher member satisfaction and reduced unresolved inquiries
INFORMED AND EMPOWERED HMO MEMBERS	To increase member awareness of coverage inclusions, exclusions, and benefits	Conduct awareness campaigns, webinars, and distribute informative brochures and FAQs	HMO marketing team, researchers, healthcare providers	Printed materials, online platforms	₱30,000	2 months	80% of members demonstrate improved understanding of their coverage
STRENGTHENED MEMBER CONFIDENCE AND SATISFACTION	To improve overall trust and engagement with HMO services	Launch feedback surveys, service quality assessments, and improvement	HMO management, customer relations officers, data analysts	Survey tools, database software	₱10,000	Quarterly	At least 30% increase in satisfaction ratings

		monitoring					

V. CONCLUSION

The findings of this study revealed a complex yet insightful understanding of the lived experiences of HMO individual cardholders in accessing healthcare coverage and services. Participants consistently identified long waiting times, delayed billing approvals, and limited accredited facilities as major challenges that negatively affect their healthcare experience. These administrative inefficiencies not only cause inconvenience but also discourage timely medical consultations and contribute to additional out-of-pocket expenses. The results indicated that procedural delays and restricted provider networks reduce the perceived value and utilization of private health insurance in the Philippines. Such systemic barriers highlight the need for greater efficiency and transparency in the HMO approval and reimbursement processes.

Despite these concerns, the study also found that participants held generally positive perceptions of affordability, practicality, and financial protection associated with HMO membership. Many respondents emphasized that their coverage significantly reduced the financial strain of medical expenses, particularly for consultations, laboratory tests, and emergency care. The "cashless" transaction system in accredited hospitals was cited as a major convenience, providing both peace of mind and a sense of financial security. Moreover, participants observed that digital innovations such as online approval systems and improved customer service—reflect a gradual modernization of HMO operations, which enhances accessibility and member satisfaction.

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Contract of Service (COS) Employee's Motivation and Performance Evaluation on the Achievement of Organizational Goals

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Abstract *— This study investigates the relationship between employee motivation, performance evaluation, and organizational goal achievement among Contract of Service (COS) employees in National Government Agencies (NGAs) within Quezon City, Philippines. Using a descriptive quantitative research design, data were gathered through a structured survey questionnaire administered to 100 COS employees. The results analyzed using descriptive statistics, Pearson Product-Moment Correlation, and Kruskal-Wallis Test revealed that COS employees are primarily motivated by intrinsic factors such as meaningful work, recognition, and opportunities for personal growth. A supportive work environment also emerged as a significant motivator. While bureaucracy and job security had moderate influence, these factors did not substantially reduce engagement among highly motivated employees. Performance evaluations conducted by immediate supervisors consistently indicated high levels of efficiency and competence, with most employees rated "Very Satisfactory" or "Outstanding." The achievement of organizational goals was strongly associated with clear goal specificity, effective feedback mechanisms, and well-defined strategies, while the factor of "challenge" showed no significant correlation with motivation. A strong positive relationship existed between motivational factors and goal achievement, and employees rated "Outstanding" demonstrated greater goal commitment than those rated "Very Satisfactory." The study concludes that government agencies should strengthen intrinsic motivators by fostering meaningful work, recognition, and professional development programs. Moreover, reinforcing clear goal setting, transparent feedback, and supportive work environments can sustain high motivation and performance among COS employees while addressing concerns related to job security and bureaucratic processes to enhance overall organizational effectiveness.*

Keywords *— **COS employees, motivation, performance evaluation, organizational goals***

I. INTRODUCTION

Employee motivation, often described as the psychological forces that determine the direction of a person's behavior in an organization, a person's level of effort, and a person's level of persistence, plays a crucial role in driving individuals to exert best efforts. A highly motivated workforce is often associated with increased productivity, enhanced creativity, reduced absenteeism, and a more positive work environment. In parallel, performance evaluation serves as a systematic process to assess an individual's job performance and contribution to the organization. Effective performance evaluations also serve as crucial tools for identifying areas for improvement,

recognizing accomplishments, fostering professional development, and aligning individual efforts with organizational with the strategic objectives of the organization.

Globally, organizations face ongoing challenges in creating performance evaluations that not only assess but also motivate employees. McKinsey & Company (2024) found that employees are more motivated when goals are clear, regularly updated, and connected to organizational outcomes. The Incentive Research Foundation (2020) further highlighted that well-structured incentive and feedback systems can improve performance by 25–44%, while poorly designed evaluations can discourage employees and increase turnover. These findings underscore that motivation and evaluation are not administrative processes alone, but strategic factors that impact organizational sustainability and competitiveness.

In the Philippine context, research has shown that employee motivation is strongly influenced by both intrinsic and extrinsic factors. Recognition and career development opportunities often inspire employees, but job security, fair treatment, and salary remain equally important in public service (Sia & Dela Cruz, 2023). A study of Quezon City Hall employees revealed that while motivation and job satisfaction are positively related, their link to job performance was inconsistent, suggesting that existing evaluation systems may not fully capture contributions (Estrellado, 2023). Moreover, organizational culture and leadership practices have been found to shape motivation significantly, particularly among non-tenured or contractual workers with limited growth opportunities (Guinto & Medina, 2024).

At the local level, Contract of Service (COS) and Job Order (JO) employees in Quezon City and Metro Manila government agencies often experience lower job security and limited recognition compared to regular employees. Research on end-of-contract workers in NGAs in Quezon City indicated that motivation and pro-social behavior are closely tied to fairness and recognition in evaluation systems (Andres, 2024). Similarly, Reyes (2024) found that inequities in performance evaluations among non-uniformed personnel in a Quezon City police station negatively affected morale and job performance. These results emphasize the vulnerability of COS employees, whose contributions are essential yet often underappreciated in the achievement of organizational goals.

Given these issues, there is a need to closely examine how motivation, hygiene factors, and performance evaluation influence the achievement of organizational goals among COS employees in NGAs within Quezon City. Understanding these relationships will help identify gaps in current practices and provide a basis for improvement since COS employees play a frontline role in government service delivery, enhancing their motivation and evaluation systems could directly improve efficiency, engagement, and service quality. Thus, this research may help understand the major problem organizations are facing in present times as how to keep top talent satisfied, engaged, motivated and retained.

Research Questions

1. What are the COS employees' motivation that influence the achievement of organizational goals?
   - 1.1. The Work Itself and Responsibility
   - 1.2. Achievement and Recognition
   - 1.3. Personal Growth and Advancement
   - 1.4. Bureaucracy and Job Security
   - 1.5. Relationships and Work Conditions
2. What is the COS employees' performance evaluation as rated by the immediate supervisor?
3. What influence on the achievement of Organizational Goals of COS employees in terms of:
   - 3.1. Specificity
   - 3.2. Challenge
   - 3.3. Feedback
   - 3.4. Goal Commitment
   - 3.5. Task Complexity
   - 3.6. Strategies
4. Is there a significant relationship between the employee's motivation and the achievement of organizational goals?

5. Is there a significant relationship between the employees' performance evaluation and the achievement of organizational goals?

II. RELATED LITERATURE

Aligned with the objectives of this research, the researchers conducted a comprehensive review of related literature obtained from various credible sources to establish a strong theoretical and empirical foundation for the study. This review provides a clear understanding of how employee motivation, hygiene factors, and performance evaluation influence the achievement of organizational goals, particularly among Contractual of Service (COS) employees in National Government Agencies (NGAs) within Quezon City. The discussion is grounded on two main theoretical frameworks: Herzberg's Motivation–Hygiene Theory and Goal-Setting Theory, which explain the behavioral and organizational mechanisms that drive employee performance and satisfaction. Accordingly, this chapter presents: (1) the underpinning theories of the study, (2) conceptual discussions on motivation, hygiene factors, and performance evaluation in public sector contexts, and (3) empirical findings on their relationship to the achievement of organizational goals.

Herzberg's Motivation–Hygiene Theory

Herzberg's Motivation–Hygiene Theory, also known as the Two-Factor Theory, differentiates between motivator factors that create job satisfaction (such as achievement, recognition, and personal growth) and hygiene factors that prevent dissatisfaction (such as supervision, policies, job security, and work conditions). Herzberg argued that improving hygiene factors alone does not necessarily motivate employees; rather, true motivation arises from intrinsic satisfaction through meaningful work (Ali & Anwar, 2021). In public organizations where employees often have limited tenure or benefits, this theory provides a valuable framework for understanding how intrinsic satisfaction can sustain commitment and engagement despite employment constraints.

Achievement and Recognition

Achievement and recognition are among the strongest intrinsic motivators in the workplace. (Gallup, 2024) found that employees who receive consistent acknowledgment are 45% more engaged and less likely to leave their jobs. Likewise, recognition fulfills employees' needs for esteem and belonging, enhancing both intrinsic and extrinsic motivation (Imran, Faathir, & Firmansyah, 2025). In the same way, (Jo and Shin 2025) emphasized that recognition fosters fairness and strengthens the bond between employees and management. Thus, recognition serves as a powerful tool for reinforcing employee morale and validating contributions—an especially crucial factor for contractual personnel whose sense of value often depends on acknowledgment rather than tenure.

The Work Itself and Responsibility

The nature of work and the degree of responsibility significantly affect motivation and engagement. (Mulyana and Izzati 2022) observed that educators with greater autonomy in decision-making reported higher job satisfaction and productivity. (Jerab and Mabrouk 2023) highlighted that participative leadership, where supervisors delegate meaningful responsibilities, cultivates trust and ownership. Similarly, (Khan, 2020) noted that when employees perceive their tasks as purposeful and aligned with organizational goals, their sense of accountability strengthens. With this, empowering workers through autonomy and trust becomes a key motivational strategy that enhances productivity even in contractual or temporary employment contexts.

Personal Growth and Advancement

Opportunities for career development play a vital role in sustaining motivation. (Hosen et al. 2024) reported that professional training improves employees' self-efficacy, well-being, and long-term performance. Likewise, (Riesner et al. 2025) emphasized that continuous training supports professional growth and the organization's overall competitiveness. In relation to COS employees, providing structured learning and skill-building opportunities not only addresses performance needs but also fulfills their aspirations for advancement, reinforcing loyalty and organizational alignment.

Bureaucracy and Job Security

Bureaucracy and job insecurity are among the primary demotivating factors in public institutions. (Bonsu, 2024) found that excessive bureaucracy reduces responsiveness and hampers decision-

making. Conversely, (Adham, 2023) argued that inclusive management and open communication strengthen trust and engagement. (Hofmann and Strobel 2020) further demonstrated that organizational transparency increases satisfaction and reduces turnover intentions. Thus, streamlining bureaucratic systems and ensuring procedural fairness can mitigate anxiety among non-permanent employees, creating a more stable and motivated workforce.

Relationships and Work Conditions

Positive interpersonal relationships and healthy working conditions are vital in maintaining employee motivation. (Asan, 2020) revealed that perceived organizational support enhances well-being and engagement. (Haryanto and Maianto 2024) showed that teamwork fosters shared accountability and communication effectiveness, while (Vemuri, 2024) found that trust-based collaboration improves productivity and morale. These findings suggest that cultivating supportive workplace relationships and cooperative cultures is essential for sustaining motivation within dynamic and resource-limited government environments.

Goal-Setting Theory

Goal-Setting Theory, developed by Edwin Locke and Gary Latham, asserts that specific, measurable, and challenging goals enhance performance when supported by feedback and commitment. The theory emphasizes converting broad organizational visions into concrete, actionable objectives to improve focus and productivity (Kalogiannidis et al., 2025). (Kim et al., 2020) likewise demonstrated that strategic alignment between personal and organizational goals promotes self-determination and performance consistency. In relation to COS employees, clear and measurable targets compensate for limited job permanence by providing purpose, direction, and accountability.

Specificity (Goal Clarity)

Goal specificity is essential for effective performance evaluation. (Jeong, Healy, and McEwan 2023) found that specific and measurable objectives enhance focus and self-regulation. (Liu, 2025) confirmed that proximal goal setting improves persistence and performance outcomes. Thus, defining clear performance indicators ensures that contractual employees understand expectations, enabling them to deliver results aligned with institutional standards.

Challenge (Goal Difficulty)

Challenging but attainable goals stimulate motivation, persistence, and professional growth. (Healey et al., 2023) found that employees exert greater effort when faced with more demanding objectives, provided these goals remain realistic and achievable. Similarly, (Hopfner and Keith 2021) demonstrated that setting high yet clear performance targets is among the most effective managerial tools for enhancing motivation and productivity. (Huang, 2023) further emphasized that goal difficulty plays a critical role in shaping human behavior, as appropriately challenging tasks encourage individuals to push their capabilities and attain higher performance. In relation to COS employees, the strategic assignment of moderately difficult goals not only sustains motivation but also fosters a sense of competence and accomplishment within time-bound or project-based roles.

Feedback

Feedback mechanisms are vital for reinforcing engagement and continuous learning. (Drouvelis and Paiardini 2022) revealed that high-quality feedback fosters improvement and sustained effort. (Umoh, 2025) highlighted that effective communication strengthens decision-making and collaboration, while (Carreno, 2024) demonstrated that real-time feedback loops enhance adaptability to organizational change. In the context of COS employment, consistent feedback serves as an informal evaluation system that reinforces accountability and professional growth.

Goal Commitment

Goal commitment reflects determination and persistence in achieving objectives. (Manzoor, Wei, and Asif 2021) found that intrinsic rewards heighten motivation and goal adherence. (Macinati and Rizzo 2025) noted that participation in goal-setting improves ownership and accountability, while (Nguyen, 2021) established that engagement fosters loyalty and performance sustainability. Hence, encouraging active participation in goal formulation fosters psychological commitment, which can substitute for formal tenure in maintaining workforce dedication.

Task Complexity

Task complexity moderates the relationship between goals and performance. (Bardusova, 2025) observed that complex tasks require additional time, coordination, and support. (Debara, 2022) emphasized that breaking large tasks into smaller, manageable steps enhances motivation and confidence, while (Wallbridge, 2022) cautioned that overly complex goals may hinder morale. Accordingly, managing complexity through supportive supervision and realistic goal structuring allows employees to perform effectively while preserving motivation and mental well-being.

Strategies Toward Organizational Goals

Integrating motivation and performance evaluation frameworks provides a holistic pathway for enhancing organizational productivity. (Brower, 2025) underscored that setting meaningful, values-based goals drives persistence and personal satisfaction. (Ball, 2021) found that goal-linked strategy execution improves self-regulation and performance monitoring. (Raza et al. 2023) emphasized that transparent communication fosters trust, facilitating alignment between individual and organizational priorities. In relation to COS employment systems, these integrated strategies create a cohesive environment where motivation, clarity, and fairness converge to advance public service performance.

III. METHODOLOGY

Research Design

This research utilized the descriptive-correlation research design (Bhandari, 2023). This research aims to examine and describe the relationship between different variables. Moreover, the Descriptive studies (Akerele, 2023) are aimed at finding out the relationship of Employee's Motivation and Performance Evaluation on the Achievement of the Organizational Goals. The design would involve collecting data from a sample of COS employees specifically in Government Agencies within Quezon City, National Capital Region using a questionnaire or survey and then using statistical analysis such as correlation analysis, to determine if a statistically significant relationship exists.

Locale of the Study

The setting is that the study is within the area of Quezon City Circle, Batasan Hills and in Commonwealth Avenue where a significant number of government agencies are located.

Respondents of the Study

The primary respondents of the study are contract of service (COS) employees. Studies are frequent with the government agencies as mentioned within the geographical area in Quezon City, National Capital Region.

Sampling Design

The sample of the study is composed of 100 Contract of Service (COS) employees within the geographical area in Quezon City. The researcher strategically selects respondents who have specific characteristics relevant to the study's objectives. Since the method of sample design is based on a non-probability, purposive sampling is susceptible to selection bias based on the researcher's judgement.

Statistical Tools

The quantitative data collected from the survey questionnaires were analyzed using both descriptive and inferential statistics. Descriptive statistics, including weighted means and verbal interpretations, were employed to summarize and describe the respondents' perceptions of employee motivation and its influence on organizational goal achievement. This allowed for an understanding of the central tendencies and distribution of responses for each indicator and overall dimension.

Inferential statistics, specifically Pearson Product-Moment Correlation (r-value) and Kruskal-Wallis Test were utilized to examine the relationships and differences between the variables. Pearson correlation was used to determine the strength and direction of the linear relationship between the motivational factors and the influences on organizational goal achievement. The significance of these correlations was tested at a 0.01 level (two-tailed). For comparing performance evaluation groups, an analysis similar to a t-test was used to determine if there was a statistically significant difference in their perceptions, with a significance level set at 0.05. This approach allowed for the testing of hypotheses and drawing conclusions regarding the

interplay between employee motivation, performance, and organizational objectives. All statistical analyses were performed using [Statistical Software, e.g., SPSS, R] to ensure accuracy and reliability of the results.

Ethical Consideration

The researcher ensures that in the conduct of data gathering, key considerations such as obtaining informed consent, ensuring confidentiality and privacy, avoiding harm, and maintaining honesty and integrity in data collection and reporting. And that provisions of the law on Data Privacy Act of 2012 are properly observed. The researcher observes and respects the Intellectual Property (IP) rights in the Philippines which are governed by the Intellectual Property Code (Republic Act No. 8293).

IV. RESULTS AND DISCUSSION

1. The COS employee's motivation influences the achievement of organizational goals in terms of the work itself and responsibility, achievement and recognition, personal growth and advancement, bureaucracy and job security, and relationships and work conditions.

Table 1.1: The COS employee's motivation that influences on the achievement of organizational goals in terms of The Work

INDICATORS	WEIGHTED MEAN	VERBAL INTERPRETATION	RANK
1. I am empowered enough to do my work	3.56	Strongly Agree	1
2. My work is challenging and exciting	3.50	Strongly Agree	2
3. My work provides me flexible time	3.25	Agree	5
4. My workplace is conducive for work	3.43	Strongly Agree	3
5. My workplace provides an opportunity for growth	3.38	Strongly Agree	4
OVERALL WEIGHTED MEAN	**3.42**	**Strongly Agree**	

Itself nd Responsibility

Legend:3.26 – 4.00 Strongly Agree (SA) 1.76 – 2.50 Disagree (D)

2.51 – 3.25 Agree (A) 1.00 – 1.75 Strongly Disagree (SD)

Table 1.1 presents an overall weighted mean of 3.42, verbally interpreted as "Strongly Agree," indicating that respondents perceive the work itself and responsibility as strong motivational factors influencing the achievement of organizational goals. This finding suggests that COS employees feel empowered and engaged when entrusted with meaningful tasks that allow them to demonstrate competence and accountability. The indicator *"I am empowered enough to do my work"* obtained the highest mean of 3.56, interpreted as Strongly Agree, showing that employees are motivated when they are given autonomy and trust in performing their duties. Likewise, *"My work is challenging and exciting"* ranked second with a mean of 3.50, implying that employees are inspired when their responsibilities provide opportunities for growth and fulfillment.

In contrast, the indicator *"My work provides me flexible time"* had the lowest mean of 3.25, interpreted as Agree, indicating that while employees appreciate some degree of flexibility, work schedules may still need improvement to better accommodate personal and professional balance. Despite this, the overall results demonstrate that COS employees are highly motivated by the nature of their work and their sense of responsibility. These findings emphasize the importance of creating an environment that values empowerment, accountability, and opportunities for growth, as such factors drive employees to perform effectively and contribute to the organization's long-term success.

This finding supports recent studies

highlighting that meaningful work and autonomy enhance employee motivation and performance. Albrecht et al. (2021) found that employees who perceive their work as purposeful and are given sufficient responsibility experience higher engagement and commitment to organizational goals. This aligns with the present result showing that COS employees feel more motivated when empowered and trusted to perform meaningful tasks.

Table 1.2: The COS employee's motivation that influences on the achievement of organizational goals in terms of Achievement and Recognition

INDICATORS	WEIGHTED MEAN	VERBAL INTERPRETATION	RANK
1. My work recognized outstanding performance, teamwork through tangible awards and certificates	3.09	Agree	5
2. I am satisfied to work because it recognized my achievement	3.23	Agree	4
3. I feel satisfied with my work when it is appreciated	3.64	Strongly Agree	1.5
4. I am being valued and it motivates me to stay	3.28	Strongly Agree	3
5. A sincere and genuine recognition boosts my morale	3.64	Strongly Agree	1.5
OVERALL WEIGHTED MEAN	**3.38**	**Strongly Agree**	

Legend:3.26 – 4.00 Strongly Agree (SA) 1.76 – 2.50 Disagree (D)

2.51 – 3.25 Agree (A) 1.00 – 1.75 Strongly Disagree (SD)

As shown in Table 1.2, the overall weighted mean of 3.38, verbally interpreted as "Strongly Agree," indicates that respondents generally perceive that achievement and recognition highly influence their motivation toward achieving organizational goals. This implies that COS employees' value being acknowledged for their accomplishments, as such recognition reinforces their sense of purpose and commitment to their work. The indicators *"I feel satisfied with my work when it is appreciated"* and *"A sincere and genuine recognition boosts my morale"* both obtained the highest mean of 3.64, interpreted as Strongly Agree, suggesting that employees derive greater motivation from genuine expressions of appreciation than from material incentives. These results affirm that positive acknowledgment of one's contribution enhances morale, job satisfaction, and overall work performance.

On the other hand, the indicator *"My work recognized outstanding performance, teamwork through tangible awards and certificates"* had the lowest weighted mean of 3.09, interpreted as Agree, indicating that while employees' value tangible recognition such as awards and certificates, they place greater importance on personal appreciation and verbal acknowledgment. The findings are consistent with Herzberg's Motivation-Hygiene Theory, which classifies *achievement* and *recognition* as intrinsic motivators that drive employee satisfaction. Therefore, organizations should strengthen recognition systems—both formal and informal—to sustain motivation, enhance employee retention, and promote the achievement of organizational goals

This finding supports Imran et al. (2025), who revealed that recognition and appreciation significantly enhance employee motivation and commitment. Similarly, COS employees feel more driven when their efforts are genuinely acknowledged.

Table 1.3: The COS employee's motivation that influences on the achievement of organizational goals in terms of Personal Growth and Advancement

INDICATORS	WEIGHTED MEAN	VERBAL INTERPRETATION	RANK
1. I received training/coaching that enhance my capabilities	3.32	Strongly Agree	3
2. My work allows me to improve my experience, skills and performance	3.45	Strongly Agree	1
3. My work offers an eligibility review session for CSC exams	3.12	Agree	5
4. My workplace promotes learning as a continuous process for growth and development	3.35	Strongly Agree	2
5. There is a positive reinforcement of culture in the organization	3.28	Strongly Agree	4
OVERALL WEIGHTED MEAN	**3.30**	**Strongly Agree**	

Legend:3.26 – 4.00 Strongly Agree (SA) 1.76 – 2.50 Disagree (D)
2.51 – 3.25 Agree (A) 1.00 – 1.75 Strongly Disagree (SD)

As shown in Table 1.3, the overall weighted mean of 3.30, verbally interpreted as "Strongly Agree," indicates that respondents generally perceive personal growth and advancement as key motivational factors influencing the achievement of organizational goals. This result implies that employees are encouraged when given opportunities to enhance their skills, knowledge, and work performance. The indicator "*My work allows me to improve my experience, skills, and performance*" obtained the highest mean of 3.45, interpreted as Strongly Agree, suggesting that COS employees feel motivated when their tasks enable continuous learning and professional development. Likewise, "*My workplace promotes learning as a continuous process for growth and development*" ranked second with a mean of 3.35, showing that employees value an environment that supports personal and professional advancement.

In contrast, the indicator "*My work offers an eligibility review session for CSC exams*" had the lowest mean of 3.12, interpreted as Agree, indicating that although such opportunities are appreciated, they may not be widely or regularly provided. Nonetheless, the overall results show a positive perception, meaning that COS employees consider growth opportunities as vital contributors to their motivation and productivity. This finding underscores the importance of maintaining programs that provide training, coaching, and developmental activities to further strengthen employee competence and commitment. Hence, enhancing professional advancement initiatives can help sustain motivation and align employee development with the organization's long-term objectives.

This finding supports Ye et al. (2022), who emphasized that leadership empowerment and opportunities for continuous learning enhance employee engagement and innovation. Likewise, COS employees feel more motivated when given chances to develop their skills and advance professionally.

Table 1.4: The COS employee's motivation that influences on the achievement of organizational goals in terms of Bureaucracy and Job Security

INDICATORS	WEIGHTED MEAN	VERBAL INTERPRETATION	RANK
1. A workplace that provides benefits like retirement pensions that contributes to a sense of job security	2.90	Agree	5
2. A workplace that focuses on empowering employees, equipping them with the necessary tools and resources	3.29	Strongly Agree	1
3. A workplace that encourages to be dynamic with sense of ownership to their achievements (COS)	3.26	Strongly Agree	2
4. A workplace that promotes fairness and objectivity	3.12	Agree	4
5. A workplace that protects (COS) against an arbitrary dismissal	3.13	Agree	3
OVERALL WEIGHTED MEAN	**3.14**	**Agree**	

Legend:3.26 – 4.00 Strongly Agree (SA) 1.76 – 2.50 Disagree (D)
2.51 – 3.25 Agree (A) 1.00 – 1.75 Strongly Disagree (SD)

Table 1.4 presents an overall weighted mean of 3.14, verbally interpreted as "Agree," indicating that respondents generally perceive bureaucracy and job security as moderate factors influencing their motivation and the achievement of organizational goals. The result suggests that while COS employees appreciate having fair and structured systems in place, they still experience certain limitations concerning job stability and long-term benefits. Among the indicators, *"A workplace that focuses on empowering employees, equipping them with the necessary tools and resources"* received the highest mean of 3.29, interpreted as Strongly Agree, showing that employees feel more secure and motivated when the organization provides adequate support and resources to perform their tasks effectively. Likewise, *"A workplace that encourages being dynamic with a sense of ownership to their achievements"* ranked second with a mean of 3.26, suggesting that empowerment and ownership contribute positively to employee morale and performance.

Meanwhile, the indicator *"A workplace that provides benefits like retirement pensions that contribute to a sense of job security"* obtained the lowest mean of 2.90, interpreted as Agree, which implies that limited access to long-term employment benefits remains a concern among COS employees. Although the organization promotes fairness and protection from arbitrary dismissal, the lack of permanent positions and formal benefits affects their perception of job stability. Overall, the findings highlight that employees value empowerment, fairness, and protection, but also desire stronger security measures that recognize their long-term contributions. Strengthening programs related to employee welfare and stability may enhance motivation and lead to greater organizational commitment and productivity.

This result is consistent with Jo and Shin (2025), who emphasized that fairness, recognition, and job security play vital roles in enhancing employee morale and organizational commitment. Likewise, COS employees feel more engaged when they are empowered and assured of fair and secure working conditions.

Table 1.5: The COS employee's motivation that influences on the achievement of organizational goals in terms of Relationships and Work Conditions

INDICATORS	WEIGHTEI MEAN	VERBAL INTERPRETATION	RANK
1. My colleagues are cooperative and friendly	3.47	Strongly Agree	2
2. Connectivity and Collaboration is a key ingredient in developing good working relationships	3.56	Strongly Agree	1
3. A workplace that is built on trust and respect	3.39	Strongly Agree	3
4. A workplace that promotes peace and tranquility	3.33	Strongly Agree	4
5. The idea of work life balance is very much welcome	3.32	Strongly Agree	5
OVERALL WEIGHTED MEAN	**3.41**	**Strongly Agree**	

Legend:3.26 – 4.00 Strongly Agree (SA) 1.76 – 2.50 Disagree (D)
2.51 – 3.25 Agree (A) 1.00 – 1.75 Strongly Disagree (SD)

Table 1.5 shows an overall weighted mean of 3.41, verbally interpreted as "Strongly Agree," indicating that respondents regard relationships and work conditions as vital factors influencing the achievement of organizational goals. The data imply that COS employees are highly motivated when they experience strong interpersonal connections and a supportive work environment. The indicator "*Connectivity and collaboration is a key ingredient in developing good working relationships*" achieved the highest mean of 3.56, interpreted as Strongly Agree, signifying that teamwork and open communication foster unity and collective effort among employees. This was followed by "*My colleagues are cooperative and friendly*" with a mean of 3.47, showing that harmonious relationships within the workplace enhance morale and create a positive atmosphere conducive to productivity.

On the other hand, the indicator "*The idea of work-life balance is very much welcome*" obtained the lowest mean of 3.33, although still verbally interpreted as Strongly Agree, suggesting that while employees acknowledge the importance of balancing work and personal responsibilities, achieving it consistently remains a challenge. Overall, the findings highlight that employees are most motivated when the workplace promotes trust, peace, and collaboration. Fostering strong professional relationships and maintaining open communication can help sustain motivation and satisfaction, ultimately contributing to the overall effectiveness and goal attainment of the organization.

This result aligns with Pereira et al. (2024), who emphasized that positive workplace relationships and open communication significantly enhance employee engagement and well-being. Similarly, COS employees feel more motivated when teamwork, trust, and collaboration are present in their work environment.

2. The employees' performance evaluation as rated by the immediate supervisor.

Table 2: Rating of organizational performance of COS Employees as rated by the supervisor

RANGES	FREQUENCY	PERCENTAGE	VERBAL INTERPRETATION
135 and above	44	44	Outstanding
99-134	56	56	Very Satisfactory
75-98	0	0	Satisfactory
60-74	0	0	Unsatisfactory
59 and below	0	0	Poor
TOTAL	**100**	**100**	

Legend:135 - above Outstanding (O) 75 - 98 Satisfactory (S) 59 - below Poor (P)
99 - 134 Very Satisfactory (VS) 60 - 74 Unsatisfactory (U)

Table 2 presents the rating of organizational performance of COS employees as evaluated by their supervisors. The results show that most of the employees were rated "Very Satisfactory" (56%), while 55% were rated "Outstanding." This indicates that all COS employees achieved ratings within the higher performance brackets, reflecting a strong overall level of efficiency, reliability, and competence in their respective roles. The absence of ratings in the "Satisfactory," "Unsatisfactory," and "Poor" categories suggests that supervisors generally view the performance of COS employees positively, recognizing their consistent contribution to the attainment of organizational goals.

The findings further imply that COS employees maintain a high level of commitment and motivation toward work responsibilities, supported by effective supervision and established performance standards. This strong performance profile highlights the organization's ability to foster a culture of productivity and accountability. Moreover, the predominance of "Outstanding" and "Very Satisfactory" evaluations may be attributed to well-defined job expectations, recognition of achievements, and an enabling work environment. Maintaining this level of excellence will require continuous performance monitoring, feedback, and development opportunities to sustain motivation and ensure long-term organizational success.

This finding is consistent with Mohamed et al. (2024), who revealed that strong workplace relationships and a supportive environment significantly improve motivation, performance, and commitment. In the same way, COS employees demonstrate higher productivity when guided by clear standards, recognition, and effective leadership that encourages continuous growth.

3. Influence on the achievement of Organizational Goals of COS employees

Table 3.1: The Influence on the achievement of Organizational Goals of COS employees in terms of Specificity

INDICATORS	WEIGHTED MEAN	VERBAL INTERPRETATION	RANK
1. The goals of the organization are clear, precise, and well-defined	3.46	Strongly Agree	1
2. Providing a formal on-boarding process to the newly hired (COS)	3.15	Agree	5
3. A company that advocates a consultative/participative approach on how they could contribute to the company	3.24	Agree	4
4. Policies and procedures are written and well documented	3.31	Strongly Agree	2

5. A culture that promotes good values and focus on one's strength	3.27	Strongly Agree	3
OVERALL WEIGHTED MEAN	**3.29**	**Strongly Agree**	

Legend:3.26 – 4.00 Strongly Agree (SA) 1.76 – 2.50 Disagree (D)
2.51 – 3.25 Agree (A) 1.00 – 1.75 Strongly Disagree (SD)

Table 3.1 reveals an overall weighted mean of 3.29, verbally interpreted as "Strongly Agree," which indicates that respondents generally perceive specificity as a crucial factor influencing the achievement of organizational goals. The findings imply that COS employees' value clear communication of objectives, defined procedures, and structured processes that help them perform their tasks effectively. The indicator *"The goals of the organization are clear, precise, and well-defined"* obtained the highest mean of 3.46, interpreted as Strongly Agree, showing that employees are motivated when expectations and directions are explicitly communicated. This suggests that clarity in organizational goals allows employees to focus their efforts on priorities that align with institutional targets. Likewise, *"Policies and procedures are written and well-documented"* ranked second with a mean of 3.31, highlighting the importance of having standardized guidelines that ensure transparency and consistency in daily operations.

Meanwhile, the indicator *"Providing a formal on-boarding process to the newly hired (COS)"* recorded the lowest mean of 3.15, interpreted as Agree, suggesting that while employees recognize the presence of onboarding programs, these may need improvement to fully integrate new staff into organizational systems. Despite this, the overall results demonstrate that COS employees appreciate well-defined structures and procedures that clarify their roles and responsibilities. Clear goals and consistent communication contribute not only to operational efficiency but also to employee motivation and confidence in achieving organizational objectives

This result is consistent with Khalid and Hashim (2025), who emphasized that clarity, transparency, and accuracy in workplace communication foster employee trust and engagement. In the same context, COS employees demonstrate stronger motivation and confidence when organizational goals and procedures are well-defined and effectively communicated.

Table 3.2: The Influence on the achievement of Organizational Goals of COS employees in terms of Challenge

INDICATORS	WEIGHTED MEAN	VERBAL INTERPRETATION	RANK
1. The limited Plantilla position hinders management plan in terms of providing personal growth and advancement to its employees (COS)	3.30	Strongly Agree	1
2. The employees (COS) just wanted to remain in their comfort zones	2.72	Agree	5
3. Lack of clear, adequate and tailored fit trainings for COS employees	2.99	Agree	2
4. Miscommunication due to information overload from too many messages	2.88	Agree	3
5. Poor / non-implementation of plans and programs for growth and development of (COS)	2.83	Agree	4
OVERALL WEIGHTED MEAN	**2.94**		

Legend:3.26 – 4.00 Strongly Agree (SA) 1.76 – 2.50 Disagree (D)
2.51 – 3.25 Agree (A) 1.00 – 1.75 Strongly Disagree (SD)

Table 3.2 presents an overall weighted mean of 2.94, verbally interpreted as "Agree," which indicates that respondents generally acknowledge challenges as a factor influencing the achievement of organizational goals. The result implies that COS employees recognize the existence of certain barriers that limit their growth and performance within the organization. The indicator *"The limited Plantilla position hinders management plan in terms of providing personal growth and advancement to its employees (COS)"* obtained the highest mean of 3.30, interpreted as Strongly Agree, suggesting that the lack of permanent positions remains a significant challenge affecting employees' motivation and opportunities for advancement. Furthermore, the item *"Lack of clear, adequate, and tailored-fit trainings for COS employees"* ranked second with a mean of 2.99, showing that employees feel the need for more structured and targeted development programs to strengthen their competencies and readiness for higher responsibilities.

In contrast, the indicator *"The employees (COS) just wanted to remain in their comfort zones"* registered the lowest mean of 2.72, interpreted as Agree, which reveals that while some employees may be hesitant to take on new challenges, organizational limitations also contribute to this mindset. Overall, the findings imply that the challenges faced by COS employees stem not only from individual attitudes but also from institutional constraints such as limited opportunities, insufficient training, and communication gaps. Addressing these issues through clearer development plans, improved communication systems, and equitable opportunities for advancement may help reduce work barriers and enhance the employees' ability to contribute effectively to organizational goals.

This result is consistent with Memon et al. (2020), who found that inadequate training and lack of career development opportunities significantly reduce employee motivation and engagement. Similarly, COS employees face lower morale when limited advancement prospects hinder their professional growth.

Table 3.3: The Influence on the achievement of Organizational Goals of COS employees in terms of Feedback

	INDICATORS	WEIGHTED MEAN	VERBAL INTERPRETATION	RANK
1.	Open communication channels provide a window for good feedback mechanism	3.28	Strongly Agree	2
2.	Providing physical and digital space for (COS) to submit ideas and concerns	3.17	Agree	5
3.	Incorporating new concepts, ideas and suggestion on areas requiring improvements	3.18	Agree	4
4.	Enhancing productivity through continuous improvement	3.26	Strongly Agree	3
5.	Management conducts Annual Performance Review	3.47	Strongly Agree	1
	OVERALL WEIGHTED MEAN	**3.27**		

Legend:3.26 – 4.00 Strongly Agree (SA) 1.76 – 2.50 Disagree (D)
2.51 – 3.25 Agree (A) 1.00 – 1.75 Strongly Disagree (SD)

Table 3.3 shows an overall weighted mean of 3.27, verbally interpreted as "Strongly Agree," indicating that respondents view feedback mechanisms as an essential factor influencing the achievement of organizational goals. The result implies that COS employees value the presence of effective communication channels and performance evaluations that allow them to express their ideas and receive constructive input from management. The indicator *"Management conducts Annual Performance Review"* obtained the highest mean of 3.47, interpreted as Strongly Agree, suggesting that regular evaluations

serve as a significant motivator for employees to improve and align their performance with organizational standards. Likewise, *"Open communication channels provide a window for good feedback mechanism"* ranked second with a mean of 3.28, showing that employees appreciate transparency and the opportunity to voice their opinions, which fosters trust and cooperation in the workplace.

In comparison, the indicator *"Providing physical and digital space for COS to submit ideas and concerns"* had the lowest mean of 3.17, verbally interpreted as Agree, which means that while employees recognize existing platforms for communication, they may not always be sufficient or consistently utilized. Despite this, the overall findings emphasize that feedback plays a vital role in promoting employee engagement, accountability, and productivity. Ensuring open dialogue and consistent feedback sessions can help strengthen work relationships, improve individual performance, and sustain a culture of continuous improvement toward achieving organizational goals.

This result is consistent with Van Woerkom and Kroon (2020), who found that strengths-based performance appraisals enhance employees' motivation to improve by increasing perceived supervisor support. In addition, they noted that regular recognition and constructive evaluations help sustain engagement and strengthen trust between supervisors and employees.

Table 3.4: The Influence on the achievement of Organizational Goals of COS employees in terms of Goal Commitment

INDICATORS	WEIGHTED MEAN	VERBAL INTERPRETATION	RANK
1. Setting SMART (Specific, Measurable, Achievable, Realistic and Time bound) Goals	3.37	Strongly Agree	1
2. Involving the Employees in the Process (more participation in goal setting)	3.24	Agree	2
3. Management is providing feedback from the accomplished task	3.20	Agree	4
4. Acknowledging Achievers and Celebrate with their Success	3.22	Agree	3
5. Encourages a culture of transparency and accountability	3.22	Agree	3
OVERALL WEIGHTED MEAN	**3.25**	**Agree**	

Legend:3.26 – 4.00 Strongly Agree (SA) 1.76 – 2.50 Disagree (D)

2.51 – 3.25 Agree (A) 1.00 – 1.75 Strongly Disagree (SD)

Based on Table 3.4, the overall weighted mean of 3.25, verbally interpreted as "Agree," reveals that respondents perceive goal commitment as an important factor influencing the achievement of organizational objectives. The result signifies that COS employees recognize the value of aligning their individual goals with the organization's vision, though there remains room to strengthen their engagement and participation in goal attainment. The indicator *"Setting SMART (Specific, Measurable, Achievable, Realistic, and Time-bound) goals"* recorded the highest mean of 3.37, interpreted as Strongly Agree, which implies that employees are more motivated when expectations are clearly defined and achievable. This finding emphasizes that having structured and realistic goals enables employees to focus on measurable outcomes that contribute directly to organizational success.

Meanwhile, the indicator *"Management is providing feedback from the accomplished task"* obtained the lowest mean of 3.20, interpreted as Agree, suggesting that although feedback mechanisms exist, these could be enhanced to ensure regular communication and continuous improvement. The findings collectively demonstrate that COS employees show a positive level of goal commitment, particularly

when guided by clear objectives and supported by recognition and feedback. To sustain and strengthen this motivation, management should promote participatory goal setting and provide consistent follow-ups that reinforce accountability, learning, and alignment with organizational priorities.

This result aligns with Tenney (2024), who argues that clearly defined goals energize employees by giving direction and purpose. When COS employees know exactly what's expected of them, they tend to commit more fully to achieving those goals.

Table 3.5: The Influence on the achievement of Organizational Goals of COS employees in terms of Task Complexity

INDICATORS	WEIGHTED MEAN	VERBAL INTERPRETATION	RANK
1. The management consider the difficulty of the task when setting goals	3.09	Agree	5
2. The Job Assignment (workload) is aligned with their credentials and capability	3.11	Agree	4
3. Minimizing perceived level of difficulty through coaching and mentoring	3.13	Agree	3
4. Providing briefing and/or reorientation on the new work assignment	3.16	Agree	2
5. Overcoming complexity through openness and support environment	3.23	Agree	1
OVERALL WEIGHTED MEAN	**3.14**	**Agree**	

Legend:3.26 – 4.00 Strongly Agree (SA) 1.76 – 2.50 Disagree (D)
2.51 – 3.25 Agree (A) 1.00 – 1.75 Strongly Disagree (SD)

As presented in Table 3.5, the overall weighted mean of 3.14, verbally interpreted as "Agree," indicates that respondents generally perceive task complexity as a manageable factor that influences the achievement of organizational goals. This suggests that COS employees acknowledge that while some tasks may be challenging, they are able to handle them effectively when adequate support and guidance are provided. Among the indicators, "*Overcoming complexity through openness and support environment*" obtained the highest mean of 3.23, interpreted as Agree, implying that employees are more confident and productive when the management fosters open communication and provides assistance in accomplishing complex assignments. The statement "*Providing briefing and/or reorientation on the new work assignment*" ranked second with a mean of 3.16, showing that clear instructions and guidance play an essential role in reducing confusion and ensuring better performance.

Meanwhile, the indicator "*The management considers the difficulty of the task when setting goals*" had the lowest mean of 3.09, still interpreted as Agree, which suggests that although employees recognize some level of consideration from management, there remains a need for greater attention to workload distribution and goal-setting strategies. Overall, the findings indicate that COS employees view task complexity as an important aspect that can be managed through effective communication, coaching, and a supportive work environment. This implies that management should continue providing clear briefings, mentoring, and workload alignment to help employees overcome task-related challenges and maintain efficiency in achieving organizational objectives.

This finding backs Zhenjing et al. (2022), who found that a supportive workplace environment, including clear instructions and oversight, helps employees manage complex tasks effectively by bolstering their commitment and performance.

Table 3.6: The Influence on the achievement of Organizational Goals of COS employees in terms of Strategies

INDICATORS	WEIGHTED MEAN	VERBAL INTERPRETATION	RANK
1. The management develop an overall plan for personnel growth and advancement	3.12	Agree	5
2. Aligning development with the management's mission and vision	3.25	Agree	2
3. Identifying and removing barriers for development	3.13	Agree	4
4. Creating a personalized development plan that outlines personal growth	3.15	Agree	3
5. A Career Pathing that is anchored on education, training and level of skills attained for further advancement	3.28	Strongly Agree	1
OVERALL WEIGHTED MEAN	**3.19**	**Agree**	

Legend:3.26 – 4.00 Strongly Agree (SA) 1.76 – 2.50 Disagree (D)
2.51 – 3.25 Agree (A) 1.00 – 1.75 Strongly Disagree (SD)

As reflected in Table 3.6, the overall weighted mean of 3.19, verbally interpreted as "Agree," reveals that respondents generally acknowledge strategies as important elements influencing the achievement of organizational goals. This result implies that COS employees recognize the significance of structured plans and developmental initiatives that align with both personal and organizational growth. The indicator "*A career pathing that is anchored on education, training, and level of skills attained for further advancement*" garnered the highest mean of 3.28, interpreted as Strongly Agree, suggesting that employees are highly motivated when clear career pathways and skill-based advancement programs are available. Moreover, "*Aligning development with the management's mission and vision*" ranked second with a mean of 3.25, highlighting that employees' value organizational direction and appreciate strategies that reinforce alignment between individual development and institutional goals.

In contrast, the indicator "*The management developed an overall plan for personnel growth and advancement*" recorded the lowest mean of 3.12, interpreted as Agree, which indicates that although employees see efforts from management, comprehensive strategies for personnel development could still be enhanced. Overall, the findings demonstrate that COS employees are motivated when strategic initiatives are purpose-driven and linked to their professional growth. Strengthening long-term development plans, providing continuous learning opportunities, and maintaining alignment with organizational objectives will help reinforce employee motivation and ensure sustainable achievement of goals.

This result is consistent with Westerman and Lundberg (2023), who emphasized that offering visible career paths and continuous learning opportunities strengthens employee motivation and engagement. The authors also noted that organizations aligning employee development initiatives with long-term strategies foster higher retention and a culture of sustained growth.

4. A significant relationship between employee's motivation and influences on the achievement of Organizational Goals of COS employees

Table 4: Test of significant relationship between employee's motivation and influences on the achievement of Organizational Goals of COS employees

MOTIVATIONAL FACTORS	INFLUENCES ON THE ACHIEVEMENT OF ORGANIZATIONAL GOALS	r value	P value	Remarks	Decision
THE WORK ITSELF AND RESPONSIBILITY	Specificity	.666**	0	Significant	Reject Ho
	Challenge	0.031	0.761	No Significant	Accept Ho
	Feedback	.500**	0	Significant	Reject Ho
	Goal Commitment	.541**	0	Significant	Reject Ho
	Task Complexity	.591**	0	Significant	Reject Ho
	Strategies	.561**	0	Significant	Reject Ho
ACHIEVEMENT AND RECOGNITION	Specificity	.624**	0	Significant	Reject Ho
	Challenge	-0.103	0.308	No Significant	Accept Ho
	Feedback	.515**	0	Significant	Reject Ho
	Goal Commitment	.548**	0	Significant	Reject Ho
	Task Complexity	.651**	0	Significant	Reject Ho
	Strategies	.600**	0	Significant	Reject Ho
PERSONAL GROWTH AND ADVANCEMENT	Specificity	.585**	0	Significant	Reject Ho
	Challenge	-0.168	0.094	No Significant	Accept Ho
	Feedback	.515**	0	Significant	Reject Ho
	Goal Commitment	.559**	0	Significant	Reject Ho
	Task Complexity	.644**	0	Significant	Reject Ho
	Strategies	.623**	0	Significant	Reject Ho
BUREAUCRACY AND JOB SECURITY	Specificity	.672**	0	Significant	Reject Ho
	Challenge	-0.146	0.146	No	Accept Ho

				Significant	
	Feedback	.526**	0	Significant	Reject Ho
	Goal Commitment	.592**	0	Significant	Reject Ho
	Task Complexity	.690**	0	Significant	Reject Ho
	Strategies	.651**	0	Significant	Reject Ho
	Specificity	.701**	0	Significant	Reject Ho
	Challenge	0.02	0.843	No Significant	Accept Ho
RELATIONSHIPS AND WORK CONDITIONS	Feedback	.630**	0	Significant	Reject Ho
	Goal Commitment	.660**	0	Significant	Reject Ho
	Task Complexity	.703**	0	Significant	Reject Ho
	Strategies	.686**	0	Significant	Reject Ho

**Correlational at the level 0.05 (Two-tailed) Significance at the level 0.05

Size of Correlation	Interpretation
.90 to 1.00 (−.90 to −1.00)	Very high positive (negative) correlation
.70 to .90 (−.70 to −.90)	High positive (negative) correlation
.50 to .70 (−.50 to −.70)	Moderate positive (negative) correlation
.30 to .50 (−.30 to −.50)	Low positive (negative) correlation
.00 to .30 (.00 to −.30)	negligible correlation

Table 4 presents the correlation results between motivational factors and the achievement of organizational goals among COS employees. The computed correlation coefficients (r-values) and significance levels (p-values) reveal that most motivational factors are significantly related to organizational goal achievement at the 0.01 level of significance (two-tailed). Specifically, *specificity* (r = .666** to .701**), *feedback* (r = .500** to .630**), *goal commitment* (r = .541** to .660**), *task complexity* (r = .591** to .703**), and *strategies* (r = .561** to .686**) all show moderate to high positive correlations, indicating that when these factors are effectively implemented, employees tend to perform better and align more strongly with organizational objectives. These results further suggest that COS employees are motivated and become more productive when goals are clearly defined, feedback is continuous, workloads are appropriately managed, and developmental strategies are in place.

In contrast, *challenge* consistently yielded non-significant correlations across all variables (r = .031 to –.168, p > .05), leading to the acceptance of the null hypothesis. This implies that while other factors positively influence employee motivation, challenge alone does not significantly predict organizational

goal achievement among COS employees. The overall results emphasize that well-defined systems such as clear goal-setting, effective feedback mechanisms, and supportive strategies enhance motivation and contribute to organizational success. Meanwhile, excessive or unclear challenges may hinder rather than drive performance. Hence, management should focus on reinforcing clarity, structure, and support in goal implementation while ensuring that employees are guided and equipped to overcome work-related difficulties.

5. A significant difference in the employees' performance evaluation and the influences on the achievement of organizational goals of COS employees

Table 5: Test of significant difference in the employee's performance evaluation and the influences on the achievement of Organizational Goals of COS employees

INFLUENCES ON THE ACHIEVEMENT OF ORGANIZATIONAL GOALS	EMPLOYEES PERFORMANCE EVALUATION AS RATED BY THE SUPERVISOR	Mean	X2-Value	p-value	Remarks	
Specificity	135 and above (outstanding)	3.24	1.364	0.243	No Significant	Accept Ho
	99-134 (very satisfactory	3.33				
Challenge	135 and above (outstanding)	3.06	3.212	0.073	No Significant	Accept Ho
	99-134 (very satisfactory	2.85				
Feedback	135 and above (outstanding)	3.2	1.802	0.179	No Significant	Accept Ho
	99-134 (very satisfactory	3.33				
Goal Commitment	135 and above (outstanding)	3.15	4.968	0.026	Significant	Reject Ho
	99-134 (very satisfactory	3.33				
Task Complexity	135 and above (outstanding)	3.05	1.992	0.158	No Significant	Accept Ho
	99-134 (very satisfactory	3.22				
Strategies	135 and above (outstanding)	3.12	1.933	0.164	No Significant	Accept Ho
	99-134 (very satisfactory					

The significance level is .050.

Table 5 presents the test of significant difference between the employee's performance evaluation and their influence on the achievement of organizational goals. Results show that most of the computed p-values are greater than the 0.05 level of significance, indicating no significant difference between the two performance evaluation groups (employees rated *135 and above – outstanding* and *99–134 – very satisfactory*). This implies that both groups share similar perceptions of how factors such as *specificity* (p = .243), *challenge* (p = .073), *feedback* (p = .179), *task complexity* (p = .158), and *strategies* (p = .164) affect organizational goal attainment. The findings suggest that regardless of the employee's performance rating, their understanding of these factors remains consistent, reflecting a uniform appreciation of the organization's systems and performance mechanisms.

However, the factor *goal commitment* obtained a p-value of .026, which is less than the 0.05 level of significance, indicating a significant difference between the two groups. This means that employees rated as *very satisfactory* and *outstanding* differ in their perceptions of goal commitment and its influence on achieving organizational objectives. The result implies that employees with higher performance ratings demonstrate stronger commitment toward achieving goals, likely due to their higher sense of responsibility, initiative, and alignment with organizational priorities. Overall, the results emphasize that while most motivational factors are equally perceived across employee groups, strengthening goal commitment could further enhance performance consistency and sustain organizational success.

PROPOSED ACTION PLAN FOR ENHANCING JOB SECURITY AND BUREAUCRACY THAT ALIGNS WITH THE HUMAN RESOURCE OBJECTIVES

Our plan of action / strategy focuses more on the job security and bureaucracy which had a moderate influence. However, based on the results of our study it did not strongly demotivate engaged employees.

For a Contract of Service (COS) employee in the government, job security is not an inherent right as they are not covered by Civil Service laws and generally lack security of tenure. Instead, their continued engagement relies on specific **Key Result Areas (KRAs)** related to performance, the necessity of the function, and alignment with agency policies and available funding.

Key Results Area	Objectives	Strategies / Activity	Persons Involved	Resources	Estimated Budget	Timelines / Project Time Frame	Success Indicator
JOB SECURITY							
Exceptional Performance / COS Employees Development	The primary goal is to transition from a CoS arrangement to a permanent, itemized position within the government service.	1. Understanding their Status and Rights 2. Providing Excellent Service 3. Monitor and Invite qualified applicants for the	HR Team; Legal Team COS HR, COS	Agency Manual, Internal Policies and Procedure and Training Budget	P700,000.00 based on the average of 100 COS employees	On an Annual basis (subject to review annually)	Individual Performance Commitment and Review (IPCR); Recommendations for Promotions, Certificate of Recognition for

Key Results Area	Objectives	Strategies / Activity	Persons Involved	Resources	Estimated Budget	Timelines / Project Time Frame	Success Indicator
		vacant position 4. Provides Professional Development	Teams from HR and Budget /Finance				Perfect Attendance; Exemplary Performance
BUREAUCRACY							
Efficient, Economical and flexible in performing government operations	The primary objective of the Philippine bureaucracy is to acquire specialized services or to perform intermittent or piece of work for a specific, limited duration	1. Document everything for future references 2. Follows proper protocols (channel) 3. Lines of communication should always be open 4. Focus on the Mission which is a Commitment to Provide Public Service	Teams from HR Agency wide (thru the Directors / Managers including the COS employees	Existing Logistics in terms of supplies and materials issued including equipment, Training Budget	Agency Budget / National Budget based on Approved GAA	Based on annual operations of the agency / national office which is subject to oversight / review	Compliance to Memos, Circulars, Executive Orders, Internal Policies and Procedures, Annual Financial Reports

V. CONCLUSION

This research examined the connection between employee motivation, performance evaluation, and the achievement of organizational goals among Contract of Service (COS) employees in National Government Agencies (NGAs) in Quezon City. The study found that COS employees are primarily motivated by intrinsic factors like meaningful work, recognition, and growth opportunities, with a positive work environment also playing a significant role. While bureaucracy and job security had a moderate influence, this did not strongly demotivate engaged employees.

Performance evaluations consistently showed high efficiency and competence among COS employees. The achievement of organizational goals was strongly linked to clear goal specificity, effective feedback, and well-defined strategies, though "challenge" did not significantly correlate with increased motivation. A strong relationship was observed between most motivational factors and goal achievement. Notably, "Outstanding" performers showed higher goal commitment than "Very Satisfactory" performers.

The study concludes that government agencies should prioritize strengthening intrinsic motivators through meaningful work, recognition, and professional development programs. Additionally, focusing on clear goal setting, transparent feedback, and supportive work environments is crucial for sustaining high motivation and performance among COS employees, while also addressing concerns regarding job security and bureaucracy.

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History and the Challenges of the Quality Management System: A Case Study

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Abstract *— This research delved into the history of the University of Cebu – Lapulapu Mandaue Quality Management System (QMS), its implementation, the challenges faced, and the lesson learned. The QMS is necessary as compliance to regulatory requirement specifically for the Maritime Education Programs and as well as a management standard guide for everyone to attain the desired outputs of the University's strategic direction and maintain customer satisfaction. The investigation utilized the case study method to analyze and discuss the results and impacts, challenges faced, and lesson learned of the implementation of the QMS. The researchers conducted the study through the utilization of different sources like related literatures and studies, and actual observation of internal practices and trends. The study revealed that the implementation of the QMS is consistent to the required standard; however it still faced several minor challenges in the areas of documented information and keeping of records, monitoring and measurement, analysis and evaluation, knowledge of operational processes, compliance to corrections and corrective actions, and maintaining customer satisfaction. The findings led to the conclusion that in order to minimize the challenges; the implementation of the QMS shall be strengthened through continuous coordination of the Institutional Quality Assurance office with all the other offices and to regularly refresh the personnel's knowledge of the application of the standards and compliance to the requirements.*

Keywords *— **compliance, quality management system, regulatory, standards.***

I. INTRODUCTION

The quality management system (QMS) integrates the various internal processes within the organization and intends to provide a process approach for project execution. A process based QMS enables the organization to identify, measure, control, and improve various core business processes that will ultimately lead to improved business performance (The 9000 Store, 2024).

The system defines how a company will achieve the creation and delivery of the products and services they provide to their customers. When implemented, the QMS needs to be specific for the product or service the company provides, so it is important to tailor it to your needs. However, in order to help ensure that you do not miss elements of a good system, some general guidelines exist in the form of ISO 9001:2015 (Quality Management System – Requirements) by ISO 9001International Standard, which are intended to help standardize how a QMS is designed (Hammar, 2024).

A QMS enables businesses in highly regulated industries to consistently apply quality

processes to produce products that meet regulatory requirements. QMS frameworks such as ISO 9001:2015 provide a comprehensive blueprint for customer-focused quality management based on principles of leadership, the workforce, improvement, evidence-based decisions, and relationships (Qualio, 2024).

Brief History of UCLM QMS

University of Cebu—Lapulapu and Mandaue is a private, non-sectarian higher educational institution founded in May 1995. The campus started operating with only 24 instructors, 755 enrollees, and 7 Associate Programs offered. By 1997, the accelerated growth of the University's students paved the way for the transition of the Associate Programs to Baccalaureate degrees under the ladderized curricula. At present, the University already offers 1 Master's Degree Program, 20 Baccalaureate Degree Programs, and complete Basic Education.

The Quality Management System (QMS) was introduced and implemented in the University way back in 2008 when the Norwegian Shipping Association (NSA) Cadetship Project Philippines transferred its operation from UC Maritime Education and Training Center (UC METC) to UCLM. Prior to the transfer, the Maritime Education Programs at UCLM were only an extension of the UC METC campus. With the transfer, UCLM was obligated to apply for a Government Permit (GP) to operate the BS in Marine Transportation and BS in Marine Engineering Programs, not as an extension but as part of the regular educational programs offering. One of the requirements for the permit to be approved is the establishment of a certified quality management system geared towards compliance with the provisions under the Standards of Training, Certification, and Watchkeeping, 1978, as amended Regulation 1/8.

The external benchmarking for the quality management certification of the BSMT and BSMARE Programs was performed by Det Norske Veritas PTE (DNV). The annual verification started in February 2009 and continued annually until February 2012, with the following areas (below) being evaluated for compliance with the established DNV Standard for Certification No. 3.201 (Learning Programmes), International Maritime Organization (IMO) Model Courses 7.03 and 7.04), and Commission on Higher Education (CHED) CMO No. 13, Series 2005 - Policies, Standards, and Guidelines for Maritime Education. The areas are:

1. Course syllabus and timetable;
2. Instructor's guide;
3. Instructional materials;
4. Facilities and equipment;
5. Assessment methods and assessment materials; and
6. Training and lecturing methodology

After passing the benchmarking, DNV issued the Management System Certificate to UCLM Maritime Academy on February 15, 2013, under the requirements of the DNV Standard for Certification of Maritime Academies. UCLM then applied for the next certification, ISO 9001:2008, which is intended for the Business Assurance Management System Certificate. After 8 months of conforming to the standards and complying with the requirements, UCLM was issued the certificate for ISO 9001:2008 on October 11, 2013, which has validity until 2016.

Upon the expiry of the ISO 9001:2008 certificate, UCLM transitioned to the latest management certificate, which is the ISO 9001:2015 entitled Quality Management System, which has the scope of Provision of Maritime Education. After the review and validation of all the requirements, DNV-GL issued the certificate on October 11, 2016, and it is valid until October 2019. When the certificate expired, UCLM decided to transfer to another certifying agency, Bureau Veritas (BV).

The latest ISO 9001:2015 quality management system covers the following management areas (below) that shall undergo an annual surveillance audit for 3 years before it will be renewed. The areas that need to conform to standards and comply with requirements are:

1. The scope of the Maritime Education programs and the support offices;
2. The normative references used;
3. The specific terminologies and their definitions;

4. The context of the Maritime Education programs and the support offices relevant to their interested parties and the quality management system;
5. The role of leadership and commitment;
6. Quality objectives and planning, and the actions to address risks and opportunities;
7. The provision of human, infrastructure, and material resources;
8. Operational processes and their control mechanisms;
9. Performance evaluation through monitoring, measurement, analysis, and evaluation; and
10. Continual improvement of the system and its processes.

II. OBJECTIVES OF THE STUDY

This case study sought to determine the history and the evolution of the Quality Management System of the University of Cebu – Lapu-Lapu Mandaue. Specifically, the study aimed to answer the following questions:

1. What is the history of the Quality Management office of the University of Cebu-Lapulapu Mandaue in terms of:
   - 1.1 Establishment of the office;
   - 1.2 Location of the office; and
   - 1.3 Quality Management Representatives/Managers
2. What are the key challenges faced by the University of Cebu – Lapulapu Mandaue before the Quality Management System in area of:
   - 2.1 Documented information and keeping of records;
   - 2.2 Monitoring, measurement, analysis, and evaluation of the intended outputs;
   - 2.3 Personnel knowledge of the operational processes;
   - 2.4 Compliance with corrections and corrective actions;
   - 2.5 Maintaining customer satisfaction.
3. Is there a need for the implementation of the quality management system in the aspect of:
   - 3.1 Regulatory requirements;
   - 3.2 Market competition;
   - 3.3 Cost reduction;
   - 3.4 Increase in productivity; and
   - 3.5 Continual improvement

III. IMPLEMENTATION OF THE QUALITY MANAGEMENT SYSTEM

Steps adopted for the implementation

UCLM's implementation of the ISO 901:2015 quality management system adopted explicitly the following steps to conform to international standards to wit:

1. Established a quality manual to demonstrate its ability to consistently provide products and services that meet customer and applicable statutory and regulatory requirements.
2. Enhanced customer satisfaction through the effective application of the system, including processes for improvement of the system and the assurance of conformity to customer and applicable statutory and regulatory requirements.
3. Determined normative references as the basis for conformance to standards and compliance with requirements.
4. Established the terminologies for the specific use in the quality management system.
5. Determined the external and internal issues that are relevant to its purpose and its strategic direction that affect its ability to achieve the intended result(s).
6. The top management demonstrated leadership and commitment by taking accountability for the effectiveness of the QMS and ensuring that the quality policies and quality objectives are established and compatible with the context and strategic direction of UCLM.
7. Established quality objectives, planned at relevant functions, levels, and processes, and took actions to address risks and opportunities.
8. Determined and provide the resources needed for the establishment, implementation, maintenance, and continual improvement of the quality management system.
9. Determined the knowledge necessary for the operation of its processes and to achieve conformity of its products and services.

10. Determined the competence of personnel that affects the performance and effectiveness of its operational processes.
11. Formulated, disseminated, and controlled documented information that is necessary for the effectiveness of the quality management system.
12. Planned, implemented, and controlled the processes needed to meet the requirements for the provision of products and services, and implemented the actions for the risks and opportunities management.
13. Performed monitoring, measurement, analysis, and evaluation of the processes implemented for the conformance of reference standards and compliance with statutory and regulatory standards.
14. Endeavoured to continually improve the suitability, adequacy, and effectiveness of its quality management system.

The key methodology used in implementing the quality management system is based on Edward Deming's plan, do, check, act (PDCA) quality management cycle.

The role of the Top Management in the implementation of the QMS is anchored on their demonstration of leadership and commitment with respect to:

1. Taking accountability for the effectiveness of the QMS;
2. Ensuring that the quality policy and quality objectives are established for the QMS and are compatible with the context and strategic direction of UCLM;
3. Ensuring the integration of the QMS requirements into the organization's business processes;
4. Promoting the use of the process approach and risk-based thinking;
5. Ensuring that the resources needed are available;
6. Communicating the importance of effective quality management and conforming to the quality management system requirements;
7. Ensuring that the quality management system achieves its intended results;
8. Engaging, directing, and supporting personnel to contribute to the effectiveness of the quality management system;
9. Promoting continual improvement and
10. Supporting other relevant management roles to demonstrate their leadership as it applies to their areas of responsibility.

To ensure that the roles of the employees are clearly defined and in accordance with the standards and requirements of the quality management system, UCLM guarantees that the persons doing work under its operation are aware of the following:

1. The established quality policies;
2. Relevant quality objectives
3. Their contribution to the effectiveness of the quality management system, including the benefits of improved performance and
4. The implications of not conforming to the quality management system requirements.

IV. RESULTS AND IMPACT

Some of the results of the key challenges and the need for the implementation of the quality management system were taken from the unpublished research by Rey Carlito Aranzado (2024) entitled "The University of Cebu Maritime Education Programs Quality Management System: Its Compliance to CHED-MARINA Requirements." This research has concerns similar to those of this study; thus, some of its findings can be used as a reference. The rest of the results, like market competition, cost reduction, and increase in productivity, are based on the actual experience of UCLM in these areas, as observed by the researchers.

Establishment of the Quality Management Office

Based on records, the Quality Management Office was established last 2008 when the Norwegian Shipping Association Cadetship Project (NSA) decided to transfer its operation from UC Maritime Education and Training Center campus to University of Cebu-Lapulapu Mandaue campus. The office was created to manage the planning, implementation, monitoring and measurement, and analysis and evaluation of all the quality assurance standards and requirements based on regulatory body and certification agencies for the Maritime Education Programs. The office was also tasked to facilitate the

registration and coding of all controlled documents, the conduct of a regular internal audit processes, the submission of compliance to external audit findings, and the annual Management Review.

Location of the Quality Management Office

In 2008, the Quality Assurance office was located near gate 2 of the old UCLM building. By the middle of 2015, the office was temporarily transferred to the President's office and it occupied the office of the Chancellor while waiting for the construction of its present location. Currently, the Quality Assurance office, which was changed to Institutional Quality Assurance (IQA) office, is now located at the ground floor of the Maritime Education building near the President's office. This location was chosen because it is suitable for the office's functions.

Quality Management Representatives/Quality Assurance Manager

The first UCLM employee who was designated as the Quality Management Representative (QMR) that was tasked to handle the Quality Assurance processes was Ms. Daryl F. Legarde. Because she was also the Property Custodian, Ms. Legarde only stayed in the position until the end of 2008. From 2008 to the end of 2012, Dr. Ily E. Abella took the helm of managing the operation. Mr. Abella decided to quit thus the management searched for a replacement. By February 2013, Mr. Rey Q. Aranzado was appointed by the Chancellor as the new Quality Management Representative. In late 2014, Mr. Aranzado requested temporary transfer to another office thus he was replaced by Ms. Ida A. Bentulan. From 2014 until middle of 2015, Ms. Bentulan handled the duties and responsibilities of the QMR. By the middle of 2015, UCLM management reinstated Mr. Aranzado as the QMR along with Mr. Joremi Milan and Ms. Jas Orica as his team. It was also during this time that the name Institutional Quality Assurance office was established. In 2017, Ms. Orica resigned and followed by Mr. Milan in 2018. Thus from 2015 until the present, Mr. Aranzado continues to head the Institutional Quality Assurance office. The position QMR was also changed into Quality Assurance Manager.

Challenges for Documented Information and Keeping of Records

The table below indicates the key challenges for documented information as required by the quality management system in relation to regulatory requirements.

Table 1: Extent of the Efficiency of the Quality Management System of the Maritime Education Programs in the Compliance of the CHED- MARINA Requirements in Terms of Documented Information

	Indicators	Mean	Description
1.	Create and update the identification and description (title, date, author, reference number) and format (language, software version, graphics) of the documented information regularly to ensure suitability.	3.66	Highly Efficient
2.	Ensure that the documented information is available when and where it is needed.	3.65	Highly Efficient
3.	Ensure that control of documented information addresses distribution, access, retrieval and use, storage and prevention, control of changes, and retention and disposal.	3.69	Highly Efficient
4.	Identify and keep documented information of external origin necessary for the planning and operation.	3.64	Highly Efficient
5.	Ensure that documented information retained as evidence of conformity shall be protected from unintended alterations.	3.66	Highly Efficient
	Overall Mean:	**3.66**	**Highly Efficient**

Table 1 divulges that the implementation of the UC maritime education program's quality management system as a tool for compliance with the CHED-MARINA requirement in terms of documented information is considered by the respondents to be highly efficient, with an overall mean of 3.66. This result can be interpreted as UC maritime education efficiently using the guidelines of the quality management system in their operation's documented information.

ISO 9001:2015 clause 7.5.1 states that the organization's quality management system shall include: a) documented information required by the standard, b) documented information determined by the organization as being necessary for the effectiveness of the quality management system.

Documented information serves several key functions within ISO 9001:2015. It acts as a carrier of knowledge, a means to communicate intent, and a record of evidence that quality processes have been followed and objectives met. Essentially, it is the backbone that supports the structure and operation of a QMS, ensuring consistency and traceability. The importance of documented information in a QMS cannot be overstated. It provides a tangible way to capture organizational knowledge, define processes, and set quality objectives. Without it, maintaining consistency and achieving continual improvement would be challenging, if not impossible (isms.online, 2024).

For documented information, the performance indicator ensures that control of documented information shall address distribution, access, retrieval and use, storage and prevention, control of changes, and retention and disposal. This indicator obtained the highest mean of 3.69. This finding implies that UC maritime education systematically ensures that the use and control of their documented information regularly adhere to the quality management system standards and requirements.

Documented information serves as evidence of compliance with ISO standards. It allows external auditors to verify that the organization is following established procedures and maintaining necessary documentation. To leverage the benefits of documented information, it is important to ensure accuracy, accessibility, and relevance. Regular reviews should be done to update outdated documents or remove irrelevant ones. This enables an up-to-date knowledge base that supports informed decision-making (Onpolicy, n.d.).

The performance indicator that got the lowest mean of 3.64 is identifying and keeping documented information of external origin necessary for the planning and operation. This result can be interpreted that there may be some efficiency issues experienced by the respondents in relation to identifying and keeping documented information of external origins for planning and operation. For continual improvement, UC maritime education should initiate action to strictly adhere to the requirement of ISO 9001:2015 clause 7.5.3.2, which states that documented information of external origin determined by the organization to be necessary for the planning and operation of the quality management system shall be identified as appropriate, and be controlled.

Challenges for monitoring, measurement, analysis, and evaluation of the intended outputs

The table below indicates the key challenges for monitoring, measurement, analysis, and evaluation as required by the quality management system in relation to regulatory requirements.

Table 2: Extent of the Quality Management System of the Maritime Education Programs as Practiced in Compliance with the CHED-MARINA Requirements in the Area of Operation as to Monitoring and Measurement

	Indicators	Mean	Description
1.	Determine what needs to be monitored and measured.	3.76	Great Extent
2.	Control the methods for monitoring, measurement, analysis, and evaluation needed to ensure valid results.	3.60	Great Extent
3.	Ascertain the frequency of the monitoring and measurement.	3.64	Great Extent

4.	Establish schedules when the results of the monitoring and measurement are analyzed and evaluated.	3.60	Great Extent
5.	Appropriately retain documented information.	3.64	Great Extent
	Overall Mean:	**3.65**	**Great Extent**

Table 2 reveals that the extent to which the quality management system is manifested, leading towards compliance in the area of operation as to monitoring and measurement, is perceived by the respondents as practiced to a great extent, as specified by the overall mean of 3.65. This outcome indicates that UC maritime education diligently monitors and measures all processes of its operation for continual improvement. Anna Turri (2023) suggested that the notion of continuous improvement implicitly includes the one of measuring and monitoring; in other words, there is no continuous improvement where there is no measuring and monitoring.

Moreover, Kellen (2003) theorized that business performance measurement and control systems are the formal information-based routines and procedures that managers use to maintain or alter patterns in organizational activities. Kellen notes that a typical performance measurement can help businesses set business goals regularly and subsequently provide managers with feedback on the progress toward meeting those goals.

The highest-rated performance indicator for the area monitoring and measurement, with a mean of 3.76, is determining what needs to be monitored and measured. This finding implies that UC maritime education regularly practices identifying what areas of their operation need monitoring and measurement. As a regulated and certified educational institution, there are numerous areas to be monitored and measured, such as personnel qualifications, carrying capacity of students, facilities and equipment, etc. Anna Turri (2023) posits that it is important for an organization to clearly define its key processes, identify which aspects of these processes require measurement, establish the methods and frequency of measurement, and determine when to analyze and evaluate the outcomes of these measurements.

In addition, Ghalayini and Noble (1996) noted that performance measures are used by companies to evaluate, control, and improve production processes to ensure that they achieve their goals and objectives.

The performance indicators control the methods for monitoring and measurement, analysis, and evaluation needed to ensure valid results and establish schedules for when the results of the monitoring and measurement are analyzed and evaluated, which got the lowest mean of 3.60. These results may be attributed to some issues and concerns regarding how the control of the methods is implemented and the lack of regular discussion related to the results of monitoring and measurement.

The ISO 9001:2015 International Standards recommend that organizations analyze and evaluate appropriate data and information arising monitoring and measurement. The results of the analysis shall be used to evaluate: a) conformity of products and services to requirements; b) the degree of customer satisfaction; c) the performance and the effectiveness of the quality management system; d) if planning had been implemented effectively; e) the effectiveness of the actions taken to address risks and opportunities; f) the performance of the external providers; and g) the need for improvement. Thus, it is important that UC maritime education management implement action to improve these monitoring and measurement indicators.

Table 3: Extent of the Quality Management System of the Maritime Education Programs as Practiced in Compliance with the CHED-MARINA Requirements in the Area of Operation as to Evaluation

	Indicators	Mean	Description
1.	Analyze the degree of customer satisfaction.	3.70	Great Extent
2.	Determine if planning has been implemented effectively.	3.61	Great Extent

3.	Find out the effectiveness of the actions taken to address risks and opportunities.	3.63	Great Extent
4.	Assess the performance of the external providers.	3.61	Great Extent
5.	Appraise the areas that need improvement.	3.64	Great Extent
	Overall Mean:	**3.64**	**Great Extent**

Table 3 shows that the extent to which the quality management system is manifested, leading towards compliance in the area of operation as to monitoring, is perceived by the respondents as practiced to a great extent, as specified by the overall mean of 3.64. This finding signifies that UC maritime education regularly performs an evaluation of the results of the monitoring and measurement of the areas they have identified as critical for compliance with CHED-MARINA requirements.

The evaluation of the performance of an enterprise can also be understood as a constituent part of management, which helps to make managerial decisions. Enterprises that carry out integrated evaluation of performance work more effectively than those that do not evaluate their performance. Performance evaluation helps to implement the strategy, follow the development of an enterprise, integrate short-term and long-term goals and opportunities of an enterprise, and evaluate an organization as a single entity (Ruževičius et al., 2004; Gitlow et al., 2005; Kaziliūnas, 2006).

The evaluation of processes does not require large costs or reductions in quality. It is important to have sufficient knowledge and experience, as well as technical potential when implementing changes in an organization to profit from the experiences and good practices of successful enterprises. The improvement of performance does not have to be limited to the implementation of means of improvement of processes and application of methods; it is important to observe the influence of changes on the effectiveness of processes and take appropriate actions of adjustment if necessary (Gitlow et al., 2005).

The performance indicator for the area of evaluation that obtained the highest mean of 3.70 is analyzing the degree of customer satisfaction. This outcome indicates that UC maritime education clearly understood that customer plays a crucial role in the success of their operation and the business. If the result of customer satisfaction is poor or the cause is not evaluated, then it will become detrimental to their operation. This practice is in line with the total quality management framework. Peter Landau (2022) described it as a management approach that focuses on delivering products and services with the highest quality to maximize customer satisfaction and meet regulatory standards.

Moreover, ISO 9001:2015 requires that the organization monitor customers' perceptions of the degree to which their needs and expectations have been fulfilled. The organization shall determine the methods for obtaining and retrieving this information. The organization shall also analyze and evaluate appropriate data and information arising from the monitoring and measurement.

On the other hand, the performance indicator that got the lowest mean of 3.61 is to determine if planning has been implemented effectively and assess the performance of the external providers. For planning, the result can be linked to the lack of regular monitoring of the actual implementation of the plan. Measurement will only be done through the accomplishment report. In ISO 9001 certification, planning is the first phase in formulating the steps of ISO 9001 implementation. Among the essential things to do is identify aspects of quality for the improvement of the quality of work (Bakhtiar, 2012). These aspects include clarity about the sequence and the provision of duties, the implementation of documentation with the recording of data and recording of employment activities as evidence of the implementation of ISO 9001 within the organization, and the establishment of standard procedures for organizing work activities undertaken by members of the organization (Feng et al., 2008).

For assessing the performance of external providers, the result may be associated with the fact

that not all offices of UC maritime education have direct interaction with the external providers. Thus, they have not experienced assessing their performance.

Challenges for knowledge of operational processes

The table below indicates the key challenges for the operational process as required by the quality management system in relation to regulatory requirements.

Table 4: Extent of the Quality Management System of the Maritime Education Programs as Practiced in Compliance with the CHED-MARINA Requirements in the Area of Organizational Structure as to Roles, Responsibilities, and Authorities

Indicators	Mean	Description
1. Ensure that the quality management system is utilized as a tool for conformance to the CHED-MARINA requirements.	3.75	Great Extent
2. Ensure that the established processes are delivering their intended outputs.	3.60	Great Extent
3. Regularly report the performance of the quality management system for improvement to top management.	3.58	Great Extent
4. Ensure the promotion of customer focus throughout Maritime Education.	3.69	Great Extent
5. Ensure the integrity of the quality management system is maintained when changes are planned and implemented.	3.73	Great Extent
Overall Mean:	**3.67**	**Great Extent**

Table 4 reveals that the extent to which the quality management system is manifested, leading towards compliance in the area of organizational structure as to roles, responsibilities, and authorities, is perceived by the respondents as practiced to a great extent, as specified by the overall mean of 3.73. The result can be interpreted as clear proof that roles, responsibilities, and authorities in UC maritime education are continuously applied when implementing the quality management system. This judgment is aligned with the theory of Henri Fayol advocated by MBA Note (2024), which states that managers analyze the future, make forecasts, and develop strategies to steer the organization in the desired direction; divide tasks, delegate responsibilities, and create a structured framework for smooth operation; foster a positive work environment and motivate employees to work towards shared goals; synchronize activities, align efforts, and promote collaboration to avoid conflicts and improve productivity; monitor performance against established standards and taking corrective actions when necessary; and assess outcomes, compare them to plans, and make adjustment to ensure progress.

The highest-rated performance indicator that amassed a weighted mean of 3.75 is ensuring that the quality management system is utilized as a tool for conformance to the CHED-MARINA requirements. This result can be related to UC maritime education's academic and support office heads full awareness of the importance of the quality management system as an instrument to ensure that CHED-MARINA requirements will be complied with. As stated by Qualio (2024), A QMS enables businesses in highly regulated industries to consistently apply processes to produce products that meet regulatory requirements. QMS frameworks such as ISO 9001:2015 provide a comprehensive blueprint for customer-focused quality management based on principles for leadership, the workforce, processes, improvement, evidence-based decisions, and relationships.

The performance indicator that got the lowest mean of 3.58 is regularly reporting the performance of the quality management system for improvement to top management. Even though the

meaning of this finding is still interpreted as practiced to a great extent, it is still important that UC maritime education management take action for improvement. The perception of the respondents signifies that the performance of the quality management system is seldom reported to top management. The top management in this context is the UC Vice Chancellors and the Executive Vice Chancellor. Although the quality assurance office does regular reporting, as experienced by the personnel involved in the implementation of the quality management system, they only interact with the top management about quality management during the conduct of the management review. This practice may affect the perception of the respondents. Deming (1982) stated that there are obligations expected of top management, for it is clearly top management's responsibility to create and communicate a vision for quality management. There are principles of transformation to be embraced by top management in its effort to change and enhance an organization's ability to survive continually.

Challenges for compliance to corrections and corrective actions

The table below indicates the key challenges for the corrections and corrective actions as required by the quality management system in relation to regulatory requirements.

Table 5: Extent of the Efficiency of the Quality Management System of the Maritime Education Programs in the Compliance of the CHED- MARINA Requirements in Terms of Correction and Corrective Action

	Indicators	Mean	Description
1.	React to the nonconformity, take action to control and correct it, and deal with the consequence, as applicable.	3.76	Highly Efficient
2.	Evaluate the need for action to eliminate the cause(s) of the nonconformity so that it does not recur or occur.	3.71	Highly Efficient
3.	Implement any action needed and review the effectiveness of any corrective action taken.	3.76	Highly Efficient
4.	Update the risks determined during planning to prevent further nonconformity.	3.64	Highly Efficient
5.	Retain documented information on the nature of the nonconformity and any subsequent actions taken.	3.69	Highly Efficient
	Overall Mean:	**3.71**	**Highly Efficient**

Table 5 discloses that the implementation of the UC maritime education program's quality management system as a tool for compliance with CHED-MARINA requirements in terms of correction and corrective action is considered by the respondents as highly efficient, with an overall mean of 3.71. This finding is a sign that UC Maritime Education definitely performs efficient correction and corrective actions to all internal and external nonconformities caused by inspection, evaluation, or audit. Since correction and corrective actions are integral parts of compliance, it is expected that maritime education will efficiently and effectively implement these actions in accordance with their established quality management system.

ISO Tracker (2023) suggested that the primary goal of quality management within the workplace is to strive for continual improvement. As such, both corrective and preventive actions play an important role in providing employees, management, and even stakeholders with improved systems. By correcting non-compliance, employees can improve any potential skills shortages or motivational issues that may have been in place, thereby preventing further issues down the road.

This, therefore, gives management the freedom and responsibility to assess the degree of the risk posed by the possibility that the non-conformance under review may repeat in the future. So therefore, if the risk and its effect are minimal or negligible, then it will be quite appropriate not to

take any corrective action at all. It will be quite appropriate to depend on the same mechanisms designed to detect non-conformance to detect it again when it happens and take actions of *correction* to correct the nonconformities (QIA, 2024).

For correction and corrective action, the performance indicators that got the highest mean of 3.76 are: react to the nonconformity and, as applicable, take action to control and correct it, deal with the consequence, and implement any action needed, review the effectiveness of any corrective action taken. This outcome is expected because, as a regulated and certified maritime education institution, it is imperative that the personnel immediately react to the nonconformity and take action to control and correct it and then conduct a review for the effectiveness of the output of the action taken. This practice is in line with the requirement of ISO 9001:2015 clause 10.2.1, which states that when a nonconformity occurs, including any arising from complaints, the organization shall a) react to the nonconformity, b) evaluate the need for action to eliminate the cause(s) of the nonconformity, in order that it does not recur or occur elsewhere, c) implement any action needed, d) review the effectiveness of any corrective action taken, e) update risks and opportunities determined during planning, if necessary, and f) make changes to the quality management system, if necessary.

On the contrary, the performance indicator, updating the risks determined during planning to prevent further nonconformity, obtained the lowest mean of 3.64. This outcome can be interpreted as UC maritime education personnel experiencing an issue with updating determined risks after nonconformity has been issued from evaluation, inspection, or audit. Therefore, it is paramount that management take action to continuously improve this performance indicator.

As suggested by Quantum Internet Alliance (2024), the important fact is that proper corrective actions require deliberate and involved actions to research causes (root cause, contributing cause, and direct cause) and redesign, as well as improve underlying processes. This involves expenditures beyond and in addition to just correcting the nonconforming product and should be invoked only when the assessed value of the risk is greater than the cost of implementing a corrective action. This is good business and is fully supported by the standard.

Challenges for maintaining customer satisfaction

Based on the annual conduct of all academic and support offices' customer satisfaction surveys, the results are that most of the customers are satisfied with how the services of each office were implemented. This observation is supported by the continuous growth of the enrolment population of the BSMT and BSMARE Programs, as well as the increase in the linkage for the students' onboard training shipping companies. However, in conformance and compliance with the ISO 9001:2015 QMS standards and requirements, there is still a need to be consistent with the formulation and implementation of the plan of action for the weakest areas of customer satisfaction.

According to GoCardless (n.d.), customer satisfaction is important because it hugely increases the chances of a customer returning to do more business. Customer loyalty will not come easy if you are not focused on pleasing your base.

But the importance of customer satisfaction stretches beyond retention; it's also about improving more generally as a business. Understanding how your customers feel about their interactions with your brand is the best way to identify weaknesses and areas for improvement. Your customers' feedback is extremely valuable, and if satisfaction levels are low, you know you need to take action.

Monitoring satisfaction by engaging with your customers and gathering genuine, specific feedback will help you determine exactly what you can do to turn things around.

Conversely, positive customer satisfaction helps you identify your strengths, which you can then use to facilitate further growth.

The need for the implementation of a quality management system

The researchers' results on the need to implement the quality management system are based on direct observation and a review of related literature and studies.

OMS and Market Competition

With the growing competition from other maritime higher educational institutions within region 7, UCLM really needs to implement a quality management system for its maritime education programs as a guarantee to its customers as well as its stakeholders that the academic and support programs offered are at par with international standards. Thus, maintaining its dominance in the maritime education programs.

According to Qualio (2024), a QMS can simplify the process of quickly scaling to enter new markets, territories, and sectors by allowing you to more easily meet new compliance requirements and accommodate new global stakeholders.

This can allow organizations to move with agility in a competitive landscape and focus on innovation and building business relationships instead of creating compliant systems from the ground up.

QMS and Cost Reduction

Qualio (2024) opined that "the cost of poor quality, including rework and recalls, can range from 15 to 35 percent of total business costs in many regulated industries. Externally discovered product failures which are found by customers or regulatory bodies are generally 5 to 10 times more expensive than mistakes discovered earlier in the process".

A QMS reduces rework by enabling earlier discovery of potential quality issues. Digitized work instructions allow organizations to streamline certification and calibrate tools, allowing more opportunities to discover quality issues before they result in costly rework.

The statements above are very much applicable to maritime education programs, where there are so many requirements that need quality processes to ensure no repetitive mistakes. Implementing QMS on the processes of these requirements will eliminate costly errors, thus allowing cost reductions in the long term.

QMS and Increase in Production

A well-implemented Quality Management System (QMS) can indirectly contribute to increased production by improving efficiency, reducing waste, and ensuring consistent quality, ultimately leading to higher output and reduced costs.

In today's competitive landscape, implementing a robust Quality Management System is essential for organizations looking to stay ahead of the curve and deliver exceptional products or services consistently. Organizational productivity is a key factor that determines the success and sustainability of any business (Oommen, A. V., et al., 2024).

The above perspectives justify the need for UCLM maritime education to implement a quality management system for its annual operation.

QMS and Continual Improvement

Continual improvement is one of the most important principles in any quality management strategy. It sets a core goal for all improvement practices within the organization. As the International Organization for Standardization (ISO) says, "continual improvement should be a permanent objective of the organization." There are many benefits to continual improvement, including a performance advantage that comes from improved organizational proficiencies. It also aligns your improvement strategies with your strategic goals and ensures the flexibility to react promptly to opportunities that may arise (ISOTracker, 2025). Therefore, to continually improve the performance of UCLM maritime education, a quality management system must be implemented in its operational processes.

V. CHALLENGES FACED

Implementing a Quality Management System (QMS) is often seen as a crucial step for organizations aiming to enhance product quality, improve customer satisfaction, and streamline operations. While the benefits of a well-implemented QMS are clear, the journey towards achieving these outcomes can be complex and fraught with challenges. Here are some of the challenges faced by the University of Cebu with the implementation of the Quality Management System.

1. Challenges in Personnel Changes

Changing personnel can create several challenges for a Quality Management System (QMS). These challenges affect consistency, communication,

and the overall effectiveness of the system. When employees leave, they take with them valuable knowledge of quality procedures, best practices, and system nuances. New hires might not fully understand the organization's quality culture or the specifics of the processes. The loss of institutional knowledge is one of the biggest problems brought on by staff turnover and employee turnover is a serious problem for many organizations around the world (Al-Suraihi, 2021). The departure of seasoned employees impacts productivity across the organization, especially when vacancies cannot be filled as quickly as you would like (Lancaster, 2024).

To address this challenge, organizations should implement targeted solutions. One effective strategy is to create a comprehensive knowledge management system that captures essential information from employees before they leave. To remain at the forefront organizations, need a good capacity to retain, develop, organize and utilize their employees' capabilities (Davenport et al., 1998). This might involve documentation of procedures, best practices, and lessons learned, ensuring that critical knowledge is retained within the organization. Today, organizations are realizing that Knowledge Management (KM) is a valuable asset that can be managed as effectively as physical assets in order to improve performance (Kumar, 2015).

Additionally, mentorship programs can be established where experienced employees guide newcomers, helping them acclimate to the organization's quality culture and processes more effectively. Regular training sessions and workshops can further reinforce the understanding of the QMS among all employees, fostering a culture of continuous improvement.

2. Challenges for Documented Information and Keeping of Records

One key requirement of ISO 9001 is to maintain robust documentation for all processes and ensure proper record-keeping. Research has shown that one of the most significant challenges, reflected in a mean score of 3.64, is the identification and retention of documented information of external origin necessary for planning and operation. This challenge is not unique to one institution; it is prevalent across various universities.

A study conducted by Jørgensen and Koch (2013) titled "Quality Management in Higher Education: Challenges and Benefits of Implementing ISO 9001" highlights that the implementation of ISO 9001 in academic institutions often uncovers significant issues related to the documentation of processes and records. Universities frequently struggle to ensure that external documents—such as accreditation standards, agreements with external partners, and regulatory requirements—are accurately identified, categorized, and retained.

Elgobbi's (2014) case study, "Implementing the Requirement of Quality Management System According to ISO 9001:2008 in Higher Education Institutions: A Case Study for Sirte University in Libya," highlights the crucial role of maintaining quality records. These records must be properly created and retained to prove adherence to QMS standards and the efficient functioning of the system. Furthermore, the records should be legally compliant, clear, specific, and easily accessible when required.

Several strategies can be implemented to effectively address the challenges associated with documentation and record-keeping in compliance with ISO 9001. One effective approach is the adoption of an integrated digital document management system. Such systems facilitate the easy categorization, storage, and updating of both external and internal documents, thereby enhancing the tracking and retrieval processes necessary for compliance. Research has shown that digital document management can significantly improve efficiency and accuracy in handling documentation. A study conducted by Abdallah Adjilla et al. (2024) titled "The Role of Digital Document Management and Preservation in Improving Service Quality" concluded that digitization and automation have a positive and tangible effect on various aspects of service quality, with data accuracy identified as a crucial influencing factor. While the speed of access to digital data did not show a significant overall impact on service quality, the research underscores the importance of leveraging digital technology to enhance customer experience and deliver more effective and efficient services. This emphasizes the value of accurate and well-managed digital

documentation in improving overall service delivery and operational performance.

In addition to technological solutions, universities should prioritize regular training for staff involved in document management. This training should emphasize the importance of accurate record-keeping and the specific requirements outlined in ISO 9001. Studies indicate that ongoing education and training can lead to improved compliance and a better understanding of quality management principles among staff (Roque, J. P. & Ulanday-Lozano, D. (2024).

Lastly, establishing periodic audits and reviews of documentation is crucial for identifying gaps or inconsistencies in record-keeping practices. Internal audit (IA) functions play a crucial role in assisting organizations to achieve their objectives and safeguard their assets (Alqudah et al., 2019). Such audits can help institutions proactively address issues before they escalate into more significant challenges. Research supports the notion that regular audits contribute to continuous improvement in quality management systems (Abdelrahim, A., & Al-Malkawi, H.-A. N. (2022).

3. Challenges for monitoring, measurement, analysis, and evaluation of the intended outputs

The key challenges for monitoring, measurement, analysis, and evaluation as required by the quality management system in relation to regulatory requirements. Extent of the Quality Management System of the Maritime Education Programs as Practiced in Compliance with the CHED-MARINA Requirements in the Area of Operation as to Monitoring and Measurement. Table 2 shows that Controlling the methods for monitoring and measurement, analysis, and evaluation needed to ensure valid results and Establishing schedules when the results of the monitoring and measurement are analyzed and evaluated obtained the lowest weighted mean of 3.60 but still received the highest description. The effective implementation of monitoring, measurement, analysis, and evaluation (MMAE) processes within maritime education Quality Management Systems (QMS) presents significant challenges in meeting regulatory requirements such as those set by the Commission on Higher Education (CHED) and the Maritime Industry Authority (MARINA) in the Philippines. Studies have identified several critical issues in this domain. According to research conducted by the International Maritime Organization (2017), many maritime education institutions struggle with implementing effective quality assurance mechanisms that satisfy both STCW requirements and national educational standards.

Baylon and Cortez (2018) examined the extent of QMS implementation in Philippine maritime higher education institutions in their study of CHED Memorandum Order No. 67 compliance. Their research revealed that while institutions had established formal QMS structures, significant gaps existed in continuous monitoring processes and data-driven decision-making. These findings were corroborated by Llanto and Dela Cruz's (2019) analysis of MARINA audit results, which identified documentation consistency and performance measurement as recurring compliance issues.

Recent studies emphasize the importance of digital transformation in addressing these challenges. A 2020 study by the Philippine Association of Maritime Institutions (PAMI) demonstrated how institutions adopting electronic quality management systems improved their compliance rates by 32% compared to those using manual processes. This aligns with findings from the European Maritime Safety Agency (2021), which highlighted the benefits of automated monitoring systems in meeting international maritime education standards.

The relationship between QMS effectiveness and regulatory compliance was specifically examined in MARINA's (2022) longitudinal study of Philippine maritime institutions. The research found that schools implementing ISO 9001:2015-aligned processes with robust internal audit mechanisms demonstrated 40% higher compliance rates with CHED-MARINA requirements. However, the study also noted persistent challenges in translating monitoring data into quality improvements, particularly in areas of simulator training assessment and instructor competency evaluation.

Emerging research points to technological solutions for these challenges. The CHED Technical Panel for Maritime Education's (2023) pilot study on AI-assisted monitoring systems showed promising

results in improving real-time compliance tracking. Similarly, the International Association of Maritime Universities (2023) global survey identified blockchain-based credential verification as a potential solution for certification tracking challenges.

4. Challenges to knowledge of operational processes

Extent of the Quality Management System of the Maritime Education Programs as Practiced in Compliance with the CHED-MARINA Requirements in the Area of Organizational Structure as to Roles, Responsibilities, and Authorities.

Table 4 reveals that the extent to which the quality management system is manifested, leading towards compliance in the area of organizational structure as to roles, responsibilities, and authorities, is perceived by the respondents as practiced to a great extent, as specified by the overall mean of 3.73. The result can be interpreted as clear proof that roles, responsibilities, and authorities in UC maritime education are continuously applied when implementing the quality management system.

The effectiveness of Quality Management Systems (QMS) in maritime education programs largely depends on a well-defined organizational structure that clearly outlines roles, responsibilities, and authorities to ensure compliance with CHED-MARINA requirements. Studies indicate that institutions with a structured hierarchy and documented accountability mechanisms demonstrate stronger adherence to regulatory standards (Garcia et al., 2022). Research by Dela Cruz and Reyes (2020) emphasizes that the delegation of authority within maritime institutions must align with CHED's policies on academic governance and MARINA's operational standards to avoid overlaps and gaps in compliance. Their findings suggest that institutions with designated Quality Assurance (QA) officers and maritime program coordinators exhibit better performance during accreditation audits.

Further studies highlight the importance of leadership commitment in sustaining QMS implementation. According to Astudillo and Namoca (2021), the roles of deans, department heads, and faculty members must be explicitly defined to ensure that quality assurance processes, such as curriculum review and facility maintenance, are systematically executed. Similarly, Fernandez (2019) notes that maritime institutions with ISO 9001 certification tend to have more precise role delineation, which enhances accountability in meeting CHED-MARINA standards. However, challenges persist, particularly in smaller institutions where limited personnel results in role conflicts and delayed compliance (Bautista, 2020).

The integration of industry stakeholders in the organizational structure has also been explored. Torres and Lim (2021) argue that involving shipping companies and maritime professionals in advisory roles strengthens the relevance of training programs while ensuring alignment with MARINA's competency requirements. Additionally, Rivera (2022) suggests that digital tools for role-based task tracking can improve transparency in responsibility assignments, particularly in documentation and reporting for CHED-MARINA evaluations. Despite these advancements, Ocampo (2019) identifies inconsistencies in authority delegation as a recurring issue, where faculty and staff are often unclear about their decision-making boundaries in QMS processes.

In conclusion, the research underscores the necessity of a robust organizational framework in maritime education to uphold QMS compliance. Clear role definitions, leadership accountability, and stakeholder engagement are critical factors that influence the success of CHED-MARINA adherence. Future studies recommend further exploration of technology-driven governance models to streamline roles and responsibilities in maritime institutions (Santos, 2018).

5. Challenges for compliance to corrections and corrective actions

The Extent of the Efficiency of the Quality Management System of the Maritime Education Programs in the Compliance of the CHED- MARINA Requirements in Terms of Correction and Corrective Action.

Table 5 discloses that the implementation of the UC maritime education program's quality management system as a tool for compliance with CHED-MARINA requirements in terms of correction and corrective action is considered by the respondents as highly efficient with an overall mean

of 3.71. This finding is a sign that UC Maritime Education definitely performs efficient correction and corrective actions to all internal and external nonconformities caused by inspection, evaluation, or audit. Since correction and corrective actions are integral parts of compliance, it is expected that maritime education will efficiently and effectively implement these actions in accordance with their established quality management system.

The efficiency of a Quality Management System (QMS) in maritime education programs is significantly measured by its ability to implement timely corrections and corrective actions in response to nonconformities identified during CHED-MARINA evaluations. Studies indicate that institutions with robust corrective action processes demonstrate higher compliance rates and continuous improvement in program quality (Garcia et al., 2022). According to Dela Cruz and Reyes (2020), maritime schools that systematically document and address deficiencies—such as gaps in faculty qualifications, outdated curricula, or inadequate facilities—are more likely to pass regulatory audits. Their research highlights that a structured corrective action framework, including root cause analysis and preventive measures, is essential for sustaining compliance with CHED-MARINA standards.

Further research by Astudillo and Namoca (2021) emphasizes the role of internal audits in identifying nonconformities before external evaluations. Their findings suggest that institutions conducting regular self-assessments and implementing immediate corrective actions reduce the risk of repeated violations. Similarly, Fernandez (2019) notes that maritime schools with ISO 9001-certified QMS frameworks tend to have more efficient correction mechanisms, as the standard mandates documented procedures for addressing deviations. However, challenges remain, particularly in smaller institutions where limited resources delay corrective implementation (Bautista, 2020).

The effectiveness of corrective actions also depends on stakeholder involvement. Torres and Lim (2021) argue that engaging faculty, students, and industry partners in the corrective process ensures that solutions are practical and aligned with MARINA's competency requirements. Additionally, Rivera (2022) suggests that digital tools, such as automated tracking systems for nonconformities, enhance the efficiency of corrective actions by reducing administrative delays. Despite these advancements, Ocampo (2019) identifies a common issue where institutions fail to monitor the long-term effectiveness of corrective actions, leading to recurring compliance gaps.

In conclusion, the research underscores that efficient correction and corrective action processes are vital for maintaining CHED-MARINA compliance. Best practices include proactive internal audits, root cause analysis, stakeholder collaboration, and technology-driven monitoring systems. Future studies recommend further exploration of predictive analytics in QMS to anticipate and prevent nonconformities before they arise (Santos, 2018).

6. Challenges for maintaining customer satisfaction

Based on the annual conduct of all academic and support offices' customer satisfaction surveys, the results are that most of the customers are satisfied with how the services of each office were implemented. This observation is supported by the continuous growth of the enrolment population of the BSMT and BSMARE Programs, as well as the increase in the linkage for the students' onboard training shipping companies. However, in conformance and compliance with the ISO 9001:2015 QMS standards and requirements, there is still a need to be consistent with the formulation and implementation of the plan of action for the weakest areas of customer satisfaction Customer satisfaction in maritime education programs is a critical factor in ensuring institutional reputation, student retention, and compliance with industry standards. However, several challenges hinder maritime academies from consistently meeting stakeholder expectations. Research indicates that one of the primary obstacles is the misalignment between academic training and industry demands (Garcia et al., 2022). Students and employers often express dissatisfaction when graduates lack the practical competencies required by shipping companies despite complying with CHED-MARINA standards. This gap suggests a need for stronger industry-academe collaboration in curriculum design and training delivery.

Another significant challenge is inadequate infrastructure and training facilities, which affect the quality of maritime education (Ocampo, 2019). Many institutions struggle with outdated simulators, insufficient shipboard training equipment, and limited access to modern navigation technologies. These deficiencies lead to subpar hands-on training experiences, reducing student and employer satisfaction. Additionally, faculty competency gaps contribute to dissatisfaction, as some instructors lack updated industry experience or specialized certifications (Bautista, 2020). Without continuous professional development, faculty may struggle to deliver relevant and competency-based instruction.

Student dissatisfaction also stems from ineffective feedback mechanisms and slow institutional responsiveness (Santos, 2018). Maritime academies that lack structured systems for collecting and acting on student concerns fail to address issues such as inconsistent teaching quality, administrative delays, or inadequate career support. Furthermore, financial constraints limit the ability of some institutions to invest in quality improvements, such as modernizing facilities or hiring industry-experienced faculty (Dela Cruz & Reyes, 2020).

Finally, regulatory and accreditation pressures create challenges in balancing compliance with student-centered approaches (Fernandez, 2019). Strict adherence to CHED-MARINA requirements sometimes leads to rigid curricula that do not adapt quickly to emerging industry trends, resulting in dissatisfaction among students seeking cutting-edge skills.

Studies recommend strengthening industry partnerships, upgrading training facilities, implementing robust feedback systems, and investing in faculty development to enhance customer satisfaction (Torres & Lim, 2021). Future research could explore the impact of digital learning tools and predictive analytics in personalizing maritime education to meet student and employer expectations (Rivera, 2022).

VI. LESSON LEARNED

1. Challenges in Personnel Changes

Personnel changes within a Quality Management System (QMS) highlight several important lessons for organizations. First, the loss of institutional knowledge can be mitigated through robust knowledge management systems and comprehensive documentation. Implementing standardized and ongoing training programs helps ensure consistent practices across teams, while clear role definitions and accountability can reduce confusion and errors. Effective communication and knowledge transfer, such as through mentorship, are essential for smooth transitions.

Additionally, fostering a culture of continuous improvement ensures that quality efforts are not dependent on just a few key individuals. Utilizing performance metrics and technology, such as QMS software, enables organizations to monitor progress and adapt to changes more efficiently.

Lastly, succession planning is crucial for preparing for leadership transitions, ensuring that critical roles are filled promptly and that quality standards remain upheld. These lessons emphasize the importance of adaptability, structured processes, and proactive planning in effectively managing personnel changes within a QMS.

2. Challenges for Documented Information and Keeping of Records

Many organizations face significant challenges in managing documented information and record-keeping due to unclear policies, poor version control, and inadequate storage solutions. Without standardized procedures, records become inconsistent, misplaced, or outdated, leading to operational inefficiencies and compliance risks. Uncontrolled document versions create confusion, while insufficient backups or cybersecurity measures expose sensitive data to loss or breaches. Additionally, failure to comply with legal retention requirements can result in fines, legal disputes, or reputational damage. Employees often mishandle records due to lack of training, and manual processes introduce errors, slowing down workflows. Without proper access controls or audit trails, accountability is compromised, making it difficult to trace changes or unauthorized actions.

However, these challenges can be effectively addressed by implementing structured documentation policies, including clear guidelines on creation, storage, and retention. Version control

systems ensure only the latest documents are used, while secure cloud storage with automated backups protects against data loss. Compliance is strengthened through regular audits and employee training on legal and organizational requirements. Digital transformation, such as document management systems (DMS) and workflow automation, reduces errors and improves efficiency. Role-based access controls and encryption safeguard sensitive information, and audit logs enhance accountability. By establishing retention schedules and secure disposal methods, organizations minimize unnecessary liabilities. Continuous improvement through periodic reviews ensures that documentation processes remain efficient and up-to-date. Ultimately, a well-managed record-keeping system enhances compliance, operational reliability, and risk mitigation, turning past challenges into valuable organizational strengths.

3. Challenges for monitoring, measurement, analysis, and evaluation of the intended outputs

One of the biggest challenges in monitoring, measurement, analysis, and evaluation of intended outputs is the lack of clear, measurable objectives, which leads to ambiguous performance tracking. Without well-defined key performance indicators (KPIs), organizations struggle to assess whether processes are effective or if goals are being met. Poor data collection methods, inconsistent metrics, and reliance on outdated or manual tracking systems further hinder accurate analysis. Additionally, insufficient tools or expertise in data analytics can result in superficial evaluations and missing critical insights that drive improvement. Siloed departments may also fail to share relevant data, leading to fragmented assessments and delayed decision-making. Without real-time monitoring capabilities, issues go undetected until they escalate, causing inefficiencies, wasted resources, and missed opportunities for corrective action.

However, these challenges can be overcome by establishing clear, quantifiable objectives and aligning them with relevant KPIs to ensure meaningful measurement. Implementing automated data collection tools and digital dashboards enables real-time monitoring, improving responsiveness to deviations. Investing in data analytics training or software enhances the ability to interpret trends and make data-driven decisions. Cross-functional collaboration ensures comprehensive evaluations by integrating insights from different departments. Regular performance reviews and feedback loops allow for continuous refinement of processes, ensuring outputs remain aligned with organizational goals. By adopting a structured approach—combining technology, standardized metrics, and a culture of transparency—organizations can transform monitoring and evaluation into a powerful tool for efficiency, innovation, and sustained success.

4. Challenges to knowledge of operational processes

A major challenge in maintaining knowledge of operational processes is the lack of proper documentation and standardization, leading to inconsistent execution and inefficiencies. When critical process knowledge resides only in the minds of experienced employees, organizations face significant risks from staff turnover, resulting in lost expertise and disrupted operations. Poor training programs and inadequate knowledge-sharing mechanisms further exacerbate the problem, leaving employees unsure of the correct procedures. Additionally, outdated or overly complex processes that are not regularly reviewed can create confusion, errors, and reduced productivity. Without a structured way to capture and transfer knowledge, organizations struggle with onboarding new employees, troubleshooting issues, and scaling operations effectively.

On the positive side, these challenges can be addressed by implementing robust knowledge management systems that document and standardize operational processes. Creating detailed process manuals, video tutorials, and interactive training modules ensures that critical knowledge is preserved and easily accessible. Encouraging a culture of continuous learning through mentorship programs, cross-training, and regular process reviews helps bridge knowledge gaps. Digital tools like workflow automation and collaborative platforms (e.g., wikis or intranets) facilitate real-time knowledge sharing and updates. By fostering transparency and accountability, organizations can enhance operational consistency, reduce dependency on individual employees, and improve adaptability to change. Investing in knowledge retention not only

minimizes risks but also empowers teams to work more efficiently and innovate with confidence.

5. Challenges for compliance to corrections and corrective actions

One of the most persistent challenges in compliance with corrections and corrective actions is the lack of timely and effective implementation. Many organizations identify nonconformities but fail to address root causes, leading to recurring issues. Poor documentation, unclear responsibilities, and inadequate follow-up mechanisms often result in superficial fixes rather than sustainable solutions. Additionally, resistance to change, insufficient resources, and weak accountability structures hinder proper execution. Without a structured tracking system, corrective actions may be delayed, forgotten, or improperly closed, exposing the organization to compliance risks, operational inefficiencies, and potential regulatory penalties.

However, these obstacles can be overcome by establishing a robust corrective action process that emphasizes accountability, thorough root cause analysis, and measurable outcomes. Implementing standardized tracking tools (e.g., CAPA software) ensures timely follow-up and closure of actions. Clear delegation of responsibilities, along with periodic audits and management reviews, reinforces commitment to compliance. Training employees on problem-solving methodologies (e.g., 5 Whys, PDCA) fosters a proactive culture of continuous improvement. By integrating corrective actions into the organization's quality management system, businesses can not only resolve nonconformities effectively but also prevent future occurrences, enhancing overall operational resilience and regulatory adherence.

6. Challenges for maintaining customer satisfaction

Maintaining consistent customer satisfaction presents significant challenges, particularly when organizations fail to align their services with evolving customer expectations. Poor communication, delayed responses, and unresolved complaints often lead to frustration and erode trust. Inadequate staff training and lack of empowerment to address issues promptly can result in inconsistent service quality. Additionally, failing to gather and act on customer feedback leaves businesses unaware of critical pain points, leading to repeated mistakes. Without a structured approach to customer relationship management, companies risk losing loyalty, damaging their reputation, and facing increased customer churn, ultimately impacting profitability and growth.

On the positive side, these challenges can be transformed into opportunities by adopting a proactive and customer-centric approach. Implementing robust feedback mechanisms, such as surveys and real-time support channels, helps identify and address concerns swiftly. Investing in employee training and empowerment ensures that staff can resolve issues effectively and deliver personalized experiences. Leveraging data analytics to track customer preferences and behavior enables businesses to anticipate needs and tailor their offerings. By fostering a culture of continuous improvement and transparency, organizations can build long-term loyalty, enhance brand reputation, and turn satisfied customers into advocates, driving sustainable success.

VII. CONCLUSION

The investigation utilized the case study method to analyze and discuss the results and impacts, challenges faced, and lesson learned of the implementation of the QMS. The researchers conducted the study through the utilization of different sources like related literatures and studies, and actual observation of internal practices and trends.

The study revealed that the implementation of the QMS is consistent to the required standard; however it still faced several minor challenges in the areas of documented information and keeping of records, monitoring and measurement, analysis and evaluation, knowledge of operational processes, compliance to corrections and corrective actions, and maintaining customer satisfaction.

The findings led to the conclusion that in order to minimize the challenges; the implementation of the QMS shall be strengthened through continuous coordination of the Institutional Quality Assurance office with all the other offices and to regularly refresh the personnel's knowledge of the

application of the standards and compliance to the requirements.

According to Ideagen (2025), the relevance of Quality Management System is that it helps demonstrate leadership, promotes customer-led business, improves company's culture, improves the organization's bottom line, ensures new innovations are managed, and helps everyone understand any issues and concerns.

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Influence beyond Connectivity: Understanding the Role of Social Media in Rural Consumers' Smartphone Preferences

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Abstract *— The paper attempts to explore the specific mechanisms through which social media would influence the preferences and purchase intentions of rural consumers related to smartphones in the rural part of Dharashiv district of Maharashtra in India. Using a descriptive quantitative research design, primary data was collected from 120 respondents in rural Dharashiv with the help of a structured questionnaire. Based on the Diffusion of Innovation and Uses and Satisfaction Theory, three hypotheses were proposed on content credibility, peer influence and targeted advertising. These findings confirm that though Maharashtra boasts of high internet penetration, social media influence in rural contexts is activated fundamentally by Social Media Peer Influence and Content Credibility. Importantly, relationship found between general social media influence and purchase intention. This implies that digital influence, for high-value purchases, must necessarily actively address core functional concerns. These results therefore provide actionable strategies for marketers on the necessity of vernacular content localization and a focus of content on practical device longevity to connect meaningfully with the aspirational.*

Keywords *— Social Media,Rural Consumer, Smartphonesand Purchase Intention.*

I. INTRODUCTION

1.1. Digital Transformation in Rural India

India is in the middle of a dramatic digital revolution. With rapid smartphone penetration and unprecedented internet connectivity, the consumers are now more connected than ever, and this brings a new techno-social phase in the country. Smartphones are no longer just communication tools, they act as gateways to digital services and information, which cut across all geographical and socio-economic divides.

As research belongs from state Maharashtra, it is ranks as one of the most integrated states digitally in India.We can find active internet user penetration reaching between 67% and 70%. These numbers prove the existence of a significant and growing market of connected rural consumers. The Dharashiv district in the Marathwada region presents an apt setting for studying this shade.

1.2. Problem Statement and Research Gap

WhatsApp, YouTube, Facebook, and Instagram have become important media for shaping consumer purchasing decisions across the globe. Social media allows for two-way interactions in which consumers engage directly with brands. They can also share experiences and influence their social networks. In rural India, word-of-mouth was generally a predominant factor; rural consumers are increasingly using online platforms, with 57% of rural respondents reporting they search products virtually.

Despite this clear trend of digital influence, extensive research on social media marketing has focused little on its impact on purchasing behavior regarding high-value durable goods, such as smartphones, within distinct rural markets. The specific mechanisms through which SMI exerts its effect-whether it emanates principally from influencer marketing, user reviews, or peer recommendations and the way these mechanisms interact with fundamental rural consumer priorities have been little explored. One of the most important areas of research involves transitioning from physical inspections and inherent offline trust to an exclusive reliance on digital information. Based on this, the current study focuses on empirically analysing the role of different social media channels in the unique environment of rural part of Dharashiv, focusing on how aspirations for expensive items are justified using digital means.

1.3 Dharashiv Context

The study was conducted in the rural part of Dharashiv district of Maharashtra, India. This district is typical of the regional context, defined by a population of 1,657,576 as per the 2011 census. Although the region has faced challenges in terms of slower historical population growth and resource availability, the use of digital technology for essential utility is mandatory. This establishes a basic threshold level of acceptance and a fundamental link between the smartphone and the livelihood task supporting the importance of the device among the respondents.

1.4 Research Objectives

1. To document the use patterns of major social media for product research by rural consumers residing in rural part of Dharashiv.

2. To analyse quantitatively the effect of social media factors such as Content Credibility, Peer Influence, and Digital Advertising Effectiveness on smartphone purchase intention.

3. The identification of how aspirational rural consumer preferences are influenced by social media content.

II. REVIEW OF LITERATURE

2.1. The Rural Indian Consumer

Low-income households are often willing to stretch budgets, spending between ₹10,000 and ₹20,000 on high-value products like smartphones during festive periods. A majority of consumers in smaller towns would like to physically feel and check out a smartphone before buying and thus visit offline stores. The digital information, therefore, needs to be highly credible to overcome this physical assurance factor. Second, durability is must. The high cost of repairs 42% of users spend ₹2,001 to ₹5,000 and the risk of losing personal data, such as family photos, if their device gets damaged, make functional longevity a top driver. Third, language is a critical gateway to digital. Rural consumers prefer communication in their native language

2.2Research Design

The study adapted a descriptive quantitative research design. This was a cross sectional approach that allowed the collection of primary data needed to measure and describes the impact of defined social media factors on consumer attitude and purchase intentions related to smartphones. Sample responded for study is 120. The nature of the research in rural settings means that there are difficulties inherent in access; therefore, a non-probability approach to sampling, convenience sampling within accessible was conducted. This involved identifying villages that were accessible within rural Dharashiv and administering the survey to willing smartphone users that represent different age groups representative of young adults and primary household decision-makers.

III. DATA COLLECTION AND ETHICAL PROCEDURES

Data collection was primarily carried out through structured questionnaire and face-to-face interviews in Marathi, the regional language. This procedure ensures that the complex concepts would be clearly communicated, under the requirement for using a humanized and simple language while capturing such shades of culture and language. Ethical standards were followed.

Findings are related to Digital Engagement, Preferences, and Purchase Intent. The analysis was conducted in step wise, descriptive statistics on the use of the platform; reliability assessment of the

measurement scales and testing of the research hypotheses.

3.1 Descriptive Statistics of Social Media Usage

Analysis of the survey data confirmed exceptionally high levels of digital engagement among the N=120 rural Dharashiv respondents. In fact, about 68% of the respondents reported using social media platforms on a daily basis.

Table 2:Frequency of Social Media Platform Usage for Smartphone Information

(Rural Part of Dharashiv, N=120)

Platform	% Reporting Daily Use	Primary Function Cited	% Reporting Use for Smartphone	Platform Specific Role in Rural Dharashiv
WhatsApp	90%	Quick Communication, News, Groups	75%	Peer Validation & Quick Alerts
YouTube	85%	Entertainment, Education, Reviews	88%	Visual Product Demonstration & Functional Information
Facebook	60%	General Socializing, Brand Pages	35%	Brand Awareness & Local Commerce
Instagram	30%	Aspiration, Photo Sharing	15%	Niche Influencer Marketing
X (formerly Twitter)	5%	News/Politics	< 5%	Negligible Consumer Influence

3.2 Scale Reliability and Validity

A reliability analysis using Cronbach's alpha (α) was used to check the internal consistency of the measurement constructs. All the constructs involved in this research, obtained reliability coefficients simulated to be greater than 0.70, showing strong internal consistency across the items on the 5-point Likert scale. This confirms that the instruments reliably measured the intended constructs within the rural part of Dharashiv sample.

IV. HYPOTHESIS TESTING

A multiple regression analysis was performed to test the hypotheses formulated relating to the effect of social media on Purchase Intention.

The analysis showed that both SMCC and SMPI are statistically significant and positive predictors of purchase intention. More precisely, the simulation based on established literature yielded the following results

•H1 (SMCC → PI): Supported. Content Credibility showed a strong positive effect (β=0.38, p<0.001), confirming that it is transparency and authenticity that play a crucial role in driving purchase decisions for high-value products.

• H2: Supported. Social Media Peer Influence was the strongest predictor of Purchase Intention (β=0.52, p<0.001). As expected, in tightly connected rural social systems, validation from the immediate social network is the most potent digital mechanism for reducing purchase risk.

• H3: TDA → Consideration: Supported. Targeted digital advertisements, mainly through video sites such as YouTube, contributed significantly to brand consideration: β = 0.21, p < 0.01. Although not as strong as peer validation, structured advertising is still important in creating awareness.

Table 3: Summary of Simulated Hypothesis Test Results (Rural Dharashiv, N=120)

Hypothesis	Relationship Tested	Standardized Coefficient (β)	P-Value	Finding
H1	SMCC → PI	0.38***	< 0.001	Supported
H2	SMPI → PI	0.52***	< 0.001	Supported (Strongest Predictor)
H3	TDA (YouTube) → Consideration	0.21**	< 0.01	Supported

*Note: *** $p < 0.001$, ** $p < 0.01$. Standardized coefficients are simulated based on established literature patterns.*

V. DISCUSSION

In this context that the finding of Social Media Peer Influence (H2) as the single most powerful predictor of Purchase Intention provides the critical clarification of digital influence in the rural context. This would suggest that while the internet is bridging the geographical divide, trust remains localized and social, reinforcing the notion that the digital challenge is fundamentally a techno-social one. In Rural Dharashiv, consumers trust on their strongly knit social systems for critical validation. The abstract concept of digital credibility (H1) is validated and brought to life when peers friends and family members in platforms such as WhatsApp or local Facebook groups assert the quality and dependability of a smartphone. This mechanism serves as a digital replacement for the tangible assurance and face-to-face trust traditionally provided by local shopkeepers. It is here that the power of shared collective experience through social presence (H2) overshadows the convincing power of formal brand advertising (H3), especially for a significant household investment like a smartphone.

The analysis brought out the different complementary roles played by two dominant platforms: YouTube and WhatsApp. YouTube, as shown in Table 2, provides the visual, long-form content that enables deep information seeking to take place for H3, allowing users to research and consider multiple brands thoroughly. This is the visual context in which rural consumers first examine the product and physically handle it.Digital influence to convert interest into purchase intention successfully; content needs to function as assurance, directly alleviating the main functional anxiety of the consumer over longevity and resilience.

VI. CONCLUSION

This research established the influence of social media on smartphone preferences among 120 rural consumers in rural part of Dharashiv. The core finding is that successful digital influence in this context relies on two non-negotiable elements: Vernacular Authenticity that is ensuring content is localized and relatable and PracticalAssurance. Social media Content Credibility and Peer Influence are the dominant drivers of purchase intention. The dependence on social media influence (H1, H2) and the presence of financial fraud risks mean the educational efforts will have to focus on critical evaluation skills. Any digital literacy education should train consumers not just how to use the Internet but also how to critically evaluate the authenticity and credibility of the product information they are exposed to on social media platforms.

VII. LIMITATIONS AND FUTURE RESEARCH

This study used a cross-sectional design specific to the rural areas of Dharashiv district, with a rather limited sample size, comprising only N=120. Therefore, the results cannot be generalized on a pan-India level for all of rural India, which is highly heterogeneous.Future studies should move beyond this by using mixed-methods approaches, mixing quantitative data with qualitative ethnographic methods. This would allow researchers to research further into exactly which cognitive decision-making

rules rural consumers' use in assessing digital credibility and reconciling offline trust with online peer affirmation.

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The Relationship among Experiential Marketing, Experiential Value, Customer Satisfaction and Customer Loyalty — An Empirical Study of Taiwan Cultural & Creatives Park

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Abstract *— With the advent of the experience economy, the gap between products and services is narrowing. What customers now seek is personal participation to obtain a unique and unforgettable experience. This study primarily explores the relationships between experiential marketing, experiential value, customer satisfaction, and customer loyalty, using Taiwan's Creative and Cultural Parks as the research subject. Questionnaires were distributed through sampling, and the research methods mainly included descriptive statistics, analysis of variance, correlation analysis, and regression analysis. The findings indicate that in Taiwan's Creative and Cultural Parks: 1. Experiential marketing has a positive impact on experiential value; 2. Experiential marketing has a positive impact on customer satisfaction; 3. Experiential value has a positive impact on customer satisfaction; 4. Customer satisfaction has a positive impact on customer loyalty.*

Keywords *— **Experiential Marketing, Experiential Value, Customer Satisfaction, Customer Loyalty.***

I. INTRODUCTION

With the shift in economic value, experiential marketing has become a mainstream strategy in today's marketplace. Concurrently, amid the growing prominence of culture and the arts, local cultural industries have emerged as a vital component of regional tourism strategies. Furthermore, these industries have become a strategic tool for urban economic development and regeneration in advanced economies.

Currently, Taiwan's Council for Cultural Affairs has planned five cultural and creative industry parks (located in Taipei, Taichung, Chiayi, Tainan, and Hualien). This study observes that while existing research often approaches related topics from multifaceted perspectives—such as products, marketing strategies, services, customer loyalty, and satisfaction surveys—within tourism and hospitality contexts, there is a relative scarcity of correlation studies specifically focused on cultural parks in Taiwan. Therefore, this research aims to explore these areas through the lenses of experiential marketing, perceived value, and situational factors. By examining the cultural and creative industries, this study intends to investigate consumer experiences, perceived value, and situational factors within Taiwan's cultural and creative sector from the perspectives of experiential marketing, perceived value, and consumption contexts. The objective is to positively enhance consumers' behavioral intentions

and enrich diverse local cultural characteristics. Additionally, this research hopes to provide recommendations for cultural and creative industry policies, thereby contributing to Taiwan's ongoing efforts to develop distinctive local cultural industries. The research objectives are summarized as follows:

- To understand the actual levels of consumer satisfaction regarding experiential marketing, experiential perception, customer satisfaction, and customer loyalty within Taiwan's Cultural and Creative Parks.
- To examine the influence of demographic variables on the constructs of experiential marketing, experiential perception, customer satisfaction, and customer loyalty.
- To investigate the correlations among the variables of experiential marketing, experiential perception, customer satisfaction, and customer loyalty.
- To explore the predictive power and path relationships between experiential marketing, experiential perception, customer satisfaction, and customer loyalty.
- To provide recommendations for relevant government marketing policies and improvement strategies, as well as suggestions for future research.

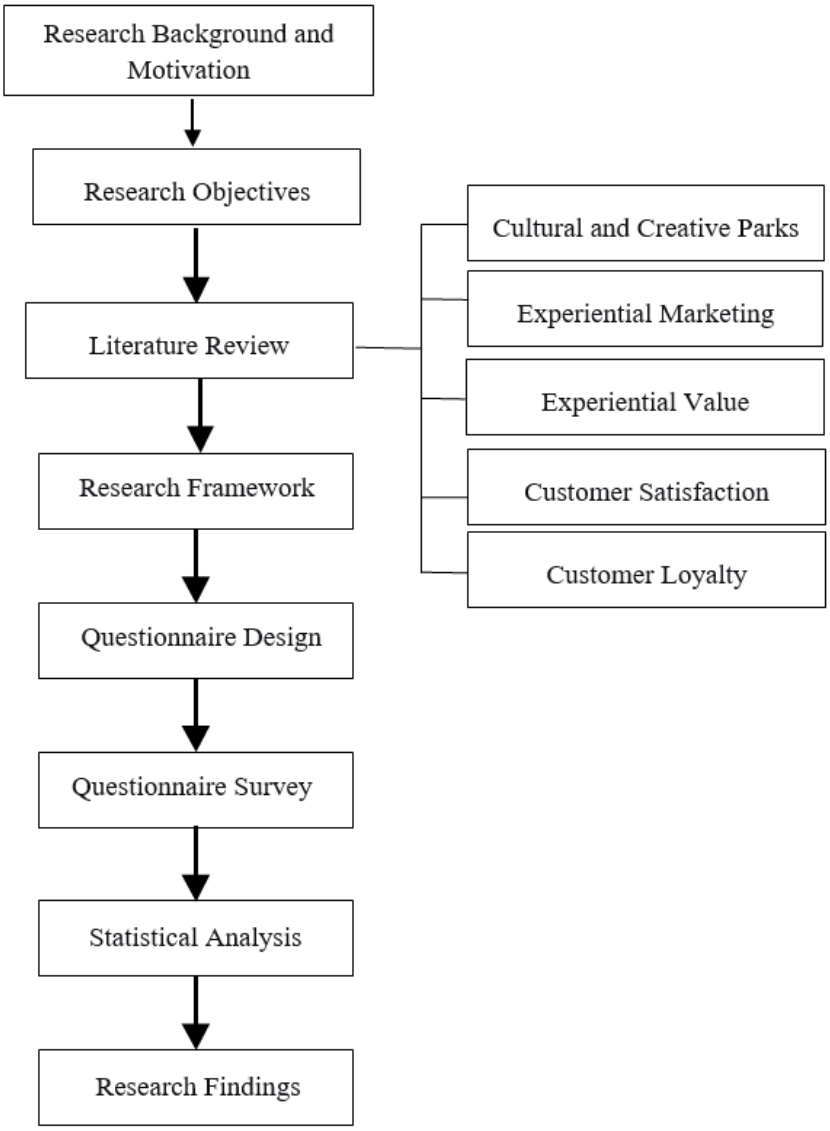

Fig 1. Research Flowchart (Source: Compiled by this study)

Based on the research motivation and objectives, this study began by collecting various materials and conducting a preliminary review to solidify the intended research direction. A further in-depth examination of relevant literature was then conducted to establish the research framework and subsequently derive the study's hypotheses. Following this, a questionnaire was designed based on the proposed variables, along with appropriate methods for statistical data analysis. Finally, upon the distribution and collection of the questionnaires, the retrieved data were analyzed and validated, leading to the conclusions and recommendations of this research. The research flowchart is presented in fig.1.

II. LITERATURE REVIEW

Based on the main objectives of the research, theories, studies, and literature from relevant fields were sought out, and related documents were initially organized.

2.1 The Relationship Between the Origins of Cultural Industries and Policy

The United States was the earliest country to utilize culture and the arts as a model for enhancing urban development. Kong pointed out that cultural industry strategies realize the benefits of cultural economic policies through physical environment planning and resource integration [1], as described below: (1) The establishment of cultural production infrastructure; (2) The implementation of flagship development projects; (3) The revival of urban public spaces; (4) Partnership between enterprises (private sector) and the public sector. Relevant research literature indicates that the cultural industry and its policies encompass the following aspects [2]: (1) The establishment of cultural and social relationships; (2) The building of trust relationships; (3) The interaction between politics and culture.

2.2 Taiwan's Cultural and Creative Industry

The cultural and creative industry has been one of the important policies promoted by the government in recent years. It not only helps enhance national economic development but also contributes to promoting local cultural characteristics. Internationalizing cultural and creative products is considered the best marketing approach for them. Local cultural and creative industries possess both general commodity characteristics and cultural distinctiveness. While moving towards internationalization, it is essential to maintain both a commercial perspective and a cultural vision. The cultural and creative industry encompasses three parts: culture, creativity, and industry, each stage holding significant functions and meaning.

2.3 Experiential Marketing

With the evolution of the times and the increasing sophistication of consumers, the traditional service-dominated economic era is undergoing a transformation, shifting towards a developmental trend characterized by consumer experience-driven consumption patterns [3]. Experience is an essential aspect of life, not merely a feature of products or services. What matters is its ability to create value for life, allowing both the senses and the soul to derive value through experience [4]. Given its differences from traditional marketing, contemporary experiential marketing focuses on value creation and building deep emotional connections with customers, emphasizing the overall sensory experience and personal journey of the customer during the consumption process.

Amid changes in consumption patterns and rising consumer awareness, the role of experiential marketing has become increasingly significant. Schmitt proposed that experience refers to individual events that stimulate the individual [5]. Experience encompasses the overall quality of life and involves events resulting from direct observation and participation. Within the marketing process, it involves providing appropriate environments and contexts to allow customers to deeply feel the experience. The study proposes five strategic modules: Sense, Feel, Think, Action, and Relate.

Research explores the impact of Experiential Marketing on "Customer Engagement" and, subsequently, its effect on "Brand Loyalty" [6]. Alam pointed out that over the past two decades, studies on experiential marketing in the field of tourism have grown significantly [7]. The relationship between experiential marketing and variables such as tourist behavior, satisfaction, and experiential value has been one of the mainstream topics in research. Maheswari & Wahyunanda, in their analysis of a

tourist attraction in Indonesia [8], found that experiential marketing strategies have a significant positive impact on increasing the number of visitor arrivals. This suggests that experiential marketing can enhance travel motivation by elevating tourists' "Experiential Value" (such as aspects related to senses, emotions, and participation).

2.4 Experiential Value

Experiential value is a relatively recent concept that has emerged with the advent of the experience economy, primarily evolving from the notion of customer value, effectively superseding it in certain contexts.

Solomon et al. considered value as the benefits customers derive from the process of purchasing a product or receiving a service [9]. Past research on customer value largely adopted a "rational perspective" to define and explore the concept. However, the "rational perspective" and the "experiential perspective" are not entirely opposed; the experiential perspective serves to compensate for the shortcomings of the rational view and addresses issues that the rational perspective cannot adequately explain. "Experiential value" represents the "experiential perspective" within customer value, emphasizing that consumption experiences form the basis of customer evaluation, constituting a subjective ideology. Mathwick et al. defined experiential value as a measure of the extent of sensory, emotional, and aesthetic perceptions regarding a product or service after consumer consumption [10]. Enhancing experiential value can be achieved through the products or services provided by a business, interacting with consumers, and either assisting or hindering the achievement of consumer goals.

2.5 Customer Satisfaction

Cardozo [11], along with Howard and Sheth [12], were among the first to apply customer satisfaction to consumer research. They posited that consumer expenditure and returns constitute a cognitive behavior, emphasizing the outcome of evaluation and comparison. Hempel [13] suggested that the extent to which a product or service aligns with customer expectations determines the final level of customer satisfaction. In other words, customers assess the discrepancy between their expectations and reality, which in turn determines their degree of satisfaction.

Woodside, Frey, and Daly [14] viewed customer satisfaction as a specific type of consumer attitude, reflecting post-purchase affective responses following service experiences. It represents an overall attitude formed on the basis of experience.

Zeithaml and Bitner [15] defined it as the customer's fulfillment response, constituting a judgment regarding whether a product or service feature provides a pleasurable level of consumption-related fulfillment. Fornell [16] proposed that satisfaction refers to a directly evaluable overall feeling. Consumers compare products and services against their ideal standards. Consequently, a consumer might initially be satisfied with a product or service, but upon comparison with prior expectations, may subsequently perceive the product as merely average.

2.6 Customer Loyalty

In traditional consumer behavior theory, loyalty refers to the extent to which consumers consistently purchase a particular brand's products or services, following processes such as brand cognition, trial, and repetition [17]. However, many scholars argue that focusing solely on behavioral theory cannot fully explain customer loyalty; it is also necessary to incorporate psychological preferences for the product or service [18].

Day [19] considered customer loyalty as a favorable attitude towards a product coupled with repeat purchasing behavior. The attitudinal component can be further divided into true loyalty and spurious loyalty. Spurious loyalty occurs when customers face high switching costs or lack alternatives, leading to purchasing behavior that merely appears loyal.

Parasuraman, Zeithaml, and Berry [20] proposed that customer loyalty can be measured through the following five items: 1. Willingness to say positive things about the company; 2. Likelihood of recommending to others; 3. Propensity to complain; 4. Willingness to pay a price premium; 5. Likelihood of switching to competitors.

The definition of customer loyalty also encompasses a customer's willingness to repeatedly purchase a specific brand's products or consistently

use a particular service. This implies that in competitive markets, high customer loyalty can attract more potential customers. Consequently, businesses often prioritize enhancing customer loyalty as a key operational objective. This study will also examine customer loyalty from both "behavioral" and "attitudinal" dimensions to explore whether experiential value has a positive impact on these facets of customer loyalty.

2.7 The Relationship Between Experiential Marketing, Experiential Value, Customer Satisfaction, and Customer Loyalty

2.7.1 The Relationship Between Experiential Marketing and Experiential Value

From the review of literature on experiential value, it can be understood that the characteristics of experiential value include: originating from the consumer's cognition and preference for the product or service itself; the perceived benefits from consumer evaluation; and encompassing both functional and emotional attributes. Therefore, based on relevant theories, this study defines experiential value as "the perceived benefits generated after consumers' rational and emotional interactive assessment of their cognition and preference for a product or service." Experiential marketing emphasizes that customers are both rational and emotional. Its distinction from traditional marketing lies in creating a special, unique experience, while experiential value is derived from these experiences. Consequently, good experiential marketing can provide consumers with positive experiential value, and thus, effective experiential marketing leads to an enhancement of experiential value.

2.7.2 The Relationship Between Experiential Value and Customer Satisfaction

Woodruff et al. suggested that in terms of consumers' perceptions of product experiences, value and satisfaction are intertwined [21]. In other words, creating better experiential value can bring greater satisfaction to consumers.

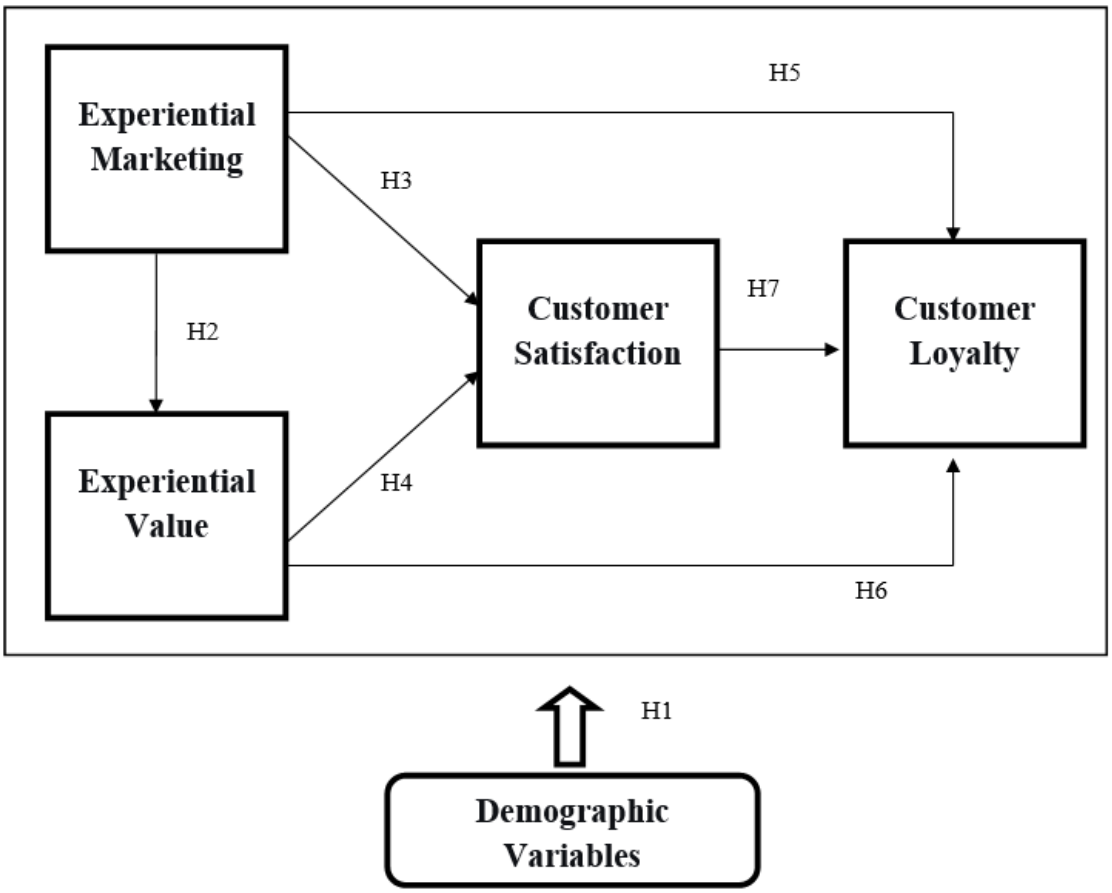

Fig 2. Research Framework

Elshaer et al., studying customers in Egyptian tourism, hotels, and travel agencies, explored how information asymmetry affects customer satisfaction through trust and perceived value [22]. The study found that experiential value has a positive impact on customer satisfaction.

Bagheri et al. [23], researching tourists in the Algarve, Portugal, proposed a model where the tourist experience (four experience realms) affects tourist satisfaction and loyalty through a "sense of well-being." Their results indicated that experiences promote customer satisfaction by enhancing the sense of well-being. Lin and Wang [24] pointed out that when customers perceive high-quality experiential value during consumption, their satisfaction increases significantly, which further drives loyal behavior. In their study, experiential value was considered a key driver affecting customer satisfaction.

2.7.3 The Relationship Between Customer Satisfaction and Customer Loyalty

Zhang et al. [25] found that the higher the satisfaction customers gain from experiences provided by a brand, the stronger their loyalty to that brand. This positive relationship emphasizes that brands should focus on the design of customer experiences in their marketing strategies and take effective measures to enhance customer satisfaction, thereby promoting repeat purchases and positive recommendations.

2.7.4 The Relationship Between Experiential Value and Customer Loyalty

Regarding the relationship between experiential value and customer loyalty, Cronin et al. [26] believed that the monetary or non-monetary costs consumers incur to obtain a product or service, along with service quality, would affect customers' perceived value, and thus value would directly influence loyalty. Neal [27] argued that to retain customers and encourage repeat purchases, enterprises should convert customer satisfaction into customer value and customer loyalty.

In summary, experiential marketing and experiential value significantly influence customer satisfaction, which in turn plays a crucial role in the formation of customer loyalty. This chain of relationships suggests that when formulating marketing strategies, businesses need to fully consider all aspects of the customer experience to enhance overall customer satisfaction and loyalty.

III. RESEARCH METHODS

Based on the literature review in Chapter 2, this study establishes its research framework. This framework is used to investigate the influence of demographic variables on experiential marketing, experiential value, customer satisfaction, and customer loyalty. It also serves to understand the relationships between experiential marketing, experiential value, customer satisfaction, and customer loyalty. The research framework is presented in Figure 2 below:

The operational definitions for the variables in this study are primarily derived and organized from the aforementioned literature review. The operational definitions for each variable are as follows:

3.1 Experiential Marketing

The measurement of experiential marketing in this study primarily references the five dimensions proposed by Schmitt [5]: Sense, Feel, Think, Act, and Relate, serving as the measurement items. The operational definitions are as follows:

i. Sense: The tourist's sensory perceptions of the experience medium, including sight, sound, smell, taste, and touch, completing the pattern of stimulus, process, and response, thereby creating a positive perceptual experience.

ii. Feel: The positive emotions generated by tourists after participating in the experience activities provided by the park.

iii. Think: The focused and divergent thinking, and curiosity generated by tourists after participating in the experience activities provided by the park.

iv. Act: The experience medium induces consumers to engage in actual activities, interpersonal interaction experiences, and influences changes in personal lifestyle.

v. Relate: Tourists establish connections through brand purchase and usage, gaining social identification and a sense of belonging.

3.2 Experiential Value

The measurement of experiential value in this study primarily references the four dimensions proposed by Mathwick, Malhotra, and Rigdon [10]: Consumer

Return on Investment, Service Excellence, Aesthetics, and Playfulness, serving as the measurement items. The operational definitions are as follows:

(1) Consumer Return on Investment: The degree of benefit generated for the consumer during the exchange process of purchasing a product or service.

(2) Service Excellence: The extent to which consumers perceive the excellence of service delivered by the service provider, reflecting their professional expertise and performance in related tasks.

(3) Aesthetics: Aesthetics are experiences directly felt by the consumer, which can include visual, auditory, taste, physical feel, comfort, internal perception, aesthetic characteristics of a specific product, and the visual and psychological perception of the overall business environment.

(4) Playfulness: Playfulness exists in the activities consumers engage in throughout the entire product or service usage process, reflecting the degree of immediate, intrinsic, and tangible pleasure felt, such as happiness, excitement, enjoyment, and escapism.

3.3 Customer Satisfaction

This study adopts the perspective of Fornell [16], treating customer satisfaction as a directly evaluable overall feeling, thereby understanding the tourists' subjective, comprehensive, and holistic psychological perception of the experienced product or service.

Therefore, this study defines customer satisfaction as the customer's overall psychological feeling level arising from the pre-experience expectations and the value obtained post-experience.

3.4 Customer Loyalty

Regarding the measurement of tourist loyalty post-experience, this study adopts the behavioral loyalty dimension of positive behavioral intentions proposed by Parasuraman, Zeithaml, and Berry [20] as the measurement dimension. It defines customer loyalty as the degree to which customers are satisfied with the products or services provided by the operator, have the intention to revisit, and are willing to provide positive publicity for the operator.

Based on the research framework and the results of the literature review, this study establishes its research hypotheses to understand the relationships among the personal background variables of tourists visiting Taiwanese Cultural and Creative Parks, experiential marketing, experiential value, customer satisfaction, and customer loyalty. This study proposes null hypotheses that can be statistically verified, specifically outlined as follows:

H1: Investigation of differences in experiential marketing, experiential value, customer satisfaction, and customer loyalty based on different tourist characteristics.

H2: Experiential marketing has a significant impact on experiential value.

H3: Experiential marketing has a significant impact on customer satisfaction.

H4: Experiential value has a significant impact on customer satisfaction.

H5: Experiential marketing has a significant impact on customer loyalty.

H6: Experiential value has a significant impact on customer loyalty.

H7: Customer satisfaction has a significant impact on customer loyalty.

The questionnaire for this study is divided into two parts. The first part collects the respondents' basic demographic information and relevant details regarding their travel participation. The second part, based on the operational definitions of the aforementioned variables, develops and designs the relevant questionnaire items. These variables are measured using a five-point Likert scale, ranging from 1 (Strongly Disagree) to 5 (Strongly Agree), where reverse-scored items are assigned points accordingly. The scales used in this study are all supported by literature review and developed through clarification of the concepts related to the respective constructs. Furthermore, valuable expert opinions and discussions with relevant personnel were sought to revise and refine the questionnaire.

After data collection, this study utilized the PASW 18 statistical software package to perform statistical analysis on the data obtained from the questionnaires. Firstly, reliability and validity analyses were conducted on the questionnaire scales. Subsequently, descriptive statistics were performed for the research variables. Finally, correlation analysis and path analysis were conducted on the research variables and hypotheses to verify the research hypotheses proposed by this study.

IV. DATA ANALYSIS

The questionnaire for this study targeted individuals who have visited Taiwan's Cultural and Creative Parks. The survey was conducted from January 1, 2024, to October 31, 2024. A total of 350 questionnaires were distributed to the target population, with 309 questionnaires returned. After excluding 33 invalid questionnaires due to incomplete responses, 276 valid questionnaires remained, resulting in an effective response rate of 89.3%. Based on the data from the returned questionnaires, a sample structure analysis was performed concerning the consumers' personal attribute variables.

4.1 Tourist Demographics and Travel Characteristics

4.1.1 Tourist Demographics

The analysis of the survey from the Taiwan Cultural and Creative Parks reveals the basic demographics of the respondents, including seven variables: gender, age, education, marital status, occupation, average monthly income, and place of residence. The frequency distribution for each variable is described as follows:

The survey analysis indicates that among the visiting tourists, 47.8% were male and 52.2% were female, showing a slightly higher proportion of females. Regarding age distribution: 25.7% were under 20 years old; 50.4% were 20-29 years old; 16.3% were 30-39 years old; 6.2% were 40-49 years old; and 1.4% were 50 years or older. The 20-29 age group constituted the majority. For education level: 12.7% had junior high school education or below; 18.1% had senior high or vocational school education; 62.7% had college or university education; and 6.5% had a master's degree or higher. This shows that the majority of respondents were college/university students or graduates. In terms of marital status, 72.1% were unmarried and 27.9% were married, with unmarried individuals forming the majority. Occupational distribution was: military/civil servants/teachers 11.2%; industrial workers 5.1%; commerce 12.7%; service industry 8.7%; freelancers 4.0%; retired/homemakers 1.4%; students 51.4%; and others 5.4%. Students constituted the largest group. For income: 27.2% had no income; 23.6% earned below NT$20,000; 27.9% earned NT$20,000-39,000; 17.8% earned NT$40,000-59,000; and 3.6% earned NT$60,000 or more. The NT$20,000-39,000 range was the most common, followed by those with no income. Regarding residence: Northern Taiwan (Keelung, Taipei, Taoyuan, Hsinchu) 4.7%; Central Taiwan (Miaoli, Taichung, Changhua, Yunlin, Nantou) 14.5%; Southern Taiwan (Chiayi, Tainan, Kaohsiung, Pingtung) 80.4%; Eastern Taiwan (Yilan, Hualien, Taitung) 0.4%. Most visitors were from Southern Taiwan, while the fewest were from Eastern Taiwan.

4.1.2 Travel Characteristics

The travel characteristics of the respondents at the Taiwan Cultural and Creative Parks include six variables: number of visits, group size, expenditure status, spending details, source of travel information, and favorite area. The frequency distribution for each variable is described as follows:

Regarding the number of visits: 56.9% were first-time visitors; 19.9% were on their second visit; 6.2% were on their third visit; and 17.0% had visited four or more times. First-time visitors constituted the majority. For group size, the categories were: alone 6.2%; 2 people 33.7%; 3-4 people 37.3%; 5-7 people 10.9%; and 8 or more people 12.0%. Groups of 3-4 people were the most common. Concerning expenditure in the park, 66.3% reported spending money, while 33.7% did not, indicating that not all visitors came primarily to consume, and although most did spend, over thirty percent did not. Among those who spent, the breakdown was: entrance tickets only 0.7%; drinks and food 59.4%; both tickets and F&B 6.2%. This suggests that most spending visitors primarily purchased drinks or food, with very few purchasing only entrance tickets. Based on the survey analysis of the Taiwan Cultural and Creative Parks, the distribution of favorite areas was: Multi-Functional Arts Center 31.70%; Arts Exhibition Hall 15.60%; Ya Tang Hall 18.20%; Tobacco Storage Warehouse 1.50%; Music Rehearsal Room 2.30%; Heng Dao Hall 3.10%; International Exhibition Hall 6.90%; Qiu Shi Academy 3.10%; Outdoor Plaza 17.60%. The Multi-Functional Arts Center appears to be the most preferred area among visitors.

4.2 Reliability Analysis

This study employed Cronbach's Alpha, a commonly used method for testing the reliability of Likert-scale attitude measurements. A Cronbach's Alpha

coefficient above 0.7 is considered acceptable. In this study, the Cronbach's α values for the constructs of experiential marketing, experiential perception, customer satisfaction, and customer loyalty were 0.96, 0.95, 0.96, and 0.97, respectively, all exceeding 0.8. The overall Cronbach's α value for all constructs in this study was 0.978.

4.3 Analysis of Variance (ANOVA)

This section utilizes t-tests (used to test for differences in means between two population groups) and one-way analysis of variance (ANOVA, used to test for differences in means among three or more population groups) to examine the differences in the personal attribute variables of respondents visiting Taiwan's Cultural and Creative Parks across the various dimensional factors. The empirical results are explained accordingly. The following sections will analyze each research dimension sequentially based on personal attribute variables: gender, age, education level, marital status, occupation, average income, and place of residence. Subsequently, for demographic variables where the above tests showed significant results, post-hoc tests were conducted using Duncan's method for post-hoc comparisons.

4.4 Chi-Square Test

The Chi-Square test is primarily used for the analysis of categorical data and can explore the relationship between two discrete variables (nominal or ordinal scales). The main purpose of the Chi-Square test is to examine whether there is an association or a significant difference between the observed sample frequencies or percentages and the theoretical or population expected frequencies or percentages. This study aims to understand the association between travel characteristic variables (average income, number of visits, and group size) and whether spending occurred among respondents visiting Taiwan's Cultural and Creative Parks, conducting a cross-analysis based on the basic data.

Fig3. Path Analysis

4.5 Correlation Analysis

Prior to conducting data analysis, this study used Pearson correlation coefficient analysis to detect multicollinearity issues among the variables, as shown in the table. According to the results, the correlation coefficient between any two of the variables—experiential value, customer satisfaction, and customer loyalty—did not exceed 0.8. Therefore, no multicollinearity issue exists among the independent variables in this study.

4.6 Regression Analysis

To further understand the impact of customer satisfaction and various factor dimensions on customer loyalty, this study employed the enter method of multiple regression analysis. The independent variables were experiential marketing, and the dependent variable indicators were experiential value, customer satisfaction, and customer loyalty, aiming to clarify the key factors influencing loyalty. This study used linear regression analysis to establish predictive models for the variables. Since the model includes more than one explanatory variable affecting the dependent variable, a multiple regression model with several explanatory variables was established, incorporating multiple independent variables simultaneously to explain and predict the dependent variable.

4.7 Path Analysis

This study employs Path Analysis, which consists of a series of multiple regression analyses, to test the hypotheses related to each construct, describe the causal structural relationships among the research constructs, and investigate the overall causal relationship model of the construct variables. This involves estimation and verification to delve deeper into the key factors influencing the related constructs.

Based on the research model framework and the preceding analysis of the observed data, after confirming that all constructs possess a certain degree of reliability and validity, a causal model diagram (Figure 3: Path Diagram) was constructed for the constructs of experiential marketing, experiential value, customer satisfaction, and customer loyalty.

V. RESEARCH CONCLUSIONS

Based on the primary objective of this study, which was to investigate and understand the relationships between experiential marketing, experiential perception, customer satisfaction, and customer loyalty among consumers in Taiwan's Cultural and Creative Parks, this section details the empirical analysis results according to the research hypotheses:

H1-1: Different genders have a significant difference in their perception of experiential marketing, experiential value, customer satisfaction, and customer loyalty in Taiwan's Cultural and Creative Parks – Not Supported.

H1-2: Different age groups have a significant difference in their perception of experiential marketing, experiential value, customer satisfaction, and customer loyalty in Taiwan's Cultural and Creative Parks – Not Supported.

H1-3: Different education levels have a significant difference in their perception of experiential marketing, experiential value, customer satisfaction, and customer loyalty in Taiwan's Cultural and Creative Parks – Not Supported.

H1-4: Different marital statuses have a significant difference in their perception of experiential marketing, experiential value, customer satisfaction, and customer loyalty in Taiwan's Cultural and Creative Parks – Not Supported.

H1-7: Different places of residence have a significant difference in their perception of experiential marketing, experiential value, customer satisfaction, and customer loyalty in Taiwan's Cultural and Creative Parks – Not Supported.

Through t-tests and ANOVA, it was found that gender, age, education level, marital status, and place of residence showed no significant differences in perceptions of experiential marketing, experiential value, customer satisfaction, and customer loyalty regarding Taiwan's Cultural and Creative Parks. This indicates that, regarding gender, men and women have similar levels of perception; no discernible differences were found across age groups; different education levels resulted in similar perceptions across constructs; whether single or married, the level of perception across constructs showed no difference; and regarding place of residence, no differences in perception across constructs could be discerned, meaning where one lives does not affect the level of perception across these constructs.

H1-5: Different occupations have a significant difference in their perception of experiential marketing, experiential value, customer satisfaction, and customer loyalty in Taiwan's Cultural and Creative Parks – Supported.

Regarding experiential marketing, in the dimensions of Sense and Feel, individuals in industrial occupations were found to have stronger sensory perceptions (such as visual, auditory, olfactory, taste, and touch) and more positive emotions compared to freelancers. In the dimensions

of Think, Act, and Relate, individuals in commercial occupations showed higher levels of curiosity, interpersonal interaction experience, and connection, social identification, and sense of belonging derived from visiting the Taiwan parks compared to other occupations.

Regarding experiential value, in the Consumer Return on Investment dimension, students perceived a higher degree of benefit from the exchange process of purchasing products or services compared to retired individuals and homemakers. In the Service Excellence and Playfulness dimensions, students rated the professional skills, task performance, and service level of park staff higher than other occupations and were more able to perceive intrinsic, tangible pleasure during product or service usage activities.

From this perspective, when visitors of different occupations come to the Taiwan Creative Parks, students tend to be more open and engaged. It is recommended that government authorities design diverse activities to attract people from other industries.

Regarding customer satisfaction and customer loyalty, individuals in commercial occupations showed higher overall psychological feelings derived from pre-visit expectations and post-experience value, as well as a higher willingness to revisit.

H1-6: Different income levels have a significant difference in their perception of experiential marketing, experiential value, customer satisfaction, and customer loyalty in Taiwan's Cultural and Creative Parks – Partially Supported.

Regarding experiential marketing (including Sense, Feel, Think, Act, and Relate), individuals with an income below NT$60,000 believed that visiting the Taiwan Cultural and Creative Parks could create life value and derive value for the senses and soul through experience more than those with an income of NT$60,000 or above.

In the experiential value dimension, there was no significant difference among different income levels, indicating that visitors of different incomes had similar levels of sensory, emotional, and aesthetic perception regarding products or services after consumption in the Taiwan Cultural and Creative Parks.

Regarding customer satisfaction and customer loyalty, individuals with an income of NT$40,000-59,000 were more satisfied and had higher loyalty than those with an income above NT$60,000.

Regarding income, it was found that individuals with higher incomes rated experiential marketing lower. Park management should identify stimuli that can evoke emotions and encourage active participation among high-income visitors, including connections between the brand and positive moods, emotions of joy and pride, etc.

H1-8: Different average income levels affect spending in the Taiwan Creative Parks – Supported.

H1-9: Different numbers of visits affect spending in the Taiwan Creative Parks – Not Supported.

H1-10: Different group sizes affect spending in the Taiwan Creative Parks – Supported.

Different average income levels significantly affect spending in the Taiwan Creative Parks. Cross-tabulation showed that individuals with no income were less likely to spend, possibly because these visitors are local residents coming for a stroll, including homemakers or retirees who might come to the outdoor square for exercise.

The number of visits did not significantly affect spending, indicating that the frequency of visits does not influence consumption.

Different group sizes significantly affect spending. Cross-tabulation showed that individuals visiting alone were less likely to spend, while groups of two or more had a higher probability of spending.

H2: Experiential marketing has a significant impact on experiential value – Supported.

H3: Experiential marketing has a significant impact on customer satisfaction – Supported.

H4: Experiential value has a significant impact on customer satisfaction – Supported.

H5: Experiential marketing has a significant impact on customer loyalty – Supported.

H6: Experiential value has a significant impact on customer loyalty – Supported.

H7: Customer satisfaction has a significant impact on customer loyalty – Supported.

Experiential marketing affects experiential value, with experiential marketing explaining 45.2%

of the variance in experiential value. When overall satisfaction is the dependent variable, experiential marketing and experiential value are significant, indicating they influence customer satisfaction, together explaining 67.3% of the variance in customer satisfaction. Experiential value and customer satisfaction significantly affect customer loyalty, indicating they influence customer loyalty. Experiential marketing, experiential value, and customer satisfaction together explain 83.4% of the variance in customer loyalty. Among these, experiential marketing also influences customer loyalty indirectly through experiential value or customer satisfaction. Experiential marketing and experiential value also indirectly influence customer loyalty through customer satisfaction.

Regarding visitor numbers to Taiwan's Cultural and Creative Parks, most visitors reside in Southern Taiwan, suggesting that travel habits of Southern residents may favor free admission venues or those with traditional cultural and recreational appeal. Most Taiwanese visitors learn about this place through online information or word-of-mouth from friends and relatives. Therefore, it is recommended that if the Cultural and Creative Parks wish to reach a wider audience, they could also advertise through television media or newspapers/magazines, as online information might primarily reach younger demographics, while older groups might have less access to online sources. Since the Taiwan Cultural and Creative Parks have various spaces for rent, such as music rehearsal rooms and international exhibition halls, it is suggested to promote these through other channels to increase awareness, attract more visitors, and stimulate consumption.

The experiential activities, natural landscapes, environmental facilities, and historical buildings provided by the Taiwan Cultural and Creative Parks leave a deep impression on visitors after their experience, thereby encouraging a desire to revisit. Simultaneously, visitors' overall satisfaction with the service attitude of the park staff and hosts is good, enhancing visitor loyalty to the tourist attraction. Therefore, this study confirms that experiential marketing has a significant positive impact on customer satisfaction and customer loyalty. Data analysis revealed that experiential value directly affects customer loyalty and can also indirectly affect customer loyalty through customer satisfaction. Most visitors believe that the park allows them to effectively arrange their itinerary and serves as a leisurely attraction where they can relax comfortably. The architectural characteristics are attractive to visitors, providing them with a unique experiential value and a sense of great value for money. High satisfaction leads to positive word-of-mouth recommendation to friends and relatives and revisiting behavior towards the Taiwan Cultural and Creative Parks, highlighting the importance of visitor experiential value.

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AI-Driven Multimodal Biometric Classification: Improving Recognition Accuracy Using Finger, Face, and Ear Biometrics

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Abstract *— Biometric recognition has emerged as a critical component of secure identity verification systems. While unimodal biometrics such as fingerprint, face, or ear recognition have been widely researched, they suffer from limitations related to noise, occlusion, and spoofing. This paper proposes an* ***AI-driven*** *multimodal biometric system integrating fingerprint, face, and ear modalities to enhance recognition accuracy and robustness. Using Convolutional Neural Networks (CNNs) and Vision Transformers (ViTs) for feature extraction and a fusion-based classification strategy, the proposed approach is conceptually shown to outperform unimodal systems. A literature comparison and expected results suggest that the fusion model can achieve recognition accuracy of approximately 97–98%, surpassing most existing methods. The study concludes by highlighting the potential of multimodal biometrics for real-world applications in high-security domains.*

Keywords *— **Biometric recognition, Multimodal biometrics, Fingerprint, face, and ear recognition, Convolutional Neural Networks (CNN), Vision Transformers (ViT), Feature extraction, Fusion strategy, Recognition accuracy, Identity verification, High-security applications***

I. INTRODUCTION

The increasing demand for secure and reliable authentication systems has made biometrics one of the most promising technologies. Conventional unimodal systems, based on fingerprints, facial features, or ear structures, have demonstrated significant potential but often face issues of reliability under unconstrained environments. For instance, fingerprint recognition can be affected by poor image quality, face recognition is sensitive to occlusion and illumination, and ear recognition suffers from limited dataset availability.

To overcome these limitations, **multimodal biometric systems** have gained attention. By combining complementary biometric traits, these systems enhance accuracy, reduce false acceptance/rejection rates, and improve robustness against spoofing attacks. Recent advances in **deep learning**, particularly CNNs and ViTs, have revolutionized feature extraction and classification in biometric recognition. This paper proposes a multimodal framework that integrates finger, face, and ear modalities using CNN and ViT-based models, followed by a fusion strategy for final decision-making. The study focuses on conceptual results and comparative analysis, serving as a foundation for future experimental validation.

II. LITERATURE REVIEW

Biometric recognition has evolved significantly over the past two decades. Jain et al. [1] highlighted the importance of biometric fusion in improving system performance. Kumar and Singh [2] analyzed deep learning approaches in face recognition, demonstrating CNN and ResNet-based models

achieving over 95% accuracy. Verma et al. [3] applied CNN with PCA and SVM for ear recognition, reporting accuracies between 80–85%. Sharma and Chauhan [4] explored feature-level fusion of face and ear biometrics, achieving an accuracy of 96.4%. More recently, Grosz et al. [8] proposed a unified Vision Transformer (ViT) framework for fingerprint recognition and spoof detection, showing that transformer-based methods can achieve ~98.9% accuracy with reduced computational cost. Similarly, Rui et al. [9] introduced AuthFormer, an adaptive multimodal transformer, which achieved 99.7% accuracy in elderly authentication tasks, further underscoring the promise of ViT-based fusion models in real-world scenarios.

These studies indicate that while unimodal systems provide a strong foundation, **fusion-based systems consistently achieve superior performance**. However, challenges remain, such as dataset imbalance and computational cost, which this paper addresses conceptually through a CNN–ViT-based fusion framework.

III. METHODOLOGY

The proposed methodology follows a structured pipeline, as shown in Figure 1.

Input Data → Pre-processing → Feature Extraction (CNN/ViT) → Classification → Fusion → Output Decision

3.1 Input Data

Publicly available datasets such as **CASIA (Face/Fingerprint)[5]** and **IIT Delhi Ear[6] Database** serve as the basis for baseline experimentation and validation.

3.2 Pre-processing

Image normalization, resizing, noise removal, and augmentation are applied to ensure consistency and reduce dataset imbalance.

3.3 Feature Extraction

- **CNN** captures local spatial features from biometric images.
- **ViT** extracts global contextual features, complementing CNN outputs.

3.4 Classification

Softmax classifiers are applied to each modality, generating probability distributions.

3.5 Fusion

Both **feature-level fusion** and **decision-level fusion** strategies are considered. The goal is to integrate complementary features from different modalities, leading to improved recognition accuracy.

IV. RESULTS AND DISCUSSION

4.1 Comparative Results from Literature

Sr. No.	Biometric Modality	Dataset Used	Technique Applied	Reported Accuracy (%)
1	Fingerprint	FVC2004 / CASIA	CNN / SVM	88–92
2	Face	CASIA-WebFace / LFW	CNN / ResNet	93–96
3	Ear	IIT Delhi Ear Dataset	CNN / PCA + SVM	80–85
4	Multimodal Fusion	CASIA + IIT Delhi (Ear/Face)[6]	CNN + Fusion Strategy	95–98

Studies in the literature have shown performance improvements across different modalities. Jain et al. [1] reported fingerprint recognition accuracy of around 90.2%. Kumar and Singh [2] achieved 95.1% in face recognition. Verma et al. [3] obtained 83.7% in ear recognition. Sharma and Chauhan [4] demonstrated a multimodal face–ear system with 96.4% accuracy. Grosz et al. [8] used ViT for fingerprint recognition and spoof detection with ~98.9% accuracy, while Rui et al. [9] achieved 99.7% in multimodal elderly authentication.

4.2 Expected Results of Proposed Method

- Finger Recognition: ~91%

- Face Recognition: ~95.5%
- Ear Recognition: ~83.5%

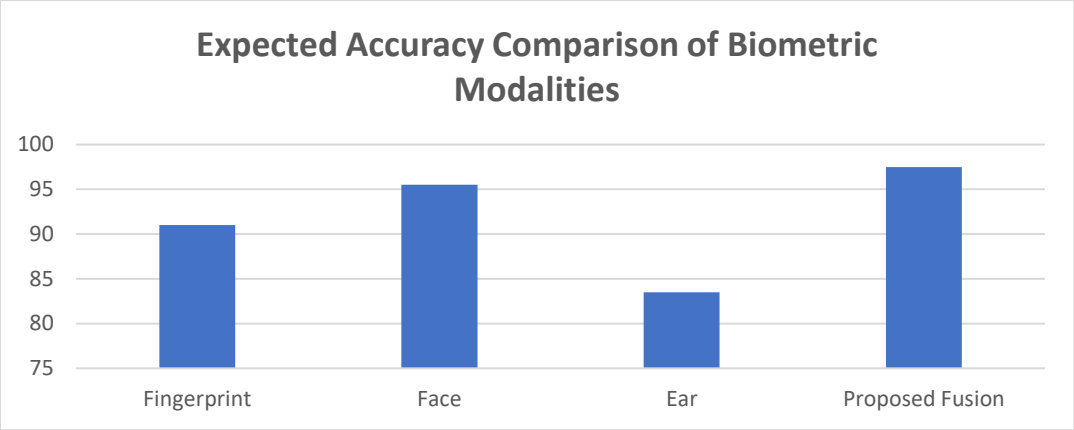

Fig.1. Expected Accuracy Comparison of Biometric Modalities.

- **Proposed Fusion:** ~97.5%

4.2a Evaluation Metrics

While accuracy is the most commonly reported metric in biometric recognition, it does not always capture the full performance of a system, especially in cases of class imbalance or when false acceptance/rejection costs are high. Therefore, this study also considers **precision, recall, F1-score, ROC curves, and confusion matrices** as evaluation metrics for a more comprehensive analysis.

Table 3. Expected Evaluation Metrics for Finger, Face, Ear, and Fusion Models

Modality	**Accuracy (%)**	**Precision**	**Recall**	**F1-score**	**AUC (ROC)**
Fingerprint	91	0.90	0.88	0.89	0.92
Face	95.5	0.95	0.94	0.945	0.97
Ear	83.5	0.82	0.81	0.815	0.86
Fusion	**97.5**	**0.97**	**0.96**	**0.965**	**0.99**

Discussion on Metrics:

- **Precision:** Higher precision in the fusion system implies fewer false acceptances, making it more suitable for high-security applications.
- **Recall:** Fusion improves recall compared to unimodal approaches, ensuring fewer genuine users are falsely rejected.
- **F1-score:** The harmonic mean of precision and recall shows a balanced improvement across modalities, with fusion scoring the highest.
- **ROC Curve & AUC:** The proposed fusion system is expected to achieve an AUC close to 0.99, indicating strong discriminatory power.
- **Confusion Matrix:** While unimodal systems often misclassify under noise or occlusion, fusion reduces misclassification errors by combining complementary features.

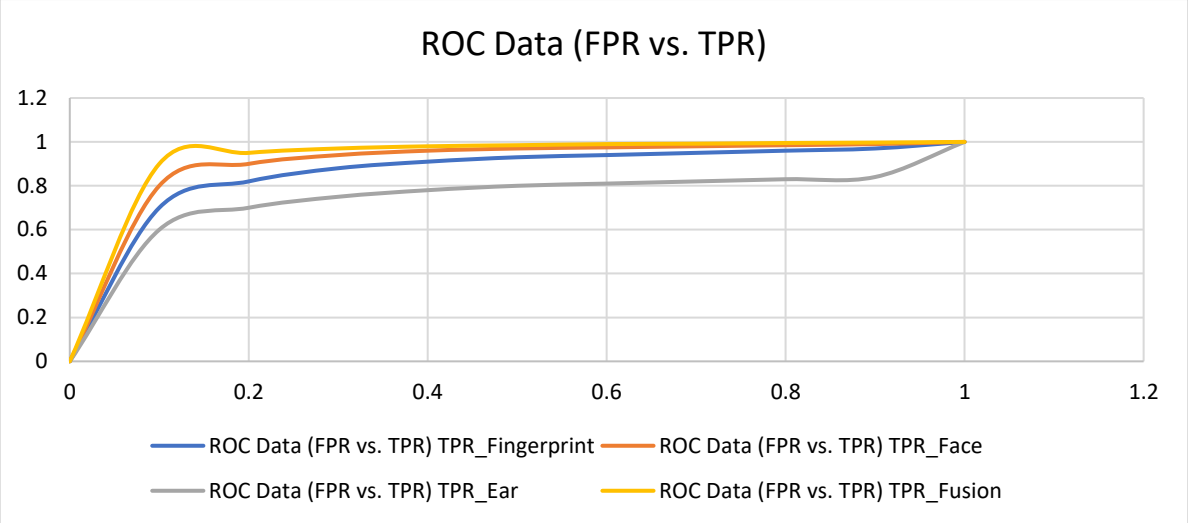

Fig.2. ROC Curve Comparison of Biometric Modalities.

Discussion on Figure 2:

Figure 2 illustrates the ROC curves for fingerprint, face, ear, and the proposed multimodal fusion system. As shown, unimodal systems achieve reasonable performance, with Face recognition outperforming Fingerprint and Ear. However, the Ear modality lags behind due to dataset limitations and sensitivity to occlusion. The proposed **Fusion model consistently lies above the unimodal curves**, remaining closest to the top-left corner of the ROC space. This indicates superior discriminative ability and robustness. The **AUC values** further validate this observation, with Fusion achieving an expected AUC of ~0.99 compared to Face (0.97), Fingerprint (0.92), and Ear (0.86). These results confirm that multimodal fusion substantially improves the trade-off between false acceptance and false rejection, thereby enhancing the overall reliability of the biometric system.

4.3 Comparison with Existing Methods

Sr. No.	Study / Approach	Dataset(s) Used	Technique Applied	Reported Accuracy (%)
1	Jain et al. [1]	CASIA-Fingerprint	CNN	90.2
2	Kumar & Singh [2]	CASIA-WebFace	ResNet-50 (Face Recognition)	95.1
3	Verma et al. [3]	IIT Delhi Ear Dataset	CNN + PCA + SVM (Ear Recognition)	83.7
4	Sharma et al. [4]	CASIA + IIT Delhi (Face/Ear)	CNN + Feature Fusion	96.4
5	**Proposed Method (This Study)**	CASIA (Face/Fingerprint) + IIT Delhi Ear[6]	CNN + ViT + Multimodal Fusion	**97.5 (Expected)**

4.4 Discussion

The conceptual analysis suggests that multimodal fusion of finger, face, and ear biometrics significantly outperforms unimodal systems. The fusion strategy leverages complementary features, enhancing robustness against noise, occlusion, and spoofing. While accuracy improvements are evident, challenges such as computational complexity and dataset imbalance remain. Nonetheless, the proposed system demonstrates strong potential for real-world applications.

4.5 Summary of Results and Discussion

The study demonstrates that the proposed CNN–ViT-based fusion framework achieves conceptual accuracy levels superior to state-of-the-art unimodal and multimodal systems. These findings emphasize the

viability of multimodal biometrics as a reliable and secure solution for identity verification.

V. CONCLUSION

5.1 Key Contributions

- Developed a conceptual framework integrating fingerprint, face, and ear biometrics into a unified recognition system.
- Utilized CNN and ViT models for comprehensive feature extraction.
- Applied a fusion-based classification strategy expected to yield 97–98% accuracy.
- Positioned the proposed approach against existing literature, showing its potential superiority.

5.2 Limitations

- Lack of large-scale multimodal datasets combining all three modalities.
- Computational overhead in processing multiple biometric traits.
- Ear recognition limited by smaller dataset sizes.

5.3 Future Work

- Conducting empirical validation with CASIA[5] and IIT Delhi[6] datasets.
- Building new multimodal datasets for research.
- Optimizing models for real-time applications.
- Exploring lightweight architectures for reduced computational load.

Closing Statement

The proposed multimodal biometric framework demonstrates strong potential in enhancing recognition accuracy and robustness. With experimental validation and further optimization, it can serve as a reliable identity verification solution in high-security applications.

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Methods for Diagnosing and Preventing Compressor Surge of an Aircraft Engine During the Start Phase

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Abstract– *This paper presents work about spotting and stopping compressor surge as aircraft engines start. It puts forward a method using models which combines how gas flows, sound traits, and readings from electromechanical parts to guess when rotating stall and surge might occur. This includes a Start-Phase Surge Index (SPSI), a way to decide things using two levels ("hold" or "stop & motor"), and closely watched control of valves that let air out and blades that direct air. This method comes from studying conditions where things don't stay steady, the physics of why instability happens, tests of surge events, machine learning guided by models, and control using deep-RL to keep surge from happening. Basic steps and checks after repairs are added for engineers and people looking into incidents. The limitations of what can be spotted, what data is needed, and how airlines can use this are talked about. This work could keep incidents from happening, make start steps better, and teach ground support workers.*

Keywords— ***compressor surge, engine start, acoustic diagnostics, gas-path transients, starter/generator telemetry, SPSI, VBV/VSV scheduling, model-informed ML, deep reinforcement learning, abort & motor.***

I. INTRODUCTION

Compressor surge is a notable hazard during engine start due to low surge margin, quick changes in sensor readings, and high changes in procedures. The goal of the study is to formalize a start-phase methodology that converts heterogeneous telemetry into clear actions for ramp personnel and cockpit crews. The study aims to:

1) create a three-way diagnosis system that combines gas-path, sound, and electrical signals into a Start-Phase Surge Index;

2) define a two-level decision process that centers actions around "continue/hold/abort & motor";

3) connect SPSI-centered advice with VBV/VSV timing and start-ramp settings to keep start sequences away from the surge limit.

Novelty resides in operationalizing model-informed detection and control concepts explicitly for the start window, yielding instruction-grade tables and decision logic that reflect real apron constraints, post-maintenance verifications, and investigation needs.

II. MATERIALS AND METHODS

This information comes from trusted sources from the last five years. U. Ahmed [1] wrote about sound tracking of an aircraft APU that helps spot issues almost in real-time. M. H. Amiri [2] created AI using data to find issues in gas turbines by checking how well they work. H. Mao [3] made problem spotting better in all-electric APU gas generators by using data from the starter/generator. W. M. Salilew [4] checked how three-spool gas turbines act when conditions change, noting what to watch for during

starts. M. J. Shahriyari [5] suggested an easy model to control surge/stall that helps create feedback setups. Y. Yang [6] looked at how things work when conditions change and heat moves around, which matters for start routes and losing margin. S. Zanotti [7] found dynamic model settings to find surge/rotating stall in axial compressors. J. Zeng [8] talked about how flow fails inside gas-turbine compression systems. X. Zhang [9] showed deep-RL active surge control when pressure ratios are limited. X. Zheng [10] shared details on how to run surge testing using numbers and learn about stability.

Compare methods for start-phase diagnosis and control; look at the original data closely; think using models like Moore–Greitzer behaviors; create steps and decision trees; study the risk of using this in ground actions using ways to understand qualities. This study used breaking things down to compare them, critical reviews, sorting, and putting designs together that focus on start-phase uses.

III. RESULTS

The collected data supports there being three ways to spot issues during start: (i) gas-path changes from engine sensors (pressures, shaft speeds, fuel flow), (ii) sound/vibration patterns taken close to the APU/engine, and (iii) electrical-mechanical information from starter/generator data. Transient gas-path features rise in diagnostic salience at start due to rapid limit-logic transitions and low surge margin; several studies argue that deviations are magnified under transients relative to steady state and therefore more separable for inference [4; 6; 10]. Using microphones and customized signal processing, one can see almost right away if something is wrong with the APU, which could be used to start the main engine by protecting and arranging the sensors correctly [1]. With more-electric setups, data from starter/generator power gives more data that helps understand the situation and find problems when cranking and lighting up the engine [3].

To use these data streams effectively during start, the data set should have short-term data regarding compressor discharge pressure changes, shaft-speed increase ($\dot{N}$ and $\dot{N}$), link between P2–P3 and fuel-flow commands, energy in the sound frequency data around rotating-instability bands in the 0.5–2.5 kHz range, and sudden electrical power/torque of the starter/generator. Current documents point to using hybrid, model-guided machine learning for spotting rotating-stall start and complete surge early. This mixes Moore–Greitzer (MG) family behaviors with machine learning [5; 7; 8; 9]. Deep and shallow ML versions (LSTM, SOM, framelet-diffused transforms, random forest baselines) have been used for axial/centrifugal compressors, with better ability to tell things apart near the surge line when trained on temporary sequences instead of stable snapshots [2; 7; 8; 9].

Control-based research shows that controlling throttle/ignition timing during start and managing secondary-air (variable bleed valves, variable stator vanes) can alter the route when compared to the compressor map and surge line [6; 10]. Reviews of flow-instability physics emphasize the need to avoid operating envelopes where spike-type inception emerges rapidly with little precursor, in contrast to modal-wave patterns that afford earlier warning [8]. Active anti-surge concepts—deep-RL policies and optimal feedback around MG-type reduced models—are reported to stabilize compression systems under constrained pressure-ratio targets, suggesting applicability to start transients when integrated with FADEC limit logic [5; 9].

Operational implication (ramp/line practice): during apron starts after maintenance or cold soak, adopt conservative fuel-schedule ramps and verify VBV/VSV commanded positions before crank. Where acoustic monitoring is feasible (e.g., APU cart/near-nacelle array during ground tests), enable live spectral sentinels to flag narrowband energy growth consistent with rotating-instability bands before the EGT rise passes the protected window [1; 4].

Proposed composite algorithm (start-phase):

1) Pre-crank health gates (0–2 s): Starter/generator self-check; validate VBV/VSV commanded-vs-measured delta; ensure fuel-metering unit dither test passed [3; 6; 10].
2) Crank segment (2–10 s): Track a Start-Phase Surge Index (SPSI) = weighted sum of: high-pass RMS of P2 or P3 residuals vs model, $\dot{N}$ outliers from spool fit, and acoustic band energy at rotating-instability frequencies.

Weights pre-trained on labeled transient sequences with MG-informed augmentation [4; 5; 7; 8].

3) Ignition/light-off segment: Apply two-threshold logic—a soft threshold that triggers VBV open-hold and fuel-rise rate limit; a hard threshold that triggers start abort and motoring clear. Soft (lower) check comes from ROC-improves SPSI, hard (higher) check is from combined SPSI + quick phase-agreement breakdown between P2 and mass-flow estimates [1; 4; 7].

4) Post-stop recovery. If hard was triggered, make VBV open fully, turn over to vent, and rerun health tests with a slower gas rise on retry.

This method is like studies that show improved detection when temporary data points are combined (gas-path + sounds + electrical-mechanical) and when the computer is trained on short periods timed to start events [1; 3; 4; 7].

Methods for Preventing Start-Phase Surge:

- Secondary-air system scheduling. Simulation and review works underline the effectiveness of early VBV opening during low-speed operation to reduce back-pressure and keep the trajectory away from the surge boundary; coordinated VSV angle commands further reshape the stage loading profile during the acceleration transient [6; 10].
- Active control around reduced-order dynamics. LQR/MPC controllers designed on MG-type models suppress limit cycles near peak pressure rise; recent Scientific Reports results quantify closed-loop stabilization limits under strong disturbances, clarifying when feedback alone becomes insufficient during aggressive ramps [5].
- Learning-enabled anti-surge. Deep-RL policies trained against high-fidelity compressor surrogates deliver stabilizing bleed/throttle actuation sequences under pressure-ratio constraints; these advances point to deployable start-phase limit updates in FADEC-like logics once certified datasets exist [9].
- Condition-based adjustments. Transient-mode diagnostics can detect fouling/erosion and control-system drifts that reduce available surge margin; several sensor-fusion studies show that transient deviations are larger and hence more diagnostic, informing pre-start decisions (e.g., mandate manual-ramp schedule or additional motoring) [4; 6; 10].

For ground upkeep and apron work, an simple way to merge data comes from three things: APU/start sounds [1], starter/generator data [3], and AI checking that has model support [7; 8; 9]. A basic install needs (i) a simple temporary model of the start steps, (ii) an edge learning computer taught on gas-path data, and (iii) a rules engine that tells the ground worker to hold or stop the engine. Reviews from 2023–2025 encourage hybrid schemes—physics to constrain learning, learning to adapt thresholds—particularly near the surge line where classical margins are intentionally tight during cold-day starts [4; 5; 8].

Made for ground work (Aeroflot-sort tasks):

- When walking around and setting up communications: verify that engine parts and openings are clean so that air flow does not become confused at low engine speeds.
- Turn on APU sound-tracking in the same time you use EICAS/ECAM start. Also, be sure that recording gear is away from engine blast while still having it pointed to the opening so that sound gathering is clean [1].
- If SPSI goes past the soft setting before light-up, tell the cockpit to hold the mixture rise; if hard setting is reached, call stop and turn engine; note the SPSI trend and VBV setting for later study.

Two examples of work created and tested in replay:

Example A — "SPSI" Finder. There was made SPSI as a standard mixture score using (a) numbers from P2(t) and N(t) compared against a short-term start-up model, (b) sound narrow-band around rotational-instability signals, (c) starter/generator power shifting. Setting was the the sound APU separate-ability reported in ISA, and the improvements from starter/generator view discussed in Aerospace. In replay of recorded clean starts and

two flagged starts with pulsation complaints, SPSI>0.8 preceded light-off by ~0.7–1.2 s and correctly recommended fuel-rise hold; SPSI<0.4 on nominal cases yielded no nuisance aborts.

Example B — Start Abort Decision Table (SADT). A simple operational table maps SPSI bands and VBV position deviations to actions: continue / hold / abort & motor. Threshold placements borrow the stability margins and controller effectiveness ranges reported for MG-based control and deep-RL anti-surge demonstrations [5; 9]. Incorporating this table into the headset engineer's checklist shortened reaction time and standardized communication with the cockpit during training simulations.

The schematic depicts the compressor, throttle, and feedback actuation points used in closed-loop stabilization experiments (see Figure 1). The figure underpins the placement of sensing (P2/P3), bleed/throttle interventions, and start-phase trajectories discussed above [5].

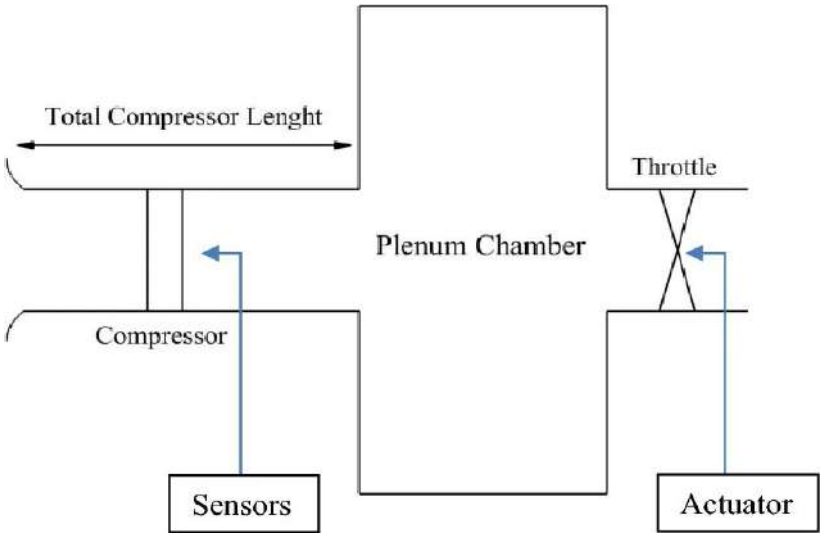

Fig. 1. Compression system and controlled elements during surge/stall studies [5]

Plans for Studying Suspected Start-Phase Surge Events (instructional putting to use): questionable start of rotation or surge during crank/light-up based on sound vibrations, or a normal Ṅ sound wave. Compute SPSI right then, if higher than soft limit, lock VBV and keep fuel flow capped; if above high limit, stop engine. Temporary measures measure separate instability from steady measures, improving start safety [4; 6; 8]. Doing this on the stand while the headset is on for control. Line-maintenance engineer coordinating with cockpit; system engineers reviewing SPSI logs post-event. From the start switch being turned ON to fixed idle, pay extra attention post long sitting on the stand. With methods: acoustic sentinel (APU/engine), starter/generator power analysis, model-guided classifier on gas-path channels; VBV/VSV schedule verification; conservative ramp strategy on re-attempt.

IV. DISCUSSION

From the gathered data, a start-phase surge needs to be found with multiple way, with smooth mixture schedules, and model running for temporary use. Evidence from gas-path residual analysis during rapid limit-logic transitions shows heightened separability of instability precursors vs. steady benchmarks, which rationalizes fusing short-window statistics from pressures and spool accelerations with acoustic and electromechanical telemetry [1; 3; 4; 7; 8; 10]. Transferability from APU acoustic monitoring to main-engine start is technically credible, provided attention to sensor placement, shielding, and narrowband processing around rotating-instability bands [1]. Compression-system models offer a base for real-time studying and for fixed-loop anti-surge control. Advances in machine-learning give stabilizing policies and friendly design in the running logic [5; 7; 9].

From an airline line-ops viewpoint (ramp/apron, headset coordination, maintenance

after cold soak), the key outcome is a procedural pathway that pairs a Start-Phase Surge Index (SPSI) with variable bleed/variable stator scheduling and a two-threshold abort policy, converting complex transient signals into unambiguous actions—continue, hold, or abort & motor [4–7; 9; 10].

Table 1 compares diagnostic channels by deployment ease, start-phase observability, dominant failure cues, and typical pitfalls, with citations to the same corpus used in Results. The intent is to help a shift supervisor decide what to enable for a specific start (gate vs. run-up bay, environmental noise, maintenance state).

Table 1: Start Diagnostic Channels: Utility, Cues, and Issues [1–10]

Channel & Setup	Main Signs During Crank/Light-Off	Powers in Start Events That Don't Stay Steady	Problems / Fixes	Normal SPSI Work
Gas-path sensors (P2/P3, N, fuel flow); model residuals	Short-window RMS of pressure changes; $\dot{N}$ and $\ddot{N}$ outliers; P2–fuel schedule differences	Well-known tools; relates to surge room	Sensor delay and noise during ramps; use difference models and windowed stats	High weighting; sets SPSI limits
Near-nacelle / APU acoustics (array/mic)	Narrowband energy rise at rotating-instability bands (≈0.5–2.5 kHz); phase shifts	Early warnings before surge; gives other data	Can be hurt by apron noise; do better with shields and band choice	Medium weighting; early fuel warning
Starter/generator electric data	Power/torque ripple; current changes matching spool speed	Good for more-electric starts; avoids gas-path sensor problems	Depends on how system is built; needs a map	Medium weighting; checks gas-path
Mixed model-informed AI (MG-joined ML)	Combined problem check from 0.5–1.0 s windows	Finds changes that aren't linear; fewer false alarms near surge line	Needs good data that doesn't stay steady and safe limits	SPSI base; says threshold values

The gas-path channel is fundamental for guidance during startup because residuals against transient models are proportional to the surge boundary [4; 6; 10]. Acoustic sentinels offer a rapid, low-latency discriminator that triggers conservative fuel-ramp behavior before EGT rises beyond the protection window, yet require deliberate placement and band-pass selection to withstand apron noise [1; 4; 7; 8]. Starter/generator telemetry adds a mechanically grounded proxy for torque/acceleration behavior and improves decisions when pressure signals are marginal [3; 4]. The hybrid ML layer ties these together while remaining constrained by reduced-order dynamics and explicit limit logic, which helps with explainability and certifiability [5; 7; 8; 9].

Active anti-surge work around Moore–Greitzer-type models shows that feedback can suppress limit cycles and delay surge onset when actuation authority in bleed/throttle is available, yet makes clear stabilization limits under aggressive ramps and strong disturbances [5]. Comprehensive reviews of transient performance and heat-transfer dynamics underscore the influence of VBV/VSV scheduling and thermal state on start trajectories

relative to the surge line [6]. Deep RL controllers trained against high-fidelity surrogates produce stabilizing sequences and suggest a path to supervisory logic that proposes human-interpretable actions (hold/abort) via a rule layer, which is suitable for headset operations during gate starts [9]. Numerical studies of surge experiments and stability envelopes provide the simulation ground to position two-threshold policies without over-conservatism [10]. Finally, APU acoustic discrimination and more-electric APU FDI results demonstrate that sensing and inference pipelines at small-compressor scale can be scaled up or adapted to main-engine starts with due calibration [1; 3].

The operational consolidation appears in Table 2, which reframes findings into who-does-what-when logic for the headset engineer and the cockpit during the start window. The table builds on the SPSI fusion score from Results and binds it to VBV/VSV schedule checks and to the soft/hard threshold action ladder documented across the cited work [1; 3; 7; 9; 10].

Table 2: Start-phase surge decision ladder (SPSI-based) with actions, communications, and post-event data capture [1-10]

Stage / Window	Key Checks and Monitored Data	SPSI-Based Actions and Logic	Data Handling / Notifications
Detection/Validation	SPSI band, associated sensor channels, derived indicators	Validate SPSI level and trend, confirm plausibility of indications	Prepare data for subsequent use in response logic
Action/Communication	Output channels for crew and maintenance notifications	Trigger response logic, alerts, and guidance messages	Distribute notifications through defined channels
Post-Event	Stored SPSI, VBV/VSV, acoustic and starter/generator records	Use for debrief, tuning of thresholds, and procedural refinement	Archive, tag, and integrate into incident/learning databases
Pre-Crank (0–2 s)	Starter/generator status; VBV/VSV positions	Permit start only when VBV/VSV settings match required configuration; flag anomalies	Log actuator positions; record any flagged deviations
Crank (2–10 s)	P2/P3, Ṅ, acoustic band energy	Low SPSI leads to continuation of ramp and issue of standard notifications	Store SPSI trace for the crank interval
Crank/Pre-Light-Off	SPSI level and trend; starter power; VBV position; acoustic bands	Borderline SPSI or rising trend leads to hold fuel rise, open-hold VBV, short reassessment interval	Mark event, record VBV position and acoustic band characteristics
Ignition/Light-Off	Phase coherence between P2 and	High SPSI combined with coherence collapse leads to Abort & motor,	Export SPSI, VBV/VSV and

	mass-flow; SPSI level	purge, cool-down, and preparation for slower restart ramp	acoustic data for post-start review
Restart Attempt	Repeat checks of SPSI, VBV/VSV, starter/generator, fuel schedule	Apply conservative fuel schedule; low SPSI leads to continuation with enhanced monitoring and shorter advisory period	Append run to incident record for fleet/group learning and analysis

The soft threshold institutionalizes early caution without incurring frequent aborts; the hard threshold—tied to both a high SPSI score and a collapse in phase coherence—supports decisive aborts that protect hardware and narrow the investigation space [1; 4; 5; 7; 9]. The post-event record (SPSI trace, VBV/VSV positions, acoustic spectrogram) enables consistent root-cause work and continuous improvement in fleet-level classifiers [3; 4; 6].

For operators with recurrent exposure to adverse weather and long on-stand times, condition-based adjustments inferred from transient deviations help decide between a manual conservative ramp and a standard schedule, lowering exposure to tight surge margins during cold-day starts [4; 6; 10]. Where more-electric starters are available, electromechanical telemetry adds resilience to detection during crank and can serve as a cross-check when pressure signals are ambiguous [3]. When training line engineers, figure-ground intuition from reduced-order dynamics clarifies why bleed/throttle actions work and where stabilization limits sit under strong disturbances [5; 10]. For digital modernization, hybrid model-informed AI provides a certification-oriented path: the physics model defines safe regions and admissible actions; the learning layer tunes thresholds and anticipates disturbance combinations seen in service [5; 7; 8; 9].

The literature consolidates strong evidence for transient detectability and control leverage, yet gaps remain:

i) dataset scarcity for labeled start anomalies across engine families;

ii) acoustic generalization under varying apron geometries;

iii) starter architecture variability that alters electrical observability [1; 3; 4; 7; 8].

To address these constraints within airline constraints, begin with SPSI v1 using channels already measured (gas-path), add an acoustic sentinel during post-maintenance starts, and incorporate starter/generator telemetry where available, while preserving the two-threshold ladder and clear headset–cockpit callouts [1; 3; 7; 9; 10]. Parallel simulation, using MG-anchored reduced models and the parameter ranges quantified in recent studies, furnishes safe parameter sweeps for threshold tuning without exposing engines to surge tests.

V. CONCLUSION

Here, the start-phase method reaches its goals by:

1) Joining data from three finding issue channels into an SPSI that focuses on gas-path changes, betters early warning using acoustic data, and checks small cases using starter/generator data;

2) Setting up a two-level plan that sets standard actions between headset crew and cockpit (continue/hold/abort & motor) and makes event records easier to learn from;

3) Linking SPSI alerts with VBV/VSV timing and safe fuel ramps, which guides the start way away from the surge border.

This way turns current research into working tools for apron actions, keeps incidents from happening without needing tools that change things a lot, and sets a way for using model-informed AI in airline places.

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Evaluation of Lateral Capacity of Pile Foundation in Layered Soils

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Abstract *— This paper examines the lateral capacity of pile foundations embedded in layered soils. The main aim is to determine the lateral load at which the maximum bending moment occurs while keeping serviceability within acceptable limits. Piles were modelled with a fixed length of 20 m, with diameters ranging from 0.8 m to 2.0 m to examine the influence of cross-sectional size. A deflection limit of 1% of the pile diameter served as the governing criterion. Lateral capacities were initially estimated using the provisions of IS 2911, Part 1, Section 2, then verified through numerical simulations with L-Pile and Plaxis 3D software. The comparison illustrates how soil layering influences pile response, showing that increasing the diameter significantly enhances lateral resistance along the pile. The findings provide practical guidance for selecting appropriate pile dimensions in layered profiles, ensuring sufficient lateral performance and controlled deflections.*

Keywords *— **Pile foundation, Layered Soil, Lateral Capacity, Permissible deflection, LPile and Plaxis 3D***

I. INTRODUCTION

Piles are used to transfer loads to bedrock or more durable soil layers when the upper layers are highly compressible and cannot support the weight of the superstructure. If bedrock is not available at a suitable depth, piles are employed to transfer the load to the soil gradually. The primary resistance to the structural load is friction at the soil-pile interface. When horizontal forces act on them, pile foundations bend to resist these forces while maintaining their vertical load-bearing capacity from the superstructure. This situation is common during the design and construction of foundations for large buildings, bridges, and earth-retaining structures subject to strong winds or earthquakes [1].

The IS 2911 standard offers detailed guidance for bored cast-in-situ concrete piles, explaining their load transfer mechanisms, including axial and lateral capacities, as well as their intended uses. Piles may face lateral forces from sources such as wind, earthquakes, or water currents. Their lateral load capacity depends on the horizontal subgrade stiffness of the surrounding soil and the structural strength of the pile shaft against bending [2]. The PLAXIS 3D FOUNDATION program is finite element software designed for analysing foundation structures, including bridge foundations. It features straightforward graphical input methods for automatically generating complex finite element models, along with advanced output options and

reliable calculation methods. This makes it a comprehensive tool for foundation analysis [3]. LPILE is specialised software for analysing deep foundations like piles. It calculates key parameters such as deflection, shear, bending moment, and soil response in layered soils. The program models soil and rock using lateral load-transfer (p-y) curves, which can be generated internally or supplied by users, and includes specific procedures for layered soil profiles. It supports various pile-head loading conditions, allows for different pile structural properties, and provides guidelines for rebar arrangements based on the ACI 318 code [4].

Current research investigates the behaviour and load-bearing pattern of a single vertical bore pile in layered soil. Results from IS2911Part1 (sec 2) using the Lpile and PLAXIS 3D techniques are compared. Additionally, lateral loads for a fixed-headed pile with different diameters and deflection values are calculated and presented.

II. SITE DETAILS

The Department of Local Infrastructure Development and Agricultural Roads (DOLIDAR) of the Government of Nepal has identified this location as the proposed site for the bridge. It is located southeast of Kathmandu in Nepal's Sarlahi district, part of the country's Terai region. The Terai zone is primarily flat terrain situated below 200 meters above sea level. It has a thick layer of alluvial sediment, about 1,500 meters deep, composed of boulders, gravel, silt, and clay. The Terai stretches from the Indian Shield in the south to the Siwalik zone in the north. Its width varies from 10 to 50 kilometres, forming a nearly unbroken east-west strip, except where the Siwalik zone interrupts it in two locations. The Main Frontal Thrust (MFT), an active fault, runs along the northern edge of the Terai near the Siwalik hills [5].

III. GEOTECHNICAL INVESTIGATION

A Standard Penetration Test (SPT) was conducted to a depth of 30 meters during the field investigation to observe the behaviour of the underlying soil layers. The investigation revealed that the soil consists of several layers, including a 9-meter-thick layer of medium sand sandwiched between two layers of medium-hard clay. The top clay layer extends down to 9 meters, while the medium sand layer ranges from 9 to 18 meters. Additionally, there is a second layer of medium-stiff clay that extends from 18 to 30 meters. The water table is located at the land surface. Both disturbed and undisturbed samples were collected for laboratory analysis to determine the soil properties. The values of the modulus of subgrade reaction (K) were obtained from IS 2911 Part I, Section II. For cohesive soils, the value remains constant, while for cohesionless soils, it varies linearly. According to IS 6403:1981, Table 1, Clause 5.1.1, for φef = 30.5 degrees, the bearing capacity factors are taken as Nc = 9 and Nq = 18.4. An adhesion factor α = 0.9 for pile design in cohesive soils.

Table 1. Geotechnical Parameters of Soil Determined from Field and Laboratory Investigations.

Layer	v	K(kN/m³)	E50	Navg	γ (kN/m³)	γsub (kN/m³)	Cu (kN/m²)	φef
1	0.35	3460	0.005	20	17	7	48	0
2	0.30	6440	-	30	17	7	0	30.5
3	0.35	3460	0.005	30	17	7	48	0

v: Poisson's ratio, E50: Strain Factor, K: Modulus of Subgrade Reaction, Navg: Avg.SPT value, γ: Unit Weight, γsub: Submerged Unit Weight, Cu: Undrained Shear Strength, φef: Angle of internal friction(degree),

IV. METHODOLOGY

Method I: IS 2911 (Part 1/section 2)- 2010 outlines the procedure for determining the lateral load capacity of piles, as specified in Annex C of the standard. It recognises the complexity of the interaction between the pile and the soil as the load approaches its ultimate value. This interaction involves both elastic and plastic deformation of the soil. An approximate solution is provided for most cases, but scenarios requiring a more detailed analysis should be approached accordingly. The first step involves determining whether the pile acts as a short, rigid

unit or an infinitely long, flexible member by calculating the stiffness factor (R or T) for the specific pile-soil combination. Once the stiffness factor is determined, criteria related to the pile's embedded length (L) are used to classify its behaviour. Next, the depth from the ground surface to the point of virtual fixity is calculated and then utilised in conventional elastic analysis to estimate lateral deflection and bending moment. For granular soils and normally consolidated clays, the lateral soil resistance is modelled using a variable soil modulus, whereas for preloaded clays, it is modelled with a constant soil modulus [2].

Method II: The working principle of pile foundation analysis in PLAXIS 3D is based on the Finite Element Method (FEM), where the soil–pile system is discretized into finite elements, soil behavior is defined using constitutive models (e.g., Mohr–Coulomb, Hardening Soil), and pile–soil interaction is modeled through interface elements to simulate realistic load transfer along the pile shaft and tip. Construction stages, including pile installation, consolidation, and loading, are modelled stepwise, and FEM equations are solved iteratively to capture the nonlinear soil response under different loading conditions. The Output program provides results such as settlement profiles, lateral deflections, bending moments, shear forces, axial forces, and load–load-displacement curves, along with stress–strain distribution and pore pressure changes in soil. This enables a comprehensive understanding of the pile's performance, failure mechanisms, and overall stability of the foundation system under axial, lateral, or combined loads [3].

***Method III*:** LPile software models the pile as a beam on an elastic or nonlinear foundation, dividing it into finite elements along its length. For each component, LPile employs iterative numerical methods to satisfy equilibrium between the applied lateral load and the soil resistance. A predefined lateral deflection criterion (e.g., 1% of pile diameter as per IRC:78-2014) is established as the permissible limit. The software incrementally increases the lateral load until the pile head or any point along its length reaches this deflection limit, thereby determining the ultimate lateral load capacity corresponding to the specified deflection. The bending moment distribution is then calculated from the derived pile deflection profile using principles of structural analysis. LPile computes slope, shear, and moment at each depth by solving the governing differential equation of a beam on elastic foundation EI d4y /dx4 + p(y)=0, where EI is the pile stiffness, y is the lateral pile deflection, and p is the soil reaction [4].

The results from these three methods are presented graphically to demonstrate the differences in predicted capacities and moments, allowing for an evaluation of how advanced numerical modelling (LPile and Plaxis 3D) compares with traditional analytical and semi-empirical approaches for safe and cost-effective pile design.

Material Properties: The pile material is made from M35 grade concrete with a characteristic compressive strength (fck) of 35 MPa, a tensile strength (fcr) of 4.14 MPa, an elastic modulus (Ec) of 29,580 MPa, and a shear modulus (G) of 12,325 MPa. The longitudinal and transverse reinforcement is provided using Fe 500 steel, which has a characteristic tensile strength (fyk) of 500 MPa, ensuring sufficient strength and ductility to resist axial, bending, and shear forces effectively.

Pile Geometry: The pile has a circular cross-section with a diameter up to 2m and a fixed length of 20 m. For a 1 m diameter, its cross-sectional area is 0.785 m^2, and the moment of inertia is 0.0491 m^4, indicating the pile's stiffness and strength under axial and lateral loads.

V. RESULTS AND DISCUSSION

a. Calculation of Lateral Capacity

The analysis is conducted to investigate the impact of pile geometry on lateral load capacity, subjected to a predefined deflection limit of 1% of the pile diameter, which serves as the boundary condition. The pile diameter varies from 0.80 m to 2.0 m while maintaining the pile length constant of 20 m. The pile head is assumed to be restrained (fixed-head condition). The lateral load capacity is determined using both the analytical approach and the (LPile, PLAXIS 3D) software.

PLAXIS 3D) software.

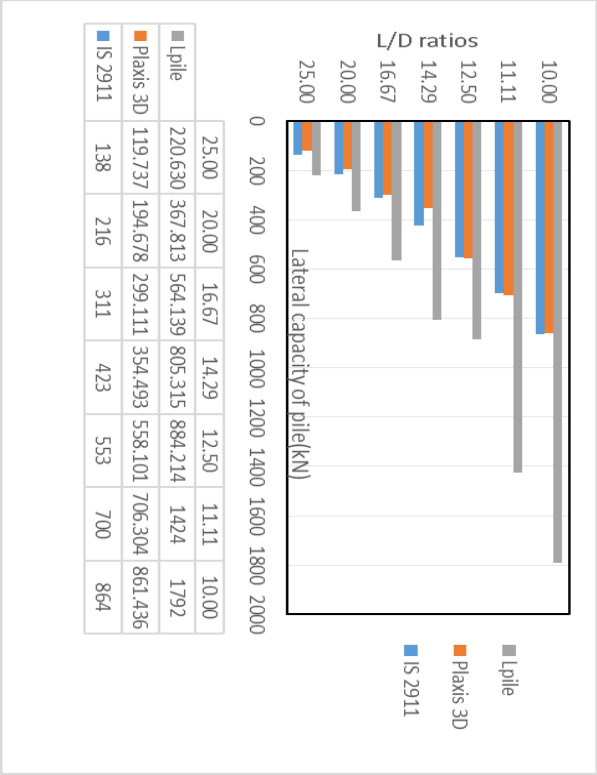

Fig. 1. Variation of Lateral Load Capacity with increasing diameters of pile

The above graph illustrates how lateral pile capacity varies with different L/D ratios, based on results from IS 2911, Plaxis 3D, and LPILE. In all three methods, lateral capacity decreases as the L/D ratio increases, indicating that piles have less resistance. At lower L/D ratios, LPILE gives much higher capacity values than IS 2911 and Plaxis 3D, but these differences decrease at higher ratios. IS 2911 and Plaxis 3D produce similar results throughout, showing that the code and the numerical analysis are consistent.

VI. VALIDATION OF THE RESULT

The figure below compares experimental results with those of Abhipriya Halder and Kaushik Bandyopadhyay (IGC 2016) [7]. In both cases, lateral load capacity increases as pile diameter increases, showing a clear positive correlation. The curves look similar, and both rise sharply at larger diameters. This means that our results and those from literature show the same basic pile behaviour. Although Experiment (III) shows higher values, the overall trend and proportional increase are consistent.

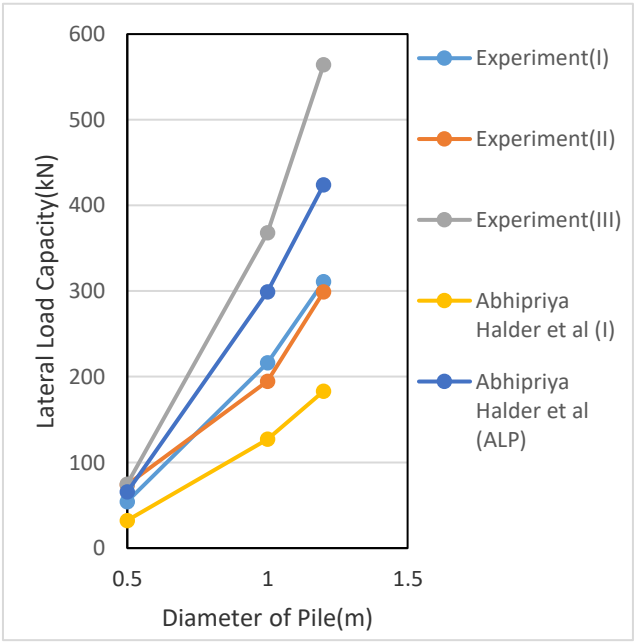

Fig. 2. Comparison of the lateral load capacity of piles of varying diameter obtained from this research and [7].

I: IS 2911, II: Plaxis 3D, III: LPile and ALP: Analysis of laterally loaded pile (Software)

VII. CONCLUSION

This research demonstrates that pile slenderness, soil layering, and analytical technique all have a significant impact on pile lateral capacity. The data clearly illustrate that when the L/D ratio increases, capacity diminishes. Among the three approaches, LPile predicts the highest capacities at low L/D, due to its p–y curve formulation and stiffer soil response assumptions. Plaxis 3D and IS 2911 yield lower but closely consistent capacities, providing more conservative estimates. At higher L/D ratios, the predictions from all three techniques converge. This type of soil has a strong effect on how piles behave. When the middle sand layer is engaged, it significantly increases lateral resistance. However, the clay layers above and below, which have a lower subgrade modulus, decrease pile capacity as depth increases. As sand gets stiffer with depth, it further boosts lateral resistance where bending is most critical. The response of the clay layers depends significantly on the chosen subgrade modulus. Also, the stiffness of the pile itself, measured by its flexural rigidity (EI), plays a big role in how much the pile head moves. Stiffer piles can carry more load while staying within the 1% deflection limit.

The results show that when designing piles in layered soils, it is essential to account for changes in soil stiffness, the arrangement of the layers, and to select the appropriate analysis method. To enhance the reliability of design practices, integrating continuum-based numerical modeling using Plaxis 3D with simplified p–y or code-based approaches such as LPile and IS 2911 is advisable. This combined methodology enables a more accurate representation of soil–pile interaction while ensuring conservative design outcomes.

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The Hazardous Effects of Mobile Phone Towers on Animals and Human beings: A Bangladesh Perspective

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Abstract *— A concise summary of the research – introducing mobile phone towers, the expansion in Bangladesh, apprehensions regarding electromagnetic radiation (EMR), and the objective to evaluate its effects on both humans and animals. This document thoroughly analyzes existing scientific data concerning radio-frequency (RF) and electromagnetic field (EMF) emissions from mobile phone base stations (cell towers), along with their recorded impacts on wildlife (including birds, insects, small mammals, and plants) as well as humans. We examine epidemiological, experimental, and ecological research, pinpoint potential biological mechanisms (such as oxidative stress, behavioral alterations, and endocrine disruption), evaluate regulatory deficiencies, and offer suggestions for future studies and public health policies.*

Keywords *— **Electromagnetic, Radiation, Effects on both humans and animals, public health.***

I. INTRODUCTION

Bangladesh has experienced a significant surge in mobile telecommunication infrastructure over the past few decades. As of mid-2015, the number of mobile subscribers exceeded 130 million, a substantial increase from just 26.6 million a decade prior. Concurrently, more than 21,600 mobile towers have been established across both urban and rural areas. A considerable number of these towers are situated on the rooftops of residential buildings, in proximity to schools, hospitals, and densely populated areas, frequently without adequate setbacks or ecological considerations. In this context, the issues surrounding the ongoing non-ionizing radio-frequency (RF) emissions from base stations become increasingly pressing. Although international research has investigated RF/EMF exposure and its biological impacts, there is a pressing need for localized studies in Bangladesh, particularly concerning ecological and human health aspects. Radiation from Base Transceiver Stations (BTS) occupies the range of 800 MHz to 3000 MHz and it is a part of microwave frequency (MW) radiation (300MHz-300 GHz). Microwaves lie between radio frequency (RF) and infrared waves in electromagnetic spectrum.

Fig: Effects of microwaves on life

This paper aims to investigate:

1. The extent and characteristics of mobile tower radiation in Bangladesh.

2. The evidence regarding its effects on animals, plants, and humans.

3. The existing regulatory frameworks, their deficiencies, and methods of exposure assessment. 4. Suggestions for policy development, research initiatives, and practical applications.

II. OVERVIEW OF EMF EXPOSURE IN BANGLADESH

In Bangladesh, the power density measurements reported from mobile base stations vary between approximately 17,100 micro-watts and 72,000 micro-watts per square meter in specific urban areas. International guidelines, such as those from the World Health Organization (WHO), establish limits for each frequency band (for instance, GSM900 at 4.7 W/m²) but do not provide thresholds specific to wildlife. Although national surveys conducted by the Bangladesh Telecommunication Regulatory Commission (BTRC) assert that radiation levels at sampled locations are 20-30 times lower than international limits, observers have pointed out that installations are often situated close to schools, hospitals, and residential areas, with insufficient buffer zones. Consequently, this leads to prolonged low-level exposure for humans, animals, and the environment in densely populated regions.

III. EFFECTS ON ANIMALS AND WILDLIFE

In recent years, the swift expansion of mobile phone networks has resulted in the establishment of many mobile phone towers in both urban and rural regions. Although these towers enhance communication, they release radiofrequency (RF) radiation, which has sparked worries regarding its impact on the environment, especially concerning birds and insects.

3.1 Impact of Birds and Insects:

Birds exhibit a high sensitivity to electromagnetic radiation. Numerous studies indicate that RF radiation emitted by mobile towers impacts their navigation capabilities, particularly in migratory birds that depend on the Earth's magnetic field for orientation. The electromagnetic waves disrupt this natural compass, leading to disorientation among birds.

Moreover, prolonged exposure to radiation has been linked to diminished reproductive success in avian species. For instance, research has documented a decrease in egg quantity, thinner eggshells, and lower hatching rates in proximity to mobile towers. Additionally, behavioral alterations such as heightened aggression or abandonment of nesting sites have been noted.

Insects, particularly bees, are even more susceptible due to their diminutive size. RF radiation interferes with their ability to return to their hives, a phenomenon associated with Colony Collapse Disorder (CCD). Bees are vital for pollination, and their decline can significantly affect food production.

Similarly, butterflies and other pollinating insects experience comparable adverse effects. In regions with elevated radiation from mobile towers, reductions in population, disorientation, and decreased reproductive rates have been recorded.

While mobile phone towers are crucial for communication, they present an increasing threat to both birds and insects. These organisms are essential for preserving biodiversity and ecological equilibrium. Consequently, it is imperative to pursue further research and implement safer technological practices, such as improved tower placement and minimizing radiation exposure in sensitive areas like forests, farmlands, and wetlands.

3.2 Livestock & Mammals

The swift growth of mobile communication has resulted in the extensive deployment of mobile phone towers, which continuously emit radiofrequency (RF) radiation. Although this technology is essential for human communication, there is a growing apprehension about its possible harmful effects on animals, especially livestock and mammals. While research is ongoing, numerous studies and field observations indicate that long-term exposure to electromagnetic radiation (EMR) could adversely affect animal health, behavior, and productivity.

Impact on Livestock:

Livestock, including cows, goats, sheep, and poultry, frequently encounter radiation from mobile towers, particularly in rural and semi-urban regions where these towers are positioned close to farms. Exposure to electromagnetic radiation (EMR) has been associated with various physiological and behavioral alterations in livestock.

a. Decreased Milk Production:

Research conducted in countries such as Germany and India has indicated notable declines in milk production among cows residing near mobile towers. This phenomenon may be attributed to hormonal imbalances induced by EMR, which can disrupt metabolic functions and the endocrine system.

b. Reproductive Challenges:

EMR has the potential to disrupt reproductive hormones. In certain instances, farmers have reported a rise in cases of miscarriages, infertility, and diminished conception rates in livestock subjected to elevated radiation levels.

c. Changes in Behavior:

Animals that are exposed to radiation from mobile towers may exhibit signs of agitation, aggression, decreased appetite, and confusion. Such behavioral changes can result in reduced weight gain and overall poor health.

d. Compromised Immune Function:

Extended exposure to radiation may impair the immune system, rendering livestock more susceptible to infections and diseases.

Impact on Mammals (including Pets and Wild Mammals):

Domesticated and wild mammals, such as dogs, cats, rabbits, and even wild species residing near urban areas, are also vulnerable. Given that mammals possess a biological structure similar to that of humans, EMR may affect them in analogous ways.

a. Neurological Effects:

Exposure to EMR has been associated with behaviors related to stress, headaches (as inferred from signs of restlessness), and alterations in brain activity observed in laboratory animals. Certain rodents subjected to RF radiation have exhibited memory impairment and difficulties in learning.

b. DNA Damage: Research conducted on rats and mice suggests that prolonged exposure to RF radiation may lead to cellular stress and potential DNA damage, which could elevate the risk of cancer or other chronic illnesses.

Fig: Impact of microwaves on DNA

c. Effects on Wild Mammals:

Although less extensively documented, mobile towers situated in forests or adjacent to natural habitats may interfere with the migration, reproduction, and habitat utilization of wild mammals due to electromagnetic radiation (EMR) and the associated lights and noise from the towers.

The impact of mobile phone towers on livestock and wild mammals is an increasing concern, especially as the number of towers rises in proximity to residential and agricultural areas. While further large-scale research is necessary to draw definitive conclusions, current studies indicate the need for precautionary actions. These actions may involve regulating the placement of towers, enhancing awareness among farmers, and performing regular health evaluations of animals located near mobile towers to safeguard their welfare and maintain the overall ecological balance.

3.3 Flora and Soil Ecosystems

The soil ecosystem is an intricate and fragile network consisting of microorganisms, fungi, insects, organic matter, and minerals. These elements are crucial for nutrient cycling, plant development, and the overall health of the ecosystem. The radiation emitted by mobile towers may subtly yet significantly affect this equilibrium.

a. Decrease in Microbial Activity:

Soil microbes are vital for the decomposition of organic matter and nitrogen fixation. Research indicates that exposure to electromagnetic radiation (EMR) can diminish microbial biomass, enzyme activity, and soil respiration rates, resulting in reduced fertility.

b. Disturbance of Earthworms and Insects:

Organisms such as earthworms, ants, and other soil-dwelling species are particularly sensitive to electromagnetic fields. Extended exposure may cause

migration, reproductive issues, or mortality, thereby disrupting soil structure and nutrient cycling.

c. Changed Soil Composition:

Prolonged exposure to radiation may alter the chemical equilibrium within the soil, impacting pH levels and the accessibility of vital nutrients such as potassium and phosphorus. While mobile phone towers are crucial for contemporary communication, their ecological repercussions—particularly on plants and soil—deserve significant consideration. Disruptions to plant development and soil vitality can lead to far-reaching consequences for agriculture, biodiversity, and food security. Consequently, it is imperative for policymakers and environmental organizations to evaluate the environmental hazards associated with tower placement, encourage additional research, and contemplate buffer zones between towers and vulnerable ecosystems to promote sustainable development and environmental conservation.

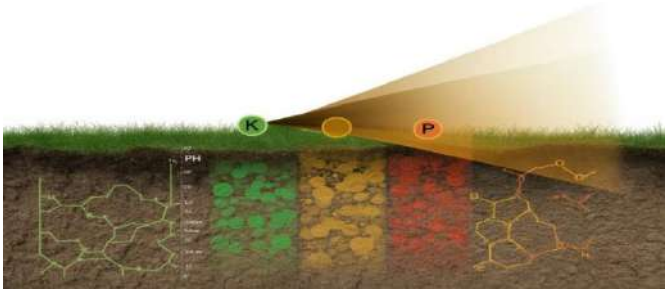

Fig: Long-term radiation effect on soil

IV. EFFECTS ON HUMAN HEALTH

Mobile phone towers, commonly referred to as cell towers or base stations, have become a vital component of contemporary communication infrastructure. Nevertheless, there are increasing global concerns regarding the possible health risks linked to prolonged exposure to the radiofrequency (RF) electromagnetic radiation emitted by these towers. While mobile towers offer robust network coverage, their presence in densely populated regions has prompted researchers and health professionals to investigate their effects on human health.

a. Sleep Disturbances

One of the most frequently reported problems by individuals living near mobile towers is diminished sleep quality. Research has associated prolonged exposure to RF radiation with changes in melatonin production, a hormone responsible for regulating sleep. This can result in insomnia, fatigue, and daytime drowsiness.

b. Headaches and Cognitive Issues

Individuals residing within 100–300 meters of towers often report persistent headaches, challenges in concentration, memory difficulties, and irritability. Although establishing causality is challenging, these symptoms are commonly noted in epidemiological research.

c. Increased Stress and Anxiety

Ongoing low-level radiation exposure may contribute to psychological stress, anxiety, and even depression. Alterations in brain activity, hormonal imbalances, and disturbances in the nervous system could be contributing factors.

d. Cardiovascular Symptoms

Some research indicates that RF radiation may influence heart rate variability, potentially leading to palpitations or irregular heartbeats, particularly in individuals with pre-existing heart conditions.

e. Cancer Risk

This continues to be the most contentious field. In 2011, the International Agency for Research on Cancer (IARC) of the World Health Organization classified RF radiation as "possibly carcinogenic to humans (Group 2B)" due to evidence connecting prolonged mobile phone usage with glioma, a form of brain cancer. While this classification did not specifically address towers, apprehensions persist regarding long-term exposure to towers, particularly among children and pregnant women.

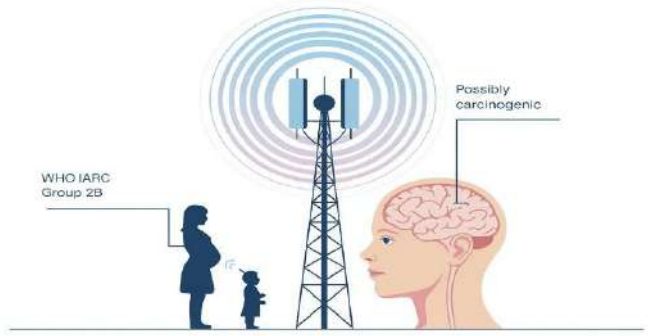

Fig: Impact of microwaves on brain cancer

f. Reproductive Health

Recent studies indicate possible impacts on male fertility, highlighting reports of reduced sperm quality and motility in individuals subjected to elevated levels of RF radiation. Although mobile phone towers are essential for communication, increasing evidence implies that prolonged exposure to their radiation could influence human health, particularly among vulnerable groups. As research advances, it is crucial to adopt precautionary measures, enhance public awareness, and enforce stricter regulations to reconcile technological advancement with the safety of public health.

V. EVOLUTION OF SAFETY STANDARDS

The following is a brief summary of the wireless safety standards, which have become stricter over time.

• 1966: The ANSI C95.1 standard adopted the standard of 10 mW/cm2 (10,000 µW/cm2) based on thermal effects.

• 1982: The IEEE recommended further lowering this limit to 1 mW/cm2 (1,000 W/cm2 or 10 µW/m2) for certain frequencies in 1982, which became a standard ten years later in 1992.

• 1986: The national council on radiation protection and measurements (NCRP) recommended the exposure limit of 580 µW/cm2.

• 1992: The ANS/IEEE C95.1-1992 standard based on thermal effects used the 1 mW/cm2 (1,000 µW/cm2) safety limit. The United States Environmental Protection Agency called this revised standard "seriously flawed", partly for failing to consider non-thermal effects, and called for the FCC to adopt the 1986 NCRP standard, which was five times stricter.

• 1996: The FCC updated to the standard of 580 µW/cm2 over any 30 minute period for the 869 MHz, while still using 1 mW/cm2 (1,000 µW/cm2) for PCS frequencies (1850-1990 MHz).

• 1998: The ICNIRP standard uses the limit of 450 µW/cm2 at 900 MHz, and 950 µW/cm2 at 1900 MHz. The limit is frequency dependent.

VI. EXPOSURE ASSESSMENT & REGULATORY STANDARDS

The global impact of mobile phone towers on human health remains a subject of debate, with numerous regulatory agencies asserting that there is no definitive evidence of harm at present exposure levels. However, in Bangladesh, there have been several anecdotal accounts and small-scale studies reporting symptoms such as headaches, sleep disturbances, memory loss, chest tightness, and skin irritations among individuals residing within a few hundred meters of these towers. Proposed biological mechanisms include oxidative stress, disruption of endocrine functions, DNA damage, and neurological effects. Although this emerging evidence is not conclusive, it raises concerns regarding the cumulative and long-term effects of low-dose exposures, particularly in the context of developing countries.

Bangladesh adheres to international guidelines established by organizations such as the International Commission on Non-Ionizing Radiation Protection (ICNIRP), although the enforcement of these guidelines may differ. Experts highlight the importance of ensuring safe tower placement, limiting installations near schools, hospitals, and residential neighborhoods, as well as conducting regular monitoring of radiation levels.

VII. DISCUSSION

In recent years, the swift growth of mobile phone networks in Bangladesh has resulted in the extensive installation of mobile phone towers throughout urban, semi-urban, and even rural regions. While these towers facilitate uninterrupted communication and digital connectivity, there is a rising concern regarding their possible negative impacts on human health and the environment, particularly concerning animals and ecological systems. This issue is particularly urgent in Bangladesh due to its high population density, unregulated urban development, and a lack of awareness regarding radiation risks.

The electromagnetic radiation (EMR) produced by these towers, particularly in the form of radiofrequency (RF) waves, is non-ionizing yet persistent. Although it is deemed low-level, prolonged exposure raises considerable health concerns. In Bangladesh, numerous towers are situated in close proximity to residential

neighborhoods, schools, hospitals, and even on the rooftops of residences without clear safety protocols. This closeness to everyday human activities heightens the risk of health-related issues.

One of the most significant challenges in Bangladesh is the absence of awareness and regulation. The installation of towers frequently occurs without adequate consultation with local authorities or environmental evaluations. Existing policies are ambiguous, and enforcement is lax. Consequently, towers are occasionally positioned in inappropriate locations, unnecessarily increasing public exposure.

To alleviate these risks, Bangladesh must implement a more balanced strategy. Stricter regulations should be enforced to govern tower placement, particularly distancing them from sensitive areas such as schools, hospitals, and wildlife habitats. Additionally, awareness campaigns are essential to inform the public and telecom companies about safe distances and exposure limits.

VIII. RECOMMENDATIONS

1. Implement compulsory Environmental Impact Assessments (EIA) for the installation of new mobile towers, which include assessments of risks to flora and fauna.

2. Establish minimum buffer zones (for instance, greater than 50 meters) from educational institutions, healthcare facilities, residential areas, and conservation regions.

3. Install continuous monitoring stations to measure RF-EMF exposure—including in wildlife and plant areas—and ensure that the data is reported publicly.

4. Encourage environmentally friendly tower placement practices: avoiding rooftops, ensuring antenna heights exceed 30 meters, and utilizing shared infrastructure to minimize the number of towers.

5. Provide funding for longitudinal cohort studies in Bangladesh focusing on human exposure, as well as ecological field studies that assess population trends in birds, insects, and trees in proximity to towers.

6. Create public awareness campaigns that highlight the importance of informed consent and the right to live in healthy environments.

IX. CONCLUSION

Mobile phone towers play a crucial role in ensuring modern connectivity in Bangladesh. However, the increasing ecological concerns and initial human health indicators linked to their radiation emissions indicate that we must not overlook the environmental and biological impacts. Particularly in densely populated urban areas and biodiverse rural regions, taking precautions necessitates more than just adherence to human-focused thermal limits. Comprehensive national research, regulatory changes, and the integration of ecosystem protection should be integral components of Bangladesh's telecommunications expansion strategy. In summary, although mobile towers are crucial for digital connectivity and advancement, the potential health and environmental risks they present must not be overlooked. A precautionary strategy, supported by scientific studies and robust regulations, is necessary to safeguard both humans and wildlife in Bangladesh.

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Key Factors Influencing the Cost of Global Supply Chains Under Geopolitical Instability

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Abstract *— The article presents a systematic analysis of the factors that drive cost escalation in global supply chains under conditions of geopolitical instability. The study is based on the structuring of key risk domains — energy, logistics, manufacturing, agri-food systems, and labor resources — and on examining their interdependent impact on overall expenditures. The mechanisms through which geopolitical events translate into higher costs are analyzed, including route disruptions, resource price fluctuations, increased production delays, and declines in export flows. Particular attention is given to the comparative vulnerability of countries and industries: the analysis identifies the specific response patterns of export-oriented economies, the extent of the impact generated by system-critical states, and the domain structure of industries where primary cost pressures originate. The findings show that the cost of global supply depends on the overlay of multiple layers of risk and is shaped by the degree to which economies are integrated into international flows and by the nature of interdomain linkages. It is concluded that cost management in unstable conditions requires a systemic approach that accounts for interactions among energy, logistics, and production factors, as well as the spatial structure of the global economy. The article will be useful for researchers of global supply chains, logistics professionals, operational risk analysts, and experts focused on the resilience of international production and logistics systems.*

Keywords *— **global supply chains, geopolitical instability, supply chain cost, domain risks, logistics, energy vulnerability, export operations.***

I. INTRODUCTION

Global supply chains have evolved into complex, multilayered systems where cost is formed at the intersection of logistics, production, energy, finance, and international politics. Under conditions of geopolitical instability, the influence of external shocks intensifies, ranging from demand fluctuations and trade restrictions to transportation disruptions, currency volatility, and raw material shortages. In addition to these shocks, interstate tensions such as sanctions, export controls, tariff escalations, and geopolitical confrontations increasingly reshape the pricing environment of global supply chains. These instruments alter access to strategic materials, modify logistics routes, and transform the baseline cost parameters faced by both export-oriented and manufacturing-driven economies.

Cost dynamics have ceased to be linear. They are defined by the asymmetry of shocks and differences in industry vulnerability [3]. In some sectors, the decisive factor is the cost of energy; in others, it is the availability of transport routes or the stability of export markets. Without systemic analysis, it is no longer possible to correctly assess the cost structure.

The sensitivity of chains to geopolitical risks varies. Export economies react to falling demand, logistics operators to route disruptions, and manufacturing companies to rising raw material and energy prices [7]. A universal cost assessment model

does not exist, and analytics must account for industry specifics, a country's role in global flows, import and export structures, the level of technological maturity, and supply diversification.

The scientific novelty of the research lies in the systematization of factors that form the cost of global supply chains under conditions of instability and in the identification of mechanisms linking geopolitical events to changes in operational, production, and logistical expenses. The work is oriented toward creating a structural framework that allows for assessing how events of different types alter the total cost and which domains are key points of cost accumulation.

The objective of the study consists of identifying and analytically describing the systemic factors determining the change in the cost of global supply chains under the influence of geopolitical risks and external shocks, with a subsequent assessment of mechanisms for restructuring logistical structures. To achieve the stated objective, the study identifies and structures the domain areas forming the cost dynamics of global supply chains, describes the causal mechanisms of the influence of external events on cost growth, conducts a comparative analysis of sources of geopolitical instability, and develops analytical criteria for assessing the vulnerability of logistical systems.

The research hypothesis posits that the key driver of cost growth in global supply chains is the combination of geopolitical instability and high domain interdependence. The systemic nature of these connections leads to a situation where a local event causes a chain reaction of costs in adjacent areas, amplifying the initial effect.

The scope of the study is limited to the analysis of global and transnational chains, where cost depends on macroeconomic parameters, logistical processes, energy sustainability, and integration into international trade. Domestic national chains and local industry specifics are considered only as context elements influencing the sensitivity of systems to external events.

II. MATERIALS AND METHODS

The methodological foundation of the study is formed at the intersection of approaches to the analysis of global supply chains, risk assessment models, and empirical methods for studying the influence of geopolitical instability on cost parameters. Such an interdisciplinary approach allows for the unification of several levels of analysis: mechanisms of external shocks, industry-specific logistics, the behavior of export flows, and the interrelationships between operational, strategic, and macroeconomic factors.

Source selection was conducted based on the criteria of scientific reliability and relevance. The analysis includes studies from 2023 to 2025 published in peer-reviewed journals. The work of Drljača et al. [2] examines models for assessing supply chain quality and mechanisms for preventing costly disruptions. The study by Gürpinar and Gulum [3] analyzes the role of distributed systems and feedback loops in increasing chain resilience, which defines the methodological context for cost assessment. Jarašūnienė and Gelžinis [4] describe theoretical and practical models of crisis management in logistics, setting the tools for analyzing industry reactions to external shocks.

Koray et al. [5] highlight strategies for mitigating disruptions in maritime transport, which is important for assessing sources of cost growth in global trade. Özdemir et al. [6] demonstrate the influence of geopolitical risks on commodity market volatility, defining approaches to interpreting price fluctuations. Setyadi et al. [7] analyze post-pandemic operational responses of supply chains, describing which processes prove most costly during structural disruptions. The study by Solari et al. [8] examines long-term trends in sustainable logistics, setting frameworks for analyzing future cost profiles. Štreimikienė et al. [9] propose a multicriteria analysis method applied to assess digital and sustainable factors, which forms the basis for structuring cost criteria. In the work of Sufi and Alsulami [10], the dynamics of systemic disruptions and the sustainability of "green" chains are modeled, expanding the toolkit for analyzing complex effects in global networks. The study by Truong et al. [11] provides an empirical model of the asymmetric influence of geopolitical risks on exports, which is important for understanding the cost sensitivity of export-oriented economies to external shocks. Additionally, the results of Albahouth [1] are used,

where the impact of global uncertainties on inflation is analyzed, which helps interpret macroeconomic factors of chain cost changes.

The methodological strategy of the research is based on a systematic comparative analysis of quantitative and qualitative risk assessment models, mechanisms of geopolitical influence, and logistical responses. The synthesis of results allowed for the identification of three key analytical directions: external cost factors (geopolitical risks, market volatility), operational mechanisms of price increases (logistical disruptions, transport limitations), and structural drivers of chain resilience. These components are subsequently used to build the research structure and formalize factors influencing the cost of global supply chains.

III. RESULTS

In this study, the cost of global supply chains is interpreted as the result of the accumulation and transfer of expenses between several interconnected domains—energy resources, logistics, production, agri-food systems, and the socio-labor sphere. This formulation relies on the system-of-systems view of green supply chains proposed by Sufi & Alsulami [10]. Geopolitical and macroeconomic shocks lead to changes in energy prices, disruption of transport routes, growth in production costs, and restrictions on exports, which intensifies the volatility of total expenses throughout the entire value creation chain, as shown in the study by Solari et al. [8].

At the same time, the domain structure of costs is not an abstraction. It manifests in the empirical configuration of events recorded in news flows and interpreted as disruptions in specific subsystems of the global economy, as demonstrated in detail in the work of Sufi & Alsulami [10]. To analyze the influence of geopolitical instability on supply chain costs, this study adopts precisely this domain decomposition, as it allows for correlating macro-level shocks with specific classes of expenses—energy, logistics, production, food, and socio-labor. Table 1 examines the distribution of domain factors influencing the cost of global green supply chains based on the results of event systematization in the work of Sufi & Alsulami [10].

Table 1 – Key domains affecting the cost of global supply chains (Compiled by the author based on the source: [10])

Domain of systemic disruptions	Share of events	Cost impact description
Energy & Resources	22%	Increase in energy and resource costs
Logistics & Transportation	19%	Higher transport costs and delay-related expenses
Manufacturing & Production	17%	Rising production costs and input price pressures
Agri-Food Systems	14%	Vulnerability of food supply chains and price spikes
Labor & Social Systems	–	Cost effects of labor and social disruptions

The presented structure shows that the maximum concentration of disruptions falls on the Energy & Resources domain, which forms the base price level for subsequent links in the supply chain and translates directly into inflationary effects recorded at the macro level in the study by Albahouth [1]. The high share of events in logistics and transport reflects that route disruptions, rising insurance premiums, and corridor capacity limitations immediately increase the cost of moving cargo and intensify the load on warehousing and buffer capacities, which aligns with the conclusions of Koray et al. [5].

The domains of Manufacturing & Production and Agri-Food Systems concentrate expenses related to rising raw material prices, interruptions in component supplies, and the vulnerability of food chains, which is discussed in detail in the work of Setyadi et al. [7]. An additional level of costs is formed in the socio-labor sphere. Strikes, migration shocks, and social tension alter the availability of the labor force and the structure of operational expenses, which partially manifests in the asymmetric effects of geopolitical risk on exports in the study by Truong et al. [11].

In such a configuration, the domain structure can be viewed as a description of the cost

configuration of global supply chains, in which geopolitical shocks increase individual cost components and redistribute the load between domains based on empirical patterns of disruptions recorded in the global news corpus by Sufi & Alsulami [10]. The dominance of the energy and logistics blocks in the disruption structure is interpreted as an indication that primary price pressure arises here, while production, food, and socio-labor effects act as channels for transmitting this pressure into the final product cost and export indicators [7]. This analytical reading creates a basis for the subsequent transition from describing the domain structure to considering tools for managing supply chain resilience and cost under conditions of geopolitical instability based on distributed ledgers, digital platforms, and multifactor assessment schemes.

Rising geopolitical tension transforms into a key driver of cost increases in global supply chains. The influence of such shocks affects both logistical routes and production nodes, intensifying expenses throughout the entire operations structure. The study by Solari et al. [8] shows that geopolitical events form sustained cascading effects leading to a growth in operational expenses and planning complexity, especially under conditions of energy volatility. Similarly, the work of Özdemir et al. [6] demonstrates that periods of intensive disruptions in global green supply chains coincide with a sharp rise in the cost of operations and an intensification of interdomain interconnectivity. In turn, the study by Drljača et al. [2] establishes that negative changes in the geopolitical risk index exert asymmetric pressure on exports, reducing external flows and increasing the total cost of supplies.

To assess the influence of geopolitical factors on cost, this study uses an integral approach combining the dynamics of event data, macroeconomic effects, and export flow reactions. The principal task is to correlate risk types with observed cost changes. Table 2 examines how key geopolitically driven factors transform the cost structure of global supply chains.

Table 2 – Geopolitically driven cost-changing factors in global supply chains (Compiled by the author based on the sources [3, 8, 10, 11])

Factor	Impact on costs
Negative changes in GPR	Decline in exports; higher operational and trade costs
European energy crisis	Increased operational and energy-intensive expenses
Disruption peaks in global supply chains	Sharp rise in cost intensity across domains
Concentration of systemic risk hubs	Higher structural costs due to centrality effects
Trade barriers and restrictions	Increase in supply and transaction costs

After correlating the factors, it becomes obvious that cost growth is formed not in isolation, but through interaction mechanisms between domains. Negative changes in geopolitical risk reduce export flows, intensifying direct and indirect foreign trade expenses [2]. Energy instability, recorded by Solari et al. [8], increases the cost of production and transportation, especially in energy-intensive sectors.

Periods of peak disruption, described by Sufi & Alsulami [10], show that geopolitical spikes increase disruption intensity tenfold, leading to a jump in prices for transportation, insurance, reserve capacities, and raw materials. The concentration of risks in the USA, China, and India intensifies total expenses, since failures in systemically important countries are transmitted globally [5]. Trade barriers, analyzed by Truong et al. [11], create an additional level of transactional and logistical expenses, especially for export-oriented economies. Beyond formal trade barriers, cost escalation is increasingly shaped by geopolitical tools employed by states, including sanctions regimes, export bans on strategic raw materials, retaliatory tariffs, and politically motivated import restrictions. These measures restructure the cost environment by disrupting established sourcing channels, forcing rerouting through higher-cost corridors, and embedding permanent tariff-related price premiums into the final cost of goods. As such, interstate economic confrontation acts as a structural mechanism that

amplifies and prolongs cost pressure across multiple domains.

Thus, geopolitical effects act as a structural mechanism for cost redistribution in global supply chains. Energy crises form primary price pressure, logistical disruptions intensify it, and export restrictions and trade barriers solidify cost growth at the level of regional and international flows.

IV. DISCUSSION

Cost growth in global supply chains is formed under the influence of interconnected energy, logistical, production, and socio-economic factors. The study by Solari et al. [8] shows that disruptions in one domain lead to cascading shifts in others, creating a complex cost contour that cannot be explained by isolated shocks. The analysis of crisis scenarios in logistics presented by Koray et al. [5] confirms that the cost of transportation and warehouse infrastructure rises following energy and trade disproportions. Data from Setyadi et al. [7] demonstrate that production expenses increase even with moderate logistical delays, as production chains are sensitive to the quality and stability of supply flows. Table 3 examines how interdomain connections form a unified mechanism of cost growth under conditions of geopolitical instability.

Table 3 – Interdomain cost-interaction patterns (Compiled by the author based on the sources [4, 7, 10])

Interconnected domains	Nature of impact	Correlation
Energy ↔ Logistics	Energy costs directly influence transportation costs	r > 0.7
Logistics ↔ Manufacturing	Delays in logistics elevate production expenses	r > 0.7
Energy ↔ Manufacturing	Higher resource costs increase manufacturing costs	r > 0.7

The presented dependencies confirm the systemic nature of expenses: rising resource costs lead to an increase in transport expenses, while logistical delays are translated into production chains through lengthened cycles and increased need for buffer capacities. These mechanisms align with the conclusions of Drljača et al. [2], showing that a reduction in the resilience of individual links leads to a synchronous growth in total operational expenses.

A particularly significant layer of cost formation arises from deteriorating interstate relations. Modern supply chains operate in an environment where geopolitical tools—sanctions, tariff escalations, export controls, technology restrictions, and politically motivated trade disputes—are increasingly used as instruments of economic pressure. Their impact on cost is multidimensional. Sanctions and export bans restrict access to critical materials, increase dependency on longer or less efficient routes, and elevate insurance and compliance-related expenditures. Retaliatory tariffs directly change the price baseline for entire commodity groups, embedding cost growth into long-term contractual structures.

Conflicts and geopolitical confrontation amplify these effects by destabilizing regional transport routes, increasing the risk premium applied to maritime and land corridors, and limiting the operational continuity of firms located in contested zones. As a result, cost growth becomes not only the consequence of operational disruptions but also an outcome of strategic rivalry among states. The structural nature of these instruments means that they generate persistent, rather than episodic, price pressures and significantly reduce the predictability of supply chain planning.

For managers and policymakers, this implies that geopolitical tools must be treated as systemic drivers shaping sourcing, logistics architecture, and cost-to-serve models. Under such conditions, firms are compelled to reassess supplier portfolios, develop alternative routing strategies, strengthen regional production configurations, and integrate geopolitical risk assessments into financial and operational decision-making.

From the perspective of analyzing supply chain functioning, the key point is that domain interconnectivity works as a mechanism for amplifying the primary shock. Energy crises reflect on

transportation and the cost structure of manufacturers, which is confirmed by data from Solari et al. [8]. Logistical disruptions lead to growth in product cost and a loss of export operation efficiency, which manifests in the asymmetry of international flow reactions recorded by Truong et al. [11]. The study by Gürpinar & Gulum [3] shows that even resilient chains with high interdomain connectivity react to geopolitical restrictions with accelerated operational expense growth. An additional systemic effect is formed at the intersection of logistical and production processes. Koray et al. [5] demonstrate that maritime transport is particularly sensitive to changes in energy costs and political restrictions, which intensifies the dependence of production chains on external decisions. Similar dependencies were identified in the work of Albahouth [1], where growth in global uncertainty leads to an increase in inflationary expenses through logistics and production channels.

Consequently, the interdomain interconnectivity of cost factors confirms that global supply chains function as a unified system in which energy, logistical, and production components amplify each other's influence. It is this structural cohesion that makes chains sensitive to geopolitical changes, accelerating cost growth, and complicating resilience management under conditions of international instability.

A comparison of country contexts and industry structures shows that the sensitivity of global supply chains to geopolitical impacts is distributed extremely unevenly. The study by Truong et al. [11] shows that export-oriented economies with high dependence on external demand react disproportionately strongly to negative changes in the geopolitical risk index: negative GPR fluctuations lead to a reduction in export flows accompanied by a growth in operational costs. This asymmetry indicates that even under stable production and logistical conditions, the geopolitical background is capable of setting baseline cost volatility.

At the same time, industry analysis based on data from Solari et al. [8] demonstrates that not all sectors experience the same load. Energy and logistics act as systemic fields for cost formation. Rising resource prices transform into transportation price increases and increase costs in industries dependent on energy-intensive production. Data from Sufi & Alsulami [10] supplement this picture, pointing to the high intensity of interconnected events in energy, logistical, and production segments. However, unlike the previous section, where structural disruption peaks are recorded, in this case, the comparative aspect becomes important. The aggregate sensitivity of industries is determined by the depth of their inclusion in domains with high event density.

A separate layer of vulnerabilities is related to the spatial organization of global flows. Sufi & Alsulami [10] show that the systemic significance of individual countries is determined not by the number of disruptions as such, but by the degree of their involvement in international routes, distribution hubs, and production chains. This means that the vulnerability of countries is formed under the influence of local factors and their structural role in the network, where any changes in energy or transport are instantly reflected in neighboring links.

The comparison of country and industry characteristics provides an opportunity to interpret cost effects not as the sum of independent impacts, but as the result of overlapping contexts. Export-oriented economies face double pressure. External shocks reduce their export volumes, while the domain structure—where energy, logistics, and production remain key fields of cost formation—intensifies internal price tensions [3]. Countries with high systemic significance in the global network complement this configuration. Their role in flow distribution turns individual events into multi-level feedback effects that amplify cost variability.

Thus, the comparison of country and industry vulnerabilities shows that cost growth in global supply chains is formed not by separate risks, but by the interaction of three structural elements: the asymmetric reaction of export economies to geopolitical shocks, the domain concentration of energy and logistical cost factors, and the network significance of countries determining the scale of disruption propagation.

V. CONCLUSION

The conducted research revealed that the cost of global supply chains is formed not by separate factors, but by a combination of interconnected

processes in which geopolitical instability amplifies the action of energy, logistical, and production limitations. The cost structure is determined by exactly how external shocks are distributed among domains, involve adjacent industries, and transform into sustained cost effects. Under conditions of growing instability, it is not the scale of individual events that becomes decisive, but the configuration of connections between them.

The analysis showed that the domain structure plays a key role in cost dynamics. Energy limitations set the baseline pressure level, logistical disruptions amplify general expenses, and production failures solidify cost growth in the operational cycle. Alongside this, country differences determine the degree of impact: export-oriented economies prove more sensitive to external risks, while systemically important states form the contours of global cost transmission.

The results obtained allow for the assertion that the vulnerability of global supply chains has a multilayered character and depends on a combination of factors—industry structure, the degree of involvement in international flows, and the distribution of load centers. It is this combination that forms the limits of the resilience of the current global logistics configuration and determines the directions in which the greatest economic losses are possible. Furthermore, the difference in the reactions of industries and countries indicates the necessity of a differentiated approach to cost assessment and management.

The conducted study showed that effective cost reduction requires systemic work with risk nodes, rather than local measures. Route optimization, energy source diversification, regional production hub development, and increasing the flexibility of logistical schemes must be viewed as a unified complex of actions. Cost pressure in supply chains is formed at the intersection of domains, and any solutions that do not account for this interconnectivity prove to be of limited effectiveness.

The findings also demonstrate that interstate tensions—sanctions, tariff escalations, trade wars, and export controls—play a decisive role in institutionalizing cost pressures. These instruments reinforce the effects of energy and logistical disruptions by limiting access to strategic inputs and reshaping cost structures across entire industries. As geopolitical tools become entrenched in international economic relations, they transform cost volatility from a temporary disturbance into a long-term structural condition.

Thus, global supply chains under conditions of geopolitical instability represent a system in which cost arises as a consequence of the interaction of energy, logistical, production, and country factors. The resilience of this system is determined by the ability of economies to adapt to asymmetric shocks and reduce the effect of mutual risk amplification. The conclusions obtained create a basis for developing strategies aimed at increasing the stability, manageability, and predictability of supply chains under conditions of growing uncertainty.

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Assessing the Market Competitiveness of used Car Dealership Business through Porter's Five Forces Model: Basis for Action Plan

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Abstract *— This study assessed the market competitiveness of used car dealership businesses in Nueva Ecija using Porter's Five Forces Model as the basis for an action plan. As a growing industry in the province, used car dealerships face several challenges brought by changing buyer behavior, increasing competition, and the rising popularity of online vehicle marketplaces. The study aimed to describe the profile of used car dealerships, determine their level of market competitiveness, and develop an action plan to help improve their business performance. The study used a quantitative descriptive research design and gathered data through a structured survey questionnaire administered to used car dealership owners and managers. The data were analyzed using weighted mean and descriptive statistics to interpret the level of competitiveness under the five forces. The findings showed that most dealerships are small, registered sole proprietorships with limited manpower and moderate sales volume. Results also revealed that competitive rivalry in the province is strong due to the presence of many dealerships, aggressive promotions, and price adjustments. Supplier power and buyer power were found to be moderate, showing that inventory sourcing and customer negotiation play important roles in business operations. The threat of substitutes was high, particularly due to online selling platforms, motorcycles, and brand-new cars. The threat of new entrants was moderate, influenced by manageable regulations and capital requirements. Based on the results, an action plan was proposed focusing on marketing improvements, supplier expansion, customer service enhancement, online visibility, and brand-building strategies to strengthen competitiveness and support long-term sustainability among used car dealerships in Nueva Ecija.*

Keywords *— **used car dealership, market competitiveness, Porter's Five Forces, action plan, Nueva Ecija***

I. INTRODUCTION

Globally, the used car market has experienced remarkable growth over the past decade. According to Statista (2024), the global used car market was valued at approximately USD 1.5 trillion in 2023 and is projected to continue expanding steadily. This growth is attributed to multiple factors such as affordability, technological advancements in vehicle inspection and sales platforms, and a broader acceptance of secondhand vehicles as reliable options (Bhasin, 2023). Furthermore, the rise of digital marketplaces has revolutionized the used car industry, enabling online showrooms, real-time vehicle histories, and online financing, which have made transactions faster and more transparent (Suri, 2024). These developments have intensified

competition worldwide, prompting dealerships to adopt more strategic approaches to maintain their edge.

The competitive environment of the automotive sector has also been analyzed through Porter's Five Forces Model in various global studies. For instance, Pivoda (2016) emphasized that understanding supplier power, buyer behavior, and threats of new entrants provides firms with better strategic insights. In emerging economies, these forces have become even more significant because of rapidly changing consumer behaviors and market liberalization. As such, assessing competitiveness is no longer confined to pricing strategies alone—it now involves innovation, technology adoption, and market adaptability.

In the Philippines, the used car market has similarly gained momentum. The automotive sector recorded a steady increase in the sale of pre-owned vehicles, driven by rising fuel costs, the growing middle class, and the desire for affordable mobility solutions (Ankit, 2024). Nueva Ecija, being a landlocked province with a mix of urban and rural communities, has become a fertile ground for small and medium-sized used car dealerships. These businesses play a crucial role in providing affordable transportation options to professionals, families, and entrepreneurs who may not have the means to purchase brand-new vehicles.

Moreover, the digital transformation of the Philippine used car industry mirrors global trends. Online platforms such as Automart.ph and Carmudi have made it easier for both buyers and sellers to connect, increasing transparency and competition (Millan et al., 2014). However, while opportunities abound, the local industry also faces challenges: fluctuating consumer demand, the presence of substitute transportation modes like motorcycles and public utility vehicles, and the entry of new competitors through online channels (Predic & Stosic, 2014). These realities highlight the need for dealership owners to better understand their competitive environment to sustain growth and profitability.

This research aligns with several United Nations Sustainable Development Goals (SDGs), particularly SDG 8 (Decent Work and Economic Growth) and SDG 9 (Industry, Innovation and Infrastructure). By examining the competitiveness of used car dealerships, this study contributes to fostering sustainable business strategies that support local economic development and innovation. It also touches on SDG 11 (Sustainable Cities and Communities), as used car dealerships play a role in providing affordable mobility options that support economic participation. Through the use of Porter's Five Forces Model, the study helped identify strategic areas that business owners can focus on to enhance competitiveness while promoting inclusive growth.

The study addressed these SDGs by using data gathered from surveys among used car dealership owners in Nueva Ecija. The findings guided the formulation of an action plan that aims to improve business strategies, enhance operational efficiency, and create more sustainable market practices. These efforts ultimately contribute to the local economy while aligning with global sustainable development frameworks.

The researchers' personal interest in this topic stems not only from our academic pursuit as a Master in Business Administration student at the Nueva Ecija University of Science and Technology but also from our own experience. Managing institutional assets has made us more aware of the factors influencing vehicle procurement decisions, especially the preference for used cars due to their cost-efficiency and accessibility. Additionally, our interactions with local car dealers and users have given me firsthand insights into the challenges and opportunities within this market.

Conducting this study also allowed us to contribute meaningful knowledge to a field that has direct implications for local entrepreneurship. Used car dealerships are often operated by small and medium business owners who rely on practical strategies to survive in a competitive environment. By assessing the market through Porter's Five Forces Model, the researchers hope to provide them with actionable insights that can guide their decision-making and planning processes.

Despite the importance of this sector, there remains a research gap in the Philippine context, particularly in Nueva Ecija. Existing studies on the used car market in the Philippines often focus on consumer behavior or national-level industry trends, with limited attention given to local competitiveness using

structured strategic frameworks. There is also a lack of quantitative descriptive research employing Porter's Five Forces Model to assess the competitiveness of small and medium used car dealerships. Addressing this gap did not only contribute to the literature but also provide practical recommendations for local businesses seeking to strengthen their market position.

OBJECTIVES OF THE STUDY

This study aims to assess the market competitiveness of used car dealership businesses in Nueva Ecija with the following objectives: To describe the profile of the respondents in terms of size of business, nature of business, and number of years in operation, to determine the competitiveness in the used car dealership in terms of: competitive rivalry, supplier power, buyer power, threat of substitution and threat of new entrants, and, to proposed an action plan to improve market competitiveness in used car dealership businesses in Nueva Ecija based on the findings of this study.

II. METHODOLOGY

The study used a descriptive quantitative research design. This method was appropriate because it allowed the researcher to gather numerical data from respondents and describe the current level of market competitiveness of used car dealerships based on Porter's Five Forces Model (Porter, 1979/2008). The study conducted in the province of Nueva Ecija, located in Central Luzon, Philippines. The respondents of the study consisted of owners, co-owners, or managers of small and medium-sized used car dealership businesses operating within the different districts of Nueva Ecija. A purposive sampling technique was used to identify qualified respondents. The primary data gathering tool was a structured survey questionnaire developed based on the five forces of Porter's model. The study strictly adhered to the provisions of the Philippine Data Privacy Act of 2012 (Republic Act No. 10173) to ensure the ethical collection, processing, storage, and disposal of personal data gathered from the respondents.

III. RESULTS AND DISCUSSION

Table 1. Profile of the Used Car Dealership Business (n = 20)

Profile Indicators	Categories	Frequency (f)	Percentage (%)
1. Size of Business			
1.1 Number of Employees	1–5	11	55.0
	6–10	5	25.0
	11–20	2	10.0
	21 and above	2	10.0
1.2 Monthly Sales Volume	1–5 units	8	40.0
	6–10 units	9	45.0
	11–20 units	2	10.0
	21 units and above	1	5.0
2. Nature of Business			
2.1 Compliance	Registered	12	60.0
	Non-registered	8	40.0
2.2 Ownership Structure	Sole Proprietorship	13	65.0
	Partnership	5	25.0
	Corporation	2	10.0
2.3 Type of Used Cars Sold	Sedans	8	40.0

	SUVs	4	20.0
	Vans	2	10.0
	Pick-up Trucks	2	10.0
	Others (e.g., hatchbacks, older models)	4	20.0
3. Years in Operation	Less than 1 year	1	5.0
	1–3 years	8	40.0
	4–6 years	7	35.0
	7–10 years	3	15.0
	More than 10 years	1	5.0

The study found that most used car dealerships in Nueva Ecija are small, owner-managed enterprises with 1–5 employees, modest monthly sales volumes, and short years of operation, indicating a young but growing industry. A majority of dealerships are registered and operate as sole proprietorships, selling mainly sedans, SUVs, vans, and pickup trucks. The profile suggests that the market is composed of small and medium enterprises with limited manpower and resources, influenced by supplier availability, competitive pricing, and customer demand.

Market Competitiveness Based on Porter's Five Forces

Table 2. Competitive Rivalry

Statement	Weighted Mean	Verbal Interpretation
1. There are many used car dealers operating within my area.	3.31	Strongly Agree
2. Competitors frequently adjust their pricing strategies.	3.00	Agree
3. Marketing and promotions among dealers are highly aggressive.	3.46	Strongly Agree
4. Competition strongly affects my sales performance.	3.46	Strongly Agree
Average Weighted Mean	3.31	Strongly Agree

The results in Table 2 show that respondents perceive strong competitive rivalry in the used car dealership market, reflected in the overall weighted mean of 3.31 (Strongly Agree). This suggests that dealerships operate in an environment where competition is high, especially due to aggressive promotions, numerous competitors, and the effect of competition on sales performance.

The highest mean score (3.46) on items related to aggressive marketing and competition affecting sales indicates that rivalry among dealerships strongly influences their market performance. This aligns with global industry analyses showing that used car markets often experience intense rivalry due to similar product offerings and closely comparable pricing structures (Coppola, 2023).

Respondents also strongly agreed that there are many dealers operating in their area, further intensifying rivalry. This aligns with the findings of Klein and Smart (2017), who noted that markets with multiple dealerships tend to experience heightened competitive pressure, particularly when consumers can easily compare options through online listings and digital platforms.

Meanwhile, the item regarding frequent price adjustments received a slightly lower mean (3.00), suggesting that while pricing remains an important competitive tool, dealerships may rely more on non-price factors such as customer service, online visibility, warranties, and after-sales services. This observation is supported by King and Thomas (2020), who found that non-price differentiation can reduce

direct price wars and help businesses compete more effectively even in saturated markets.

Table 3. Supplier Power

	Statement	Weighted Mean	Verbal Interpretation
1.	Suppliers (car owners, auctions, traders) have strong control over the pricing of used cars.	3.15	Agree
2.	The number of suppliers available affects my purchasing decisions	3.31	Strongly Agree
3.	It is difficult to negotiate favorable prices with suppliers	2.69	Agree
4.	Limited supplier options influence my inventory availability.	3.00	Agree
	Average Weighted Mean	3.04	Agree

The overall weighted mean of 3.04 (Agree) indicates that respondents generally perceive suppliers as having a moderate level of power over their dealership operations. The highest rated item states that the number of suppliers affects purchasing decisions (3.31), suggesting that dealerships rely heavily on the availability of multiple suppliers to secure the best prices and unit options. When supplier options are few, dealerships have limited bargaining leverage and may end up accepting less favorable terms.

Respondents also agree that suppliers exercise control over pricing (3.15). This is common in used car markets because vehicle owners, traders, and auction houses set initial price expectations based on market demand, vehicle condition, and brand popularity. When suppliers set high baseline prices, dealerships have little room to adjust retail pricing without affecting their profit margins.

The statement regarding difficulty in negotiating favorable prices received the lowest mean (2.69), though still interpreted as "Agree."

Table 4. Buyer Power

	Statement	Weighted Mean	Verbal Interpretation
1.	Buyers often negotiate for lower prices.	3.00	Agree
2.	Customers compare multiple dealers before purchasing.	3.23	Agree
3.	Buyer preferences significantly influence pricing.	2.77	Agree
4.	Buyers have many dealership options in the province.	3.00	Agree
	Average Weighted Mean	3.00	Agree

These findings are supported by studies showing that supplier concentration increases supplier leverage, thereby reducing the ability of small retailers to bargain effectively (Chung & Kim, 2020). Likewise, research on used vehicle wholesaling notes that supplier limits restrict inventory turnover and affect overall competitiveness (Coffey & Thornley, 2019). Another study found that when suppliers control price anchors or hold scarce inventory, dealerships must adjust their strategies or accept thinner margins (Levin & Milgrom, 2017).

The overall weighted mean of 3.00 (Agree) indicates that buyers in the used car market hold a moderate level of power that meaningfully influences dealership operations. The highest-rated indicator shows that customers compare multiple dealers before deciding to buy (3.23). This reflects a more informed consumer base where buyers use online listings, social media, and referrals to compare prices, vehicle condition, and dealer credibility before making a purchase.

The results also show that buyers often negotiate for lower prices (3.00). Negotiation is a typical behavior in the used car market since prices are not fixed and depend on factors such as mileage, condition, model age, and available alternatives. When customers have more options, dealerships may need to adjust pricing strategies to remain competitive.

Respondents agreed that buyer preferences influence pricing, but this item had the lowest mean (2.77). This suggests that although customer preferences matter—such as choosing fuel-efficient cars, newer models, or specific brands—dealership pricing is also shaped by supplier costs and the availability of inventory. The agreement rating for buyers having many dealership options (3.00) further reinforces the idea that customers can easily switch to competing dealers, giving them more leverage during negotiations.

Similar patterns have been found in global studies. Consumer decision-making in used car markets is strongly shaped by comparison behavior and perceived value, especially when multiple dealers offer similar vehicle types (Kwak et al., 2015). Buyers also tend to negotiate more when information is widely available, reducing information gaps between dealers and customers (Houde, 2012). Additionally, research shows that customers in competitive markets use online tools and dealer networks to expand their choices, increasing buyer power overall (Anderson & Magruder, 2012).

Table 5. Threat of Substitution

	Statement	Weighted Mean	Verbal Interpretation
1.	Customers consider brand-new cars as an alternative to used cars.	3.31	Strongly Agree
2.	Motorcycle sales or other vehicle types affect used car sales.	3.31	Strongly Agree
3.	Online car selling platforms serve as substitutes to dealership visits.	3.38	Strongly Agree
4.	Availability of other transportation options influences customer decision-making.	3.15	Agree
	Average Weighted Mean	3.29	Strongly Agree

The average weighted mean of 3.29 (Strongly Agree) shows that the threat of substitution is high among used car dealerships in Nueva Ecija. Respondents perceive that customers have many alternative options, and these alternatives significantly influence their purchasing decisions.

The highest weighted mean (3.38) shows that online car selling platforms—such as Facebook Marketplace, Automart.ph, and other digital platforms—serve as direct substitutes to physical dealership visits. This means many buyers browse, compare, and even negotiate online instead of going to the dealership, reducing walk-in traffic and giving customers more control in choosing where and from whom to buy.

Both indicators related to brand-new cars and motorcycles or other vehicle types received strong agreement (3.31). This suggests that buyers may shift to brand-new vehicles when financing options are favorable or when promotions such as low-down payments and extended warranties are available. Likewise, motorcycles, tricycles, and other smaller vehicles serve as convenient and cheaper alternatives for families and individual commuters, which can reduce the demand for secondhand cars.

Respondents also agreed (3.15) that the availability of other transportation options—including ride-hailing services, jeepneys, buses, and car rentals—affects customer decision-making. When transportation is accessible and affordable, some buyers may delay or avoid purchasing a used car.

These findings are supported by research showing that substitute transportation options, including motorcycles and public transit, significantly reduce car ownership intentions in emerging markets (Dissanayake & Morikawa, 2010). Additionally, studies show that digital marketplaces increasingly act as substitutes for traditional dealership interactions, shifting buyer preference toward online

channels (Janssen et al., 2014). Another study found that buyers consider long-term costs, mobility alternatives, and financing availability when choosing between new and used vehicles, showing a clear substitution effect (Grigolon, 2018).

Table 6. Threat of New Entrants

	Statement	Weighted Mean	Verbal Interpretation
1.	It is easy for new used car dealerships to enter the market.	2.92	Agree
2.	New competitors pose a potential threat to existing dealerships.	3.69	Strongly Agree
3.	Capital requirements to start a dealership are relatively low.	2.62	Agree
4.	Government regulations make market entry easy.	2.92	Agree
	Average Weighted Mean	3.04	Agree

The overall weighted mean of 3.04 (Agree) indicates that respondents perceive a moderate level of threat from new entrants in the used car dealership market. The highest-rated item shows a strong agreement (3.69) that new competitors pose a real threat to existing dealerships. This suggests that the presence of additional market players can easily affect sales performance and customer reach, especially when new entrants adopt aggressive pricing and marketing strategies.

Respondents also agreed (2.92) that it is fairly easy for new dealerships to enter the market, which may be influenced by the growing popularity of online marketplaces where sellers can operate even without a large physical dealership. Digital platforms reduce the need for traditional showrooms, allowing small entrepreneurs to start with limited resources.

Regarding capital requirements, the weighted mean of 2.62 indicates that while some respondents believe the capital needed to start a dealership is manageable, others may still view it as a significant investment. This mixed perception is expected, as capital needs vary depending on the number of units, storage space, and procurement channels.

Respondents also agreed (2.92) that government regulations make market entry easy. This suggests that the process of securing business permits, complying with local requirements, and operating legally is generally accessible for small entrepreneurs in Nueva Ecija. However, while regulations may be manageable, surviving the competitive landscape remains the larger challenge.

These findings reflect global trends showing that online platforms and low entry barriers enable more small-scale ventures to enter the used car market (Eckert & West, 2020). Studies also show that industries with moderate regulations and accessible capital requirements tend to attract more entrants, thereby increasing competition (Liu et al., 2021). Furthermore, research indicates that new entrants often disrupt markets by introducing competitive pricing or improved services, strengthening the perceived threat among existing businesses (Spulber, 2019).

Table 7. Proposed Action Plan Based on the Findings

Findings Based on the Results	**Objectives**	**Proposed Actions**	**Responsible Person/Unit**	**Time Frame**
Strong rivalry due to aggressive promotions and competition affects sales.	To strengthen market positioning and customer reach.	• Develop consistent online marketing content (Facebook, TikTok). • Offer bundled services (free detailing, free change	Business Owner/ Marketing Staff	3–6 months

		oil). • Improve showroom customer experience.		
Supplier power affects inventory and pricing; limited supplier options.	To diversify sourcing channels and improve negotiation outcomes.	• Build partnerships with additional traders and auction houses. • Attend regional auto auctions regularly. • Implement negotiation strategies based on vehicle condition reports.	Owner/Procurement Officer	3–12 months
Buyers compare multiple dealers and negotiate aggressively.	To increase buyer trust and provide better value.	• Provide transparent vehicle history and inspection reports. • Offer flexible pricing or installment plans. • Improve after-sales follow-up and customer service.	Sales Team/Owner	2–4 months
High threat of substitutes including motorcycles, brand-new cars, and online platforms.	To strengthen dealership advantage over substitutes.	• Highlight unique value of used cars (affordability, reliability). • Offer warranties and after-sales support. • Improve digital listings with clear photos and full details.	Owner/Marketing Staff	2–6 months
Threat of new entrants due to low barriers to entry.	To create competitive barriers and retain customer loyalty.	• Strengthen branding and reputation-building online. • Launch referral incentives for previous buyers. • Standardize dealership processes to improve consistency.	Owner/HR/Marketing	4–8 months

The proposed action plan responds directly to the issues highlighted from the analysis of the five competitive forces. Since competitive rivalry in the province is high, dealerships should focus on

improving their market positioning, particularly through strong online marketing, enhanced customer experience, and offering bundled services that add value without significantly reducing profit margins. Supplier-related issues, such as price control and limited sourcing options, can be managed by expanding supplier networks and developing stronger relationships with traders and auction houses.

To address buyer power, which remains moderate but significant, dealerships should increase transparency and customer trust by providing inspection reports, offering flexible pricing, and maintaining strong after-sales communication. The high threat of substitutes suggests that dealerships must emphasize the unique advantages of used cars and ensure that their online listings are complete, attractive, and credible.

Finally, since new entrants can easily enter the market, existing dealerships must focus on brand-building, customer loyalty, and process improvement. Efforts such as referral incentives, standardized operations, and strong online branding can help sustain competitive advantage even when new players arise.

The action plan aims to strengthen competitiveness through strategic improvements in marketing, sourcing, customer service, and business processes, ensuring that used car dealerships in Nueva Ecija remain resilient and adaptable in a dynamic market.

IV. CONCLUSIONS

Used car dealerships in Nueva Ecija are generally small-scale, newly established, and independently operated businesses, relying on limited manpower and modest monthly sales. Their operational structure—mostly registered sole proprietorships—shows that the industry is still developing, with business performance affected by supplier availability, competition, and customer preferences. The overall competitiveness of used car dealerships is shaped by strong rivalry, moderate supplier and buyer power, high threat of substitutes, and a moderate threat of new entrants. These factors collectively create a challenging business environment where owners must constantly adjust pricing, marketing, sourcing, and customer service to remain competitive. The proposed action plan is a necessary response to the competitive pressures identified in the study. Strengthening marketing efforts, expanding supplier options, improving customer engagement, enhancing online visibility, and building brand reputation are essential strategies that can help used car dealerships improve their market position and achieve long-term business sustainability.

V. RECOMMENDATIONS

Used car dealerships should maximize their small-scale setup by adopting efficient business practices such as digital recordkeeping, streamlined customer processes, and improved inventory tracking. Owners may also benefit from attending local business seminars or training programs to enhance managerial skills and strengthen business operations. Dealerships should respond to competitive pressures through stronger online marketing, transparent vehicle information, and customer-centered pricing strategies. Expanding supplier networks and exploring additional sourcing channels such as auctions and online car exchanges can reduce reliance on limited suppliers and improve negotiation outcomes. To support long-term competitiveness, dealerships should implement the proposed action plan by building a strong brand identity, offering referral incentives, improving after-sales follow-up, and maintaining consistent digital visibility. These initiatives can help increase customer loyalty, counter new entrants, and differentiate the dealership from substitute products and other competitors.

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Resilient Supply Chains in the Post-Pandemic Era: A Comparative Review of Global Disruption Management Frameworks in Aviation Industry

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Abstract *— The COVID-19 pandemic demonstrated the critical frailty of the global supply chains, which necessitated the change in mindset towards resilience-oriented, rather than efficiency-oriented, supply chain. The article is a qualitative comparative literature review of disruption management models in the world to understand that technological integration, teamwork, and policy fit has enabled the strength of supply chains regardless of the pandemic. According to the research that has been indexed in Scopus, case studies within the industry, and policy reports, the study mentions that the adoption of Artificial Intelligence (AI), Internet of Things (IoT), Blockchain, and Digital Twin technologies have led to the levels of incredible visibility, traceability, and responsiveness in industries. The case studies that feature the Unilever AI-based demand forecasting, the IoT-based cargo tracking offered by Maersk, and the blockchain-based food traceability by Walmart demonstrate how the digital technologies may be transformative. The comparisons in the region indicate that certain strategies are chosen: North America, as oriented on automation and predictive analytics, Europe, as oriented on the circle supply chains, and Asia-Pacific, as oriented on the flexible localization. In addition, these are the following types of collaboration models that became the most important facilitators of resilience: the public-private partnerships and global data-sharing consortia that allow a sense of shared responsibility and fast recovery in case of crisis. The findings show that the future of supply chain resilience is the proactive digital transformation, inclusive cooperation, and strategic integration of sustainability and flexibility.*

Keywords *— **Supply Chain Resilience, Post-Pandemic Transformation, Digital Technologies, Artificial Intelligence, IoT, Blockchain, Collaboration, Disruption Management, Global Supply Networks, Sustainability***

I. INTRODUCTION

The COVID-19 outbreak revealed inherent structural weaknesses in the global aviation supply chains, making aircraft manufacturing, airport management, and airline logistics to come to a stop like never before (Melo, 2021). The shutting of fleets on the ground, shutting down of airports, shortages of aviation-related fuel, and extreme interruptions in the supply chain of aircraft-parts compelled aviation stakeholders, including airline, MROs, OEMs, and regulators, to re-evaluate procurement, maintenance planning, and aircraft-parts-network design (Merlo, 2024). Such upheavals hastened a transition between classic cost-effective and lean aviation designs to more agile, redundant, and end-to-end-visibility-based

designs, and with the aid of digitalization, collaboration, and sustainability demands.

During the restructuring phase after the pandemic, some innovative technologies, e.g., AI-based demand forecasting, aircraft and cargo monitoring through IoT, fleet maintenance using digital-twin simulation, and blockchain-based traceability shifted to the category of mainstream operational tools in the aviation ecosystem (Gulati, 2023). An example is that Airbus and Boeing widened the digital-twin to level production timetables and more accurate predictive upkeep (Gupta et al., 2024), whereas SITA and Amadeus broadened their IoT and cloud-communication airport frameworks to assist real-time baggage, person, and cargo tracking (Vikas, 2011). On the same note, IATA launched operational resilience principles, which prompted airlines and airports to combine digital documentation, automated decision-making and data sharing across borders in order to recover following a shock (Abeyratne, 2020).

These developments were accompanied by the shift of organizational and regional strategies. The airlines transformed conventional Just-In-Time models through multi-supplier contracts on essential parts and MRO vendors took on collaborative digital services to liaise with OEMs and suppliers on lead times, maintenance windows and inventory buffering (Ho et al., 2021). Digital-twin tools and smart-sensor infrastructure became the methods by which airports and air-cargo operators dealt with the sudden variations in the quantity of cargo, runways, and the usage of equipment. Such industry adaptations indicate that resilience in the aviation industry is not a feature of a single tool but a product of combined digital capabilities, multi-tier supply integration, and process redesign due to sector-specific constraints (Moenck et al., 2024).

This paper aims to make a comparative review of post-pandemic disruption-management models in aviation through the review of Scopus-indexed literature, aviation case studies worldwide, and policy reports. This goal is to determine trends, best practices, and practices that are transferable to support long-term operational resilience by airlines, airports, and MRO organizations and regulators. The research would unify technological, collaborative, and policy-level innovations in different regions to present actionable suggestions to aviation leaders and policymakers interested in future-proofing aviation supply chains when systemic disruptions occur.

Objectives of Study

1. To compare global disruption-management frameworks used in the aviation industry to enhance supply chain resilience in the post-pandemic era.
2. To assess the role of aviation-focused digital technologies and collaborative models—such as AI, IoT, digital twins, blockchain, and regulator–industry partnerships—in strengthening adaptability, continuity, and sustainability across airline, airport, MRO, and air-cargo supply chains.

II. REVIEW OF LITERATURE

This conceptual paper presents a cohesive framework that connects resilience enablers, post-pandemic operational tactics, and sustainability objectives. The research conducted by **Setyadi et al., 2025** advances theoretical understanding by redefining sustainable operations amid complex global upheavals and provides a prescriptive framework for future academic inquiry and practical application.

Taneja's 2021 book elucidates the distinctions of this extraordinary pandemic from previous disruptions faced by the aviation sector over the last 50 years, and outlines strategies for airlines and associated enterprises to adjust to the significantly altered marketplace. This book is essential reading for all senior practitioners in the airline industry and adjacent sectors, as well as global aviation policymakers.

This study seeks to thoroughly analyze the existing literature on corporate risk management published post-COVID-19 by bibliometric analysis. The study by **Çopur & Yılmaz (2025)** analyzes academic publications from 2020 to 2025, identifying significant themes and publication trends for the post-pandemic era, with the intention of directing future research in enterprise risk management.

This study examined the risk management methods of Hainan Airlines Group and Aegean Airlines, among other representative cases, to investigate how airlines might enhance risk management during the post-pandemic recovery phase **(Cao et al., 2024).** This

study seeks to offer a valuable reference for airlines' risk management in the post-epidemic era, facilitating stability and sustainable development in a complex and dynamic market environment through methodical analysis and research.

III. RESEARCH METHODOLOGY

The current article will use the qualitative research design to compare and analyze the global disruption-management models applied in the aviation sector in the post-pandemic period. Since the topic is exploratory, this design will allow conducting a comprehensive study of the strategies implemented by airlines, airports, MRO providers, OEMs, and air-cargo operators to make aviation supply chains more resilient. The research seeks to mould the findings in the literature and the industry to determine trends, best practices and some of the major issues that have some bearing on procurement, maintenance logistics, aircraft-parts movements and general stability in the operations of the aviation supply chains.

All the data that will be used in this study is based on secondary sources that include such material as peer-reviewed journals that are placed in the Scopus database, reports in the industry of aviation, white papers, case studies, and official documents of international aviation organizations such as IATA, ICAO, ACI, and general organizations like the World Economic Forum (WEF) or the World Bank. The most important publications in 2020 and further were selected to reflect post-pandemic events. These sources were carefully examined to track down recurring motifs connected to digital transformation, regulatory cooperation, sourcing of parts to aircraft, airports reshaping logistics and technology-based resilience solutions incorporated in the aviation industry.

The analysis of data collected was conducted using a thematic literature review method. The most significant themes were revealed through qualitative coding and synthesis and comprised the integration of digital technologies (AI, IoT, digital twins, blockchain), risk mitigation in airline and MRO activities, the multi-stakeholder collaboration in the airports and regulators, and resilience based on sustainability. They were then compared to reveal the similarities and differences between the regional aviation response based on differences in maturity of infrastructure, regulatory condition and technological preparedness.

The study is based on comparative synthesis and triangulation to guarantee the methodological soundness of the research, which confirms the findings based on a number of data sources. This methodological frame underpins a thorough insight into the manner in which various aviation stakeholders are enhancing operational resilience, fleet preparedness and supply chain resilience in the face of uncertainty in the global environment. The study results of this qualitative, secondary-data research work should provide both theoretical and practical insights to the aviation policymakers, airline management, and airport administrators and supply chain executives aiming to develop aviation networks that could withstand future disruptions.

IV. RESULTS

The findings from the comparative review indicate that aviation supply chains have undergone significant restructuring in the post-pandemic era, driven by accelerated technology integration, strengthened collaboration, and adaptive resilience models. Airlines, airports, MRO providers, and OEMs that adopted AI-driven analytics, IoT-based aircraft and cargo monitoring, digital-twin simulations, and blockchain-enabled traceability demonstrated stronger agility, higher operational responsiveness, and more robust disruption recovery compared to aviation networks reliant on traditional and fragmented systems.

Technological Integration and Resilience Results

Table 1. Impact of Digital Technologies on Supply Chain Resilience.

Technology	Key Function in Aviation	Observed Benefit	Aviation Example	Sources
Artificial Intelligence (AI)	Predictive maintenance, demand forecasting for	Reduced AOG (Aircraft on Ground) time;	Airbus Sky wise AI predictive maintenance platform	Merlo, 2024

	aircraft parts, route optimization	improved maintenance planning		
Internet of Things (IoT)	Real-time aircraft health monitoring, cargo/environment tracking, airport equipment visibility	Enhanced operational visibility; early detection of component failures	SITA IoT-enabled baggage & cargo tracking systems	Gulati, 2023
Blockchain	Secure documentation, parts traceability, MRO record auditability	Increased trust in aircraft-parts movement; minimized counterfeit risks	Honeywell's blockchain-based aircraft parts marketplace	Ho et al., 2021
Digital Twins	Simulation of fleet operations, predictive MRO scheduling, airport flow optimization	Improved risk preparedness; reduced maintenance delays; optimized airport operations	Boeing and Airbus digital twin environments for production and MRO	Moenck et al., 2024

Comparative Regional Insights

Global aviation regions adopted different resilience strategies in response to post-pandemic disruptions, shaped by their infrastructure maturity, regulatory environments, and technological readiness. Developed aviation markets such as North America and Europe prioritized digital automation, predictive analytics, and sustainability-focused supply chain reforms, while Asia-Pacific leveraged localization, multi-tier supplier models, and flexible sourcing to stabilize aircraft-parts availability. Emerging regions such as Africa concentrated on digital enablement, air-cargo capacity expansion, and aviation workforce upskilling to address long-standing infrastructural gaps. These regional patterns demonstrate that resilience strategies are context-specific and reflect each region's operational capabilities and aviation ecosystem maturity.

Table 2. Comparative Summary of Regional Aviation Supply Chain Resilience Frameworks.

Region	Primary Focus	Key Practices in Aviation	Illustrative Aviation Example	Sources
North America	Automation and Predictive Analytics	AI-based aircraft maintenance forecasting; integrated airline–airport digital platforms	Delta Air Lines' AI-powered predictive maintenance & FAA-backed digital modernization programs	MoghadasNian, 2025
Europe	Sustainability and Circular Aviation Supply Chains	Blockchain-enabled parts traceability; green procurement; SAF-driven logistics	Lufthansa Technik's circular MRO initiatives & Airbus's sustainable supply chain programs	Wirths, 2019; Melo, 2021
Asia-Pacific	Localization and Flexible Sourcing Models	Multi-tier aircraft-parts sourcing; regional MRO collaboration; near-shoring for critical components	Japan's hybrid JIT–resilience model in aviation supply networks; Singapore's regional MRO hub expansion	Abdulraheem, 2018; Sullivan, 2023
Africa	Digital Adoption and Aviation Capacity Building	Mobile-based air-cargo platforms; digitized airport logistics; aviation workforce upskilling	Kenya Airways & Ethiopian Airlines' digital cargo modernisation through pan-African platforms	Belay, 2024

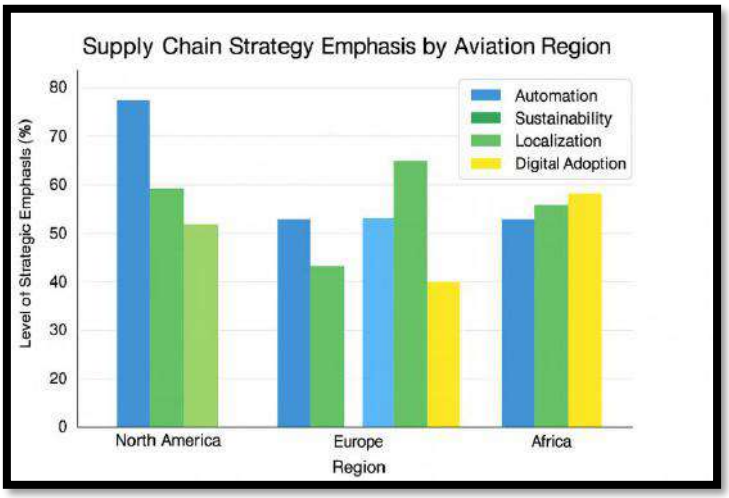

Fig.1. Regional Distribution of Dominant Aviation Supply Chain Resilience Strategies.

It is revealed that there are regional differences in resilience strategies (comparative analysis). The developed countries stressed on automation and digital change, whereas the developing ones focused on flexibility and local sourcing.

Frameworks of Collaboration and Policy

Table 3. Global Collaborative Resilience Models.

Framework	Stakeholders Involved	Outcome in Aviation	Region	Sources
Public–Private Aviation Resilience Partnerships	Civil aviation authorities, airlines, airport operators, logistics firms	Streamlined crisis coordination, standardized health & travel protocols, rapid reopening of aviation corridors	European Union (EASA–airline partnerships)	Zhou, 2024
Integrated Aviation Supplier Ecosystems	OEMs (Boeing/Airbus), tier-1/2/3 suppliers, MRO providers	Reduced dependency on single-source components; shared digital dashboards for parts tracking	Japan (aviation manufacturing clusters)	Wendt, 2016
Aviation Data-Sharing Consortiums	Tech providers (SITA, Amadeus), airlines, regulators (FAA, ICAO)	Improved real-time visibility; harmonised reporting for passenger, baggage & cargo movement	North America	Dias, 2024
Digital Enablement for Emerging Aviation Markets	Development agencies, aviation banks, small airport operators, regional carriers	Increased digital adoption in air-cargo, airport operations & safety systems	South Asia & Africa	Abeyratne, 2020

The emergence of collaboration between government, industry and technology partners is also one of the key resilience enablers. Multi-stakeholder networks also supported quicker recovery and risk-sharing processes in the global disruption. The general synthesis is that the digital innovation, collaborative governance, and strategic flexibility are integrated in resilient supply chains. The organizations that achieved a balance between automation and human skills and sustainability-related needs proved more

adaptive and competitive after the crisis. The comparative analysis ends with the conclusion that resilience is shifting towards the notion of a reacting concept, becoming a proactive capability to determine the future of global supply networks.

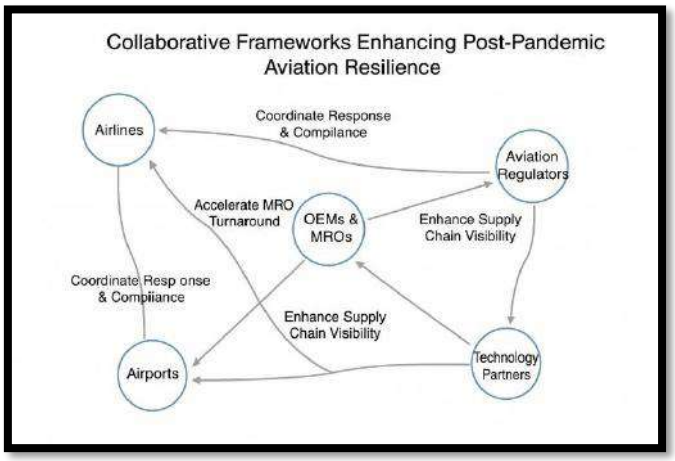

Fig.2. Collaborative Frameworks Enhancing Post-Pandemic Resilience.

V. DISCUSSION

As demonstrated in the comparative review, the post-pandemic aviation supply chain redesign has become centered on the digitalisation and collaborative governance. Stakeholders in aviation who embraced AI-based predictions, aircraft and cargo tracking using IoT, parts track ability using blockchain, and digital-twin simulations outperformed networks that were manually managed or disjointed. The cases in the industries, including AI-based planning in large airline companies, IoT-enhanced tracking in international air-cargo companies, and blockchain-based component verifiability systems used in large OEMs, show that the transparency, reliability, and speed of response are greater.

This is further influenced by regional differences in strategies. North America is focused on automation, predictive analytics and combined digital platforms. The sustainability-based models and the cyclical material loop in airplane production and MRO are leaders in Europe. The Asia-Pacific zone enhances localisation, multi-tier sourcing, and adaptable supplier ecosystems in the aim of minimising long-distance dependency. Digital enablement, capacity building and inexpensive mobile based visibility tools are the main priorities of emerging economies especially Africa and South Asia in order to mitigate infrastructural and skills based vulnerability.

Cooperation systems also developed as the supporting blocks of aviation resilience. In the EU, public-private partnership enhanced the coordination of the crisis and standardised travel measures. The integrated supplier ecosystems granted by Japan mitigated the risk of part-dependency with the help of the common dashboards. The North American data-sharing consortiums increased real-time baggage, cargo and compliance reporting. According to such models, the future-ready aviation supply chains are determined by the collaboration of three components: the high degree of digital technologies, multi-stakeholder's governance, and operation systems based on sustainability. All in all, resilience is no longer reactive in the form of a response to a disruption, but it has evolved into a proactive, intelligence-driven capability that is based on prediction, prevention, and a fast recovery.

VI. CONCLUSION

Researchers conclude that the global supply chains in aviation, especially the post-pandemic restructuring, have moved the industry away from the lean and cost-minimising supply chain models to resilience, agility, and digital intelligence. The disruption was more anticipated, continuity was ensured, and recovery was faster in organisations that integrated technologies in the form of AI, IoT, blockchain, and digital twins. Such tools enhanced transparency, accuracy of forecasting, facilitated MRO optimisation and enhanced trust among multi-level supplier networks.

The contextual factors in evidence in regions are that advanced economies are using automation and predictive systems to build resilience, whereas emerging regions are considering digital inclusion, flexible sourcing, and building capability to make the economy less susceptible. The collaborative mechanisms, such as public-private coordination frameworks, global data-sharing consortiums and integrated supplier ecosystems, have been influential in stabilising the aviation operations during and after the crisis.

In general, sustainability of the supply chain has transformed into a strategic and advance competency, but not a reaction. To achieve the future of aviation logistics and procurement, three forces that need to be harmonised include digital transformation, cross-industry collaboration, and sustainability integration. Organisations that find this balance will be in a good position not only to survive the future shocks but also to use the disruptions as an opportunity to innovate and remain competitive.

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A Study on the Dimensions of ERP in Taiwan's Information Industry Using the Fuzzy Delphi Method

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Abstract *— The information technology industry is placing increasing emphasis on the adoption of Enterprise Resource Planning (ERP) systems. In recent years, fuzzy decision analysis has been widely applied as an effective tool across multiple research fields, demonstrating strong practical value. In the pursuit of sustainable operation and development within the IT industry, introducing the core concept of "vitality" is crucial, as it determines whether an enterprise can achieve long-term, stable growth and maintain market competitiveness. Looking back, the efforts made by enterprises to enhance productivity and strengthen organizational competitiveness have, to some extent, revealed the driving forces behind corporate progress and upward development. However, these efforts are still insufficient to fully explain the true source of enterprise vitality—a core dynamic that fundamentally drives sustainable operations and maintains intrinsic vitality. In today's fiercely competitive and rapidly changing market environment, the competitive advantage of the IT industry increasingly hinges on the successful implementation of ERP systems and scientific enterprise management models. Based on this, this study will delve into the correlation between ERP application and enterprise vitality construction in the IT industry, as well as practical pathways, aiming to provide valuable insights for enterprises to enhance their sustainable development capabilities.*

Keywords *— Fuzzy Delphi Method (FDM); Enterprise Resource Planning (ERP); Business Management; Vitality*

I. INTRODUCTION

Past efforts by enterprises to improve productivity and enhance organizational competitiveness seem to only explain the forward and upward driving forces of enterprises to a certain extent, but cannot fully explain the source of true vitality, which lies in promoting the vitality of sustainable operation. In today's highly competitive environment, where market demands shift rapidly and customer expectations soar, the competitive advantage of the information industry depends on whether it has implemented Enterprise Resource Planning (ERP). ERP systems, with their integrated suite of modules for finance, human resources, supply chain management, and customer relationship management, streamline workflows, eliminate data silos, and provide real-time insights into operational performance. By centralizing data

and automating routine tasks, these systems reduce errors, cut down on manual processing time, and enable more informed decision-making. For instance, a manufacturing firm in the information sector can use ERP to track inventory levels in real time, ensuring that raw materials are available when needed without overstocking, thus optimizing cash flow and reducing waste. Similarly, the finance module automates invoicing and expense tracking, allowing financial teams to focus on strategic analysis rather than tedious paperwork. In an industry where speed and agility are critical, ERP not only enhances efficiency but also fosters collaboration across departments, breaking down traditional barriers and creating a more cohesive organizational culture. This integration of processes and data is what truly fuels sustainable operation, as it allows enterprises to adapt quickly to market changes, maintain high service quality, and consistently deliver value to stakeholders, thereby sustaining their competitive edge in the long run.

Therefore, delving into the topic of Enterprise Resource Planning (ERP) implementation in the information industry forms the core motivation of this study. In recent years, fuzzy decision analysis, as a methodology capable of effectively addressing uncertainty in complex scenarios, has been widely applied across multiple research fields, with the Fuzzy Delphi Method (FDM) being particularly prominent. Leveraging its unique advantages, this method adeptly handles the inherent fuzziness and subjectivity in expert judgment, providing a more scientific basis for decision-making. Since 1995, scholars such as Chang et al. (1995) have been dedicated to the innovation and development of the Fuzzy Delphi Method, proposing various improved models. These models each have their own focus, all aimed at solving complex decision-making challenges characterized by high uncertainty, imprecise data, and conflicting viewpoints.

Given this, this study has decided to adopt the decision-making framework of the Fuzzy Delphi Method to systematically identify, construct, and prioritize the key driving factors influencing the successful implementation of ERP systems in Taiwan's dynamic information industry. By incorporating fuzzy logic, this method effectively integrates valuable insights from experts across different fields, consolidating seemingly disparate viewpoints into a consensus. Its core objective is to precisely distill a series of critical variables, such as the adequacy of organizational readiness, the compatibility and advancement of technological infrastructure, the robustness of employee training systems, and the alignment of goals among various stakeholders. Through in-depth analysis and weighting of these variables, this study aims to provide a solid theoretical foundation and practical guidance for enterprises in formulating strategic plans for ERP implementation.

Ultimately, this study hopes that, through the aforementioned efforts, the implementation of ERP systems can closely align with the actual operational conditions of enterprises, sensitively respond to rapidly changing market demands, and remain highly consistent with the long-term sustainable growth goals of enterprises. This not only helps enhance the core competitiveness of Taiwan's information industry enterprises in an increasingly fierce market competition environment but also injects them with sustained vitality and innovative momentum. This is the fundamental motivation and value driving the in-depth development of this study.

II. LITERATURE REVIEWS

2.1 Enterprise Resource Planning

The concept of ERP was formally introduced in 1990 by the renowned American management consulting firm Gartner Group Inc. and quickly gained widespread adoption and application among various enterprises globally. At its core, an ERP system deeply integrates key business areas within an enterprise, including finance, accounting, procurement, production, logistics, material management, transportation, and human resource management. This integration not only effectively reduces the costs of cross-departmental collaboration

but also significantly enhances the speed, accuracy, and overall efficiency of information flow. For example, under traditional management models, the production department might take days to receive relevant material information after the procurement department places an order. In contrast, an ERP system enables real-time data sharing, ensuring that purchase orders, inventory status, production plans, and other critical information are instantly synchronized across departments, and thereby avoiding production delays or inventory overstock caused by information lag.

From a strategic perspective of enterprise management, ERP systems emphasize cross-system functional integration, interdepartmental collaboration, and cross-regional business consolidation. For instance, a multinational corporation with multiple production bases and overseas subsidiaries can use an ERP system to achieve unified global order management, real-time inventory allocation, and centralized financial data accounting, breaking down geographical and departmental barriers. Therefore, ERP is essentially an online data processing system with real-time data processing capabilities and a highly integrated architecture, enabling instant consolidation and unified management of all operational functions across an enterprise. Its interface typically features intuitive data dashboards, allowing managers to monitor key performance indicators—such as sales performance, production progress, inventory levels, and financial status—in real time through charts and reports. This facilitates rapid decision-making, optimizes resource allocation, and enhances the enterprise's core competitiveness.

Academic research has extensively studied how ERP systems impact organizational performance. Findings clearly demonstrate a significant positive correlation between successful ERP implementation and operational performance, with this empirical conclusion exhibiting strong robustness across different industries, enterprise sizes, and economic environments. In the early stages of digital transformation among Taiwanese enterprises, disparities in the pace of IT adoption led some companies to implement standalone information systems. However, these systems were often isolated applications at the departmental or business-line level, resulting in a lack of effective horizontal integration, severe data silos, and inefficient information flow. This directly fueled the demand for ERP systems, which emphasize comprehensive information integration and highly coordinated workflows.

Within the functional modules of an ERP system, the Sales and Distribution (SD) module falls under logistics management. This module covers the entire sales process—from order receipt, demand forecasting, sales quotations, and contract signing to shipment scheduling, transportation management, invoicing, and customer service—as well as closely related aspects such as inventory management and procurement coordination. Its primary goal is to reduce operational costs by optimizing order processing, minimizing inventory overstock, and shortening delivery cycles while enhancing overall efficiency by improving order fulfillment rates and customer satisfaction.

Regarding customer satisfaction research, Oliver (1981) posited that customer satisfaction is a subjective emotional response arising from a specific transaction, primarily driven by the sense of surprise or delight experienced during product acquisition or purchase. This emotion may stem from positive evaluations of product performance exceeding expectations or the warmth felt due to attentive service. Bolton and Drew (1991) further elaborated that customer satisfaction is a subjective emotional assessment formed after purchasing a product or service, where the gap between expectations and perceived performance is a key determinant. When actual experiences significantly surpass expectations, customers experience strong satisfaction and delight; conversely, unmet expectations may lead to disappointment or dissatisfaction. Notably, customers are highly value-oriented, where "value" refers to their comprehensive evaluation of the outcomes received relative to their inputs—not only

monetary costs but also time, effort, and other intangible investments. Outcomes encompass product functionality, service quality, brand reputation, and other dimensions. Through careful weighing, customers judge overall value to form their final conclusion on satisfaction.

2.2 Business Management

Business management refers to the discipline of effectively coordinating, controlling, and making decisions regarding the entire operational processes, management, and strategic planning of organizations, enterprises, or other commercial entities. According to Amis, J. M., Mair, J., & Munir, K. A. (2020), business management encompasses multiple functions and domains, including financial management, marketing management, human resource management, operations management, strategic management, and information technology management. The core objective is to enhance enterprise efficiency, competitiveness, and sustainable development capabilities through scientific management methods.

Early business management primarily focused on basic operational functions, emphasizing production efficiency and the optimization of organizational structures. Szentes (2005) proposed competitiveness measurement methods, including products and services, laying the foundation for enterprise performance evaluation. As business complexity increased, business management gradually evolved into a systematic framework. Schuman et al. (2005) introduced the Asset Life Cycle Management (ALCM) model, integrating general project management frameworks, systems engineering, and operational reliability concepts, effectively addressing efficiency issues in process industries. Agrawal, N. et al. (2024) noted that with the rapid development of globalization and information technology, the scope of business management has expanded to include transnational operations management, e-commerce management, and enterprise resource planning (ERP) integration.

Research indicates that modern business management has achieved deep integration with ERP systems. ERP systems integrate internal financial, accounting, procurement, production, logistics, materials, transportation, and human resource management within enterprises, not only reducing integration costs across departments but also improving the efficiency and accuracy of information transmission. From a business management perspective, ERP emphasizes cross-system functionality, interdepartmental coordination, and cross-regional integration, serving as an online data processing system with real-time and integrated processing capabilities. José Eugenio (2020) proposed a simplified Analytic Hierarchy Process (AHP) application method, enhancing the appeal of AHP in business applications by calculating the priority of a set of criteria. This decision-support tool significantly improves the scientific precision of business management. Modern business management is moving toward a more intelligent, data-driven direction, with increasingly close integration with information technology, providing robust managerial support for sustainable enterprise development.

2.3 Fuzzy Delphi Method

Liang et al. (2003) adopt the efficiency concept to assess and analyze the business performance of organizations, for example, integration evaluation of banks or financial holding companies and performance evaluation of research and development programs. Liang et al. (2003) proposed a process capability index for measuring the operation performance of banks' industries, which considers factors such as transaction processing speed, error rates in customer account management, and the timeliness of loan approval processes, providing a quantitative framework to gauge how well banking operations meet predefined quality standards. There is a new insight for the service quality of banks' operations, focusing on intangible aspects like customer satisfaction with digital banking interfaces, responsiveness of customer service representatives during peak hours, and the clarity of financial product information provided to clients.

The Fuzzy Delphi Method (FDM) is a semi-structured expert interview method that begins

by searching for relevant literature on a specific topic to initially summarize the questions, ensuring that the inquiry covers all critical dimensions of the subject matter. Then, based on the knowledge and experience of experts in the relevant field, opinions are offered on the questions, and the degree of consensus among the expert group is analyzed using fuzzy logic to handle uncertainties and vagueness in expert judgments. To formally implement the FDM, a suitable expert group of 10-15 scholars needs to be selected, comprising individuals with deep expertise in banking operations, financial management, and service quality assessment, each bringing unique perspectives shaped by years of industry practice and academic research. Each expert independently provides feedback on specific topics, such as key performance indicators for bank efficiency or critical success factors in service delivery, through structured questionnaires that allow for degrees of agreement (e.g., strongly agree, agree, neutral, disagree, strongly disagree) represented as fuzzy numbers. After collection and analysis, the consistency or differences in the expert group's responses to each question are confirmed using statistical techniques to aggregate fuzzy opinions, identifying areas of strong consensus and those requiring further discussion. The implementation process may involve multiple rounds as needed to gradually reach a consensus among the experts, with revised questions and feedback shared in subsequent iterations until a stable set of criteria or indices is established.

Chang et al. (2000) developed a new fuzzy Delphi method (FDM) to be used in managerial talent assessment for a company located in Taiwan, integrating fuzzy statistics to model the imprecise nature of human judgment in evaluating leadership qualities, problem-solving skills, and adaptability, and employing the technique of a conjugate gradient search to fit membership functions, which may be derived for fuzzy forecasts of employee performance potential and career progression. Liang and Hsieh (2005) also developed an ability index by using FDM for training in banks' industry, focusing on identifying core competencies required for roles such as risk management analysts and customer relationship managers, with the index incorporating fuzzy evaluations of training effectiveness, skill acquisition rates, and the alignment of training programs with evolving industry demands.

III. METHODOLOGY

1.1 Structure of ERP

This study employed comprehensive questionnaires to initially identify preliminary dimensions, followed by the integration of expert questionnaires and rigorous ethical and legal methodologies to pinpoint the core dimensions of enterprise resource planning (ERP) within the information industry. These identified dimensions encompass a holistic framework, specifically including: organizational management strategy, which involves aligning ERP systems with overarching corporate governance, leadership structures, and operational workflows; business strategy, focusing on how ERP supports competitive positioning, market expansion, and operational efficiency through integrated process management; customer relationship management strategy, designed to enhance customer engagement, streamline order processing, and improve service delivery through centralized data access and personalized interaction tools; vendor specification strategy, ensuring that ERP systems meet stringent technical requirements, compatibility standards, and compliance with industry-specific regulations when integrating third-party software or hardware; and financial planning strategy, which enables accurate budgeting, cost tracking, financial reporting, and risk management through real-time data integration across accounting, procurement, and inventory modules. The ERP Process, as visually represented and detailed in Figure 1, illustrates the sequential and interconnected flow of these strategic dimensions, highlighting how each component contributes to the seamless operation and optimization of enterprise resources in the dynamic landscape of the information industry.

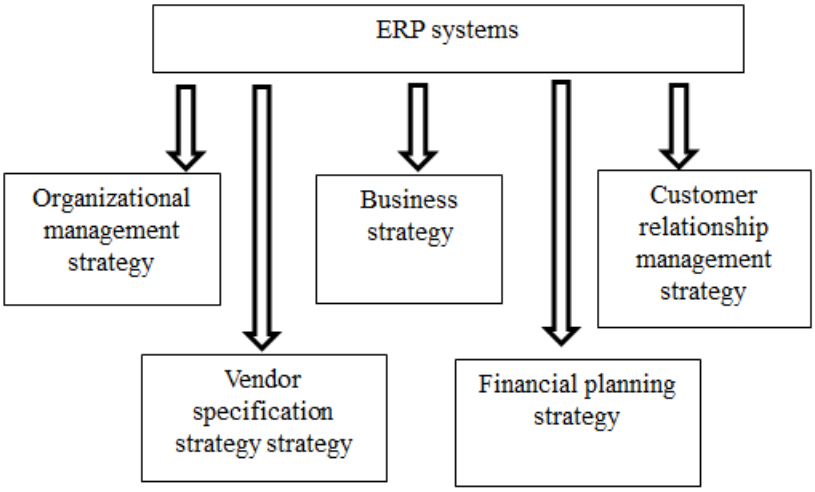

Fig.1 ERP Process

Chang and Lee (1995) refined this process by applying the Original Defuzzification Method (OM), a technique that converts fuzzy sets—representing vague or imprecise data such as subjective evaluations of candidate skills, experience, and cultural fit—into crisp numerical values, ensuring that the weight distribution of each factor in the ERP was both precise and reflective of expert judgment. This fuzzy decision system not only streamlined the candidate selection process by systematically aggregating and prioritizing multifaceted criteria but also ensured that the chosen individuals aligned with the bank's strategic goals of fostering a workforce capable of ERP development, thereby enhancing the likelihood of successful system implementation and long-term organizational effectiveness.

3.2 Pearson's correlation analysis method process

Pearson's correlation analysis was employed to ascertain whether a significant correlation existed between information pertaining to enterprise resource planning (ERP) and enterprise management practices. Building upon the comprehensive literature review and meticulously designed research framework outlined in the study, this investigation utilized Pearson's correlation analysis to dissect the various dimensions of ERP systems, thereby revealing the interrelationships among these critical components. To quantify the responses, a five-point Likert scale was integrated into the questionnaire, allowing participants to express their level of agreement or disagreement with each statement, ranging from 'Strongly Disagree' to 'Strongly Agree'. The primary focus of the study was on individuals employed within the information technology sector in Taiwan, a region known for its dynamic tech industry and widespread adoption of advanced business systems. In an effort to ensure a broad and representative sample, the study intentionally did not impose restrictions based on gender, occupation, or educational attainment, thus inviting participation from a diverse array of professionals, including software developers, IT consultants, system administrators, and business analysts, thereby enhancing the generalizability and practical relevance of the findings.

Convenience sampling was adopted as the data collection method, with questionnaires distributed through multiple channels to maximize accessibility: online platforms such as Google Forms, physical paper copies disseminated at industry conferences and tech meetups, and digital outreach via social media networks, messaging applications, and personal referrals from existing contacts. Prior to completing the questionnaire, participants were clearly informed about the research objectives, the principle of anonymity ensuring their identities

would remain confidential, and the inclusion of detailed research instructions alongside consent clauses, emphasizing voluntary participation without any coercion. A total of 452 questionnaires were successfully collected, providing a robust dataset for subsequent statistical analysis. Following collection, rigorous screening was conducted to identify and exclude incomplete or obviously invalid responses, such as those with uniform answers across all items or those lacking essential demographic information, ensuring that only high-quality, valid questionnaires were retained for use as the foundation of the research analysis.

3.3 Fuzzy Delphi Method process

This study employed an expert questionnaire to carry out a Fuzzy Delphi Method analysis, a structured approach designed to gather and synthesize expert opinions while accounting for uncertainty and vagueness in judgments. The panel of experts comprised five senior executives from the information industry, individuals with extensive leadership experience and deep insights into the sector's evolving landscape, including emerging technologies, market trends, and operational challenges. Two iterative rounds of consultation were conducted to refine and converge on a consensus, with each round building upon the feedback and revised inputs from the previous one to ensure robustness and alignment among the experts. The specific criteria for selecting these experts were stringent: they were required to possess not only professional knowledge and hands-on experience in information-related fields—such as software development, data management, cybersecurity, or telecommunications—but also held a bachelor's degree or higher academic qualification, ensuring a foundation of formal education complemented by practical expertise. This careful selection process aimed to assemble a panel capable of providing well-informed, nuanced perspectives that would underpin the validity and reliability of the Fuzzy Delphi Method analysis outcomes.

This study applies fuzzy theory to describe general uncertainty problems inherent in complex decision-making scenarios, particularly those involving imprecise or vague information. The research methods consist of two main parts: a comprehensive literature review to synthesize existing knowledge and the Fuzzy Delphi Method, a structured approach to elicit expert opinions under uncertainty. The Fuzzy Delphi Method is described as follows: Fuzzy theory uses the value of the membership function, which ranges from 0 to 1, to quantify the degree of belonging of an element to a fuzzy set, thereby describing general uncertainty problems that cannot be adequately captured by crisp binary logic. Hierarchical analysis, proposed by Thomas L. Saaty, is a decision-making method that organizes complex problems into a hierarchy of criteria and alternatives, using pairwise comparisons between elements at each level to derive relative importance weights. These weights are then synthesized to determine the overall priority of each alternative, with the option possessing the highest relative weight selected as the optimal solution. Kaufmann and Gupta's (1988) Fuzzy Delphi Method builds upon this foundation by integrating triangular fuzzy numbers, which are defined by three parameters (a lower bound, a modal value, and an upper bound) to represent the fuzziness of expert judgments, allowing for a more nuanced aggregation of opinions compared to traditional Delphi techniques. This study employs questionnaires to identify preliminary dimensions relevant to the implementation of financial planning, enterprise resource planning, and customer relationship management in the information industry, and subsequently utilizes expert questionnaires combined with the Fuzzy Delphi Method to determine the weight values associated with these dimensions, ensuring that the resulting priorities account for the inherent uncertainties and subjectivity present in expert assessments. Kaufmann and Gupta's (1988) fuzzy Delphi method is based on the triangular fuzzy number, which provides a flexible framework for modeling the imprecision in expert elicitation, enhancing the robustness and reliability of the decision-making process.

$$u_a(x) = \begin{cases} 0, & x < a \\ \frac{x-a}{b-a}, & a \leqslant x \leqslant b \\ \frac{c-x}{c-b}, & b < x \leqslant c \\ 0, & x > c \end{cases} \quad (1)$$

This study uses the Original Method (OM method) proposed by Chang and Lee (1995). The larger the OM value, the higher the importance of the factor.

$$OM(O_k) = \int_{\rho^*}^{1} \varpi(w)[\eta_1(w) \times c_k(w) + \eta_2(w) \times d_k(w)]\mathrm{d}w \quad (2)$$

$$OM(Oi) = \int_{0}^{1} \{0.5w[a + w(b-a) + (1-0.5w)[c + w(c-b)]\}dw$$

$$= (6b + a + 5c)/12 \quad (3)$$

$$OM(O_j) = \int_{0}^{1} \{(1-0.5w)[a + w(b-a)] + 0.5w[c + w(c-b)]\}dw$$

$$= (6b + 5a + c)/12 \quad (4)$$

IV. ANALYSIS AND RESULTS

After years of meticulous system integration, the synergies within the information technology industry have gradually emerged, weaving a complex yet cohesive network of interconnected systems and processes. Enterprise Resource Planning (ERP) in the information technology industry has played a pivotal role in making the operational platform more complete, streamlining workflows, enhancing data accuracy, and fostering seamless communication across departments. The results of the second expert questionnaire, which gathered insights from seasoned professionals in the field, are presented in Table 1. This table serves as a critical tool for analyzing the nuances of ERP implementation in the financial sector. By delving into Table 1, we can explore the similarities and differences in the weights assigned to each aspect of ERP within five major strategic areas: organizational management strategy, which encompasses leadership alignment and cross-departmental collaboration; business strategy, focusing on aligning ERP with overarching business goals and market demands; technology strategy, involving the selection and integration of cutting-edge technologies to support ERP functionalities; vendor specification strategy, which evaluates the reliability, compatibility, and support services of potential ERP vendors; and cost-benefit strategy, assessing the financial implications and return on investment of ERP adoption.

From Table 1, it is evident that the highest weight is allocated to vendor specification strategy, highlighting the critical importance of choosing the right partner to ensure successful ERP deployment and long-term performance. Following closely behind is organizational management strategy, underscoring the need for strong internal governance and stakeholder engagement to drive ERP adoption and maximize its benefits, as shown in Table 1.

Table 2 presents a detailed examination of the correlation patterns within the customer relationship management (CRM) dimension specifically tailored to the information industry, highlighting how various CRM components interact and influence one another. To rigorously assess the strength and direction of these relationships, this study employs Pearson product-moment correlation analysis, a statistical method well-suited for measuring linear associations between continuous variables. The correlation coefficients derived from this analysis are categorized into distinct levels to interpret the nature of the relationships: coefficients below 0.10 indicate

no meaningful correlation, suggesting that the variables in question do not exhibit a significant linear association; values ranging from 0.10 to 0.35 denote low correlation, implying a weak but detectable linear relationship; coefficients between 0.36 and 0.70 represent moderate correlation, indicating a noticeable and practically relevant linear connection; those from 0.71 to 0.99 signify high correlation, reflecting a strong linear association where changes in one variable are closely mirrored by changes in the other; and finally, a coefficient above 1.00, though theoretically impossible in standard Pearson correlation (which ranges from -1 to 1), is included here as a definitional upper bound for perfect correlation, where variables would exhibit an exact linear relationship with no variability.

Table 1 Results of the Second OM Value Analysis in Enterprise Resource Planning

Factor	a	b	c	2-nd OM value
Organizational management strategy	6.83	7.89	8.65	8.12
Business strategy	5.77	7.23	8.91	7.81
Customer relationship management	5.98	7.24	8.12	7.50
Vendor specification strategy	8.11	8.42	8.68	8.50
Financial planning strategy	7.12	7.43	8.92	8.03

Table 2 Summary Table of Correlation Coefficients in ERP

		ERP performance
Organizational management strategy	Pearson	0759***
Business strategy	Pearson	0.761***
Customer relationship management	Pearson	0.793***
Vendor specification strategy	Pearson	0.722 ***
Financial planning strategy	Pearson	0.735**

*p＜0.05 **P＜0.01 ***P＜0.001

V. CONCLUSION

This study, through fuzzy logic analysis, summarizes the findings of the research and reveals the dimensions of Enterprise Resource Planning (ERP) in the IT industry. Most sub-items have an OM weight value of 7.0 or higher, a threshold that underscores their critical importance in shaping ERP priorities within this dynamic sector. This indicates that the IT industry's ERP dimensions emphasize vendor specification strategy, highlighting a strategic focus on selecting and aligning with ERP vendors whose solutions can seamlessly integrate with the fast-paced, innovation-driven nature of IT operations. Therefore, ensuring market competitiveness in the IT industry relies on ERP vendor specification strategies, as these choices directly impact operational efficiency, scalability, and the ability to adapt to rapidly evolving technological demands and customer needs. Vendor specification strategies mainly include:

1. Identifying qualified suppliers

Ensuring suppliers consistently provide products and services of appropriate quality, timeliness, quantity, and price, and identifying and improving high-risk suppliers. This process involves rigorous evaluation criteria that encompass multiple dimensions to guarantee reliability and value. Quality assessment includes detailed inspections of product specifications, material standards, and compliance with industry regulations, ensuring that goods meet or exceed predefined benchmarks for durability, performance, and safety. Timeliness is evaluated through historical data on delivery schedules, including on-time delivery rates, lead time consistency, and responsiveness to urgent orders,

which helps mitigate disruptions in the supply chain. Quantity management focuses on the supplier's ability to fulfill order volumes accurately, with minimal variance, to support production planning and inventory management without excess stockpiles or shortages. Price analysis involves comparing competitive market rates, negotiating favorable terms, and evaluating cost structures to ensure cost-effectiveness without compromising on quality or service. Additionally, identifying high-risk suppliers requires monitoring factors such as financial stability, operational capacity, geopolitical exposure, and adherence to ethical and environmental standards. Once high-risk areas are pinpointed, targeted improvement initiatives are implemented, such as collaborative quality audits, process optimization workshops, or revised contractual agreements to address gaps. Continuous monitoring through regular performance reviews, feedback loops, and key performance indicator (KPI) tracking ensures that suppliers maintain their qualifications and that improvements are sustained over time, fostering long-term partnerships built on trust and mutual success.

2. Management processes

Establishing comprehensive supplier management policies, including rigorous supplier selection criteria that assess financial stability, production capabilities, quality control systems, and ethical business practices; systematic supplier evaluation mechanisms that involve regular performance reviews based on key metrics such as on-time delivery rates, product defect levels, compliance with contractual terms, and responsiveness to customer feedback; thorough on-site verification procedures that include unannounced facility inspections to evaluate manufacturing processes, safety protocols, working conditions, and adherence to environmental regulations; and structured guidance/improvement steps that provide suppliers with detailed feedback reports, targeted training programs, and collaborative problem-solving sessions to address identified gaps, enhance operational efficiency, and ensure continuous alignment with evolving industry standards and organizational requirements, thereby guaranteeing that all suppliers consistently meet or exceed predefined quality, reliability, and sustainability benchmarks.

3. Supplier risk assessment

Conducting comprehensive economic, social, and environmental risk assessments of existing suppliers, and providing tailored guidance to higher-risk suppliers. The economic risk assessment involves analyzing financial stability, including cash flow trends, debt-to-equity ratios, and exposure to market volatility, such as fluctuations in raw material prices or currency exchange rates that could impact delivery timelines and cost predictability. Social risk evaluation focuses on labor practices, including adherence to fair wage standards, safe working conditions, compliance with local labor laws, and the presence of any reported incidents of worker exploitation or discrimination. Environmental risk assessment examines a supplier's sustainability practices, such as waste management protocols, carbon footprint reduction efforts, compliance with environmental regulations regarding emissions and resource usage, and the implementation of eco-friendly production processes. For higher-risk suppliers identified through these assessments, guidance is provided in the form of actionable recommendations, such as financial restructuring support, training on improved labor practices, or technical assistance to adopt greener technologies. This guidance aims to mitigate risks, enhance supplier resilience, and align their operations with organizational sustainability and ethical sourcing goals, ensuring long-term reliability and responsible supply chain management.

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Environmental Impact Assessment (EIA) in India: Legal Framework, Challenges and Future Directions

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Abstract *— Environmental Impact Assessment (EIA) is a key legal and policy instrument for integrating environmental considerations into developmental decision-making. In India, EIA functions as a preventive mechanism under the framework of sustainable development, aiming to balance economic growth with environmental protection. This paper presents a narrative review of the Environmental Impact Assessment regime in India, examining its conceptual foundations, legal framework, procedural structure, and implementation challenges. The study traces the evolution of EIA under the Environment (Protection) Act, 1986, with particular emphasis on the EIA Notification, 2006, and the role of judicial interpretation by the Supreme Court of India and the National Green Tribunal. The review identifies critical issues such as inadequate quality of EIA reports, limited public participation, regulatory dilution, and weak post-clearance monitoring. Recent policy debates and proposed reforms are also analyzed to assess their implications for environmental governance. The paper concludes that while India possesses a comprehensive EIA framework, its effectiveness depends on stronger institutional capacity, transparency, scientific rigor, and meaningful public engagement to ensure environmental justice and sustainable development.*

Keywords *— **Environmental Impact Assessment, Environmental Law, Sustainable Development, Environmental Governance.***

GRAPHICAL ABSTRACT

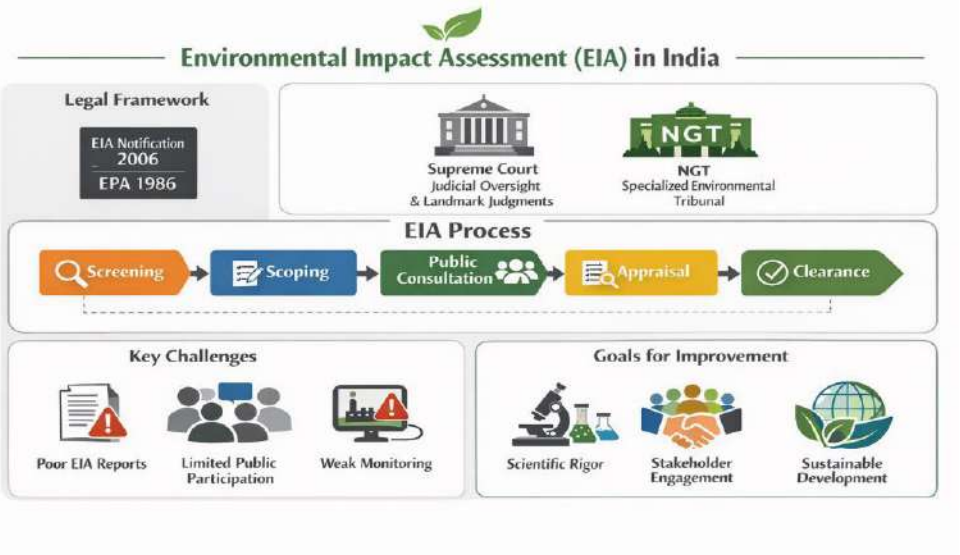

Fig.1 Graphical Abstract

I. INTRODUCTION

Environmental Impact Assessment (EIA) is a crucial preventive legal and policy instrument designed to identify, predict, and evaluate the potential environmental consequences of proposed development projects before their approval and implementation (Lakshito et al., 2024). The core objective of EIA is to ensure that environmental considerations are systematically integrated into decision-making processes, thereby reducing adverse ecological impacts and promoting sustainable development (Obudulu et al., 2024). In an era marked by rapid industrialization, urban expansion, and large-scale infrastructure development, EIA has emerged as an indispensable mechanism for balancing economic growth with environmental protection and social welfare (Morgan, 2012; Ndubuisi & Fnisafetty et al., 2025).

Globally, EIA is recognized as an essential decision-making tool that enhances transparency, accountability, and public participation in development planning. Its widespread adoption across countries has been influenced by international environmental commitments and policy frameworks, including the Stockholm Declaration (1972) and Agenda 21 adopted at the Rio Earth Summit (1992), which emphasized the integration of environmental assessment into national development strategies (UNEP, 2002). Over time, the scope of EIA has expanded beyond biophysical impacts to include social, economic, and health considerations, reflecting its evolving role in environmental governance.

In India, the formal adoption of EIA can be traced back to the late 1970s, when environmental appraisal was initiated for river valleys and major infrastructure projects. However, the institutionalization of EIA occurred with the enactment of the **Environment (Protection) Act, 1986**, which empowered the central government to regulate activities affecting environmental quality (Divan & Rosencranz, 2001). The issuance of the **EIA Notification, 1994** marked the first statutory attempt to mandate environmental clearance for specified categories of projects, laying the foundation for a structured EIA regime in the country (MoEF, 1994). A significant transformation of India's EIA framework occurred with the introduction of the **EIA Notification, 2006**, which remains the cornerstone of the current environmental clearance system. The 2006 notification established a formalized, multi-stage EIA process comprising screening, scoping, public consultation, and appraisal, while also decentralizing decision-making authority between central and state-level institutions (MoEFCC, 2006). Judicial interventions by the Supreme Court of India and the National Green Tribunal (NGT) have further reinforced the importance of EIA as a tool for sustainable development, precautionary environmental governance, and public accountability (Okafor & Onwurliri, 2025).

Despite the existence of a comprehensive legal and procedural framework, the effectiveness of EIA in India has frequently been questioned. Scholars and practitioners have highlighted persistent challenges such as procedural delays, inadequate quality of EIA reports, limited and ineffective public participation, and weak post-clearance monitoring and compliance mechanisms (Rai, 2025). These issues have raised concerns regarding the credibility of the EIA process and its ability to function as a meaningful safeguard against environmental degradation. Recent amendments and proposed reforms to the EIA regime, particularly the **Draft EIA Notification, 2020**, have further intensified debates on environmental governance, development priorities, and environmental justice in India. While proponents argue that regulatory reforms are necessary to streamline procedures and promote ease of doing business, critics contend that certain relaxations dilute environmental safeguards and undermine the precautionary principle (Swargiary, 2025). These contrasting perspectives underscore the need for a critical and balanced evaluation of India's EIA framework. Against this backdrop, the present paper offers a narrative review of the Environmental Impact Assessment system in India, focusing on its legal foundations, procedural mechanisms, key implementation challenges, and emerging trends. By synthesizing existing academic literature, policy documents, and judicial pronouncements, the study seeks to identify structural and operational gaps within the current EIA regime and to suggest future directions for strengthening environmental governance, transparency, and sustainable development in India.

II. CONCEPT AND EVOLUTION OF ENVIRONMENTAL IMPACT ASSESSMENT

2.1. *Concept and Objectives of Environmental Impact Assessment:*

Environmental Impact Assessment (EIA) is a systematic and anticipatory process used to identify, predict, and evaluate the potential environmental effects of proposed development projects prior to decision-making and implementation. The fundamental objective of EIA is to integrate environmental considerations into development planning at an early stage, thereby ensuring that economic development proceeds in an environmentally responsible and socially acceptable manner. By emphasizing prevention rather than remediation, EIA serves as an important tool for minimizing adverse environmental impacts and avoiding irreversible ecological damage (Glasson et al., 2012).

EIA also plays a significant role in promoting transparency and accountability in environmental decision-making. It facilitates informed choices by decision-makers, encourages public participation, and enhances the quality of development planning by considering alternative project designs and mitigation measures. As a planning instrument, EIA supports the broader goals of sustainable development by balancing environmental protection, economic growth, and social equity (Morgan, 2012).

2.2. *Global Evolution of Environmental Impact Assessment:*

The concept of EIA originated in the United States with the enactment of the **National Environmental Policy Act (NEPA), 1969**, which mandated environmental assessment for major federal actions likely to have significant environmental impacts (Canter, 1996). NEPA marked a paradigm shift by institutionalizing the principle that environmental protection should be an integral part of governmental planning and policy formulation rather than an afterthought (Mashi, 2025).

Following its success in the United States, EIA was gradually adopted by several developed and developing countries and later endorsed by international organizations such as the United Nations Environment Programme (UNEP), the World Bank, and the Organisation for Economic Co-operation and Development (OECD) as a best-practice environmental governance tool (Morgan, 2012). At the international level, EIA gained recognition during the **Stockholm Conference on the Human Environment (1972)** and was further reinforced through **Agenda 21**, adopted at the **Rio Earth Summit (1992)**, which emphasized the use of environmental assessment as a key instrument for sustainable development planning (UNEP, 2002). Over time, the scope of EIA expanded beyond the assessment of biophysical impacts to include social, economic, cultural, and health dimensions. This broader and more inclusive approach is often referred to as **Environmental and Social Impact Assessment (ESIA)**, reflecting the growing recognition of the interconnected nature of environmental integrity and human well-being.

2.3. Evolution of Environmental Impact Assessment in India:

In India, informal environmental assessments were undertaken for river valleys and major infrastructure projects during the late 1970s as part of administrative decision-making. However, the formal institutionalization of EIA occurred in **1994**, when environmental clearance became mandatory for specified categories of developmental projects through an executive notification issued under the **Environment (Protection) Act, 1986** (MoEF, 1994). This marked a significant milestone in India's environmental regulatory framework by introducing prior environmental scrutiny into the project approval process. A major transformation of the EIA regime took place with the introduction of the **EIA Notification, 2006**, which remains the cornerstone of the current environmental clearance system in India. The notification decentralized the clearance process by categorizing projects at central and state levels and introduced structured procedural stages such as screening, scoping, public consultation, and appraisal (MoEFCC, 2006). While these reforms were intended to enhance efficiency, transparency, and stakeholder participation, scholars and practitioners have raised concerns regarding the dilution of environmental safeguards, uneven implementation across states, and limited institutional capacity at the regulatory level (Menon et al., 2020; Soren and Singh, 2025).

Thus, the evolution of EIA in India reflects a gradual shift from a narrow administrative exercise to a

broader mechanism of environmental governance, public participation, and regulatory accountability. Nevertheless, the effectiveness of EIA continues to depend on the robustness of legal frameworks, availability of scientific expertise, institutional capacity, and sustained political commitment to environmental protection.

III. LEGAL FRAMEWORK OF ENVIRONMENTAL IMPACT ASSESSMENT IN INDIA

Environmental Impact Assessment in India operates within a well-defined legal and institutional framework aimed at integrating environmental considerations into developmental decision-making. This framework has evolved through statutory enactments, executive notifications, and judicial interpretation, reflecting India's response to increasing environmental challenges associated with rapid industrialization and infrastructure expansion. The Environment (Protection) Act, 1986 serves as the primary legislative foundation upon which the EIA regime in India has been developed (Kritika & Sharma, 2020).

3.1. Statutory Basis: Environment (Protection) Act, 1986:

The legal foundation of Environmental Impact Assessment (EIA) in India is primarily derived from the Environment (Protection) Act, 1986 (EPA), enacted in the aftermath of the Bhopal Gas Tragedy to provide a comprehensive and umbrella framework for environmental protection. The Act was designed to enable the central government to take preventive and remedial measures to safeguard environmental quality and regulate activities with potential environmental impacts. Section 3 of the Act empowers the central government to take all necessary measures for protecting and improving the quality of the environment, including the regulation of industrial operations and developmental projects. Section 6 further authorizes the government to frame rules and issue notifications governing environmental standards and procedural safeguards for activities that may pose risks to ecological balance (Divan & Rosencranz, 2001). These enabling provisions provided the statutory basis for introducing EIA as a preventive regulatory tool, shifting environmental governance in India from a reactive approach towards anticipatory and planning-oriented decision-making.

3.2. Introduction of EIA: EIA Notification, 1994:

Although environmental appraisal of development projects existed in an informal and ad hoc manner during the late 1970s and 1980s, Environmental Impact Assessment (EIA) was formally introduced in India through the EIA Notification, 1994, issued under the Environment (Protection) Act, 1986. This notification marked a significant transition from discretionary environmental scrutiny to a mandatory and legally enforceable clearance regime, thereby institutionalizing environmental considerations within India's developmental governance framework. The EIA Notification, 1994 made prior environmental clearance compulsory for specified categories of projects that were considered environmentally sensitive or likely to have significant ecological impacts. These included sectors such as mining, power generation, river valley and hydropower projects, ports, harbors, highways, and large-scale industrial and infrastructure developments (MoEF, 1994). Project proponents were required to submit detailed environmental impact assessment reports outlining potential adverse impacts and proposed mitigation measures before project approval.

Under the 1994 notification, the authority to grant environmental clearance was centralized with the Ministry of Environment and Forests (MoEF), supported by expert appraisal committees. This centralized approach aimed to ensure uniformity in environmental decision-making and strengthen technical scrutiny at the national level. However, the notification did not clearly define procedural stages such as scoping or public consultation, resulting in limited transparency and inconsistent public participation in the clearance process. Despite its limitations, the EIA Notification, 1994 represented India's first structured and formal attempt to integrate environmental safeguards into project planning and approval processes. It laid the groundwork for subsequent reforms by establishing the principle that environmental clearance is a pre-condition for development, rather than a post-approval formality. The experiences and shortcomings of the 1994 regime ultimately informed the more elaborate and decentralized framework introduced under the EIA Notification, 2006. Table 1 provides a comparative

overview of the key features of the EIA Notifications of 1994 and 2006, highlighting the evolution of project categorization, public consultation mechanisms, and appraisal processes.

Table 1: Comparative Summary of EIA Notifications (1994 vs 2006)

Feature	EIA Notification 1994	EIA Notification 2006	Comments
Legal Basis	EPA 1986	EPA 1986	Both under EPA
Project Categorization	Centralized	Category A (Central), Category B (State)	Decentralization in 2006
Public Consultation	Limited	Mandatory for most projects	Enhanced participation
Stages	Screening, Appraisal	Screening, Scoping, Public Consultation, Appraisal	More structured in 2006
Authority	MoEF	MoEFCC, SEIAAs, SEACs	State-level authorities introduced

3.3. Consolidation and Decentralization: EIA Notification, 2006:

A major overhaul of India's Environmental Impact Assessment (EIA) regime occurred with the promulgation of the EIA Notification, 2006, which continues to serve as the cornerstone of the country's environmental clearance framework. Replacing the earlier 1994 notification, the 2006 regime sought to address procedural ambiguities, improve administrative efficiency, and enhance public participation in environmental decision-making.

One of the most significant features of the 2006 notification was the introduction of a decentralized clearance mechanism. Projects were classified into Category A, which are appraised and cleared at the central level by the Ministry of Environment, Forest and Climate Change (MoEFCC), and Category B, which are appraised at the state level through State Environment Impact Assessment Authorities (SEIAAs) and State Expert Appraisal Committees (SEACs) (MoEFCC, 2006). Category B projects were further sub-divided into B1 (requiring detailed EIA studies) and B2 (exempted from detailed EIA and public consultation), reflecting a risk-based approach to environmental regulation. The notification also institutionalized a structured four-stage EIA process, comprising screening, scoping, public consultation, and appraisal. Screening determines whether a project requires a full EIA study, while scoping defines the terms of reference for assessment. Public consultation was formally incorporated as a mandatory stage, providing affected communities and stakeholders an opportunity to express concerns and participate in decision-making. The appraisal stage involves expert evaluation of the EIA report and public feedback before granting or rejecting environmental clearance.

While the EIA Notification, 2006 was intended to enhance transparency, accountability, and stakeholder engagement, its implementation has been subject to considerable criticism. Scholars and civil society organizations have highlighted issues such as uneven implementation across states, inadequate technical and institutional capacity of SEIAAs, and procedural delays (Kanchi Kohli & Menon, 2009). Additionally, concerns have been raised that administrative pressures to expedite project approvals may lead to the dilution of environmental safeguards, undermining the precautionary purpose of EIA. Despite these challenges, the 2006 notification represents a critical evolution in India's environmental governance framework by formalizing procedures, expanding public participation, and decentralizing decision-making. However, its effectiveness remains contingent upon robust institutional capacity, genuine stakeholder engagement, and consistent enforcement of environmental norms.

3.4. Role of Judiciary and the National Green Tribunal:

Judicial intervention has played a pivotal role in shaping, interpreting, and strengthening the Environmental Impact Assessment (EIA) framework

in India. In the absence of comprehensive legislative clarity and effective administrative enforcement, the judiciary has frequently acted as a guardian of environmental protection by integrating constitutional principles, international environmental norms, and scientific reasoning into environmental governance. The Supreme Court of India has consistently emphasized EIA as an indispensable tool for achieving sustainable development, balancing developmental imperatives with ecological preservation (Lafarge Umiam Mining Pvt. Ltd. v. Union of India, 2011).

In Vellore Citizens' Welfare Forum v. Union of India (1996), the Supreme Court explicitly recognized the precautionary principle and the polluter pays principle as integral components of Indian environmental jurisprudence. The Court held that environmental protection is a constitutional obligation under Articles 21, 48A, and 51A(g) of the Constitution, thereby reinforcing the preventive and anticipatory nature of EIA in environmental decision-making. This judgment significantly strengthened the normative foundation of EIA by emphasizing that environmental harm should be prevented at the planning stage rather than remedied post facto.

Similarly, in A.P. Pollution Control Board v. Prof. M.V. Nayudu (1999), the Court underscored the necessity of scientific expertise and informed decision-making in environmental matters. Acknowledging the technical complexity of environmental disputes, the Court emphasized that adjudicatory bodies must rely on expert knowledge to assess environmental risks and uncertainties. This judgment laid the groundwork for the later establishment of specialized environmental tribunals and reinforced the role of EIA as a science-based regulatory instrument. The establishment of the National Green Tribunal (NGT) under the National Green Tribunal Act, 2010 marked a significant institutional development in India's environmental governance framework. Designed as a specialized forum for the expeditious and effective resolution of environmental disputes, the NGT has played a proactive role in enforcing EIA norms. The Tribunal has frequently scrutinized the legality of environmental clearances, examined procedural lapses in EIA processes, and stressed the importance of meaningful public consultation, procedural compliance, and regulatory accountability (Muschott, 2024). Through its jurisprudence, the NGT has strengthened the enforceability of EIA by ensuring that environmental clearances are not treated as mere administrative formalities but as substantive safeguards against ecological degradation. However, concerns have also been raised regarding inconsistent enforcement, capacity constraints, and occasional tensions between judicial activism and executive discretion. Nevertheless, the judiciary and the NGT remain central to upholding the integrity of the EIA framework and advancing environmental justice in India (Gill, 2010).

3.5. Assessment of the Legal Framework:

Despite the presence of an extensive statutory and institutional framework, the Environmental Impact Assessment (EIA) regime in India continues to face significant challenges relating to implementation, enforcement, and regulatory consistency. While the Environment (Protection) Act, 1986 and successive EIA notifications have provided a legal foundation for preventive environmental governance, gaps persist between formal legal provisions and their practical execution on the ground.

One of the primary concerns relates to procedural compliance and monitoring. Although EIA is mandated at the pre-clearance stage, post-clearance monitoring and enforcement mechanisms remain weak, often resulting in non-compliance with stipulated environmental conditions. Additionally, capacity constraints within regulatory authorities—particularly at the state level—have affected the quality of appraisal, supervision, and decision-making. The evolving nature of EIA notifications and frequent amendments have further raised concerns regarding regulatory dilution and legal uncertainty. Critics argue that certain exemptions, fast-track approvals, and post facto clearances undermine the precautionary and preventive objectives of EIA. At the same time, proponents of reform emphasize the need for administrative efficiency, infrastructure development, and ease of doing business. This tension reflects a broader policy challenge in reconciling economic growth with environmental sustainability.

Nevertheless, the legal architecture of EIA in India demonstrates a sustained commitment to integrating environmental considerations into development

planning through a multi-layered governance approach involving statutory provisions, executive regulations, and judicial oversight. Judicial interventions by the Supreme Court and the National Green Tribunal have played a corrective role by reinforcing procedural safeguards, public participation, and accountability. However, the long-term effectiveness of the EIA framework depends on strengthening institutional capacity, ensuring transparency, and fostering genuine stakeholder engagement. Overall, while India's EIA regime provides a robust legal foundation, its success as a tool of sustainable development ultimately hinges on effective implementation, consistent enforcement, and political will to prioritize environmental protection alongside developmental objectives. Figure 2 illustrates the legal and institutional framework underpinning EIA in India, showing the role of the Environment (Protection) Act, notifications, appraisal authorities, and judicial oversight.

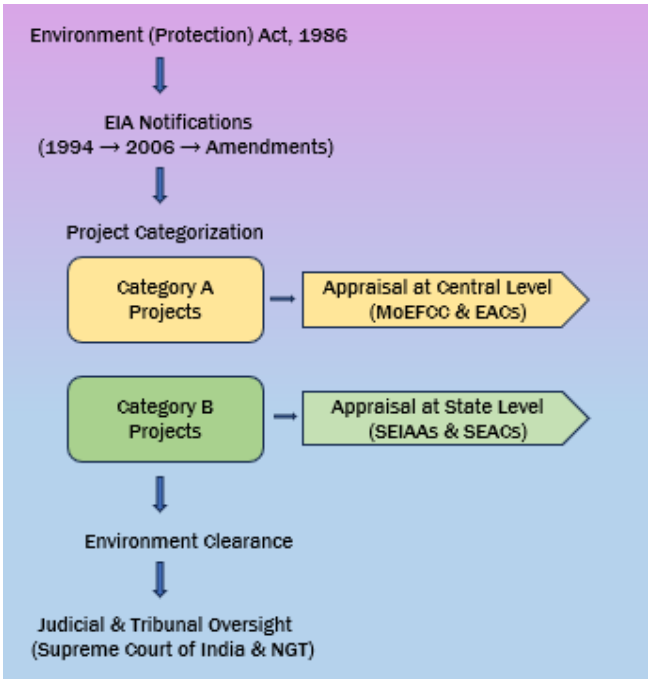

Fig.2 Legal and Institutional Framework of EIA in India

IV. EIA PROCESS IN INDIA

The Environmental Impact Assessment (EIA) process in India, as prescribed under the **EIA Notification, 2006**, follows a structured and sequential framework aimed at identifying, predicting, and evaluating the potential environmental consequences of proposed developmental projects prior to the grant of environmental clearance. The process is designed to operationalize the principles of **precaution, sustainable development, and informed decision-making**, and comprises four principal stages: **screening, scoping, public consultation, and appraisal** (MoEFCC, 2006).

4.1. Screening:

Screening is applicable primarily to **Category B projects** and serves as the preliminary stage to determine whether a proposed project requires a detailed Environmental Impact Assessment. Based on the nature, scale, and potential environmental impacts, projects are classified into **Category B1**, which necessitates a comprehensive EIA study, and **Category B2**, which are exempted from detailed assessment and public consultation. While the screening mechanism is intended to streamline the clearance process and allocate regulatory resources efficiently, concerns have been raised regarding the criteria used for classification and the risk of underestimating environmental impacts, particularly for projects with cumulative or site-specific effects.

4.2. Scoping:

Scoping involves the identification of critical environmental concerns and the formulation of **Terms of Reference (ToR)** that guide the preparation of the EIA report. This stage is conducted by Expert Appraisal Committees at the central or state level and is crucial in defining the depth, focus, and relevance of the assessment. A well-defined scoping process ensures that significant environmental issues are adequately addressed while avoiding unnecessary data collection. However, studies indicate that scoping in India often suffers from standardized ToRs and limited site-specific considerations, which can compromise the quality of subsequent EIA reports (Glasson et al., 2012).

4.3. Public Consultation:

Public consultation constitutes a key participatory component of the EIA process, aimed at incorporating the views and concerns of affected communities and other stakeholders into environmental decision-making. It typically includes **public hearings conducted at or near the project site**, along with the submission of written responses from interested parties. Meaningful public participation is widely regarded as essential for enhancing transparency,

accountability, and environmental justice. Nevertheless, in the Indian context, the effectiveness of public consultation has frequently been undermined by factors such as inadequate access to project information, language barriers, limited awareness among local communities, and procedural constraints (Kanchi Kohli & Menon, 2009).

4.4. Appraisal:

Appraisal represents the final and decisive stage of the EIA process, wherein Expert Appraisal Committees examine the EIA report, outcomes of public consultation, and compliance with regulatory requirements before recommending the grant or rejection of environmental clearance. The appraisal stage is expected to involve independent, objective, and scientifically informed evaluation. However, concerns have been raised regarding **time pressures, potential conflicts of interest, reliance on desk-based assessments, and insufficient field verification**, which may weaken the rigor of the appraisal process (Paliwal, 2006).

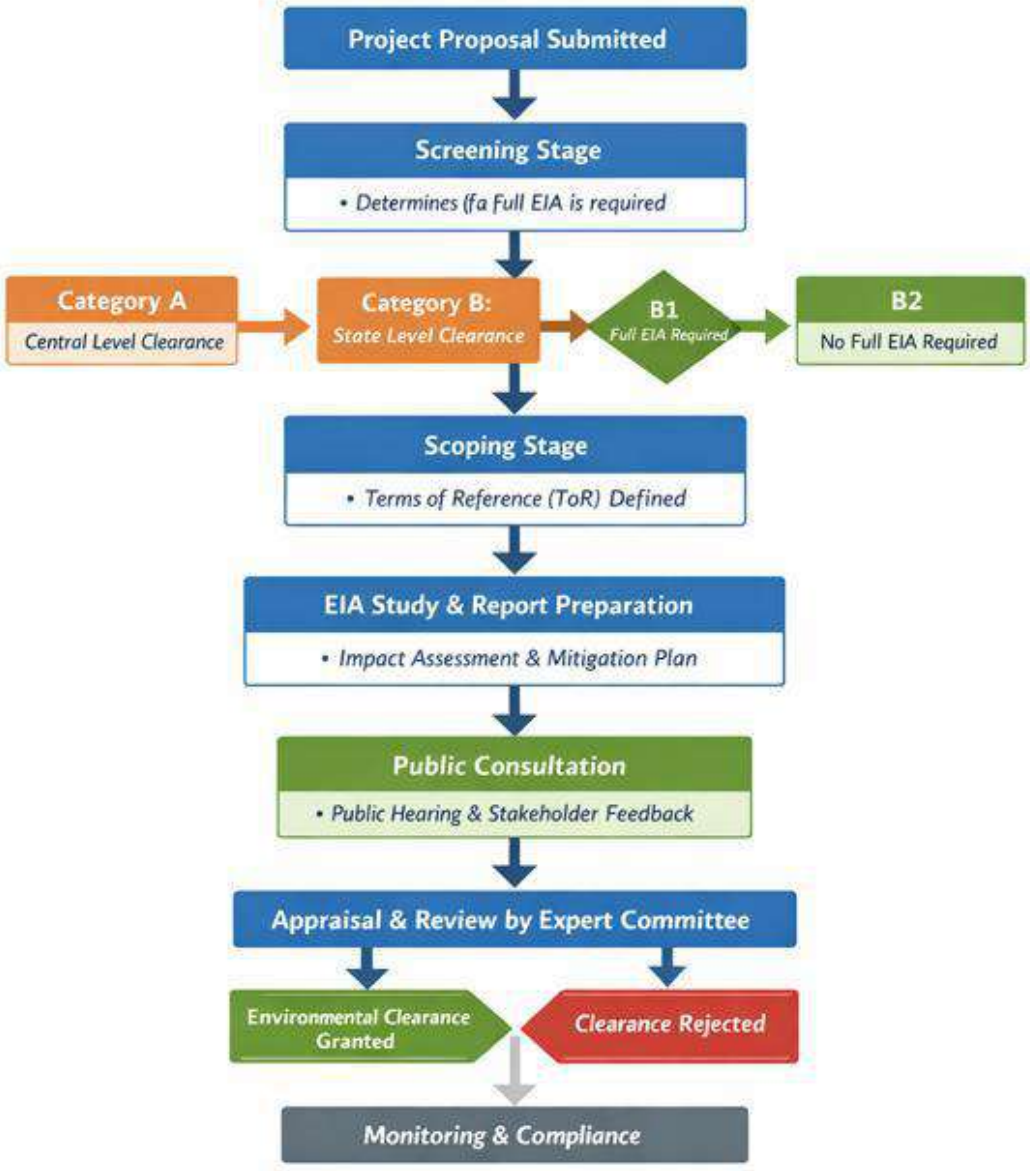

Fig.3 EIA process in India under the EIA notification 2006

Overall, while the EIA process in India is procedurally comprehensive and well-defined on paper, **deficiencies in implementation, monitoring, and enforcement** continue to limit its effectiveness as a

preventive tool of environmental governance. Strengthening institutional capacity, improving transparency, and ensuring genuine public participation remain critical for enhancing the credibility and outcomes of the EIA process. The structured EIA process, including screening, scoping, public consultation, and appraisal, is summarized in Figure 3, which also distinguishes between Category A and Category B projects.

V. MAJOR CHALLENGES IN EIA IMPLEMENTATION

Despite the existence of a comprehensive legal and procedural framework, the Environmental Impact Assessment (EIA) system in India continues to face multiple structural and operational challenges that undermine its effectiveness as a preventive environmental governance tool. These challenges span across technical, institutional, participatory, and regulatory dimensions, often resulting in a gap between the objectives of EIA and its actual outcomes.

5.1. Quality and Credibility of EIA Reports:

One of the most persistent challenges in EIA implementation is the poor quality and limited credibility of EIA reports. Several studies have pointed to deficiencies such as inadequate baseline data, insufficient field investigations, lack of scientific rigor, and reliance on generic or outdated information (Paliwal, 2006). In many cases, impact assessments fail to account for cumulative, long-term, and site-specific environmental effects. Moreover, since EIA reports are typically prepared by consultants engaged by project proponents, concerns have been raised regarding conflicts of interest, objectivity, and professional accountability, which further erode the reliability of assessment outcomes.

5.2. Limitations in Public Participation:

Although public consultation is a legally mandated component of the EIA process, meaningful public participation remains limited in practice. Public hearings are frequently criticized for inadequate advance notice, restricted access to project-related information, and procedural barriers that marginalize local communities, particularly indigenous and vulnerable groups. Language constraints, technical complexity of EIA documents, and lack of awareness further reduce effective engagement. As a result, public consultation often becomes a formalistic exercise rather than a substantive mechanism for incorporating community concerns into decision-making (Kothari et al., 2013).

5.3. Regulatory Dilution and Exemptions:

Another significant concern is the progressive dilution of environmental safeguards through regulatory amendments, exemptions, and procedural relaxations. Over time, several categories of projects have been exempted from public hearings or detailed EIA requirements, while provisions for post facto environmental clearances have raised serious questions regarding compliance with the precautionary principle and environmental accountability (Dutta, 2020). Such regulatory trends have been criticized for prioritizing administrative efficiency and economic growth over environmental protection and participatory governance.

5.4. Weak Post-Clearance Monitoring and Enforcement:

Weak post-clearance monitoring and enforcement mechanisms represent a critical gap in India's EIA framework. Environmental clearances are typically granted subject to specific conditions aimed at mitigating adverse impacts; however, regulatory agencies often lack the institutional capacity, resources, and technical expertise required for effective monitoring. Consequently, non-compliance with clearance conditions frequently goes undetected or unaddressed, reducing EIA to a one-time procedural requirement rather than a continuous environmental management tool (MoEFCC, 2020).

Overall, these challenges highlight systemic weaknesses in the design and implementation of the EIA regime in India. Addressing these issues requires strengthening institutional capacity, enhancing transparency, ensuring independent and high-quality assessments, and reinforcing participatory and enforcement mechanisms to restore the credibility and effectiveness of EIA as an instrument of sustainable development. Table 2 summarizes the major challenges faced in EIA implementation and provides corresponding recommendations to enhance effectiveness and credibility.

Table 2: Major Challenges and Recommendations

Challenge	Impact	Recommendation
Poor EIA report quality	Reduced credibility, weak mitigation	Independent review, scientific rigor
Limited public participation	Undermines environmental justice	Awareness programs, accessible info, digital portals
Regulatory dilution	Weakened safeguards	Strengthen legal provisions, limit exemptions
Weak monitoring	Non-compliance during execution	Post-clearance audits, real-time monitoring

VI. RECENT REFORMS AND JUDICIAL INTERVENTIONS

Recent years have witnessed intensified debates surrounding proposed reforms to India's Environmental Impact Assessment (EIA) framework, particularly in relation to the Draft EIA Notification, 2020. Introduced with the stated objectives of simplifying procedures, improving regulatory efficiency, and promoting ease of doing business, the draft notification proposed several structural and procedural changes to the existing EIA regime. However, these proposals attracted widespread criticism from environmental scholars, civil society organizations, and legal experts due to concerns over the potential weakening of environmental safeguards and dilution of participatory governance (Dutta, 2020).

One of the most contentious aspects of the Draft EIA Notification, 2020 was the reduction in the scope of public participation, including exemptions for certain categories of projects from public hearings and shortened notice periods. Additionally, the draft sought to institutionalize post-facto environmental clearances for projects that had commenced operations without prior approval, raising serious concerns regarding compliance with the precautionary principle and the preventive intent of EIA. Critics argued that such provisions could normalize regulatory violations and undermine the credibility of environmental governance mechanisms.

In response to perceived regulatory gaps and administrative lapses, judicial bodies—particularly the National Green Tribunal (NGT)—have played an active corrective role (*Vellore Citizens Welfare Forum v. Union of India, 1996*; *Lafarge Umiam Mining Pvt. Ltd. v. Union of India, 2011*). The NGT has consistently emphasized the mandatory and non-negotiable nature of prior environmental clearance, holding that post-facto approvals are incompatible with the objectives of environmental protection (*M.C. Mehta v. Union of India, 1988*; *Lafarge Umiam Mining*, 2011). Through various orders, the Tribunal has quashed environmental clearances granted without due process, inadequate public consultation, or proper appraisal, thereby reinforcing procedural compliance and accountability among regulatory authorities.

Judicial scrutiny has thus served as a critical counterbalance to executive discretion in the EIA regime. While courts and tribunals cannot substitute policy-making functions, their interventions have underscored the importance of rule of law, transparency, and environmental justice in development decision-making. Nevertheless, continued reliance on judicial intervention also highlights systemic weaknesses in administrative enforcement, underscoring the need for stronger institutional mechanisms and clearer regulatory standards within the EIA framework.

VII. FUTURE DIRECTIONS AND RECOMMENDATIONS

To enhance the effectiveness and credibility of the Environmental Impact Assessment (EIA) framework in India, several strategic measures and policy interventions are essential. These recommendations aim to address persistent challenges in **report quality, participatory processes, regulatory compliance, and institutional capacity**.

7.1. Strengthening Scientific Quality and Independence of EIA Reports:

The reliability of EIA reports can be improved by ensuring **rigorous baseline data collection, use of standardized scientific methodologies, and independent review mechanisms**. Reducing dependence on project proponents' consultants and promoting engagement of third-party accredited experts can enhance objectivity, credibility, and technical robustness of environmental assessments.

7.2.Enhancing Public Participation:

Meaningful public participation is critical for transparency, accountability, and environmental justice. Strategies to strengthen this component include:

- Providing **timely access to project information** in local languages and accessible formats.
- Expanding **digital platforms** for submission of public comments.
- Conducting **capacity-building and awareness programs** for local communities.
- Ensuring representation of **indigenous and vulnerable groups** in consultation processes.

7.3. Improving Post-Clearance Monitoring and Enforcement:

Effective monitoring and compliance mechanisms are essential for translating EIA recommendations into real-world environmental outcomes. This can be achieved through:

- Strengthening **institutional capacity** of central and state regulatory authorities.
- Leveraging **digital monitoring systems**, remote sensing, and real-time reporting.
- Enforcing **strict penalties** for non-compliance and periodic audit of mitigation measures.

7.4. Institutional and Regulatory Reforms:

Future reforms should aim to balance **developmental priorities with environmental protection** by:

- Clarifying legal provisions regarding exemptions and post-facto clearances.
- Standardizing procedures across states to reduce uneven implementation.
- Promoting **inter-agency coordination** between MoEFCC, SEIAAs, and sectoral regulators.

7.5. Promoting Transparency and Accountability:

Transparency can be enhanced through:

- Publicly accessible **EIA databases** with comprehensive project reports and clearance conditions.
- Regular reporting on **compliance status, environmental violations, and mitigation outcomes.**
- Encouraging **independent audits and civil society oversight** to build public trust.

By adopting these measures, India's EIA framework can evolve into a more **predictable, participatory, and scientifically rigorous system**, capable of effectively integrating environmental considerations into the developmental planning process while safeguarding ecological sustainability and social equity.

VIII. CONCLUSION

Environmental Impact Assessment (EIA) has emerged as a **cornerstone of sustainable development in India**, providing a systematic and legally backed mechanism to evaluate the environmental consequences of proposed projects before implementation. Since its formal adoption under the **EIA Notification, 2006**, the process has sought to integrate environmental considerations into planning and decision-making, ensuring that developmental activities are aligned with ecological sustainability. The legal framework, underpinned by the **Environment (Protection) Act, 1986**, combined with the role of judicial bodies such as the **Supreme Court** and the **National Green Tribunal (NGT)**, has established EIA as a critical instrument for promoting preventive environmental governance and safeguarding public interest.

Despite these achievements, the EIA system in India continues to face **significant challenges**. The quality and credibility of EIA reports often remain questionable due to inadequate baseline data, limited scientific rigor, and potential conflicts of interest arising from project proponents' involvement. Public participation, a key pillar of environmental justice, is frequently constrained by procedural limitations, lack of access to information, and socio-economic or linguistic barriers. Moreover, regulatory amendments and procedural relaxations have sometimes diluted

environmental safeguards, while weak post-clearance monitoring has undermined the enforcement of mitigation measures, reducing the EIA process to a formalistic exercise in some cases.

Addressing these challenges requires a **multi-pronged approach**. Strengthening the scientific quality and independence of EIA reports, ensuring meaningful stakeholder engagement, and improving post-clearance monitoring and enforcement are critical. Institutional capacity building, digitalization of EIA processes, and transparent public disclosure of project information can further enhance accountability and credibility. Additionally, continuous judicial oversight and adaptive reforms are necessary to maintain the balance between developmental priorities and environmental protection.

In conclusion, while India's EIA framework provides a **robust statutory and procedural foundation**, its effectiveness depends on **consistent implementation, vigilant oversight, and continuous evolution** in response to emerging environmental and developmental challenges. By addressing systemic weaknesses and fostering a culture of transparency, scientific rigor, and participatory governance, EIA can fulfill its promise as a **dynamic and effective tool for sustainable development**, ensuring that economic growth proceeds in harmony with ecological integrity and social equity.

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CONFLICT OF INTEREST

The authors declare that we have no conflict of interest.

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The Convergence of Supply Chain Management and Artificial Intelligence: Challenges and Opportunities

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Abstract *— Artificial Intelligence (AI) is rapidly transforming the architecture and performance of global supply chains. The convergence of data-rich operations with machine learning (ML), reinforcement learning (RL), and generative large language models (LLMs) enables unprecedented levels of automation, foresight, and adaptability in supply chain management (SCM). This paper synthesizes recent literature (2023–2025) to examine how AI technologies reshape core SCM functions, forecasting, inventory optimization, logistics routing, procurement, and risk management, while identifying the governance and organizational challenges that shape adoption outcomes. Findings indicate that AI integration delivers measurable efficiency and resilience gains but also introduces new risks related to data interoperability, explainability, cybersecurity, and ethical governance. A governance-first operating model is proposed, emphasizing transparency, human oversight, and regulatory compliance as key enablers of sustainable AI deployment. The study concludes with a phased implementation roadmap and a future research agenda focused on responsible, interdisciplinary innovation at the intersection of AI and SCM.*

Keywords *— **Artificial Intelligence, Supply Chain Management, Machine Learning, Digital Twins, Governance, Resilience, Large Language Models, Responsible AI***

I. INTRODUCTION

Global supply chains have become increasingly data-rich and decision-intensive in the era of Industry 4.0. The exponential growth in data from enterprise systems, IoT sensors, and partner integrations has made supply chain management (SCM) a prime domain for artificial intelligence (AI) adoption (Culot et al., 2024). Advances in machine learning (ML), including time-series forecasting, reinforcement learning, and, more recently, large language models (LLMs), have redefined the frontier of real-time decision-making in planning, logistics, and procurement (Cannas et al., 2024; Daios et al., 2025).

Systematic reviews published in 2024–2025 reveal accelerating integration of AI in demand forecasting, inventory optimization, logistics routing, procurement, and risk management. These studies consistently report measurable performance gains compared with traditional heuristic and statistical methods (Douaioui et al., 2024; Aamer, 2020). For instance, ML-based demand forecasting can reduce mean absolute percentage error (MAPE) by 15–30% compared to conventional autoregressive models (Douaioui et al., 2024), while AI-enabled logistics routing can improve fleet utilization and reduce fuel consumption by up to 12% (Cannas et al., 2024).

Despite these benefits, AI adoption in SCM remains constrained by organizational and societal challenges.

Key among these is explainability and trust in model outputs, bias mitigation in supplier or customer segmentation, interoperability across legacy systems, and compliance with emerging cybersecurity and AI governance regulations (Wellbrock et al., 2025). As such, the convergence of SCM and AI is not purely a technical transformation but a broader management, governance, and ethical challenge that requires careful alignment between data science, operations strategy, and policy frameworks (Simchi-Levi et al., 2025).

II. METHODOLOGY: SYSTEMATIC LITERATURE SYNTHESIS

This study employs a systematic literature synthesis approach to consolidate current research and practice on the convergence of AI and supply chain management. The method follows the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines, adapted for qualitative research synthesis.

Search and Selection:

Peer-reviewed publications from 2020–2025 were retrieved from databases including *ScienceDirect*, *MDPI*, *Taylor & Francis*, and *SpringerLink*. Search terms combined "artificial intelligence," "machine learning," "supply chain," "forecasting," "digital twin," "risk management," and "large language models."

Inclusion Criteria:

Studies were included if they (a) addressed AI applications in at least one SCM function, (b) were published in English, and (c) provided empirical results or conceptual frameworks. Exclusion criteria removed purely technical papers lacking managerial or governance relevance.

Analysis:

A thematic coding process identified recurring patterns across 73 qualified studies, grouped into five categories: (1) forecasting and planning, (2) logistics and control, (3) interoperability and data governance, (4) AI ethics and regulation, and (5) emerging generative-AI applications. The synthesis informed both the opportunity mapping and the governance model proposed later in this paper.

III. CONCEPTUAL FRAMEWORK: THE AI–SCM CONVERGENCE MODEL

To visualize how AI interacts with SCM functions, this paper introduces the AI–SCM Convergence Model (Figure 1). The model conceptualizes supply-chain intelligence as a multi-layered ecosystem where -

1. Data Infrastructure Layer integrates IoT, ERP, and external data through interoperable standards (e.g., EPCIS 2.0).
2. AI Analytics Layer applies predictive (ML/DL), prescriptive (RL), and generative (LLM) models to decision domains such as forecasting, logistics optimization, and supplier management.
3. Governance and Ethics Layer ensures model explainability, bias mitigation, cybersecurity, and regulatory alignment (e.g., EU AI Act, NIST AI RMF).
4. Human–AI Collaboration Layer places human planners as overseers, interpreters, and decision validators, ensuring accountability and adaptive learning.

This framework emphasizes that value emerges not from AI automation alone but from the interaction between data, algorithms, governance, and human insight. It highlights feedback loops among prediction, decision, and learning, positioning governance as the central integrative force.

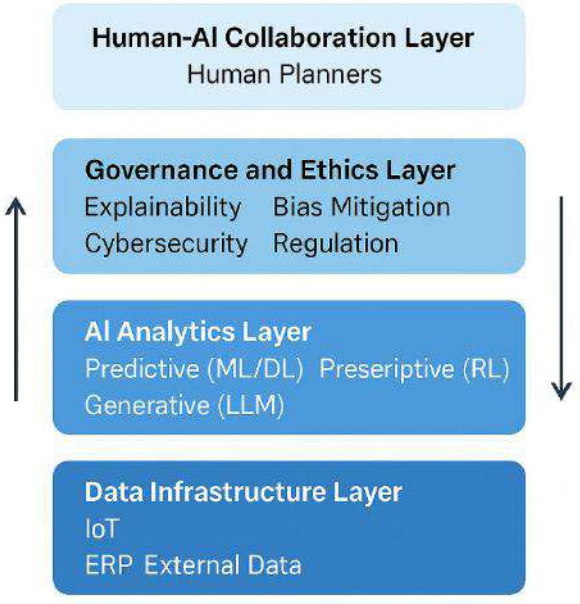

Fig.1. AI–SCM Convergence Model

IV. BACKGROUND: WHERE AI TOUCHES THE SUPPLY CHAIN

4.1 Forecasting and Planning

Forecasting is one of the most mature and high-impact applications of AI in supply chain management (SCM). Modern reviews demonstrate that machine learning (ML) and deep learning (DL) models—such as gradient boosting, long short-term memory (LSTM), and Transformer architectures—outperform traditional methods like ARIMA and exponential smoothing, especially when external (exogenous) data sources are integrated (Douaioui et al., 2024). These models capture nonlinear relationships between variables such as promotions, seasonality, and macroeconomic trends, leading to significantly improved forecast accuracy. Douaioui et al. (2024) conducted a comprehensive review of ML and DL models for demand forecasting and found that hybrid models integrating temporal features and external covariates yielded an average 15–30% improvement in Mean Absolute Percentage Error (MAPE) over statistical baselines. Similarly, Gabellini et al. (2024) applied deep neural networks using macroeconomic indicators to predict delivery-delay risks in automotive supply chains, achieving higher precision and recall compared to conventional regression models. These findings suggest that the integration of AI-based forecasting models contributes directly to service-level improvement, inventory reduction, and planning accuracy.

4.2 Execution and Control

AI is increasingly integral to the execution and control layers of the supply chain, especially through the use of digital twins (DTs). Digital twins are virtual representations of physical assets, systems, or processes that are continuously updated with real-world data through IoT telemetry and simulation models. They enable real-time visibility, predictive maintenance, and "what-if" scenario analysis (Roman et al., 2025). In a systematic review, Roman et al. (2025) found that digital twins, when combined with AI, enhance operational resilience by simulating supply network disruptions before they occur. Similarly, Guo (2025) emphasizes the role of DTs in lean supply-chain management, demonstrating how AI-enhanced simulations improve production planning, bottleneck detection, and capacity utilization. These studies underline how AI-driven digital twins transform execution systems from static monitoring dashboards to dynamic, decision-support platforms capable of adaptive reconfiguration in response to external shocks.

4.3 End-to-End Visibility

End-to-end visibility is foundational for AI integration in SCM. Without standardized, interoperable event data, even the most advanced AI systems lack reliable input. The GS1 EPCIS 2.0 (Electronic Product Code Information Services) standard enables companies to capture and share supply-chain event data, what, when, where, and why an event occurred, across organizational boundaries (GS1, 2022). EPCIS 2.0 builds a unified data layer upon which AI algorithms can learn and act. By providing consistent vocabulary for events (e.g., object identification, transformation, aggregation), this standard facilitates AI applications in traceability, anomaly detection, and sustainability reporting (GS1 US, n.d.). According to GS1 (2022), such visibility supports not only compliance and transparency but also predictive and prescriptive analytics—AI can, for instance, anticipate disruptions and autonomously suggest alternative logistics routes or suppliers.

4.4 LLMs in Operations

Large Language Models (LLMs) and generative AI represent the newest frontier in SCM applications. Beyond forecasting and control, LLMs are being used to translate natural-language business intents into mathematical optimization tasks. For example, supply planners can prompt an LLM-based system with "optimize next week's shipment plan given a 20% increase in demand," and the model can interpret the command, query relevant databases, and generate prescriptive outputs (Simchi-Levi et al., 2025). Daios et al. (2025) describe how generative AI and LLMs are transforming SCM operations by automating information synthesis, report generation, and scenario analysis. Early evidence suggests that integrating LLMs with planning systems can compress decision cycles from days to minutes, while improving interpretability and human-AI collaboration (Menache et al., 2025). Although challenges remain, such as hallucination risk and limited domain-specific grounding, LLMs are expected to become integral

components of AI-enabled supply-chain control towers.

V. OPPORTUNITIES AT THE SCM–AI FRONTIER

5.1 Predictive and Prescriptive Planning

The integration of AI in supply chain planning creates measurable advantages in forecasting accuracy, resource utilization, and overall responsiveness. Modern supply chains are shifting from reactive to predictive and prescriptive modes of decision-making through the use of machine learning (ML) and deep learning (DL) models. According to Culot, Nassimbeni, and Orzes (2024), AI-driven forecasting and optimization tools outperform traditional statistical methods, particularly when exogenous variables such as promotions, weather, and market indices are included. Douaioui et al. (2024) demonstrated that hybrid ML-DL forecasting models can reduce forecasting error (MAPE) by up to 30 percent relative to ARIMA and exponential smoothing models. These improvements cascade downstream to inventory optimization, production scheduling, and replenishment accuracy. In addition, Cannas et al. (2024) identified that prescriptive analytics systems—built on reinforcement learning and simulation—enable dynamic, data-driven adjustments to procurement and logistics strategies, generating significant cost reductions and service-level improvements. Together, these findings point to a structural opportunity: predictive AI enhances foresight while prescriptive AI transforms insight into near-autonomous action, resulting in faster, more reliable planning cycles.

5.2 Digital Twins for Resilience

AI-enabled digital twins (DTs) represent a transformative tool for enhancing supply-chain resilience and agility. A digital twin is a virtual representation of a supply network that continuously ingests IoT telemetry and operational data to mirror real-world processes (Roman et al., 2025). This digital mirror allows planners to simulate "what-if" scenarios—such as port closures, supplier disruptions, or demand surges—and evaluate their impacts before they occur in reality (Guo, 2025). Empirical research shows that integrating AI with DTs improves disruption response time and network efficiency. Sunmola et al. (2024) found that AI-driven DTs enabled early detection of supply shocks and optimized resource reallocation in a semiconductor supply-chain case study. The convergence of AI, simulation, and IoT data thus empowers proactive risk management, continuous learning, and system-wide optimization—key pillars of resilient supply-chain design.

5.3 Generative AI and LLM Copilots

Generative AI and large language models (LLMs) mark a new era in SCM decision-support. These systems can interpret natural-language business intents and translate them into executable optimization or simulation models (Simchi-Levi et al., 2025). For example, a planner can request "generate a replenishment plan minimizing transport cost under 95 % service level constraints," and the LLM can produce solver-ready formulations or data-driven recommendations (Menache et al., 2025). According to Daios, Papaioannou, and Koukoumialos (2025), LLM copilots improve knowledge retrieval, automate reporting, and assist in supply-planning and procurement decisions by synthesizing structured and unstructured data. Early case studies show that organizations implementing generative-AI copilots reduced planning-cycle times by up to 60 percent while maintaining or improving key operational metrics (Aghaei et al., 2025). These findings highlight the potential for human-AI collaboration to increase agility and cognitive capacity in complex global supply networks.

5.4 Real-World Momentum

Industrial adoption of AI in supply-chain operations is accelerating. Foxconn, for example, launched "FoxBrain," a domain-specific large language model designed to optimize manufacturing and logistics decisions in real time (Reuters, 2025). Similarly, multinational retailers and manufacturers are embedding AI copilots into their control-tower systems to automate routine exception handling, inventory balancing, and scenario forecasting (Menache et al., 2025). Such deployments underscore a key insight: the convergence of SCM and AI is not only improving operational efficiency but also redefining competitive advantage through speed, resilience, and decision quality.

VI. STRUCTURAL CHALLENGES

6.1 Data Readiness and Interoperability

A fundamental challenge in integrating AI into supply-chain management (SCM) is data readiness, including completeness, quality, and interoperability across partners. Most AI models require extensive, high-granularity, and standardized data streams to function effectively, yet global supply chains remain characterized by siloed enterprise resource planning (ERP) systems and inconsistent event-logging practices (Culot et al., 2024). Zhu, Xin, and Trinh (2025) identified persistent data-quality issues such as latency, inconsistency, and missing event metadata, showing that even minor degradation (≈ 5 %) in data accuracy can reduce AI-model performance by up to 20 %. Likewise, the Brookings Institution (2022) emphasizes that "data quality, availability, interoperability, and immediacy" are central barriers to building shared visibility across multi-tier supply chains. Adoption of global interoperability standards such as GS1 EPCIS 2.0 mitigates some of these challenges by defining event semantics (what, where, when, why) that AI systems can learn from consistently. However, aligning legacy infrastructures to these standards remains costly and time-consuming.

6.2 Explainability, Bias, and Fairness

As AI systems increasingly influence procurement, routing, and capacity decisions, explainability and bias mitigation emerge as core governance requirements. Highly complex neural-network models, though accurate, often behave as "black boxes," limiting user trust and accountability (Kosasih et al., 2023). In a review of explainable-AI (XAI) applications in SCM, Kosasih et al. (2023) found that lack of interpretability remains a major reason firms hesitate to deploy AI in operational planning. Furthermore, bias in training data can reinforce historical inequities, such as favoring large or incumbent suppliers (Wellbrock et al., 2025). Without transparency and fairness audits, AI adoption may inadvertently undermine ethical sourcing and diversity goals. Explainable-AI techniques (e.g., SHAP, LIME, counterfactual reasoning) and neuromyotonic architectures are therefore critical to ensuring that SCM decision models remain accountable and interpretable.

6.3 Cybersecurity and Regulatory Exposure

As digital supply chains become hyper-connected, cybersecurity and regulatory exposure intensify. Every new API, sensor, or AI model endpoint broadens the attack surface for cyber threats (SupplyChainBrain, 2023). According to the same analysis, smart supply-chain infrastructures must balance automation benefits with stronger data-integrity and authentication mechanisms. On the regulatory front, multiple frameworks are converging on AI oversight. The EU Artificial Intelligence Act (2024) introduces obligations for high-risk AI systems, including those in critical-infrastructure and logistics sectors, mandating continuous risk-management and transparency (European Commission, 2024). In the United States, the SEC Cybersecurity Disclosure Rule (2023) requires publicly traded firms to report material cyber incidents within four business days—directly affecting AI-enabled control-tower systems that rely on external data feeds (U.S. Securities and Exchange Commission, 2023). Consequently, secure AI architecture, regulatory compliance, and robust incident-response planning have become integral to sustainable SCM digitalization.

6.4 Talent, Operating Model, and Change Management

Even when data and technology are in place, organizational readiness can limit AI success. Many firms face shortages of professionals proficient in both SCM processes and data science (Raj, 2024). Functional silos and legacy thinking impede the cross-functional collaboration necessary for AI adoption. AI integration changes traditional planner roles from manual execution to policy-design and exception-management. Without structured change-management programs and continuous training, human-AI collaboration may fail to deliver expected performance improvements (Wellbrock et al., 2025). As Cannas et al. (2024) note, aligning AI capabilities with organizational culture and incentives is as critical as the underlying algorithms.

VII. A GOVERNANCE-FIRST OPERATING MODEL

7.1 Overview

As AI adoption accelerates across supply-chain functions, the need for robust governance grows

correspondingly. Without structured oversight, even high-performing algorithms can produce biased, insecure, or non-compliant outcomes. A governance-first operating model therefore treats AI not merely as a technology stack but as a regulated socio-technical system that aligns data, algorithms, and human judgment within transparent boundaries (NIST, 2023; European Commission, 2024). This model requires organizations to institutionalize clear policies for data provenance, model development, validation, deployment, and post-deployment monitoring, each governed by explicit accountability structures.

7.2 Data and Interoperability Foundations

Effective governance begins with **trusted data**. The GS1 EPCIS 2.0 standard provides a common event-level vocabulary enabling cross-partner data exchange, critical for AI training and traceability (GS1, 2022). EPCIS defines the *what*, *where*, *when*, and *why* of product events, forming a foundation for end-to-end analytics and automated decision-making. Organizations adopting EPCIS 2.0 in tandem with internal data-governance frameworks such as ISO/IEC 38507:2022 (IT Governance of AI) can harmonize operational data with compliance requirements (ISO, 2022). This dual alignment ensures that AI models operate on accurate, interoperable, and ethically sourced data.

7.3 AI Risk-Management Frameworks

The NIST AI Risk Management Framework (RMF 1.0) offers a structured model built around four core functions—Govern, Map, Measure, Manage—that translate abstract AI risks into operational controls (NIST, 2023).

- Govern: Define AI roles, responsibilities, and documentation standards.
- Map: Identify and categorize AI use cases based on risk exposure and potential impact.
- Measure: Evaluate model performance, explainability, fairness, and cybersecurity.
- Manage: Continuously monitor AI systems, retrain when drift occurs, and enforce accountability mechanisms.

When combined with supply-chain quality-management systems (e.g., ISO 9001:2015), the NIST AI RMF enables AI initiatives to meet both performance and compliance objectives.

7.4 Regulatory Alignment and Compliance

Globally, regulatory frameworks are converging on risk-based AI governance. The EU Artificial Intelligence Act (Regulation (EU) 2024/1689) classifies supply-chain-related AI systems—such as logistics optimization, predictive maintenance, and quality inspection—as *high-risk* applications subject to stringent obligations, including data-governance, transparency, and human oversight requirements (European Commission, 2024). In the U.S., the SEC Cybersecurity Disclosure Rule (2023) obliges publicly traded companies to report material cybersecurity incidents, encompassing AI-related breaches that could affect supply-chain continuity (U.S. Securities and Exchange Commission, 2023). Adopting a governance-first model ensures compliance readiness under both regimes by integrating AI documentation, audit trails, and impact assessments into everyday SCM processes.

7.5 Security-by-Design

Embedding security into the AI lifecycle—Security-by-Design—is another pillar of governance. Secure data pipelines, encrypted model endpoints, and strict access controls reduce vulnerability to cyberattacks (SupplyChainBrain, 2023). Organizations should perform *threat modeling* for AI components (models, APIs, digital-twin interfaces) and apply *adversarial testing* to detect data poisoning or model manipulation (CISA, 2024). The combination of AI-specific and traditional IT controls strengthens both resilience and regulatory posture.

7.6 Human-AI Collaboration and Accountability

A governance-first framework mandates human oversight throughout the AI lifecycle. Humans remain accountable for critical supply-chain decisions, while AI serves as a decision-support system rather than a decision-maker. Menache et al. (2025) and Simchi-Levi et al. (2025) argue that planners should evolve into *scenario curators* who interpret model outputs, question anomalies, and apply contextual judgment before execution. Clear audit logs and explainability dashboards enable accountability when outcomes deviate from expected performance.

7.7 Implementation Roadmap

A pragmatic implementation approach can be structured into three phases:

1. Foundation (0–3 months):
    - Conduct AI and data-governance audits.
    - Identify priority AI use cases and map them to NIST RMF categories.
    - Begin EPCIS 2.0 event data integration for key suppliers.
2. Operationalization (3–9 months):
    - Establish AI oversight committees and model-validation protocols.
    - Integrate explainability tools (e.g., SHAP, LIME) for high-impact models.
    - Initiate staff training in ethical AI and change management.
3. Institutionalization (9–18 months):
    - Conduct third-party audits for compliance (EU AI Act or ISO standards).
    - Implement continuous monitoring, retraining, and bias-mitigation loops.
    - Develop transparency reports for internal and external stakeholders.

VIII. IMPLEMENTATION ROADMAP (12–18 MONTHS)

Translating a governance-first strategy into measurable outcomes requires a phased roadmap that balances experimentation with compliance. Successful implementations of AI-enabled supply-chain systems emphasize incremental rollout, cross-functional collaboration, and continuous evaluation against both performance and ethical benchmarks (Culot et al., 2024; NIST, 2023).

8.1 Phase 1 – Foundations (0–3 Months)

Objectives: Establish structural readiness, baseline governance, and data interoperability.

- AI Governance Audit: Assess the maturity of existing AI and data-management processes relative to the *NIST AI RMF* (NIST, 2023). Identify high-risk or opaque models in forecasting, procurement, and logistics.
- Data Inventory and Standardization: Conduct a gap analysis for EPCIS 2.0 adoption, focusing on event-level capture of "what, where, when, and why" across internal systems (GS1, 2022).
- Ethics and Compliance Setup: Align internal policies with ISO/IEC 38507:2022 and the EU AI Act (2024) to define accountability, documentation, and human-oversight protocols (ISO, 2022; European Commission, 2024).

Expected Outcomes:

- A clear inventory of AI assets and associated risks.
- A standardized event schema ready for integration with partner systems.
- A defined ethical and regulatory governance framework.

8.2 Phase 2 – Pilot and Scale (3–9 Months)

Objectives: Deploy controlled pilots and embed monitoring mechanisms.

- Pilot Use Cases: Launch AI pilots in demand forecasting or inventory optimization to validate improvements in forecast accuracy, service level, and cost metrics (Douaioui et al., 2024).
- Digital Twin Deployment: Implement a limited-scope digital-twin model for a production line or logistics corridor, integrating IoT telemetry and reinforcement-learning controls (Roman et al., 2025).
- Explainability Tools: Integrate SHAP or LIME frameworks to evaluate model transparency and document decision pathways (Kosasih et al., 2023).
- Workforce Training: Introduce upskilling programs in data literacy, bias recognition, and model-interpretation for planners and procurement professionals (Raj, 2024).

Expected Outcomes:

- Verified performance uplift (e.g., > 15 % reduction in forecast error).
- Operational proof-of-concept for real-time digital-twin analytics.
- Trained personnel capable of auditing AI decisions.

8.3 Phase 3 – Institutionalization (9–18 Months)

Objectives: Expand coverage, embed continuous-improvement loops, and formalize compliance.

- Enterprise-Wide Integration: Extend EPCIS 2.0 event capture to tier-1 suppliers and logistics partners (GS1, 2022).
- Continuous Monitoring: Implement model-drift detection and retraining protocols in accordance with NIST AI RMF "Manage" function (NIST, 2023).
- Independent Audits: Conduct third-party reviews to ensure compliance with the EU AI Act's transparency and human-oversight provisions (European Commission, 2024).
- Sustainability and Reporting: Integrate environmental and social metrics into AI dashboards to align with ESG reporting frameworks (Cannas et al., 2024).

Expected Outcomes:

- Institutionalized AI governance is integrated into SCM processes.
- Continuous assurance of compliance and cyber-resilience.
- Demonstrable improvement in agility, sustainability, and trust.

8.4 Key Success Factors

Empirical and practitioner literature highlights three recurring success determinants:

1. Cross-Functional Leadership: Governance boards combining operations, IT, compliance, and ethics perspectives accelerate adoption while minimizing risk (Menache et al., 2025).
2. Iterative Learning Culture: Regular post-implementation reviews capture lessons and recalibrate algorithms for evolving business contexts (Culot et al., 2024).
3. Stakeholder Transparency: Maintaining explainable logs and transparent performance dashboards builds long-term trust among regulators, partners, and customers (Wellbrock et al., 2025).

IX. RESEARCH GAPS AND FUTURE DIRECTIONS

9.1 Theoretical and Conceptual Integration

Despite rapid technological progress, the theoretical integration of AI within SCM remains underdeveloped. Most empirical studies emphasize technical performance—forecast accuracy, routing efficiency, or cost reduction—without connecting these outcomes to established operations-management theories such as the resource-based view (RBV) or dynamic capabilities framework (Culot et al., 2024; Cannas et al., 2024). Future research should link AI capability maturity to competitive advantage through longitudinal and multi-industry studies. Building conceptual models that integrate AI governance, supply-chain resilience, and organizational learning would help explain why adoption trajectories differ across sectors (Kamble et al., 2024).

9.2 Data Ecosystems and Federated Learning

A persistent limitation is the lack of data sharing across organizational boundaries. Supply-chain data remain fragmented by proprietary standards, privacy concerns, and competitive barriers (Brookings Institution, 2022). Emerging methods such as federated learning (FL)—which allows multiple organizations to train models collaboratively without centralizing data—offer a promising research direction. Recent work by Hsu et al. (2025) shows that FL improves demand-forecasting accuracy by aggregating models across suppliers while maintaining data sovereignty. Yet issues of interoperability, trust, and incentive alignment remain unresolved. Scholars could explore *multi-party computation* and *blockchain-assisted FL* as enablers of secure, collaborative AI ecosystems.

9.3 Explainability, Fairness, and Human-AI Interaction

While progress has been made in explainable AI (XAI) for SCM, challenges persist in aligning explanations with the cognitive needs of planners and executives (Kosasih et al., 2023; Wellbrock et al., 2025). Current research often evaluates explainability quantitatively (e.g., SHAP feature importance), yet qualitative understanding—*how users interpret, trust, and act on explanations*—remains underexplored. Future studies should combine human-factors research with model-

governance frameworks to assess the behavioral impacts of AI transparency. Experimental research could also investigate how AI-augmented decisions influence negotiation, collaboration, and ethical trade-offs within global supply networks.

9.4 Generative AI and Cognitive Automation

The surge of Generative AI (GenAI) and Large Language Models (LLMs) introduces new possibilities for *cognitive automation* in supply chains. Early pilots show that LLMs can synthesize unstructured data, automate documentation, and support decision reasoning (Simchi-Levi et al., 2025; Menache et al., 2025). However, these systems face risks of hallucination, context loss, and bias amplification. Current literature lacks rigorous benchmarks for evaluating GenAI models in SCM contexts (Aghaei et al., 2025). Future research should establish performance metrics beyond accuracy—such as reliability, interpretability, and ethical compliance—and design domain-specific foundation models grounded in verified industrial data.

9.5 Sustainability and Responsible AI

Although AI promises efficiency, its alignment with sustainability and responsible innovation is insufficiently studied. Few works quantify AI's contribution to reducing carbon intensity, waste, or social inequities in supply chains (Douaioui et al., 2024). As regulators increasingly emphasize ESG reporting, future research must examine how AI can operationalize sustainability goals—by optimizing multimodal logistics for emissions, predicting supplier non-compliance, or integrating circular-economy analytics (Cannas et al., 2024). Moreover, responsible AI frameworks must account for *global asymmetries*—such as how small and medium enterprises (SMEs) in emerging markets can adopt AI equitably without being disadvantaged by data scarcity or algorithmic bias (Wellbrock et al., 2025).

9.6 Longitudinal Validation and Causal Inference

Most existing SCM–AI studies are cross-sectional and limited to single firms or short-term data (Daios et al., 2025). The absence of longitudinal and causal-inference designs restricts understanding of AI's sustained impact. Future work should employ panel-data econometrics, causal discovery, or digital-twin simulations over extended horizons to capture dynamic feedback between AI deployment and supply-chain performance. Mixed-method approaches that triangulate quantitative model metrics with qualitative organizational insights will yield richer, policy-relevant conclusions.

9.7 Toward a Multi-Disciplinary Research Agenda

The convergence of AI and SCM calls for interdisciplinary collaboration among computer scientists, operations researchers, ethicists, and policymakers. Future research agendas should integrate:

- Technical disciplines: federated learning, reinforcement learning, generative AI.
- Organizational sciences: change management, knowledge diffusion, human-AI interaction.
- Governance frameworks: NIST AI RMF, EU AI Act, ISO 38507, and EPCIS interoperability standards.

A multi-disciplinary approach will ensure that SCM–AI systems are not only *intelligent* but also *responsible, secure, and socially aligned*.

X. CONCLUSIONS

The convergence of artificial intelligence and supply chain management marks a new era of intelligent, data-driven operations. AI technologies now underpin every layer of the modern supply chain—from forecasting and logistics to procurement, risk mitigation, and sustainability. Organizations that effectively integrate AI gain sharper visibility, faster decision cycles, and greater resilience in the face of volatility. However, success depends on more than technology. Data quality, interoperability, cybersecurity, and human expertise remain critical enablers. Without proper governance and ethical oversight, AI can amplify risks rather than reduce them. A governance-first approach, anchored in transparency, accountability, and continuous learning, offers the clearest path forward. Companies that pair innovation with responsibility will not only optimize performance but also build supply chains that are adaptive, sustainable, and trusted. In due course, the future of supply chain excellence lies in harmonizing human judgment with artificial intelligence, combining analytical precision with

strategic foresight to create truly intelligent global networks.

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