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2021 5th Annual Systems Modelling Conference (SMC) | 978-1-6654-3815-5/21/$31.00 ©2021 IEEE | DOI: 10.1109/SMC53803.2021.9569924

2021 5th Annual Systems Modelling Conference (SMC) | 978-1-6654-3815-5/21/$31.00 ©2021 IEEE | DOI: 10.1109/SMC53803.2021.9569904

2021 5th Annual Systems Modelling Conference (SMC)

Reset, Ready, Go: Co-design the future through modelling

Canberra, Australia

September 14-15, 2021

ISBN: 978-1-6654-3815-5

2021 5th Annual Systems Modelling Conference (SMC)

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IEEE Part Number: CFP21SMJ-ART

ISBN: 978-1-6654-3815-5

ISBN: 978-1-6654-3815-5

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ISBN: 978-1-6654-3815-5

2021 5th Annual Systems Modelling Conference (SMC) | 978-1-6654-3815-5/21/$31.00 ©2021 IEEE | DOI: 10.1109/SMC53803.2021.9569950

A Qualitative Analysis for Implementing Supply Chain Risk Management Practices in Bangladesh in the Event of Earthquake

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***Abstract*— While Bangladesh is a developing nation, the country's economy regularly suffers in the aftermath of a natural disaster, such as an earthquake, due to the significant number of severe deaths and economic destruction. Bangladesh's supply chain management framework, notably in the services industry, is insufficient. The study's goal is to portray a scenario in which an earthquake destroys both the economy and the people of Bangladesh. However, the country's building industry is rapidly increasing. This research aims to analyze the application of supply chain risk management and its implementation in Bangladesh. This research studied and highlighted difficulties in handling the present earthquake situation in Bangladesh at all phases of operation. In addition, the methodology used to answer the research question is mentioned. It is also intended to create and maintain an effective earthquake emergency supply chain. A systematic SWOT (Strength, Weakness, Opportunities and Threat) analysis was conducted to understand better and obtain a real scenario of supply chain management in Bangladesh and how one may use this method and tackle the issues. The article also emphasizes the limits and offers a way for overcoming them. The purpose of this study is to assist policymakers in selecting this criterion for establishing advanced supply chain risk management to minimize damage to people and the economy. The study's limitations and future research directions are explored to create a fast, risk-free Bangladesh.**

Keywords—Supply Chain Risk Management, Qualitative, Model, Bangladesh, Earthquake, Supply Chain etc.

I. Introduction

Bangladesh, with approximately 152 million inhabitants, is the world's eighth-most populated area, accounting for 2.16 percent of the total worldwide population [1]. Bangladesh is at greater risk of moderate to severe earthquakes, and an earthquake with a magnitude greater than seven on the Richter scale in the Bay may have significant effects [2]. Several major and small earthquakes have impacted Bangladesh in recent years. Earthquake resistance is one of the most difficult issues in construction engineering. Years of research have given a variety of solutions for earthquake tolerance, as total safety is not possible. There are some dangers associated with the result of every earthquake. So, if we include the supply chain in our design, we can minimize damages.

Yet, not all supply chains face the same constraints. Achieving supply chain resilience must implement risk management efforts to control supply chain operations via continual risk assessment and vulnerability reduction [3].

There are several problems and dangers associated with global supply chains [4], [5], [6]. The quantitative methods of Supply Chain Risk generally employ one of two approaches: (i) evolving conventional assets or supplying prototypes to compensate for the probability of supply problems, or (ii) improving game-theoretic prototypes to investigate the interconnected decision making between providers and industries [7].

Recently supply chain risk management has gained the attention of practitioners and academicians. Several studies have addressed supply chain risk management aspects [8]. Ref. [9] claiming that identifying risks is the first step in developing a risk management strategy. According to ref. [10], while the discipline of supply chain risk management (SCRM) has grown alongside the main field of supply chain management (SCM), there is still very little literature that honestly approaches the topic of supply chain risk identification.

Service Supply Chain is a service network that reshapes many operational entities to meet the needs of consumers by utilizing modern management technology to disintegrate and reconstruct a system [11].

There are examples of supply chain management being used on a small scale in the manufacturing industry. The service industry is gradually becoming another backbone of the Bangladeshi economy.

This study aims to provide an overview of supply chain risk management and determine how Supply Chain Management may be applied for earthquakes. Assessing its applicability in Bangladesh, as well as identifying its limitations and proposing some solutions. The technique used to answer the research question is outlined in the next section. The limitations of this study, as well as future research guidelines, are discussed.

II. Research Questions

1. Why does Bangladesh require Supply Chain Risk Management in the event of an earthquake?

2. How much would the idea of earthquake risk management via supply chain activities minimize earthquake hazards?

3. What issues may limit Supply Chain Risk Management methods in Bangladesh?

4. How can the practice of Supply Chain Risk Management assist in the reduction of earthquake risk in Bangladesh?

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III. RESEARCH OBJECTIVES

The study's main objective is to overview Supply Chain Risk Management practices for the earthquake in Bangladesh. However, the specific objectives of the study are:

• To explore to see how Supply Chain Risk Management can be implemented for earthquakes and its suitability check-in Bangladesh;

• To find out the challenges of Practices of Supply Chain Risk Management for the earthquake in Bangladesh;

• To provide some recommendations based on findings.

IV. LITERATURE REVIEW

Supply chain risk may be divided into various areas, and best practices for construction can be reviewed or recommended to minimize and prepare for potential interruptions. There are four supply chain risks: supplier-side risk, demand-side risk, operational risk, and security or catastrophic risk [12]. The purpose of this article is to discuss catastrophe risk or significant disruptions caused by earthquakes, which can cause disturbances in life and the economy.

Supply chain risk management has received a lot of attention as one of the most effective ways to reduce catastrophe consequences [13]. The dynamics, hazards, and uncertainties of catastrophes and operations are part of supply chain risk management [14]. Reliability is a critical component of the supply chain. Recently, there has been a considerable rise in the research of supply chain reliability [15]. This article generally defines a feasible supply chain risk management strategy for Bangladesh to minimize the earthquake risk. The articles describe the post-earthquake occurrence, severe maintenance operations, repairing facilities in the event of a physical disruption, and steps to recover from the disruption.

V. METHODOLOGY

Research methodology is an approach that guides researchers via the research process. This paper addresses literature reviews as a research approach and outlines many Supply Chain Risk Management reviews. This study aims to provide an overview of the research topic and monitor its evolution through time. This paper's sample characteristics are Specific research papers and research questions. The analysis and assessment are qualitative research. The contribution of the issue is made from themes in literature and its perspective. The research method is a study through qualitative analysis, using secondary data collected from journal papers, and internet data sources such as websites of various organizations and catalogues. The gathered data regarding the earthquake in Bangladesh is provided in conclusions, and the collected information about supply chain-related theories is offered in the theoretical model.

VI. KEY CONCEPTS OF SUPPLY CHAIN RISK MANAGEMENT

A. *Supply Chain Risk Management*

Supply chains are growing more complicated than ever before, with numerous new parts being discovered daily. Detailed risk management plans are used to avoid, minimize, or mitigate and control recognized hazards if that is not feasible [16]. Supply Chain Risk Management refers to organized methods and software that will assist a company in rapidly and efficiently adapting to future risks and disasters with supply chain interruptions [17]. Supply chain management aids in loss reduction by recognizing hazards early. It also allows for rapid response to unforeseen occurrences and meets or surpasses laws, regulations, and safety standards [18]. Supply chain risk management is critical, and it should be practiced and implemented more frequently.

B. *Supply Chain Risk Management (SCRM) for the earthquake in Bangladesh*

Bangladesh's system is not very robust, particularly in the services sector. There are examples of supply chain management being used on a small scale in the manufacturing industry [11]. Many concerns affecting the effective operation of this management and the efficient usage of relief have been studied in research studies on emergency supply chain and relief distribution [19], [20]. To mitigate the consequences of the tragedy, global supply chains require a recovery strategy. Modern technologies like radio-frequency identification (RFID), enterprise resource planning (ERP), and general packet radio service (GPRS) can be utilized as SCRM tools [21]. Although the supply chain risk management system has received considerable attention and is widely used globally, it is still not widely used in Bangladesh. Many firms in the industry sector are now interested in adopting supply chain risk management to mitigate risk. Supply chain risk management discipline is critical to preventing economic losses and the loss of many lives. As a result, greater emphasis should be placed on **Supply Chain Risk Management (SCRM),** and knowledge of its use in daily life should increase.

VII. BACKGROUND OF EARTHQUAKE HISTORY IN BANGLADESH

A. *Earthquake Situation and Tectonic Position of Bangladesh:*

Bangladesh is located at the intersection of multiple active sub-duction zones [2]. The Ganges-Brahmaputra delta in Bangladesh results from the convergence of three plates: the Indian plate, the Eurasian plate, and the Burma platelets [22]. The Shilling plateau surrounds the nation to the north, the Indian shield to the west, the Indo-Barman hills to the east, and the Bay of Bengal to the south. [22]. According to [2] Bangladesh is divided into three seismic zones:

Zone I: High Risk - Mymensingh, Sylhet, Rangpur, Lalmonirhat, Kurigram, Rajshahi etc.

Zone II: Moderate Risk- Bogra, Dinajpur, Dhaka, Comilla, Panchgar, Chittagong etc.

Zone III: Low Risk- Khulna, Jessor, Barisal, Patuakhali etc.

B. *The History of the Earthquake in Bangladesh:*

According to [23] and [24], the following Table depicts the history of earthquakes in Bangladesh (TABLE I.):

TABLE I. THE HISTORY OF THE EARTHQUAKE IN BANGLADESH

History of Earthquakes in Bangladesh			
Date	***Region***	***Depth***	***Magnitude***
27/08/2020	North Vanlaiphai, India	10 km	5.3
30/08/ 2020	Khagrachari, Chittagong	38 km	5.1
25/04/2015	Barpak region, Nepal	15 km	7.8
09/10/2010	Narayanganj	16 km	4.8
01/12/2008	Rangamati	47 km	5.0
11/07/2007	Chittagong, Bandarban, Rangamati	21 km	5.1
07/26/2003	Rangamati	17 km	5.7
06/20/2002	Rangpur, Thakurgaon, Almanagar	43 km	4.5
12/19/2001	Dhaka	7 km	4.5
07/22/1999	Maheshkhali Island, Cox's Bazaar	11 km	4.2
06/12/1989	Banaripara	9 km	5.1
02/06/1988	Sylhet; India (Tripura-Assam)	45 km	5.8

The following graph summarizes the TABLE I :

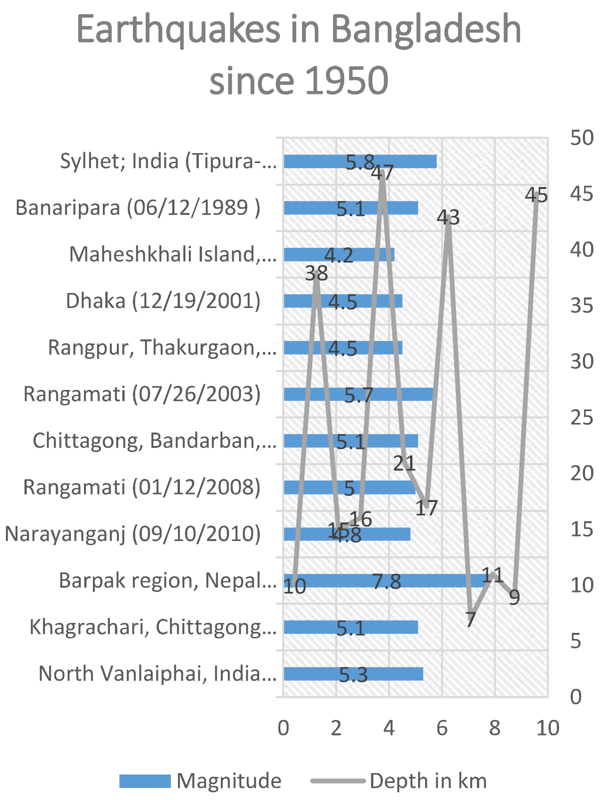

Fig. 1: The History of the Earthquake in Bangladesh.

The graph above (Fig. 1) depicts earthquakes in Bangladesh in increasing order since 1950. The quake's maximum magnitude (7.8) occurred in 2015. Six earthquakes of magnitude 5.0 hit Bangladesh in 2020. The most recent major quake happened on June 21, 2020, near North Vanlaiphai, India.

VIII. SUPPLY CHAIN RISK MANAGEMENT MODEL FOR EARTHQUAKE

Some researches focused on strategic responses, and several others focused on the basic framework of Supply Chain Risk management that can also be considered proactive approaches because the majority are dealing with risks before incidents or accidents occur. So, according to [21], we developed a model and provided specific explanations that will be useful for earthquake supply chain management in Bangladesh. Supply Chain Risk Management Model (Fig. 2) for earthquake comprises of three approaches:

1. Risk Identification;
2. Risk Management;
3. Risk Reduction.

Fig. 2: Supply Chain Risk Management Model for Earthquake.

The details are given below:

1. <u>Risk Identification:</u>

- The installation of the main entrance and exit on the ground level that is not wide enough to allow for worker movement in the workplace.
- Narrow exit gates than required
- Blocked Passages, aisles, corridors, stairways
- No fire door installed
- No exit sign
- Blocked exit gate
- Improperly illuminated exit sign
- Locked collapsible gates on different floors
- The fire door does not swing in the direction of travel
- Lack of necessary gates
- No extra stairs

2. <u>Risk Management:</u>

<u>Response Items</u>

1. Structural components, power lines, gas ovens, mirrors, and glasses pose a threat.

2. Secured location

3. First-aid unit area

4. Contact information for paramedic's organizations

5. Building emergency gate

Pre-earthquake preparedness measures

1. Talking with family members on the warning system (evacuation route).

2. Keeping a first-aid kit at home 3. Keeping a battery-powered functioning flashlight

4. Having a functional radio that runs on batteries

5. Having a hard-surfaced bed and table

6. Having a helmet for each member of the family

Activities to perform immediately after an earthquake

1. Leave the house/apartment as quickly as possible after the first tremor and stay in an open space

2. Put the helmet on and ask everyone else to do so

3. While exiting, ask the neighbours to leave the house/apartment

4. Switch off electric and gas lines and do not make any fire

6. Do not stay close to buildings and electric poles

7. If not able to leave the residence, take refuge in one corner of the house; if the residence is a building with concrete columns take refuge at the bottom of a column

8. If your house is made of tin, take refuge under the bed

9. Heavily loaded demolition disposal management

3. Risk Reduction to improve earthquake preparation and evacuation:

Strategies to Improve Earthquake Preparation

1. Seminars and films about the scientific nature of earthquakes can educate workers.

2. Regular direct training exercises for employees on how to remain peaceful and resolute during earthquakes.

3. Refreshment training sessions may be held all year round by distributing leaflets, posters, banners, and manuals.

4. Evaluation of employees' conduct following each earthquake and its use to improve future performance

5. Each factory should be designed and built with enough gap between it and the next building.

6. Renovation of departure gates per ILO guidelines, building size, and worker count.

7. Each industry should have at least four gates.

8. Design and construction materials must be earthquake resistant.

10. Operating RMG factories in specifically built buildings to ensure maximum compliance

11. Integration of seismic training with continuing fire training

12. Frequent evacuation simulations as needed

13. Ensuring a rapid emergency response to ensure a seamless rescue in the event of an earthquake.

IX. SWOT on Supply Chain Risk Management regarding Earthquake in Bangladesh

SWOT analysis is applied throughout Supply Chain Risk Management in the event of earthquake to identify strengths, weaknesses, risks, and opportunities in management plans. The table (TABLE II) depicts the SWOT analysis of supply chain risk management in the event of earthquake.

TABLE II. SWOT on Supply Chain regarding Earthquake in Bangladesh

SWOT on Supply Chain regarding Earthquake in Bangladesh	**Positive**	**Negative**
	Strength	***Weakness***
Internal Influence	• Long-term benefits are achieved and earthquake risks are optimized. •Any size institution or residential building can make this plan • Creating a plan and taking proper prevention will reduce the economic loss of the country.	• No simple model to maintain. • Training is expensive and time-consuming. • The plan only help to lessen the effect of the hazard, don't prevent the earthquake • Lack of literature on supply chain risk management in the aftermath of an earthquake in Bangladesh.
	Opportunities	*Threats*
External Influence	• The plan can start from the resources available for execution. • The plan will help in adapting with unexpected situations. • The plan will give appropriate assistance to the victims. • The plan will help to achieve effective recovery.	• The strategy will only aid to a limited extent in the event of an earthquake; • Popularity amongst everyone will require several years.

X. Strategies regarding SWOT analysis

According to the analysis of SWOT in Bangladesh, the best-possible strategy can be applied in Supply Chain Risk Management in the earthquake (Fig. 3).

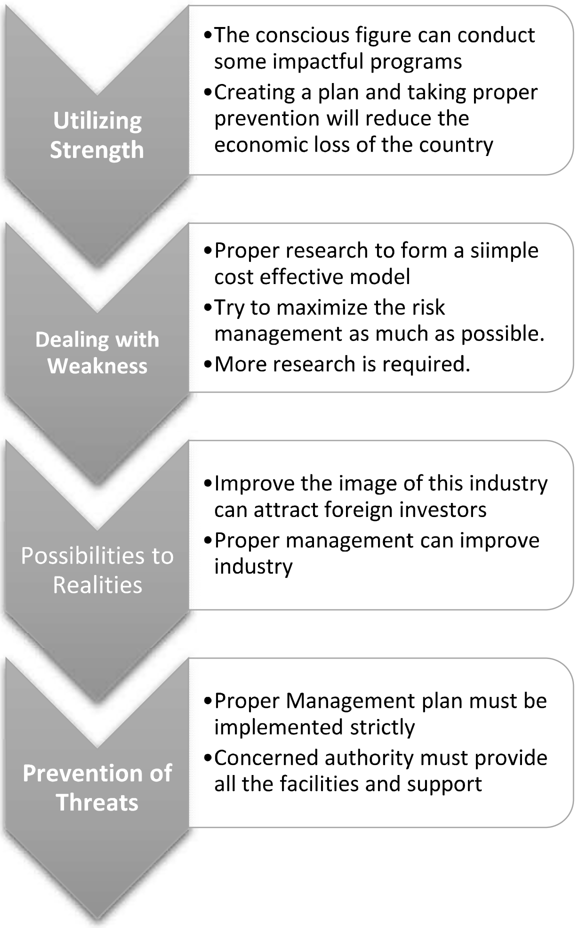

Fig. 3: Strategies regarding SWOT analysis.

XI. Discussion and Future Suggestions

The study's weakness, in our opinion, was the lack of a large body of literature on supply chain risk management in the aftermath of an earthquake in Bangladesh. I believe there is still a lot of room for exploration in the SCRM area. However, as supply chain partnerships have evolved to a more efficient and practical level, complexity and changeability have risen. It is critical for Bangladesh, which relies on a highly collaborative supply chain, to research and uses supply chain risk management. My research was limited to the supply chain interruption induced by the recent earthquake in Bangladesh. In the future, there will be more natural or human-caused disasters. Various calamities may cause new issues in the supply chain system. As a result, the ultimate objective of industries worldwide is to build a robust supply chain system. On the other hand, a robust supply chain is still in the theoretical stage; the challenge for future researchers will be how to bring it into a practice phase to prove the theory's applicability. Another topic for the individuals who follow might be to separate supply chain risk management into particular catastrophes or hazards.

Suggestions:

1. Making primary earthquake risk management knowledge compulsory;

2. Making future construction earthquake-proof;

3. To make existing buildings earthquake-proof as much as possible;

4. A practice step to establish the existing theories effectiveness.

Recommendations:

- Establishing a robust supply chain system for risk reduction in order to increase the use of supply chain in disaster management;
- Awareness-raising programs;
- Motivate the common people and encourage them to maintain the systems which will be taken by the authorities;
- Supply chain risk management throughout the context of so many other types of disasters or risks.

XII. Conclusion

Proper management not only reduces the disaster risk but also helps a country to overcome the post-disaster effects. As Bangladesh is a developing country, a disaster like an earthquake can hamper the economy. If proper management is not taken can leave a long impact that will be hard to overcome. A good risk management plan with a supply chain model has proposed above in the article, which covers risk management, identification and effect. A model framework with a supply chain is proposed in this paper to minimize the severity of the earthquake. As recently the earthquake is occurring at an alarming rate, a precaution model is essential. This article presents that modelling through supply chain risk management. The flowchart in the paper suggests the possible risk management, risk identification process suitable in Bangladesh's perspective.

This article suggests a long term solution that may not prevent the problem but indeed mitigate the effects. From training the people to taking proper steps, this article shows a planned earthquake management model.

In this paper, a strategic way is suggested that could be used in industries to have a safe environment during the earthquake. Earthquake is one of the frequent disasters that's happening in Bangladesh. Although it is not that alarming yet in Bangladesh, a proper strategy can ease the earthquake effect on a large scale, saving lives and the economy.

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Implementation of Artificial Neural Network on Regression Analysis

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***Abstract*— Artificial neural network (ANN) works as a very effective tool in both classification and regression problem. The main advantage lies in the fact that it can draw fine distinctions, patterns, or hidden information of data explicitly without complex mathematical considerations. This study aimed to use the neural network on regression problem to achieve a better performance with a lower computational cost. After constructing the initial architecture, we added randomized weights and biases to the model. The performance of the model is evaluated on a well-known benchmark regression dataset named Auto MPG. The datasets were split among train, validation, and testing in a ratio of 50%-30%-20%. After subsequent tuning of hyperparameters, the refined architecture was able to perform predicting regression variable with a great efficiency and less computational time. The metrics of accuracy were taken as mean absolute error (MAE), root mean square error (RMSE) and mean absolute percentage of error (MAPE). Comparative study with the others state-of-the-art metaheuristic algorithms reveals the effectiveness of the proposed ANN. Evaluating the experimental results, it was obvious that, most often ANN did lead the other approaches with all the metrics of accuracy with a least computational time. It is also seen that, in some cases, though ANN revealed a very competitive result with other approaches, however the reduction in computational cost overcame the drawbacks and put neural network in leading.**

Keywords*— regression analysis, artificial neural network, backpropagation, deep learning

I. Introduction

Artificial neural network (ANN) is a biological structure identical to the working mechanism of human nerve system [19]. Neural network is being implemented broadly on versatile application areas for its dynamic learning ability that is capable to extract pattern and learn from the data and create a framework which can be used for classification, pattern recognition and forecasting [2]. Most fundamental feature of the neural network that makes it accepting in comparison with others is the capability of learning structured network that eventually get trained by modifying its structural parameters through identifying the contribution to computational loss with respect to each parameter. This modification of parameters through learning helps to create a refined model on which completely new dataset, not previously exposed to the network can be applied and simulated [19].

A typical neural network generally incorporates a signified number of local processing nodes that typically operates in parallel and queued in layers [3]. The raw input information is usually stored by the first layer reflecting the similar action of optic nerves in human visual system. Each successive layer has the decoded output from its immediately preceding layer as input after processing it with respective weights and bias as well as modifying it through the activation function, transfer it to the immediate successive layer as input like the in the same way neurons in the nerve system interact with each other [2]. The final output of the system is being processed in the last layer. Each acting node has its respective knowledge of processing. The layers constitute of a densely interconnected network that is achieved by connecting one node with all the nodes lied in immediately preceding layer as well as connecting with all the nodes lied in the immediate successor layer [20].

The essential characteristic of neural network is regarded as its ability of self-adaption [12]. The work frame of neural network enables it to put weights and bias individually to all the inputs received in each node in each layer and intuitively modifying them according to their contribution to computational loss which is calculated through partial differentiation with respect to each input [13]. The weights and bias term are being updated with respect to the average cumulative calculation based on whole dataset and with respect to subsequent iteration [12]. Both weights and bias enable the model to be compatible with completely different datasets.

Conventional algorithms as well as their hybridized approaches are frequently used in classification and regression problems [14-16]. Conventional classification and regression algorithms mainly work with linearly separable data [5][11]. If the data is of non-linear, then conventional algorithms incorporate higher dimensional space in order to process the data [11]. However, as the algorithms works with linearity often, they draw overfitting which leads to subsequent test loss due to overtrained. This is the case where neural network exceeds over other conventional algorithms [21]. Even a simple two or three hidden layered neural network can explicitly draw a fine distinction between different classes to determine without detailed complex mathematical model [7-9]. Another noticeable fact is that, when it comes about large amount of data, the work frame of neural network enables it to deal with such kind of data very efficiently in comparison with those conventional classifiers.

Ou et al. [10] applied different types of neural network structure on both relatively small and large size database. They structured all the neural networks with varying size of hidden layers ranging from somewhat 1 to 325. On the large dataset, the computational accuracy was varied from 86.34% to 97.54%. On small dataset the computational accuracy was ranged from 83.69% to 98.31%. On both cases, it could be quite evidenced that, for any size dataset, neural network

2021 5th Annual Systems Modelling Conference (SMC) | 978-1-6654-3815-5/21/$31.00 ©2021 IEEE | DOI: 10.1109/SMC53803.2021.9569881

would be able to perform significantly satisfying in case of classification or pattern recognition problem. Al-Massri et al. [20] incorporated neural network to classify and predict tumors. Their database and attribute were relatively very large. They achieved an accuracy of 100% which is very much acceptable in case of tumor like disease detection in which greater accuracy is of most necessity.

Bataineh et al. [1] applied neural network on regression model using some test datasets along with other algorithms to compare. They achieved a reduction in RMSE and MAE of about 82.97% and 81.23% respectively in comparison with other approaches. Khalil et al. [3] applied neural network in order to predict heating and cooling loads on which they achieved a satisfactory performance with error value less than 0.002. Li et al. [4] implemented neural network on regression problem along with fruit fly optimization algorithm in which they achieved a promising level of performance having MAPE value ranging from 1.25 to 2.75 which seemed to be very acceptable.

Setiawan et al. [6] incorporated a hybrid approach of harris hawks optimization (HHO) with support vector regression (SVR) in order perform regression problems. On regression problems, they achieved moderate levelled performance in comparison with others consuming a significant amount of time which seemed to be not optimized. A promising strategy would be to apply neural network to regression problems to achieve satisfactory level of performance as well as less computational time.

The ANN tries to recognize hidden information, pattern, or data without complex mathematical programming. Furthermore, regularization enables the ANN to be efficient in testing a dataset as well as making it compatible to apply on similar type unknown datasets. There lie a limited number of works that experimented comparative analysis of ANN with hybridized regression algorithms like HHO-SVR. Therefore, in this paper, the authors apply ANN in regression problems in order to achieve satisfactory performance with a least computational cost evaluated with comparing the state-of-the-art hybridized algorithms.

The novelty and contribution of this study is manyfold. (1) This study proposes a two-step ANN to increase the forecasting accuracy in regression analysis by minimizing the forecasting errors with a lower computational cost. (2) In the proposed ANN, a two-step tuning is used to select the best hyperparameters. The learning rate and number of hidden layers are tuned in the first step, and subsequently on basis of those parameters, the number of nodes in each hidden layer are tuned in the second step. (3) The Taguchi DOE is utilized to select the best parameter values for the ANN. (4) Finally, the performance of the proposed ANN for solving the regression problems is tested by solving a standard benchmark dataset problem named Auto MPG.

The rest of the paper is organized as follows. The next section presents the methodology. Section III presents the experimental results and discussion. Finally, section IV presents the conclusions with future research directions.

II. Methodology

A. Artificial Neural Network (ANN)

The ANN works as an integrated network of layer which is comprised on nodes. A basic neural network constitutes of basically 3 types of layers which are input layer, hidden layer and output layer. The input layer resembles the input features that act as an estimator of the output, and it constitutes of single layer. The number of nodes in the input layer is equal to the number of input features of the dataset and therefore, it can vary from 1 to any number. The number of hidden layer and the number of nodes in each hidden layer is assumed as hyperparameter of the corresponding neural network architecture. It completely varies from model to model and tuned in response to corresponding performance. Though increasing the number of hidden layer and number of nodes in each layer increase the computational cost greatly. However, it enables the model to draw clear pattern or to recognize hidden information or to generate absolute distinctions lying in the dataset which is not possible for conventional approaches. The output layer resembles the final response output of the model and is comprised of single layer just like input layer. Similar to the input layer, the number of nodes in output layer is equal to the number of different types of output of the model needed to predict. Thus, for neural network, both the estimator inputs and response outputs could be of either continuous or categorical. The parameters of the model are regarded as the weights and bias assigned to each node. At each node the data is processed as multiplying the corresponding weights with input received from nodes of previous layer and then adds the corresponding bias with the multiplied term. There is another fundamental factor in architecture of neural network and that is the activation function. Activation function is assigned to each hidden layer and output layer of neural network architecture. Activation function can be regarded as medium of transformation of data from one shape to another. It takes the data processed at each node as input and after functional processing generates output which would be sent to next layer as an input of corresponding node of the layer. The basic architecture of neural network is shown in Fig. 1. It represents a basic intuition about the interactive network among all the layers in a conventional neural network. Here, the input parameter is denoted as X; where X_i indicates the i^{th} input feature. Node in the hidden layer is denoted as n where n_i^l indicates i^{th} node of l^{th} hidden layer, and the output is denoted by O. Here, the number of input features are 2, the number of hidden layers is 2, the number of nodes in each layer are 3, and type of output is 1. In practical experience, all the elements just said before can vary from 1 to any number depending on the model to construct and the dimensions of dataset.

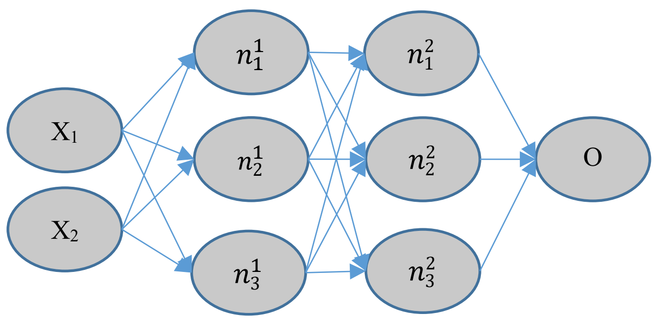


Fig. 1: A basic neural network architecture

There lies weights and bias at each node of hidden layer and output layer. If we denote the weight as w and the bias as b, then we can say that, at node n_1^1, there lies weights w_1^1 and bias b_1^1. As, in any node, the input comes from all nodes from previous layer, thus, w_1^1 should be equal to $[w_1, w_2]$. As the bias acts as a single term, then it remains unidimensional. The term n_i^l would resemble node i of layer l. Therefore, at every node n_i^l, there lies weights w_i^l and bias b_i^l and the number of weights assigned in w_i^l is equal to the node of layer $(l-1)$. If we denote z_i^l as intermediate output, f^l as the activation function and a_i^l as the final output processed through activation function at each node n_i^l, then the forward propagation maintains the following equations.

$$a^{l-1} = \begin{bmatrix} a_1^{l-1} \\ a_2^{l-1} \\ \vdots \\ a_i^{l-1} \\ \vdots \end{bmatrix} \quad (1)$$

$$z_i^l = w_i^l a^{l-1} + b_i^l \text{, where } a^0 = \text{input feature}, X \quad (2)$$

$$a_i^l = f^l\left(z_i^l\right) \quad (3)$$

The final output is $O = a^L$, where L is the output layer. Using the final output, the computational loss is easily calculated through observed value. To adjust the weights and biases, the partial differentiation of computational loss with respect to those weights and biases are calculated. Using the vectorized form, the backpropagation is expressed through following equations

$$dw^l = dz^l * (a^{l-1})^T \quad (4)$$

$$db^l = dz^l \quad (5)$$

where, dz^l is the elementwise multiplication of da^l and $f^{l'}(z^l)$.

Finally, the weights and biases are updated using the partial differentiation and the learning rate such as

$$w^l = w^l - \alpha * dw^l \quad (6)$$

$$b^l = b^l - \alpha * db^l \quad (7)$$

where, α is the learning rate.

Having updated weights and biases at each iteration with respect to their contribution to computational loss, neural network performs upgrading significantly. After completing significant number of iterations, the neural network can easily find out the hidden pattern or information lied in dataset and effectively predicts the output with a great computational accuracy. This simple mechanism of generating weights and biases at each node and refining them through backpropagation at each iteration, enables neural network to work very robustly and efficiently to both classification and regression problem without explicit mathematical programming.

B. *Metrics of Accuracy*

In calculating prediction either for classification or regression problem, the level of performance could easily be observed through different types of computational error values. If there remain actual and predicted values for every data point, then the following standard statistical measures can promisingly reflect the performance accuracy of the model [6][17-19].

$$\text{MAE} = \frac{1}{N}\sum_{i=1}^{N}|A_i - P_i| \quad (8)$$

$$\text{RMSE} = \sqrt{\frac{1}{N}\sum_{i=1}^{N}(A_i - P_i)^2} \quad (9)$$

$$\text{MAPE} = \frac{1}{N}\sum_{i=1}^{N}\left|\left(\frac{A_i - P_i}{A_i}\right)\right| \times 100\% \quad (10)$$

where, N is the number of samples in dataset and A_i is the actual or observed value of i^{th} observation and P_i is the predicted value of i^{th} observation.

C. *Mechanism of ANN Algorithm*

Fig. 2 represents the flowchart of overall functional procedure of regression model affiliated by ANN.

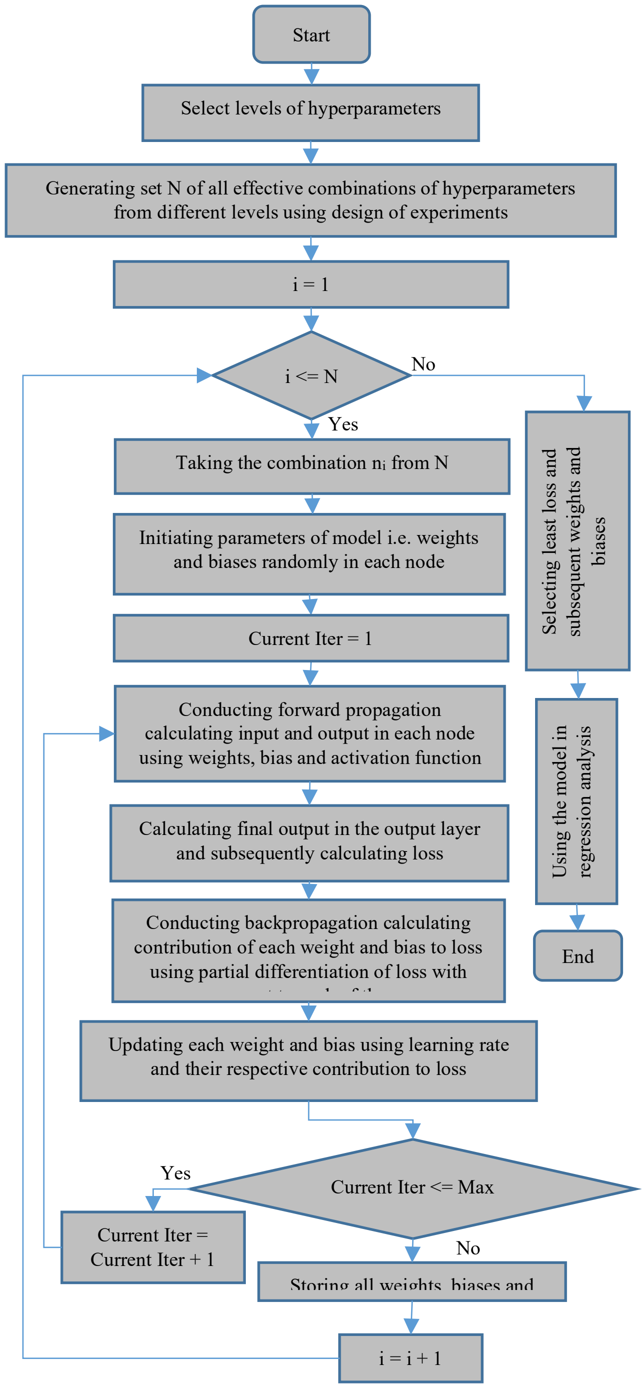


Fig. 2: Flowchart of overall functional procedure

Initially, the algorithm starts with selecting different levels of hyperparameters and creates a set of combining all effective combinations of hyperparameters. Then, it takes each combination into account and initiates randomized weights and biases with respect to each node. Furthermore, each weight and bias are improved through subsequent iteration. The working mechanism of ANN algorithm through each iteration is presented through the following six steps:

(1) *Creating Initial Architecture of the Neural Network*

Initial architecture includes number of hidden layers, activation function in each hidden layer, number of nodes in each hidden layer, initial weight, and bias in each node, learning rate, activation function in output layer, splitting training and validation and testing size, number of iterations, early stopping criteria, selection of loss function, selection of optimizer.

(2) *Calculating Input and Output in Each Layer*

The sample data would regard as initial input and passes through the first hidden layer and calculating intermediate output using the weights and biases of respective layer and generating final output through activation function that would transfer to next hidden layer as input. Thus, simultaneously each hidden layer gets input from its predecessor and after processing it with corresponding weights, biases and activation function would provide the output to successor hidden layer as input.

(3) *Calculating Computational Loss*

The output in output-layer is the final predicted response of the model. The computational loss is calculated using predicted output and observed output governed by loss function.

(4) *Implementing Backpropagation*

Backpropagation enables updating weights and biases in each node of each hidden layer using partial differentiation of average computational loss with respect to individual weights and biases and subsequent learning rate.

(5) Step 2 to step 4 is repeated until either the required iteration is finished, or the early stopping criteria is activated. The early stopping criteria is generally expressed as how many times it would be accepted that the validation accuracy in present iteration is less than previous iteration.

(6) Step 1 to step 5 is repeated modifying the architecture until satisfactory performance of the model is achieved.

Finally, the best combination of hyperparameters having acceptable performance among all combinations is selected as the final result.

III. Results and Discussion

A. Setup of Hyperparameter of ANN Architecture and Parameters of the Model

The performance of neural network depends completely on the fine adjustment of the parameters; i.e., weights and biases whose initiation is set to randomized. The fine adjustment of weights and biases is automatically achieved through backpropagation after each iteration. However, the performance of backpropagation is not achieved automatically. The performance of backpropagation fully dependent on selection of hyperparameter which are the number of hidden layers, selection of activation function in each layer, number of nodes in each hidden layer, learning rate. A two-step parameter tuning is used to select the best hyperparameters for the ANN. In the first step the learning rate and number of hidden layers are tuned. Based on the best parameters of the first layer, the number of nodes in each hidden layer are tuned in the final step.

The well-known Taguchi DOE [23] is used to determine the best parameters for the ANN. The Taguchi DOE is examined with a number of parameter levels. The number of parameter level is also important for parameter setting that determines the orthogonal array as well as the different combinations in DOE. Literature revealed that the DOE with three different parameter level generate better solution in various fields. For example, Asadujjaman et al. [22] applied Taguchi design of experiment (DOE) with 3-level parameters in immune genetic algorithm for solving project scheduling problems. They achieved satisfactory result considering three different levels of parameters. Moreover, Packianather et al. [23] applied Taguchi DOE with 3-level parameters to optimize multilayered feedforward neural networks on which they achieved promising performance in generating quality solutions. Therefore, in this study, a 3-level parameter in Taguchi DOE is used to tune the first layer of the ANN parameters for the regression problem. In DOE analysis, we considered learning rate, number of hidden layer and number of nodes in each hidden layer as parameters. We have experimented learning rate and number of hidden layers with three different level, such as [0.001, 0.01, 0.1] and [3, 5, 7] respectively. For number of nodes in each hidden layer, we experimented an effective 5-level approach as 3-level approach would not be suitable enough to explore the possibility of best results and the levels are [10, 50, 100, 150, 200]. Applying DOE analysis, the best parameter values were: 0.01 for learning rate, 5 for number of hidden layer and [150, 150, 100, 50, 10] for array describing node number in each hidden layer. Additionally, the activation function for hidden layer was taken as the rectified linear unit and for output layer, linear. The number of iterations was taken as maximum 40 and the early stopping criteria was set to 5.

B. Experimental Results

To have a better intuition, we conducted experiment on a benchmark regression dataset named Auto MPG [6]. To apply the dataset on model, we segregated the dataset on 50% training, 30% validation and 20% testing. Fig. 3 displays the quality of predictions of regression model built by ANN.

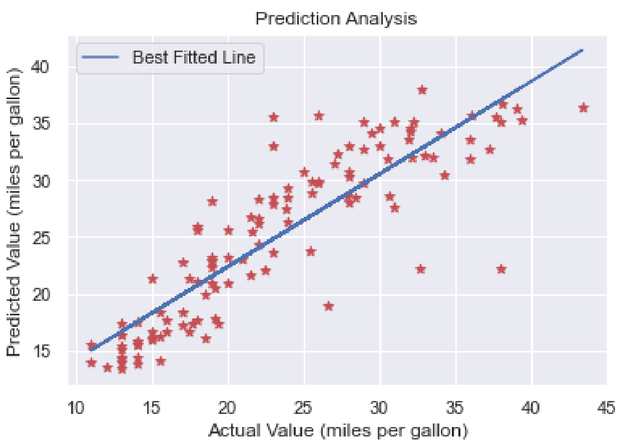
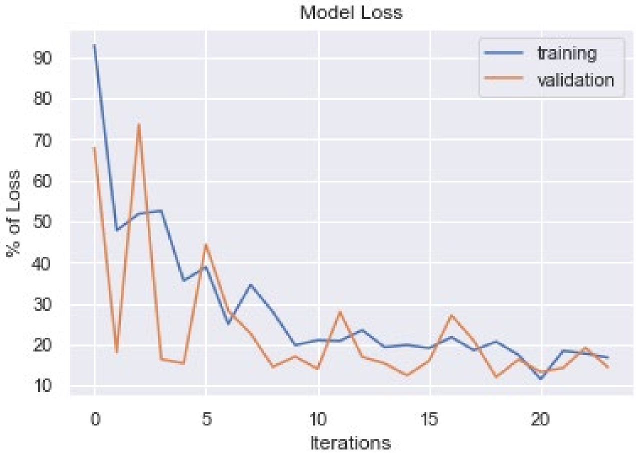


Fig. 3: Prediction analysis of regression model

Putting actual values on x-axis and predicted values on y-axis, it would be clearly visible that the trend of best fitted line is almost of equidistance from both actual and predicted values and that surely assures that on overall, the actuals and predictions are significantly closer.

Fig. 4 shows the convergence of loss with respect to the iterations for both training and validation. MAPE is considered as the loss function of our model to optimize. For both training and validation, it would be easily visible that, the loss is drastically converged per iteration reaching the least value within just 24 iterations.



The neural network approach was compared with respect to hybridization of SVR with metaheuristic algorithms including HHO, Dragonfly Algorithm (DA), Sine Cosine Algorithm (SCA), Antlion Optimizer (ALO), and Gray Wolf Optimizer (GWO) on both Radial and Sigmoid kernel which are the state-of-the-art methods [6].

Table I presents the comparative results based on the MAE. It is seen that, according to computational cost, Sigmoid kernel of SCA-SVR approach achieved the best result (time: 2 seconds), however it concluded with comparatively larger value of MAE. The computational cost is very closed to the best result; i.e., 2.1 seconds. Based on the training MAE, our ANN approach is competitive; whereas in testing the proposed ANN outperforms all the algorithms with a lower value of MAE. Considering the overall training and testing results, it could be stated that, the ANN approach achieved the best result with a lower computational cost. Taking both the cost and accuracy into consideration it could be obviously concluded that, the ANN approach achieved as the most suitable condition because in comparison to second best result, that is 18.60% greater in testing MAE in addition to increase in computational time up to 471.43%.

Table II presents the comparative analysis based on the RMSE for both training and testing achieved through ANN and other hybridized metaheuristics approaches. It is seen that, in training, the DA-SVR achieves best result in terms of less error (RMSE: 3.90). On the other hand, in testing, radial kernel of HHO-SVR, SCA-SVR and GWO-SVR approaches achieved the best accuracy (RMSE: 4.79), however resulted in a greater computational cost. Here, in terms of the computational cost, the proposed ANN outperforms all the algorithms. Moreover, in testing the result of ANN is very closed to the best value; i.e., RMSE: 4.80. Thus, in reference to both computational cost and error value, it could be easily justified that, the ANN approach achieved accepting results as compared to best result, the testing RMSE of ANN is just 0.21% greater with the reduction in computational time up to 82.50%.

TABLE I: COMPARISON OF MAE FOR AUTO MPG

Dataset	Method	Kernel	Costs		Trainin g	Testing
			Iter .	Time (sec)	MAE	MAE
Auto MPG	ANN	-	24	2.1	3.25	**3.28**
	HHO-SVR [6]	Radial	13	12	3.18	3.93
		Sigmoid	16	13	4.68	4.08
	DA-SVR [6]	Radial	9	4	**3.10**	4.15
		Sigmoid	23	7	5.15	4.04
	SCA-SVR [6]	Radial	12	9	3.16	3.92
		Sigmoid	5	**2**	4.47	4.05
	ALO-SVR [6]	Radial	20	11	3.18	4.06
		Sigmoid	20	8	4.47	4.00
	GWO-SVR [6]	Radial	27	12	3.12	3.89
		Sigmoid	14	6	4.45	4.02

TABLE II: COMPARISON OF RMSE FOR AUTO MPG

Dataset	Method	Kernel	Costs		Training	Testing
			Iter.	Time (sec)	RMSE	RMSE
Auto MPG	ANN	-	24	2.1	4.56	4.80
	HHO-SVR [6]	Radial	13	12	4.06	**4.79**
		Sigmoid	16	13	12.53	5.11
	DA-SVR [6]	Radial	9	4	**3.90**	5.08
		Sigmoid	23	7	16.91	5.07
	SCA-SVR [6]	Radial	12	9	4.05	**4.79**
		Sigmoid	5	**2**	11.42	5.02
	ALO-SVR [6]	Radial	20	11	3.95	4.95
		Sigmoid	20	8	11.29	4.95
	GWO-SVR [6]	Radial	27	12	4.03	**4.79**
		Sigmoid	14	6	11.24	5.00

Table III represents the comparison of performance of ANN and other hybridized metaheuristics algorithms in terms of the MAPE for both training and testing. In terms of the computational cost, SCA- SVR (time: 2 seconds) is the best performing algorithm, whereas the proposed ANN is the second-best algorithm with a run time of 2.1 seconds. Here, in reference to less error for both training and testing, the ANN approach outperforms all the state-of-the-art algorithms with a lower value of MAPE. Therefore, in reference to both computational cost and error value, it could be concluded that, the ANN approach achieved the most satisfying output.

TABLE III: COMPARISON OF MAPE FOR AUTO MPG

Dataset	Method	Kernel	Costs		Training	Testing
			Iter.	Time (sec)	MAPE	MAPE
Auto MPG	ANN	-	24	2.1	**12.48**	**12.45**
	HHO-SVR [6]	Radial	13	12	21.60	27.69
		Sigmoid	16	13	27.66	27.71
	DA-SVR [6]	Radial	9	4	21.36	30.07
		Sigmoid	23	7	29.39	27.43
	SCA-SVR [6]	Radial	12	9	21.48	27.72
		Sigmoid	5	**2**	26.87	27.64
	ALO-SVR [6]	Radial	20	11	21.95	29.03
		Sigmoid	20	8	27.04	27.27
	GWO-SVR [6]	Radial	27	12	21.08	27.76
		Sigmoid	14	6	26.61	27.47

The ANN outperforms the state-of-the-art approaches in few measurements (Table I-III) with a lower value of different measurement errors and a lower computational cost. In other cases, the results of the ANN are very competitive. The reason behind it lied in their method of adaptability to handle the data. Usually, conventional approaches are likely to deal with linearly separable data. When data is of nonlinear, traditional approaches conduct nonlinear mapping putting the raw input data into a higher dimensional space followed by searching for a linear separating hyperplane in the new higher dimensional space. However, if the data is attributed with much complex nonlinearity like our benchmark dataset, then it is quite hard to distinct the hidden patterns of data with higher dimensional space which lacks the model to perform accurately. Again, such adaptation of higher dimensional space needs computational time as well as very often makes the model more tending to be inclined to training data which leads to poor testing performance. ANN is adapted with much simpler, however effective to interconnected network of node which enables it to recognize the hidden pattern or information of data easily without the aid of high dimensional space and therefore requires less time. Therefore, the proposed ANN approach achieves higher accuracy in regression analysis with a lower computational cost.

IV. Conclusions

In this study, we applied an ANN to construct a regression model effectively and efficiently. To tune the parameters, the weights and biases through backpropagation effectively, we obtained adjustment in the architecture of neural network based on the intuition of Taguchi DOE analysis. To test the effectiveness and efficiency of the model, we initiated an experiment on the regression model using the well-known benchmark dataset Auto MPG. Furthermore, we conducted a comparative analysis with some state-of-the-art metaheuristics approaches to verify the performance of the ANN. The extensive computational experimental results revealed that, the presented ANN model is successful to train regression models to predict the continuous variable efficiently. Comparing with the state-of-the-art algorithms, it is seen that, the neural networks can dive deeply through the data than other approaches. Sometimes, the resulted values achieved were little bit greater than others, however the reduction in computational time successfully beat the other algorithms. When the data imposes non-linearity, conventional algorithms incorporate higher dimensional space to draw linearity, however that very often subsequently leads to overfitting and thus the performances between training and testing impacts vary drastically. As the ANN can explicitly draw the hidden information or pattern without incorporating higher dimensional mathematical calculation, thus obviously, there lies a consistency between the performances of training and testing. Moreover, significantly one of the promising aspects of neural network is the achievement of better accurate performance with a comparatively very lower computational cost. Thus, when it would come to adapt big data or complex data, it would be able to process the data with an efficient performance in addition with less computational cost. In the future, a hybridization approach of neural network with conventional regressor like support vector regressor or decision tree regressor would be a potential approach to have a better performance. Moreover, fusing the neural network with reinforcement learning would also be a promising initiative as a future research direction.

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Involving Motorbikes in Blood Pickup Services: A Mathematical Modelling Perspective

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***Abstract*—The inclusion of smaller-size vehicles to enhance the performance of logistics systems has been a new trend in logistics, spanning from bicycles to drones. On the other hand, the motorbike has long been known as a common transportation mode, especially in developing countries, which opens the possibility to implement this vehicle mode in a healthcare logistics environment. Therefore, in this article, we discuss the possibility to involve a motorbike in the blood pickup service system. Here, we propose to mathematically model the system as a blood pickup routing problem with heterogeneous vehicle modes (BPRP-HV). Numerical experiments are then conducted, and managerial insights are derived from the results.**

Keywords—healthcare logistics, blood supply chain, blood logistics, blood pickup routing, motorbike, heterogeneous vehicles

I. Introduction

Blood is an important commodity with many essential functions that support human's life, such as the transportation of nutrients and oxygen to the lungs and tissues. The availability of blood products is also essential for numerous medical treatments, including organ transplantation, surgery, and cancer and blood disorder treatments. Accordingly, improper management of the blood supply chain may cause the scarcity of blood and may result in patient deaths and/or complications [1]. However, challenges in managing the blood supply chain arise due to the perishable characteristic of blood products. Therefore, any improvement in the management of the blood supply chain that could minimize waste will create a direct impact as a life-saving product [2].

Following [1], the scope of managing a blood supply chain spans from the collection of blood donors to the fulfilment of patients' demands. This scope is executed through five distinct echelons, namely donors, mobile collection sites (CSs), blood centres (BCs), demand nodes, and patients. In this study, we put our focus on the collection of blood products from the donors and CSs (collection nodes) to the BC, which we refer to as blood pickup services.

We are interested in analyzing the impact of involving motorbikes in blood pickup services. To the best of our knowledge, this form of solution has not been studied yet, as previous studies in the blood supply chain management (BSCM) and blood pickup services only focused on the assumption of using a traditional collection car or truck as the transportation mode. Motorbike is a popular alternative transportation in developing countries (see Fig. 1), which is known for its cheaper acquiring and maintenance costs [3]. Besides, motorbike also offers flexibility to travel throughout traffic and small roads, so that it generally has higher speed and is suitable for developing countries.

Fig. 1. An Example of Motorbike Implementation for Logistics Service

We propose to model the involvement of motorbikes in blood pickup services with a mathematical model approach. Specifically, we develop a mixed-integer linear programming model for a blood pickup routing problem with heterogeneous vehicle (BPRP-HV). The presence of heterogeneous vehicle options is considered since a motorbike usually has a different load capacity and travel speed than the traditional pickup truck. Therefore, using this model, we can compare our proposal with the traditional blood pickup service with a homogeneous transportation mode. Then, further analysis on several important ratios, such as speed and capacity ratio between the pickup truck and motorbike are performed.

The rest of the document is structured as follows. In section II, we present the literature review of related works. The description of the BPRP-HV is discussed in Section III. Section IV presents the results of our numerical experiments. Then, Section V discusses the results from a managerial perspective. Finally, Section VI presents the conclusions and suggestions for future research.

2021 5th Annual Systems Modelling Conference (SMC) | 978-1-6654-3815-5/21/$31.00 ©2021 IEEE | DOI: 10.1109/SMC53803.2021.9569938

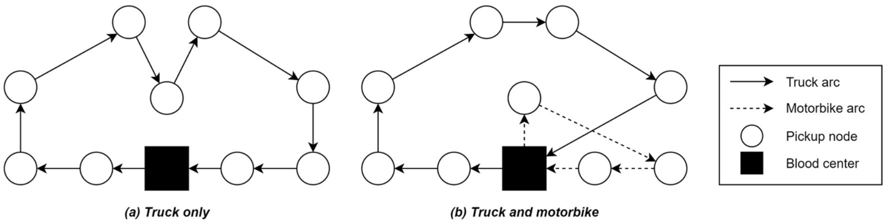

Fig. 2. Graphical Representation of Blood Pickup System with Truck Only and Combination of Truck and Motorbike

II. Literature Review

A. Blood Supply Chain Management

Though blood products substitutes are under technological development, the need for donor blood and its derived products still exists [4]. BSCM is concerned with managing the flow of blood products from donors to patients through five elements: donors, mobile collection sites, blood centres, demand nodes, and patients [1]. Thus, optimal coordination of the operations of BSCM is crucial to ensure blood products are delivered to patients safely while minimizing shortage and wastage. Operational problems in BSCM research are mostly concerned with the collection, transportation, testing, component processing, inventory management, and transfusion [1]. To solve these operational problems, several solution approaches are derived in the literature, such as simulation (see [5]), mathematical programming (see [6]), exact algorithm (see [7]), and heuristics (see [8]).

In this study, we develop a mathematical programming model for blood pickup services within BSCM. This approach has been successfully implemented by several previous research in BSCM. Özener [9] used a mathematical model to improve the supply of platelet in BSCM. They tried to maximize the amount of donated blood used in platelet production. Another study from [10] tackled the collection and appointment scheduling operations in blood donation sites to maximize platelet production. Iswari et al. [8] developed the original formulation of the blood pickup routing problem (BPRP) as a mixed-integer programming formulation. They also developed a simulated annealing-based algorithm as a heuristic solver to minimize the total travel cost of the operations. Yu et al. [11] developed a heuristic method called simulated annealing heuristic with restart strategy to solve the BPRP presented in [8]. In particular, the original BPRP formulation of [8] considered the usage of homogeneous pickup trucks to perform the delivery services.

B. Motorbike in Logistics Services

Moving on, the usage of small-size vehicles in various delivery systems has been largely assessed due to a lot of potential benefits. Small-size vehicles generally have faster speed and more cost efficiency to be implemented in the "last-mile" delivery [12]. A study from [13] also reported that the usage of small-size vehicles can improve energy efficiency, produce lower emissions, and obtain lower traffic disturbance in city logistics operations.

Various companies have also developed and used small-size vehicles for their logistics operations. For instance, Amazon has long been known to implement an advanced fleet of unmanned aerial vehicles (UAVs) for their small-parcel delivery services [14]. Other companies also have been developing their UAV-based operations, such as Google with their *Project Wing* [15][16]. Likewise, other forms of transportation modes are also considered, such as bicycle messengers [17] and self-driving robots [18].

Meanwhile, in developing countries, transportation companies also consider using motorbikes to perform their last-mile delivery services. In Southeast Asia countries, for instance, several companies such as Gojek in Indonesia made a significant disruption in the transportation business by managing the motorbike taxi business with advanced information technology [19]. They successfully compete with the incumbents of transportation business in developing countries, such as *bajaj*, minivan, pedicab, and taxicab [20]. In this regard, the usage of motorbikes for urban transportation on a busy road may reduce the risk of being trapped in *macet* or the total gridlock [20]. Moreover, the presence of poor road infrastructure and public transportation services in developing countries also lead to the proliferation of motorbike riders [21]. This phenomenon is also supported by other reasons to acquire a motorbike, such the ease of ownership and cheaper economic operations [22].

In particular, the concept of motorbike-based delivery also has been formally included in [23], who coded a term of the *pony express*. The pony express encompasses any form of crowdsourcing logistics model in e-commerce last-mile delivery in urban areas. Seghezzi et al. [23] analyzed the usage of flexible motorbike riders to deliver goods from a warehouse or store to the customers. They concluded that this concept offers an opportunity to improve the service level to the end-customers, as well as providing the opportunity for the riders to earn extra money from the delivery task. All in all, considering these important phenomena of the inclusion of motorbikes in delivery services hitherto, we are interested in assessing its possibility to be implemented in the BSCM context.

III. Mathematical Formulation of BPRP-HV

BPRP-HV is defined on a graph $G = (V, A)$ with $n + 2$ vertices, where $V = \{0, 1, \dots, n, n+1\}$ is the set of all nodes and A is the $i, j \in V$ arcs between nodes. It models the process of collecting blood packages in n collection sites using a set of heterogeneous vehicles, where these vehicles are classified into c different modes. Fig. 2 presents the graphical representation of BPRP-HV as well as the comparison between the truck only scenario and the proposed situation.

Then, to capture the perishability of the blood platelet, the pickup packages must be transferred to the BC $\{0\}$ before a pre-defined duration τ. The objective function of the BPRP-HV is to obtain the minimum number of total travel time incurred by the vehicles, which corresponds to the time efficiency of the pickup process since time is an essential criterion of such system [1]. Moreover, following [8], the BPRP-HV model is subjected to several assumptions: (i) the age of blood is assumed to be started at its picked up, (ii) each collection site has a hard time window $[o_i, e_i]$ and its location is already known by the decision-maker, and (iii) the donation quantities, service time, travel distance, and travel time between nodes are assumed to be deterministic.

Here, we first define the notations, sets, parameters, and decision variables required to develop the mathematical model of BPRP-HV. Then, using all the notations presented, the mixed-integer programming formulation for the BPRP-HV model can be fully presented.

- Notations, Sets, and Parameters

n = number of pickup nodes
c = number of vehicle type
$N = \{1, \dots, n\}$ set of pickup nodes
$N0 = \{0,1, \dots, n\}$ set of pickup nodes and BC $\{0\}$
$V = N \cup \{0, n+1\}$ set of pickup nodes and two BC nodes (the real node $\{0\}$ and the imaginary node {n+1})
$C = \{1, \dots, c\}$ set of vehicle type
$K_c = \{c_1, \dots, c_{|c|}\}$ set of vehicles of type c
d_{ij} = Travel distance from node i to j
S_j = Supply quantity of pickup nodes j
m_i = Service time of pickup node i
o_i = Opening time of pickup node i
e_i = Closing time of pickup node i
Cap_c = Capacity of vehicle type c
$Speed_c$ = Speed of vehicle type c
Num_c = Number of vehicles with type c available
τ = Blood spoilage time
M= A large number for big-M constraint

- Decision variables

$X_{ijkc} \in \{0,1\}$ = 1 if vehicle k of type c travels from node i to j and 0 if otherwise
a_{ikc} = Arrival time of vehicle k of type c at pickup node i

Objective function

$$\min \sum_{i \in V \setminus \{j\}} \sum_{j \in V \setminus \{i\}} \sum_{k \in K_c} \sum_{c \in C} \left(\frac{d_{ij}}{Speed_c}\right) \cdot X_{ijkc} \quad (1)$$

Subject to:

$$\sum_{j \in V \setminus \{i\}} \sum_{k \in K_c} \sum_{c \in C} X_{ijkc} = 1, \ \forall i \in N \quad (2)$$

$$\sum_{j \in V} X_{0jkc} = 1, \ \forall k \in K_c, c \in C \quad (3)$$

$$\sum_{i \in V} X_{i,n+1,k,c} = 1, \ \forall k \in K_c, c \in C \quad (4)$$

$$\sum_{i \in V \setminus \{j\}} X_{ijkc} = \sum_{l \in V \setminus \{j\}} X_{jlkc}, \ \forall j \in N, k \in K_c, c \in C \quad (5)$$

$$\sum_{i \in V\{j\}} \sum_{j \in V\{i\}} X_{ijkc} \sum_{j \in N} S_j \leq Cap_c, \ \forall k \in K_c, c \in C \quad (6)$$

$$o_i \leq a_{ikc} \leq e_i, \ \forall i \in V, k \in K_c, c \in C \quad (7)$$

$$a_{ikc} + \left(\frac{d_{ij}}{Speed_c}\right) + m_i - M \cdot (1 - X_{ijkc}) \leq a_{jkc}, \\ \forall i \in V \setminus \{j\}, j \in V \setminus \{i\}, k \in K_c, c \in C \quad (8)$$

$$\sum_{i \in N0} X_{i,n+1,k,c} \cdot a_{n+1,k,c} - \sum_{j \in N} X_{0jkc} \cdot a_{jkc} \leq \tau, \\ \forall k \in K_c, c \in C \quad (9)$$

$$X_{ijkc} \in \{0,1\}, \ \forall i \in V \setminus \{j\}, j \in V \setminus \{i\}, k \in K_c, c \in C \quad (10)$$

$$a_{ikc} \geq 0, \ \forall i \in V, k \in K_c, c \in C \quad (11)$$

Equation (1) sets the objective function of the problem. Equation (2) defines that each customer is visited exactly once and only by one vehicle. Equations (3) and (4) respectively ensure that vehicles must depart once from the BC node and return to the BC $n+1$. The empty tour of unused vehicles from BC $\{0\}$ to $n+1$ is also regulated by (4). Equation (5) is the flow conservation constraint to ensure that a vehicle that visits a certain j node must also depart from the node itself. Equation (6) is the capacity constraint, while (7) and (8) are the time window constraints to ensure that the arrival time of vehicle k at node j is within the previously defined time window of node j. Here, we set the value of M to be the same as the value of $max_{i \in V}(e_i)$. Equation (9) is deployed to avoid the spoilage of blood platelets during a tour, with the assumption that the age of blood starts at the pickup time. Finally, (10) defines the four-index decision variable as a binary variable and (11) defines the lower bound of the arrival time a_{ikc}.

IV. Numerical Experiments

This section describes the experiments conducted to assess the possibility of involving motorbikes in a blood pickup process system. We first define the experiment design. Afterwards, we present the numerical results.

A. Experiment Design

First, all experiments are conducted in a personal computer with AMD Ryzen 5 2600 Six-Core Processor 3.4 GHz, 16 GB of memory, NVIDIA GeForce GTX 1650 Super GPU, and a Windows 10 operating system. Here, the commercial software GUROBI version 9.0.1 is called to solve the mathematical formulation with a time limit of one hour (3600 seconds).

Then, 30 test instances are generated as a base to perform the numerical analysis. Here, we design a scenario where the pickup nodes are randomly dispersed in a $5000\ m\ x\ 5000\ m$ area, with the number of pickup nodes varies from 6 to 18 nodes. We consider the situation where the BC is always located in the middle of the area (0,0). Each of the pickup nodes j has a random supply S_j of $U(10{,}50)$ and incurs a $U(5{,}10)$ minutes service time m_j for each visit. In each of these instances, a portion of pickup nodes is subjected to a randomly generated hard time window. We consider six different scenarios for each number of customers n, these are $\{0\%, 20\%, 40\%, 60\%, 80\%, 100\%\}$ which constitutes the portion of customers that has a pre-defined time window [24]. Further, the distance between nodes is calculated with Manhattan distance to resemble the road network [16], while the blood spoilage time τ is set as 6 hours [8]. Then, another aspect that needs to be clarified is the specification of vehicles modes. We set the average speed of the traditional pickup truck to be 40 km/h. Then, in terms of the capacity of vehicles, we consider the uncapacitated truck for simplicity purposes. Therefore, the value of Cap_{truck} is set as $sum_{i \in N0}(S_i)$.

Moreover, to assess the attractiveness of our proposal, we consider the situation where the operator deploys a single uncapacitated blood pickup truck as a benchmark condition. It is important to note that even at this simplest scenario where $c = 1$ and $K_c = \{1\}$, the BPRP-HV still can be seen as a

TABLE I. RESULTS OF ALTERING SPEED RATIO

Scenario	*Scenario Code*	*Speed ratio (Truck : Motorbike)*	$\overline{Obj}$ *(min)*	$\overline{dT}$ *(km)*	$\overline{dM}$ *(km)*	$\overline{\#T}$ *(%)*	$\overline{\#M}$ *(%)*
Truck only	1	-	38,36	24,96	0,00	100,00	0,00
Truck+Motorbike	2	1 : 1	37,99	25,41	0,40	99,09	0,91
	3	1 : 1,1	37,93	25,49	0,40	99,09	0,91
	4	1 : 1,2	37,87	24,98	0,74	98,54	1,46
	5	1 : 1,3	37,75	24,51	1,69	96,59	3,41
	6	1 : 1,4	37,61	24,40	1,69	96,59	3,41
	7	1 : 1,5	37,47	24,12	2,77	94,83	5,44

TABLE II. RESULTS OF ALTERING CAPACITY RATIO

Scenario	*Scenario Code*	*Capacity ratio (Truck : Motorbike)*	$\overline{Obj}$ *(min)*	$\overline{dT}$ (km)	$\overline{dM}$ (km)	$\overline{\#T}$ *(%)*	$\overline{\#M}$ *(%)*
Truck only	1	-	38,36	24,96	0,00	100,00	0,00
Truck+Motorbike	8	1 : 0,1	37,75	25,04	0,74	98,72	1,28
	9	1 : 0,15	37,65	24,14	1,63	97,24	2,76
	7	1 : 0,2	37,47	24,12	2,77	94,56	5,44
	10	1 : 0,25	37,13	22,35	4,43	90,91	9,09
	11	1 : 0,3	36,84	22,16	4,63	88,98	11,02
	12	1 : 0,35	36,67	19,86	6,87	84,22	15,78
	13	1 : 0,4	36,21	19,89	7,11	82,63	17,37

generalization of the travelling salesman problem with time windows [24], which itself belongs to the class of NP-hard problems.

B. Experiment Results

Moving on, we will discuss the results of our experiment in this subsection. In total, there are 13 scenarios implemented to all 30 test instances. Each scenario corresponds to a different ratio of either speed or capacity between the pickup truck and motorbike, alongside the benchmark condition (truck only) which is set as a scenario code '1'.

- Observation I: The effect of altering speed ratio

The first observation we are interested to make is to understand the effect of the speed ratio between the truck and motorbike. The reasoning of this observation is obvious: the main attractiveness of involving a smaller-size vehicle in a logistics process is the presence of traffic congestion [13], and the motorbike itself is largely known as an effective option to transport on congested roads [22]. In this part, we set the speed of the motorbike to be varied within a set $\{100\%, 110\%, 120\%, 130\%, 140\%, 150\%\}$ of the truck speed, which is set to be 40 km/h. Meanwhile, the capacity ratio of truck and motorbike is set to be constant at $1{:}\ 0{,}2$ which is based on the average size comparison between those two transportation modes [25].

Table 1 shows the results of our experiment in altering the speed ratio. $\overline{\boldsymbol{Obj}}$ states the average optimal objective value (total travel time, in minutes) of all instances for each scenario, $\overline{\boldsymbol{dT}}$ and $\overline{\boldsymbol{dM}}$ respectively present the average total distance travelled by truck and motorbike in km, while $\overline{\boldsymbol{\#T}}$ and $\overline{\boldsymbol{\#M}}$ respectively exhibit the proportion of collection nodes served by the truck and motorbike to indicate the occupation rate of each transportation mode. From Table 1, it can be seen clearly that as the average speed of the motorbike increases, the occupation rate of the motorbike also rises, which indicates the tendency of the decision-maker to exploit the benefit of a motorbike in travelling the road faster. As the occupation rate of the motorbike enlarges, the total travel time and the total distance traveled by truck also gradually decline. These observations imply that the inclusion of a motorbike in a blood pickup system may result in higher time efficiency and the reduction of costs since the transport mean cost of a truck is generally larger than a motorbike [23].

- Observation II: The effect of altering capacity ratio

In the same way, our second observation is executed regarding the ratio of capacity between truck and motorbike. As it has been shown that the speed of a motorbike is one important determinant in the decision to deploy a motorbike or not, it is also interesting to see whether the capacity of motorbike implies similar results or not, since obviously, the main limitation of a small-size vehicle such as motorbike for logistics is the constraint of capacity [18]. Here, we set the capacity of the motorbike to be varied within a set $\{10\%, 15\%, 20\%, 25\%, 30\%, 35\%, 40\%\}$ of truck capacity. On the other hand, we set the speed ratio of truck and motorbike as 1 :1,5 to ensure that the occupation rate of the motorbike will not be non-existent (see Table 1).

Table 2 present the results of our experiment in altering the ratio of capacity. The results suggest that the increasing value of motorbike load capacity derives a similar impact to the increasing value of motorbike speed. As the capacity of the motorbike escalates, the decision-maker logically tends to deploy the motorbike more. This results in a higher occupation rate of the motorbike, which in turn will decrease the total distance travelled by truck and reduce the total travel time.

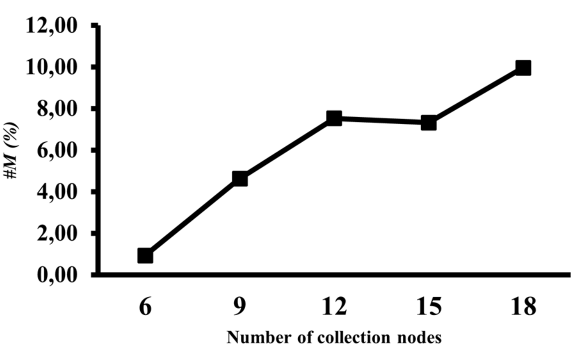

Fig. 3. Effect of number of nodes to the occupation rate of motorbike

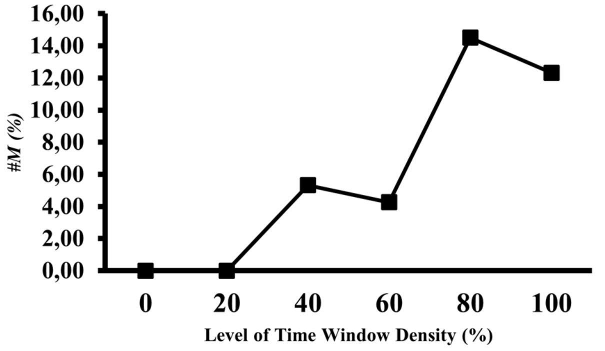

Fig. 4. Effect of time window density to the occupation rate of motorbike

This observation also reveals one important consideration of involving the motorbike in a blood pickup process. Consider n_{first} and n_{last} as the first and last customers to be visited by the motorbike. To deploy a motorbike, the decision-maker must also consider the extra travel time and distance incurred to travel these arcs: $(0, n_{first})$ and $(n_{last}, 0)$. With the objective function to minimize the total travel time, deploying the motorbike will only be beneficial when the reduction of truck's travel time is higher than $\left(\frac{d_{(0,n_{first})} + \ldots\ldots + d_{(n_{last},0)}}{Speed_{motorbike}}\right)$. In this regard, the capacity of motorbike will determine the maximum number of pickup nodes that can be served by the motorbike, and therefore, will affect the reduction of travel time that can be made by deploying the motorbike. Simply put, the decision-maker may be less interested to deploy the motorbike if this mode can only serve one customer.

- Observation III: The effect of the number of pickup nodes and time window density

Afterwards, we aim to analyze the impact of other factors which may influence the decision to implement a motorbike in a blood pickup system. Two factors embedded into the process of generating test instances, namely the number of nodes and the density of the time window are considered.

Fig. 3 and Fig. 4 display the line charts of the average optimal occupation rate of the motorbike for each level of n and time window density It is shown from Fig. 3, that as the number of pickup nodes escalates, the average occupation rate of motorbikes also tends to increase. This implies that, although it has a limitation on the load capacity, the motorbike can be utilized by the decision-maker to serve the pickup nodes with a smaller value of demand which typically appears more as the total number of nodes increases. Moving forward, Fig. 4 also tells us that the occupation rate of the motorbike tends to increase as the density of the time window escalates. This implies that the decision-maker can obtain a benefit from the presence of a motorbike when facing a highly time-constrained situation since the motorbike can be deployed to serve a portion of nodes that have a tight time window or similar time window to the one served by the truck. Moreover, this last point can also be confirmed by comparing the results of scenarios '1' and '2' in Table 1. It has been shown that even when we relax the speed advantage of the motorbike, the inclusion of one motorbike can still help to enhance the operational quality of the blood pickup system by reducing the total travel time and total distance travelled by truck.

V. Managerial Insights

Here, we continue to analyze our proposal from the managerial perspective. Our results suggest that the involvement of motorbikes in blood pickup services offers some potential advantages. It is suggested that as the speed is higher, the occupation rate of motorbikes also tends to enlarge. This may result in a higher time efficiency of the pickup process. Moreover, motorbikes can be deployed to serve a portion of nodes that have a tight time window or similar time window to the one served by the truck. Thus, it offers potential benefits when facing a highly time-constrained situation, which is common in healthcare logistics. The involvement of motorbikes in the blood pickup services can also reduce the operational costs since the transport mean cost of a motorbike is generally smaller than a pickup truck [23]. Additionally, the maintenance and acquisition costs of a motorbike are also relatively cheaper. This offers a potential reduction in the total systemwide cost, which is crucial in assuring the affordability of healthcare services.

However, the involvement of motorbikes also has some potential drawbacks that needed to be considered by decision-makers in a blood supply chain. Firstly, riding a motorbike offers opportunities for expressive usage of the vehicle and riders tend to enjoy riding at a higher speed [26]. From a safety perspective, this tendency of high-speed riding, alongside the natural characteristic of blood pickup services as a time-constrained task, might result in a higher accident risk. If crashes happen, motorcyclists have a higher risk of injury due to the lack of protection devices to prevent or reduce the injury. It is noted that the chance of fatal or serious injury of motorcyclists is almost eight times higher than a car driver [3]. Therefore, decision-makers must be selective in acquiring the riders and must consider their capability in dealing with a high-pressure task. This is crucial for reducing the chance of acquiring risk-prone individuals who experience more mental workload and are more likely to experience crashes [27].

Then, decision-makers must also consider the environmental aspect of the usage of motorbikes. Although motorbike generally has an advantage of lower fuel consumption, this transportation mode also has a limitation of load capacity which may result in a requirement of performing multiple tours instead of a single large one [12]. In this regard, the motorbike has been noted by [28] as a large contributor to the air pollution of Tehran city in Iran. Moreover, the emission contribution of motorbikes is also influenced by several factors, such as road characteristics, traffic volume, vehicle type, driving conditions and driver behaviour [29]. Therefore, further analysis on this aspect is important to be performed.

Other aspects to be considered are the additional costs incurred and the perishability characteristic of blood products. From the cost perspective, the involvement of motorbikes may result in a reduction of acquiring and maintenance costs, however, decision-makers must also face the additional salary cost for the extra riders needed to perform the blood pickup services with a motorbike. Meanwhile, from the perspective of quality, transporting blood products requires cold-chain storage [1]. Thus, the usage of motorbikes for the blood pickup services means that the decision-makers must consider installing extra cold-chain storage, which obviously will result in another additional cost.

VI. CONCLUSIONS

In this article, we discuss the possibility to involve motorbikes in blood pickup services. Here, we propose to mathematically model the system as a blood pickup routing problem with heterogeneous vehicle modes (BPRP-HV). Our results suggest that the proposed situation of involving motorbikes in the blood pickup system is an attractive option. It is shown that with appropriate selections of design on the load capacity and average speed, the inclusion of motorbikes can lead to a reduction of total travel time and total distance travelled by truck, which corresponds to the higher time and cost efficiency of the pickup process. Nevertheless, our managerial discussions point out that the inclusion of a motorbike into a time-constrained task like this may result in a safety issue, which must be considered by the decision-maker.

Then, several future directions can be derived from this research. First, we have discussed that the perishability of blood products implies that these products need to be handle carefully with a cold-chain system. In this regard, research on designing the motorbike equipped with a cold-chain box for the blood pickup process could be an interesting direction. Secondly, our results suggest that the involvement of a single motorbike can enhance the performance of the blood pickup system. Therefore, further research can analyze the scalability of this proposal from safety and economic perspectives. Lastly, our analysis was limited from a modelling perspective and some assumptions made here may not be feasible in the real-life environment. Thus, extending this research with a real case study could be a meaningful contribution.

ACKNOWLEDGMENT

This research is partially supported by the Department of Mechanical and Industrial Engineering UGM through the program of Hibah Penelitian DTMI UGM.

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Sustainable Electricity Generation from Hazrat Shahjalal International Airport, Dhaka: A Milestone for Green Energy in Aviation

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2021 5th Annual Systems Modelling Conference (SMC) | 978-1-6654-3815-5/21/$31.00 ©2021 IEEE | DOI: 10.1109/SMC53803.2021.9569935

Abstract— **Airports, as a key infrastructure of the air transportation system, are the junctions of air and ground transportation. It is an extremely energy-intensive area. This is due to the large buildings (both passenger terminals and non-passengers areas) equipped with heating and air-conditioning systems, and the high-power demand for lighting and electric equipment, and the energy requirements from the many facilities located within the airport vicinity. Higher energy consumption arises the concern of leaving a higher amount of carbon footprint, which has a substantial impact on the environment and their local communities unless the energy is green. The aim of this paper is to indicate the possibility of generating green energy by applying the road power generation (RPG) concept to the airport. Hazrat Shahjalal International Airport, Dhaka, Bangladesh's largest airport has been considered for this scenario. A conceptual design of power conversion mechanism has been developed by widely used computer-aided design software in the Aviation industry named CATIA-V5. The electrical energy that can be potentially generated based on the current and future fleet of Bangladeshi passenger airlines has been predicted. The study shows that a considerable amount of green energy can be generated from this system.**

Keywords— Road Power Generation, Conveyor Roller, Center of Gravity, Renewable Energy, Taxiway, AC/DC.

I. Introduction

The aviation industry is growing rapidly day by day, and airports play a crucial part in this industry as a platform between the surface-based and air transport modes. With an improved global economy, the aviation industry in third-world nations is also growing very fast. People prefer traveling by air more than any other medium of transport because traveling by air is more time-efficient and safe. According to the Airports Council International Europe (ACI Europe) report, in 2014, at least 400 airports in Europe had hosted the transport of 1800 million passengers and 18.4 million tons of cargo using 1.8 million air operations. In 2019, the European Union airports saw a 3.3% increase in passenger traffics [1].

Hazrat Shahjalal International Airport (HSIA) is located in the capital city Dhaka, Bangladesh. Currently, this airport can facilitate around 8 million passengers annually. And, this number will rise to 24.8 million by the year 2035. A joint study by the Japan International Cooperation Agency (JICA) and Civil Aviation Authority, Bangladesh (CAAB) suggests that HSIA airport will host around 185,000 air operations (international, domestic, and other) in 2035 [2]. Keeping that in mind, the construction of the third terminal of the airport is currently on going with the help of the JICA [3].

For conducting day-to-day operations in an airport, a large amount of energy is consumed daily, and among them, electricity is the most important of all resources. According to the Civil Aviation Administration of China, the airport industry consumes up to 8% of the total energy in the transport industry [4], [5]. A large portion of the electricity in an airport is consumed by the terminal, mostly used for air-conditioning, cooling, and heating purposes. Perdamaian et al. [6] had made an estimated calculation that the third terminal of Soekarno-Hatta International Airport, Indonesia, consumes up to 27700.107 GJ or 7.694 MWh electricity. Almost 86% of them are consumed in the heating, ventilation, and air conditioning (HVAC) systems; the other 14% of electricity is used for lighting and other purposes.

Consequently, In the next 20 years the global energy demand will register a sharp increase by a third.This rapid increase in energy consumption is likely to have a significant environmental impact in the near future. As a consequence, carbon dioxide (CO_2) and hazardous gas emissions have been increased 50% worldwide in the last couple of decades. The burning of fossils to produce electricity can contribute to disastrous phenomena such as global warming and climate change [7]. To reduce the emission of greenhouse gases into the environment, renewable energies can be a sustainable way to produce energy. Researchers and scientists are coming up with new ideas for producing energy in an eco-friendly way. They are continuously trying to develop more effective and unique energy conversion systems.

In this paper, a new conversion system is proposed that can tap the kinetic energy of moving vehicles while passing over a conveyor roller, which is called Road Power Generation (RPG). The concept of RPG is relatively new, and the general concept of RPG is quite simple. It is designed to utilize the unused energy from different kinds of vehicles. This method can be useful for nations with high traffic and high population.

Fatima and Mustafa [8], in their work, tried to utilize all kinds of vehicles to produce electricity. Their work gave an approximate prediction of the output power and voltage generated from average-sized vehicles. Their proposed model consists of a moving plate that would capture the kinetic energy from the slightest movement from the road surface, and then it is transferred to a keyway flywheel system. This captured energy is converted into electrical energy. Ashwin et al. [9] have conducted similar experiments. They have concluded that this produced electricity can contribute to total energy production and can be used for road battery charging units, street lighting, and various domestic applications.

Kanase et al. [10] have mentioned three different mechanisms of producing electricity via the RPG method, and they are as follows: rack-pinion mechanism [11], flip plate mechanism, and roller mechanism. They have also pointed out some of the important advantages of this method. According to their work, this method produces clean energy, has a low life cycle cost, no extra manual work is needed, occupying less floor area, and energy production throughout the year. The following Fig. 1 illustrates the general working principle of the RPG.

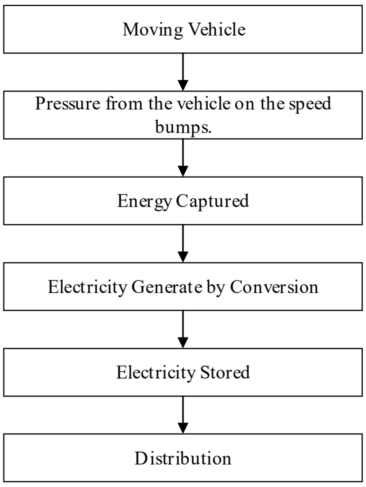


Fig. 1. General Principle of the RPG method.

Srivastava [12] and Mukherjee [13] have proposed systems with small radial flux generators and ineffective topologies. The most common model in RPG is a model base on the flip plate. Generating electricity from road speed breakers by using a roller mechanism is quite new [14]. Vehicles passing over speed breakers are the source of generating electricity.

Zebda et al. [15] have proposed a theoretical model of the fourth kind of speed breaker, which is slightly different than the existing model. They have proposed a version of the RPG that can convert hydraulic energy to electrical energy. However, their research indicates that it is more viable for small vehicles such as cars. Thus, it would not be viable for us to use it in the airport. There is another issue with the hydraulic system is that the maintenance cost is high.

Hossain et al. [16] had built the RPG device using a roller mechanism instead of a flip plate. They had used the three-wheeler (CNG) as their test vehicle to generate electricity. They have concluded that the electricity production using this method depends on the weight of the vehicle. According to their study, if the influx of the vehicle is significantly high, this system can fulfill the demand for electricity in a small area. Therefore, in theory, at a busy airport, this can be a viable solution to any electricity need of the airport.

The application of this RPG is more suited for busy cities like Dhaka, Beijing, or Jakarta (in Southeast Asia) because of the high influx of traffic. However, these methods are not been implemented in an airport yet.

Another existing renewable method that could be implemented in the airport is by installing solar panels. With our current technology, solar panels are quite expensive, and they take a huge amount of space. One of the major drawbacks of solar panels is the weather. In the winter and rainy seasons in Bangladesh, the visibility reduces quite significantly. During that time the production of electricity would reduce as well. Therefore, solar panels cannot be the only solution to build a self-sustained airport.

Similarly, we could also consider wind turbines as a source of renewable energy. However, if the wind farm is placed near an airport, it can cause some serious safety hazards, especially to the smaller aircraft. A report from the University of Kansas suggests that if the wind farm is located near the airport, the aircraft can encounter crosswinds and roll hazards [17]. Also, it can interfere with the communication system of the aircraft. So, we can conclude that the wind farm cannot be a perfect solution for electricity production, especially for airports.

Therefore, in this research, we are adopting a similar concept of RPG using a roller mechanism with an upgrade, producing electricity from conveyor rollers in an airport (taxing road). Instead of using road bumps, we are going to use conveyor rollers that is more convenient because it will not reduce the speed of the aircraft on the taxiway. This paper contains a theoretical model of this new and reliable source of electricity in an airport, which produces clean and pollution-free energy without leaving any carbon footprints on the environment.

II. Dhaka airport and new opportunity for RPG

As mentioned above, the main implementation of our research work would be on the airports. Recently, the Civil Aviation Authority of Bangladesh (CAAB) is working on a new project of extending the Hazrat Shahjalal International Airport (HSIA), Dhaka. Therefore, this could be a great opportunity to use this proposed model to reduce the dependency on outsourced electricity. It is a well-known fact that third-world nations are struggling to produce enough electricity to meet the demands of the rising population. Our proposed method will help HSIA to be a self-sustained airport in terms of energy production. Not only that, with the proper number of traffic, it may also help to reduce the overall national electricity deficit as well. As there will be an extension of the airport (the third terminal), new fleets of aircraft will also be joining the government and private airlines of Bangladesh very soon, which will only increase the production of electricity using the proposed method. Fig. 2, shows a 3d model of the new third terminal of the HSIA, which is currently under construction.

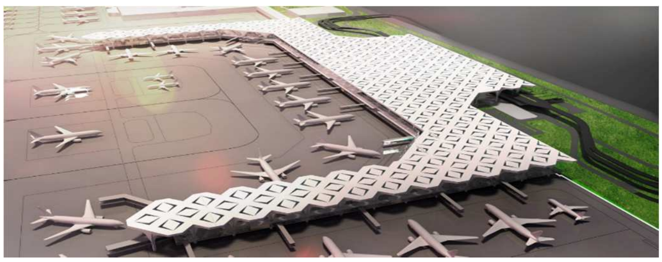


Fig. 2. 3d modeling of the third terminal of the airport [18].

Currently, Hazrat Shahjalal International Airport is hosting around 27 local and international commercial airlines. And, among the most common commercial aircraft in the airport are as follows: ATR 72, Dash 8, Boeing 737, Boeing 777, and Boeing 787. Fig. 3 shows the aircraft types currently operated by domestic airlines. There are also many other local and international cargo and private aircraft that make their route to HSIA. As mentioned earlier, this airport is able to facilitate 8 million passengers for now, and the influx of travelers will increase very soon. Table 1 shows the annual aircraft and passenger movement at HSIA forecasted by JAICA. Currently, The HSIA has only one runway, which is 3,505 m long. The second runway, parallel to the first runway, is under construction along with the expansion of the third terminal. Around 190 flights are handled in the airport daily, with the construction of the second runway, the daily flight number will be doubled as predicted.

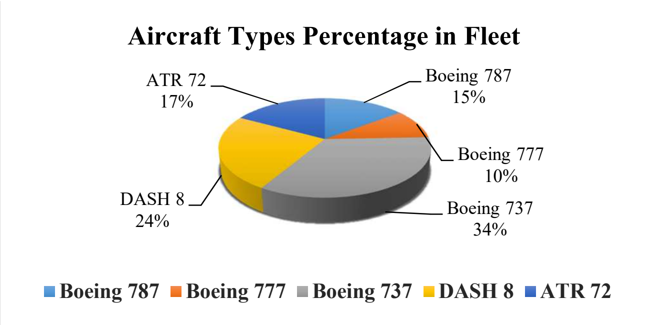


Fig. 3. Aircraft types percentage in domestic airlines' fleet.

TABLE I. JAICA FORECAST OF AIRCRAFT AND PASSENGER MOVEMENT AT HSIA

Year	Passenger Movement (Millions)	Aircraft Movement (Thousands)
2015	6.482	74483
2020	10.745	120579
2025	16.072	168338
2030	22.997	210165
2035	31.837	269394

The ground vehicles are of similar importance. They are the main assisting tools for the maintenance of the aircraft. Biman Cargo and Biman Bangladesh Airlines are the main operators in this case. If the RPG device is positioned in the right place, the production of electricity can increase by many folds.

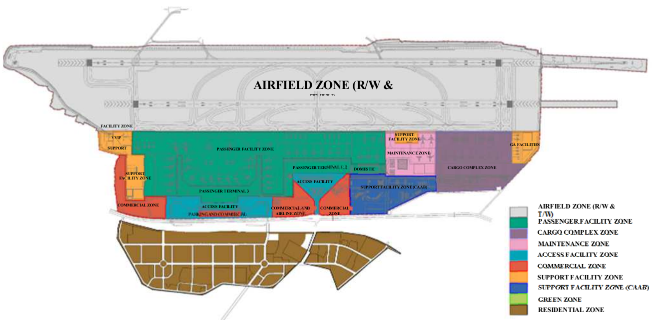


Fig. 4. Map of the HSIA airport [18].

Airport Taxiway is considered the ideal place to install the proposed RPG model. The main reason for choosing the taxiway is the taxying speed of aircraft. Aircraft move with much slower speed (generally 20-30 knots) on the taxiway in comparison to the runway. Therefore, it is easier to control the aircraft in any adverse situation. A newly increased aircraft fleet and the added ground vehicle can accelerate the production of electricity. The working principle of the newly proposed RPG device using a conveyor roller mechanism will be discussed in the next section.

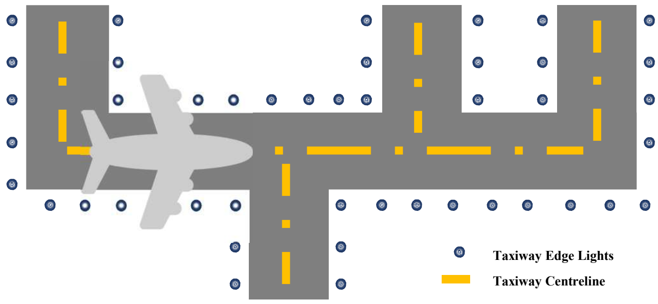


Fig. 5. A typical airport taxiway.

III. Working Principle and Design of the Proposed Model

Cylindrical-shaped four rollers have been placed one after another horizontally. Each roller consists of two sprockets and two bearings on each side. Bearings are fixed inside the horizontal supporting frame. The rotor shaft is placed under and mid-section of the roller. The rotor shaft also consists of the sprocket and bearing on each side. The rollers and the rotor shaft are connected through a drive chain, which is placed on the sprockets. The rotor shaft is connected with the generator. A conveyor belt wraps up four rollers. The proposed model has been designed using the CATIA-V5. Fig. 6 depicts the proposed model.

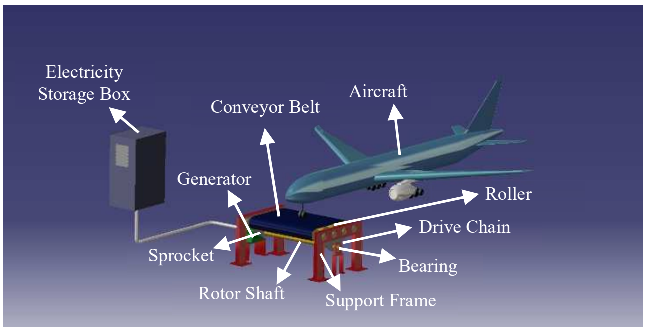


Fig. 6. Proposed RPG model design.

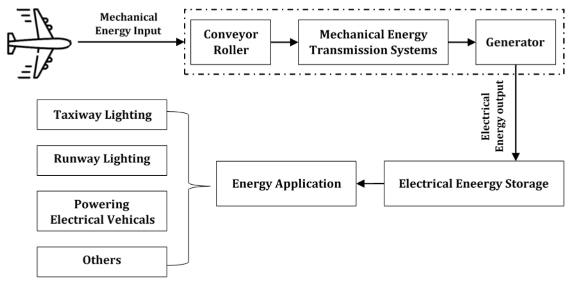


Fig. 7. Simplified block diagram of the proposed RPG model.

Passing aircraft provides rotation to the rollers, which are then transmitted to the rotor shaft through the drive chain. The generator is connected with the rotor shaft which converts the mechanical energy into electrical energy. A separate storage system stores the generated electrical energy that can be used at a later period of time as required. Fig. 7 shows the simplified block diagram of the proposed model and harvested energy applications. Here, Aircraft do not necessarily need to reduce actual taxing speed.

IV. Electrical Power Generation Calculation

In this section, annual electrical power generation at Hazrat Shahjalal International Airport, Dhaka using the proposed model and the calculation steps has been discussed.

A. *Aircraft's CG calculation:*

The rotation of the roller depends on the load applied by the aircraft's wheels. To calculate the load exerted by an aircraft's wheels, we have determined the center of gravity (CG) of the particular aircraft. The CG of an aircraft is the point over which the aircraft would balance. The values of the Leading Edge Mean Aerodynamic Chord (LEMAC), Trailing Edge Mean Aerodynamic Chord (TEMAC), Mean Aerodynamic Chord (MAC), and the CG in percentage of MAC also have to be known in order to determine the location of the CG.

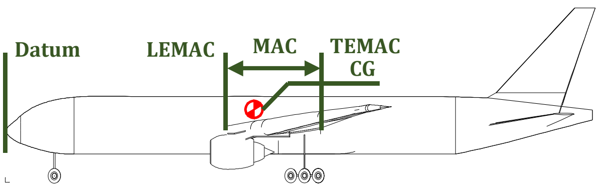


Fig. 8. Datum, LEMAC, MAC, TEMAC, CG location in a typical aircraft.

Fig. 8 shows the Datum, MAC, LEMAC, TEMAC, CG locations of a typical aircraft. For a particular type of aircraft, Datum, MAC, LEMAC, TEMAC, and the allowable range of CG is fixed and determined by the manufacturer of that aircraft. The location of CG moves forward and afterward within its limits with the aircraft's overall weight variations throughout the flight. Table 2 shows the location of the CG for the narrow and widebody aircraft while passing over the conveyor rollers. The weight (W_0) of the individual aircraft is taken randomly and does not exceed the allowable weight limit provided by the manufacturer. Other values are assumed as they are restricted by the manufacturer in general. The location of the CG in relation to the datum line is calculated using (1):

$$CG = LEMAC + \frac{MAC \times CG\%}{100} \tag{1}$$

TABLE II. CG VALUES FOR SELECTED TYPES OF NARROW AND WIDEBODY AIRCRAFTS

Aircraft Type	W_0 (kg)	LEMAC (m)	MAC (m)	CG (%MAC)	CG (m)
ATR 72	22,500	11.23	2.37	30	11.92
Dash 8	28,700	13.43	2.4	30.7	14.17
Boeing 737	75,100	16.16	3.96	26	17.19
Boeing 777	348,334	30.25	7.07	28.9	32.29
Boeing 787	250,022	25.72	6.27	27.3	27.43

B. *Nose Wheel Static Load Calculation*

The proposed RPG model of this study is designed in such a way that only the nose wheel of the aircraft touches the conveyor roller while moving over it. The motion of the aircraft can be described from (2):

$$m\frac{dV_\infty}{d_t} = T - D - \mu_r(W - L) \tag{2}$$

Here, m is the mass of the aircraft, V_∞ is the instantaneous velocity, T is the thrust force, D is the drag force, μ_r is the rolling resistance friction coefficient, W is the weight, and the lift force is denoted as L.

In this study, the static load has been considered for the calculation in order to simplify the calculation process. The static load (F_N) applied by the nose wheels is calculated by (3) and (4):

$$x_2 = (x_0 + x_3) - CG \tag{3}$$

$$F_N = \frac{W_0 x_2}{x_3} \tag{4}$$

Where W_0 is the overall weight of the aircraft, x_2 is the distance between CG and main landing wheel, x_3 is the distance between nose and main landing wheel, x_0 is the distance between datum and nose wheel. Fig. 9 depicts the acting loads and the relevant distances.

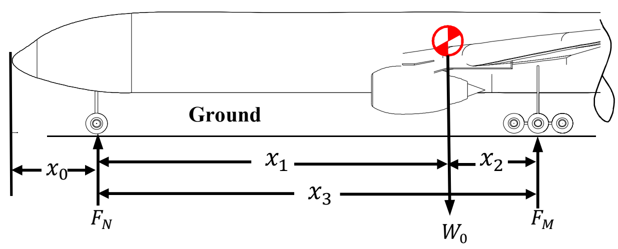


Fig. 9. Load distribution and various distances of a typical aircraft.

The static load applied by the nose wheels and the relevant distances of the five aircraft are shown in Table 3. Rolling resistance that could be generated is also shown in Table 3. However, it was not considered in the calculation along with other internal resistances that come from various static and friction components in shafts, bearings, axels, etc. Rolling resistance is calculated from (5):

$$F_K = \mu_r \times F_N \tag{5}$$

Here, F_k is the rolling resistance, μ_r is the typical rolling friction coefficient of the wheel on a hard surface, F_N is the static load applied by the nose wheels.

TABLE III. NOSE WHEEL STATIC LOADS OF THE SELECTED TYPES OF AIRCRAFTS

Aircraft Type	x_0 (m)	x_3 (m)	x_2 (m)	F_N (kgf)	μ_r	F_K (kgf)
ATR 72	3.03	10.77	1.88	3927.58	0.05	196.38
Dash 8	3.74	13.94	3.51	7226.47		361.32
Boeing 737	4.09	15.6	2.5	12035.26		601.76
Boeing 777	5.90	31.3	4.91	54642.81		2732.14
Boeing 787	5.41	25.83	3.81	36878.97		1843.95

C. Rotor Shaft's RPM Calculation

Nose wheel load induces torque to the roller, which is calculated by using (6):

$$\tau = F_N \times D \qquad (6)$$

Where τ is the induced torque F_N is the load applied by the nose wheel, D is the height of the roller above the ground.

The induced torque can also be calculated by (7). Substituting τ value provides the rotation of the roller.

$$N_1 = \frac{60}{2\pi}\sqrt{\frac{\tau}{Mr}} \qquad (7)$$

Here, N_1 is the rotation per minute of the roller, r is the radius of the roller, and M is the mass of the roller.

And then rotor shaft's RPM N_2 is calculated using (8).

$$N_2 = 4 \times N_1 \qquad (8)$$

Table 4. shows the rotor shaft's RPM generated by the selected types of aircraft while passing over the conveyor roller a single time.

TABLE IV. ROLLER AND ROTOR SHAFT RPM GENERATED BY THE SELECTED TYPES OF AIRCRAFTS

Aircraft Type	M (m)	r (m)	D (m)	τ (kgf)	N_1 (rpm)	N_2 (rpm)
ATR 72				1826.51	33.34	133.36
Dash 8				3540.97	46.42	185.68
Boeing 737	750	0.2	0.05	5897.28	59.9	239.6
Boeing 777				26774.98	127.65	510.6
Boeing 787				18070.69	104.86	419.44

D. Output Electrical Power Calculation

To begin with output power calculation, induced Electric Magnetic Force (e.m.f) needs to be calculated. Each aircraft, while passing the conveyor roller rotates the rotor shaft connected with the generator. This rotation induces e.m.f inside the generator. A DC (direct current) self-excited shunt-wound generator is assumed to be connected with the rotor shaft. A Zener diode has been integrated to the system for voltage stabilization. The equivalent circuit diagram is shown in Fig. 10.

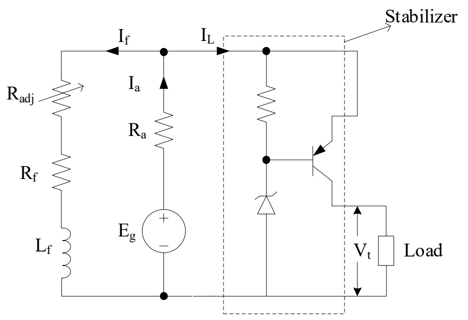


Fig. 10. Equivalent circuit diagram of the generator.

So, the induced e.m.f E_g is calculated from (9):

$$E_g = \frac{PN\emptyset Z}{60A} \qquad (9)$$

Where, P is the number of poles of the generator, N is the rated RPM of the generator, φ is the flux per pole, Z is the total number of conductors on the armature, A is the weave wound.

After that, the terminal voltage V_t is calculated from (10):

$$V_t = E_g - I_a R_a \qquad (10)$$

Where I_a is the armature current, and R_a is the armature resistance.

Thereafter, the output power P_output is calculated from (11):

$$P_{output} = V_t I_L \qquad (11)$$

Where I_L is the load current.

Table 5. shows the output power generated by the selected type of aircraft while passing over the conveyor roller a single time.

TABLE V. OUTPUT POWER GENERATED BY THE SELECTED TYPE OF AIRCRAFTS

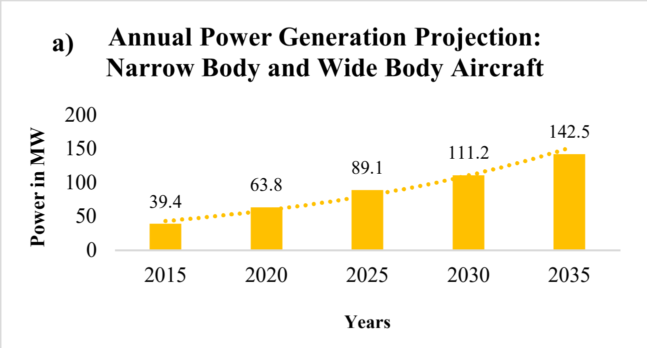
Aircraft Type	E_g (v)	V_t (v)	P_{output} (watt)
ATR 72	61.56	56.52	1130.4
Dash 8	85.71	80.67	1613.4
Boeing 737	110	104.96	2099.2
Boeing 777	235.7	230.66	4613.2
Boeing 787	193.62	188.58	3771.6

V. RESULTS AND DISCUSSION

In the previous section, we have constructed a theoretical model of the RPG device by using data for the most used aircraft in the HSIA airport. We have calculated the possible energy output from each type of aircraft. The results can vary slightly because we have not considered other secondary vehicles or ground vehicles, which can contribute to the overall electricity generation of the airport.

From Table 5, it is quite evident that the output from the RPG device is very much dependent on the size of the aircraft. Hence, the power generated from Boeing 777 and Boeing 787 is significantly higher than the other aircrafts available in the airport. Widebody aircraft can produce more electricity than narrow body aircraft. We have also calculated the mean power output from all five types of aircraft (from Table 5), and we are going to predict the overall power output from this RPG device annually.

Based on the aircraft movement data mentioned in the earlier section of this paper, electrical power that can potentially be generated annually by using the proposed RPG model is presented in Fig. 11 (a). It is assumed that only the aircraft types, shown in Fig. 3, are associated with all the aircraft movement. The mean value of the output powers calculated from Table 5 is also taken into account for the projection purpose.



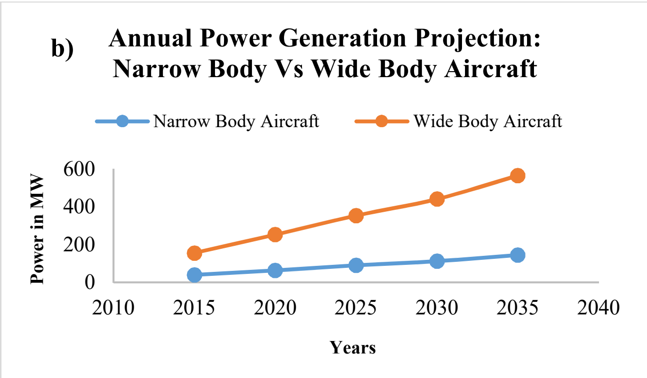


Fig. 11. Annual electrical power generation projection at HSIA (a) Narrow body and Wide body aircraft, (b) Narrow body Vs Wide body aircraft.

According to the projections above, annual electrical power generation using our proposed method is entirely dependent on the total movement of the aircraft. Total movement of the aircraft was approximately 74483 in 2015. Calculation shows that we could have produced 39.4 MW of electricity annually with our proposed model. Similarly, in the year 2035, the total movement of the aircraft will be approximately 269394. According to our prediction in the year 2035, we will be able to produce 142.5 MW of electricity annually. If the influx of the traffic or the movement of the aircraft increase, the power generation will increase simultaneously.

From Fig. 11 (b), we can see that the narrow-body aircrafts having a similar number of flights produce a similar amount of electricity annually, which is 40 MW in the year 2015 year and 144.9 MW in the year 2035. On the other hand, wide-body aircraft produce much higher electricity. According to our calculation, in 2015, wide aircraft could have produced 156.1 MW of electricity. Similarly, it is projected to produce 564.7 MW of electricity in the year 2035.

VI. Conclusion, Limitation and Future works

In this paper, we have not considered aircraft landing and takeoff. We have proposed the RPG device should be added to the taxing way of the new terminal. The electricity will be produced during the time of taxing or other ground operations. Apart from the aircraft, several ground vehicles (e.g., Refuelers, Ground Power Units, Buses, Air Start Units) can also contribute to the production of electricity with our proposed model. Any kind of movement over the roller will generate electricity. As a result, the production of the electricity will not be dependent on the aircraft only; however, at present, our primary target is to generate electricity from the movement of the aircraft.

A theoretical approach for generating electricity from the conveyor roller has been discussed. Our calculation has concluded that with a widebody aircraft, the generation of electricity is much higher, and with a narrow-body aircraft, the production of electricity is much less. We have proposed to install the device on the taxiway to avoid landing risks, e.g., speed, landing position, crosswind, wet landing, etc., in any weather condition.

Unlike the solar panels, our proposed model is not dependent on the weather or the sun. So, the source of renewable energy is more reliable; because the source is from kinetic energy. On a different note, there are many road bumps on the entry point of HSIA, also, near the parking lot. We could also utilize these existing speed bumps by upgrading them to produce electricity. This can also help us increase the production of energy.

In the near future, a prototype could be built. Several other features could be added to this device as well. For instance, during the winter or the foggy season, the visibility of the aircraft reduces quite significantly. Sometimes, it is difficult to pinpoint the location of the aircraft on the ground during the time of taxing. So, some modifications or additions to the proposed device could tell us the precise location of the aircraft on the ground in the airport.

The proposed model has some limitations that need to be addressed in future studies. Detailed dynamic analysis, external and internal resistances need to be included in the calculation; therefore, the precise prediction of the power generation is possible. Furthermore, system protection from adverse weather and the associated risks are also subject to the investigation.

The concept of RPG with a conveyor roller is a novel idea. It can produce clear and pollution-free energy. Even though the concept of power generation from renewable sources is not new, the concept of RPG has not been explored as much as other concepts. Therefore, the research work on this specific topic could revolutionize if proper attention is given.

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A Sliding Mode Control of an Electromagnetic Actuator Used in Aircraft Systems

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***Abstract*— A nonlinear electromagnetic actuator (EMA) system that consists of a mechanical motion and electromagnetic circuit is considered in this paper. The dynamics of the electrical and mechanical parts of the system were modeled. Steady-state conditions, in which the actuator position, actuator velocity, and coil current were assumed constants, were used as reference approaches for closed-loop scenarios. A sliding mode control method was applied to design the closed-loop coil voltage such that the nonlinear system slides along a certain sliding surface. The reliability of the presented control law was approved under a wide range of steady-state actuator position dispersions and coil voltage disturbances using Monte-Carlo simulation method. Numerical results with 1000 simulations were obtained to test the presented control law. The simulated results ensured the ability of the EMA to reach the steady-state conditions with fast response, excellent overshoot, and outstanding performance despite the wide range of system uncertainties.**

Keywords—* *Sliding mode, Control, Electromagnetic, actuator

I. Introduction

Electromagnetic actuators EMAs are widely used in the aircraft' industry. The main uses for EMAs are primary flight controls (ailerons, rudders, and elevators), secondary flight controls (flaps, slats, spoilers, and stabilizers), landing gears (extension/retraction of landing gears, steering of nose-wheels, and wheels braking), and engine (steering of the variable stator vanes and bleed valves, controlling thrust reversers, and controlling the geometry of nozzles and air intakes) [1]. This wide range of applications has motivated many researchers to study the dynamics and control of these devices. Linear control approaches are typically used with electromagnetic actuator systems such as Linear Quadratic Regulator controllers [2], proportional-integral-derivative (PID) control [3,4], and Model Predictive Control in which the system model is considered to predict the future behavior of the system variables [5,6]. Finite set predictive control model combined with PI controller and Kalman-based estimator was used in [7]. A back stepping technique was used in [8] to stabilize the nonlinear electromagnetic actuator system based on the worst-case scenario of the magnetic force. Lookup tables that relate the magnetic flux, the position, and the magnetic force with the position, the magnetic force were used.

A robust control law was designed in [9] for the electromagnetic actuator system. A combination of backstepping and sliding mode control was used to control the mechanical and electrical components of the system. In [10], a position feedback control strategy for three degrees of freedom actuator was employed using optical images sensor. A single mass model of an actuator and landing reference control approach of an electromagnetic actuator were presented in [11,12]. The velocities of the moving parts were estimated based on Lyapunov function.

In [13,14], a new nonlinear model with lumped parameter of the electromagnetic actuator was developed. The model considered the nonlinearity of the system and the friction of the moving parts. In [15], a witty control system was used with the goal of achieving a fine and precise control of an electromagnetic actuator. A revised recurrent Jacobi polynomial neural network (RRJPNN) control along with two remunerated controls and an altered bat search algorithm (ABSA) approach was presented. Various ways of modeling, designing, and controlling a linear electric actuator along with industrial applications were reviewed in [16].

It can be noticed from the literature that the available control algorithms are either complicated and accurate or simple wither lower accuracy. This work combines the simplicity and accuracy. It presents sliding mode control of a nonlinear electromagnetic actuator (EMA). First, the system was modeled. Then, the steady-state reference was generated based on the steady-state actuator position. Next, the nonlinear sliding mode control method was used to guide the EMA to track the shaped reference. Then, system performance was assessed using Monte Carlo simulation method in the presence of steady-state actuator position dispersions and moving piston mass deviations.

II. System Model

Typically, the electromagnetic actuator (EMA) system consists of two mechanical and electrical approaches. In this work, the mechanical setup involves one valve, one spring, and one moving piston while the electrical circuit holds two coils (left and right coil) which winding a fixed magnetic circuit. The two presented setups are settled in a frame that is manufactured to dampen vibrations. Schismatic of EMA

2021 5th Annual Systems Modelling Conference (SMC) | 978-1-6654-3815-5/21/$31.00 ©2021 IEEE | DOI: 10.1109/SMC53803.2021.9569865

system is presented in Fig. (1). More details about EMA systems and their work principles can be found in [17].

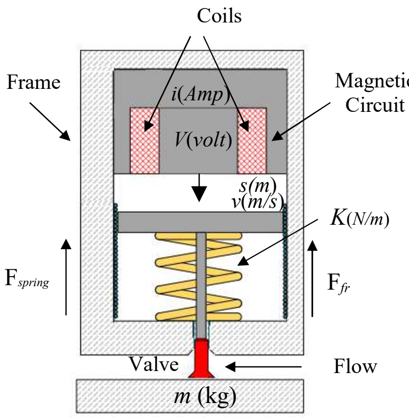

Figure 1 Electromagnetic Actuator Schematic

In Fig. (1), m is the moving piston mass and K is the spring stiffness. F_{fr} and F_{spring} are forces that are generated due to friction and spring, respectively.

The variables $s(t)$, $v(t)$, and $i(t)$ are the actuator position, velocity, and, current, respectively, which are considered as the system states: $[s(t)\ v(t)\ i(t)] = [\ x_1\ x_2\ x_3]$. Moreover, the coil voltage, V is considered as the system input: $[V]$=[u]. A full state-space representation (SSR) of the electromagnetic actuator system can be obtained as follows [9],

$$\begin{aligned} \dot{x}_1 &= x_2 \\ \dot{x}_2 &= \frac{1}{m}\left(\frac{1}{2}x_3^2\mu(x_1) + F_{ext}(x_1,x_2)\right) \\ \dot{x}_3 &= \frac{1}{L(x_1)}\left(u - Rx_3 + x_2x_3\mu(x_1)\right) \end{aligned} \tag{1}$$

where F_{ext} is the external force which can be defined as the summation of the friction and spring forces as expressed in Eq. (2).

$$F_{ext} = -\lambda x_2 - Kx_1 \tag{2}$$

The magnetic permeability $\mu(x_1)$ and magnetic inductance $L(x_1)$ are inversely proportional to the actuator position as shown in Eqs. (3) and (4), accordingly.

$$\mu(x_1) = N^2 \frac{\rho_X}{(\rho_x x_1 + \rho_0)^2} \tag{3}$$

$$L(x_1) = \frac{N^2}{(\rho_x x_1 + \rho_0)} \tag{4}$$

where R, N, ρ_x, and ρ_0, λ are coil resistance, coil winding, airgap reluctance, magnetic reluctance, and friction coefficient, respectively. All the system parameters are gathered from a real EMA system. Table 1 presents the proposed system parameters values [9].

Table 1 EMA parameters values

Parameter	Value	Definition
K	120	Spring stiffness (N/m)
λ	5	Friction coefficient (N/m^2)
R	0.4	coil resistor (Oms)
N	70	Coil turn
ρ_x	2.8	Airgap reluctance (H^{-1}m^{-1})
ρ_0	630	Magnetic circuit reluctance (H^{-1})
m	0.1	Mass (kg)

III. Sliding Mode Control

Practically, in most control approaches, there are differences between an actual system and its represented mathematical model. These variances emanate from uncertainties in view of system parameters changes or external dispersions. Achieving reliable controllers for nonlinear systems that suffer uncertainties is a challenging task in engineering.

Sliding mode control is developed to overcome control issues in nonlinear dynamical systems. The nonlinear control method principle is based on constructing a sliding mode surface, generating a discontinuous control signal, and eventually forcing the presented nonlinear system to track the surface.

Considering the electromagnetic actuator system in the affine form:

$$\dot{x} = \begin{bmatrix} x_2 \\ \frac{1}{m}\left(\frac{1}{2}x_3^2\mu + F_{ext}\right) \\ -\frac{1}{L}Rx_3 + \frac{1}{L}x_3x_2\mu \end{bmatrix} + \begin{bmatrix} 0 \\ 0 \\ \frac{1}{L} \end{bmatrix} u \tag{5}$$

$$y = x_1$$

where

$$f(x) = \begin{bmatrix} x_2 \\ \frac{1}{m}\left(\frac{1}{2}x_3^2\mu + F_{ext}\right) \\ -\frac{1}{L}Rx_3 + \frac{1}{L}x_3x_2\mu \end{bmatrix}, \quad g(x) = \begin{bmatrix} 0 \\ 0 \\ \frac{1}{L} \end{bmatrix}, \quad h(x) = x_1 \tag{6}$$

The sliding mode control steers the system output (actuator position) tracking the steady-state actuator position

(x_{1st}) so that the system action is governed by the sliding mode surface S, which can be obtained by

$$S = \left(\frac{d}{dt} + k_1 \right)^{r-1} e \tag{7}$$

where k_1 is a constant positive value, r is a relative system degree (r =1), and e is a system error presented in terms of the system output and steady-state actuator position:

$$e = x_{1st} - x_1 \tag{8}$$

Thus, the sliding mode surface equation can be written as follows

$$S = \ddot{e} + 2k_1\dot{e} + e \tag{9}$$

The sliding control command is obtained by differentiating Eq. (9) so

$$\dot{S} = \dddot{e} + 2k_1\ddot{e} + k_1^2\dot{e} \tag{10}$$

To simplify the computation, Lie derivative method is

$$\dot{e} = \dot{x}_{1st} - L_f h(x) \tag{11a}$$

$$\ddot{e} = \ddot{x}_{1st} - L^2{}_f h(x) \tag{11b}$$

$$\dddot{e} = \dddot{x}_{1st} - L^3{}_f h(x) - L_g L_f^2 h(x)u \tag{11c}$$

used:

where

$$L_f h(x) = \frac{\partial h}{\partial x} f(x) = \begin{bmatrix} 1 & 0 & 0 \end{bmatrix} \begin{bmatrix} x_2 \\ \frac{1}{m}\left(\frac{1}{2}x_3^2\mu + F_{ext}\right) \\ -\frac{1}{L}Rx_3 + \frac{1}{L}x_3x_2\mu \end{bmatrix} = x_2 \tag{12}$$

$$L^2{}_f h(x) = \frac{\partial\left(L_f h(x)\right)}{\partial x} f(x) == \frac{1}{m}\begin{pmatrix} \frac{1}{2}N^2 \frac{\rho_X}{\left(\rho_x x_1 + \rho_0\right)^2} x_3^2 \\ -Kx_1 - \lambda x_2 \end{pmatrix} \tag{13}$$

$$L^3{}_f h(x) = \frac{\partial\left(L^2{}_f h(x)\right)}{\partial x} f(x) = \begin{pmatrix} \frac{\lambda}{m^2}\left(Kx_1 + \lambda x_2 - \frac{N^2\rho_x}{2\left(\rho_x x_1 + \rho_0\right)^2} x_3^2\right) \\ -\left(\frac{K}{m} + \frac{N^2{\rho_x}^2}{\left(\rho_x x_1 + \rho_0\right)^3} x_3^2\right) x_2 \\ + \frac{N^2\rho_x}{m\left(\rho_x x_1 + \rho_0\right)^2} x_3 \begin{pmatrix} \left(\frac{\rho_x x_2 x_3}{\left(\rho_x x_1 + \rho_0\right)}\right) \\ -\left(\frac{Rx_3\left(\rho_x x_1 + \rho_0\right)}{N^2}\right) \end{pmatrix} \end{pmatrix} \tag{14}$$

$$L_g L_f^2 h(x) = \frac{\partial\left(L_f^2 h(x)\right)}{\partial x} g(x) = \frac{\rho_x x_3}{m\left(\rho_x x_1 + \rho_0\right)} \tag{15}$$

There are several ways to perform the effectiveness of the proposed sliding mode in finite time. A very well-suited approach is to decrease the sliding surface function, Eq. (10) can be written in term of the sliding surface function [18], yields

$$\dot{S} = -k_2 sgn\,(S) - k_3 S \tag{16}$$

where k_2 and k_3 are positive values.

After computing all the required sliding mode surface derivations, Eqs. (10) and (16) are employed to create the sliding mode surface:

$$\dddot{e} + 2k_1\ddot{e} + k_1^2\dot{e} = -k_2 sgn\,(S) - k_3 S \tag{17}$$

Equation (17) shows the created surface of the sliding mode in terms of sliding control command.

Substituting Eqs. (11), (12), (13), (14), and (15) into Eq. (17) and solving for the coil voltage (u):

$$u = \frac{\begin{pmatrix} \begin{pmatrix} -k_2\,\text{sgn}\begin{pmatrix} \left(\ddot{x}_{1st} - \frac{1}{m}\left(\frac{1}{2}N^2\frac{\rho_X}{\left(\rho_x x_1 + \rho_0\right)^2}x_3^2 - Kx_1 - \lambda x_2\right)\right) \\ +2k_1\left(\dot{x}_{1st} - x_2\right) + \left(x_{1st} - x_1\right) \end{pmatrix} \\ -2k_1\left(\ddot{x}_{1st} - \frac{1}{m}\left(\frac{1}{2}N^2\frac{\rho_X}{\left(\rho_x x_1 + \rho_0\right)^2}x_3^2 - Kx_1 - \lambda x_2\right)\right) - k_1^2\left(\dot{x}_{1st} - x_2\right) \end{pmatrix} \\ + \begin{pmatrix} \frac{\lambda}{m^2}\left(Kx_1 + \lambda x_2 - \frac{N^2\rho_x}{2\left(\rho_x x_1 + \rho_0\right)^2}x_3^2\right) - \left(\frac{K}{m} + \frac{N^2{\rho_x}^2}{\left(\rho_x x_1 + \rho_0\right)^3}x_3^2\right)x_2 \\ + \frac{N^2\rho_x}{m\left(\rho_x x_1 + \rho_0\right)^2}x_3\left(\left(\frac{\rho_x x_2 x_3}{\left(\rho_x x_1 + \rho_0\right)}\right) - \left(\frac{Rx_3\left(\rho_x x_1 + \rho_0\right)}{N^2}\right)\right) \end{pmatrix} - \dddot{x}_{1st} \end{pmatrix}}{\left(\frac{\rho_x x_3}{m\left(\rho_x x_1 + \rho_0\right)}\right)} \tag{18}$$

In order to achieve a steady-state case, the nonlinear EMA system has been stabilized around an equilibrium operating vector. The steady-state conditions, which assume that the actuator position, actuator velocity, and coil current, are constants, were utilized to create a reference approach. The reference trajectory can be readily satisfied by substituting Eq. (3) into Eq. (1) and setting the resultant equation to zero:

$$\begin{cases} x_{2st} = 0 \\ x_{3st} = \sqrt{\dfrac{2(Kx_{1st})}{\left(N^2 \dfrac{\rho_X}{\left(\rho_x x_{1st} + \rho_0\right)^2}\right)}} \\ u_{st} = Rx_{3st} \end{cases} \tag{19}$$

IV. Results and Discussion

After creating the EMA system reference [Eq. (19)] and designing the sliding mode coil voltage required to track the certain reference [Eq. (18)], the closed-loop scenarios are simulated to verify the proposed control method. First, in nominal case, with x_{st} = [0.005 0 5.9 2.35] and m=0.1 kg is obtained to design the coil voltage required to track the nominal steady-state reference. Second, in the off-nominal case, many dispersed steady-state actuator position and mass are obtained to perform the reliability of the proposed nonlinear control method. The influence of the change of the steady-state actuator position x_{1st} = [0.001 0.009] m and the moving piston mass m= [0.05 0.15] kg is considered using the Monte-Carlo simulation method. Monte-Carlo simulation is employed to impose random steady-state actuator position and moving piston mass disturbances [19-21]. Figures 2 (a) - 2 (d), present the actuator position, actuator velocity, coil current, and coil voltage, profiles respectively, under nominal conditions. These figures show that the actuator position, actuator velocity, coil current references are tracked remarkably using the sliding mode control. Figure 2 (a) shows that the actuator position reaches the steady-state value in 0.34 s with excellent performance and zero overshoot.

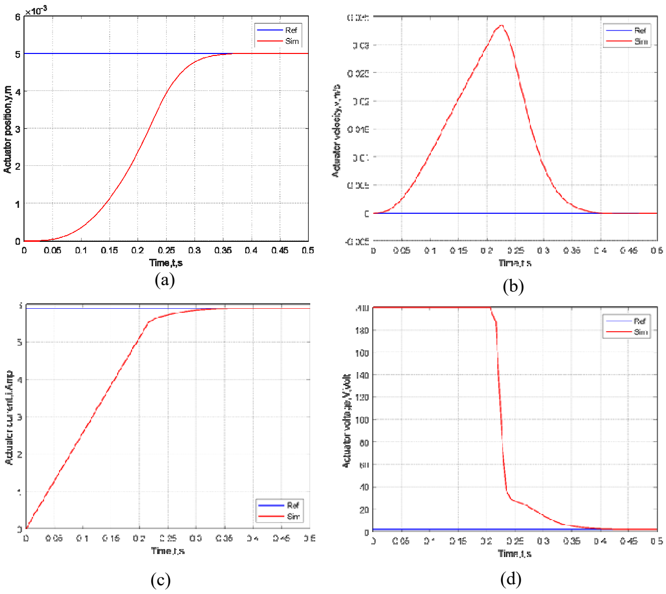

Figure 2 Reference and real profiles for nominal conditions (x_{1st} = 0.005 m, m=0.1 kg); (a) actuator position vs. time; (b) actuator velocity vs. time; (c) coil current vs. time; (e) coil voltage vs. time.

Figures3 (a)-3(d) present the residual actuator position, actuator velocity, coil current, and coil voltage histories, respectively for 1000 Monte Carlo trials. These figures indicate that the real profiles track the reference trajectories accurately using the proposed control method. Figure 3(d) shows that the maximum and minimum real coil voltage are bounded between 0 and 200 volts for all the simulated tests. Therefore, the EMA system reaches the steady-state approach without excessing the allowable constraints [9].

Table 2 summaries Monte-Carlo scenarios. The results demonstrate that the minimum, maximum, mean, and standard deviation steady-state errors are roughly zero. Furthermore, the maximum settling time and overshoot for all the profiles do not exceed 0.382 s and 5.8%, respectively. The simulated EMA system has a remarkable performance with fast response and low overshoot.

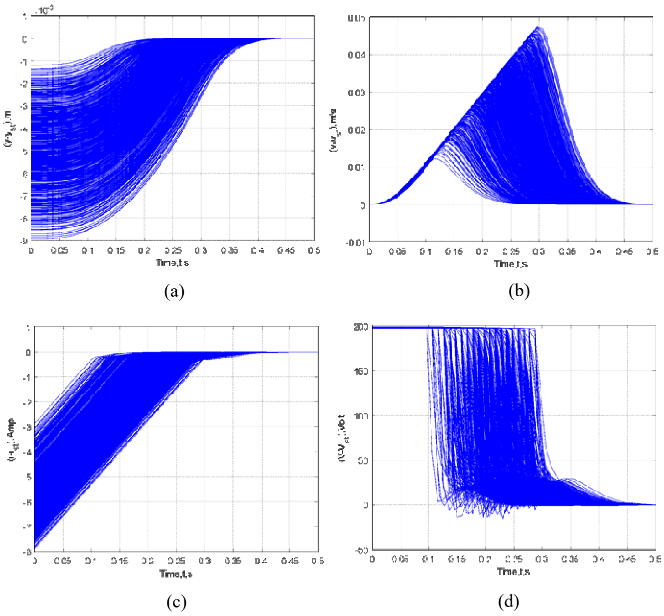

Figure 3 EMA residual profiles for 1000 Monte-Carlo trials; (a) ball position vs. time; (a) actuator position vs. time; (b) actuator velocity vs. time; (c) coil current vs. time; (d) coil voltage vs. time

Table 2 Statistics results at steady-state positions.

State Error	Mean	Minimum	Maximum	Standard Deviation
Actuator position (m)	9.93e-07	-3.679e-09	5.883e-06	1.1798e-06
Actuator velocity (m/sec)	-2.693e-05	-9.005e-05	-1.038e-08	2.501e-05
Actuator current (Amp)	0.00015085	-1.732e-05	0.00062766	0.00014323
Actuator voltage (Volt)	-0.025105	-0.13567	0.24052	0.022552
Settling time (s)	0.295	0.2127	0.382	0.0332
Overshooting (100%)	1.1276	0	5.8323	1.2571

V. Conclusion

A proposed algorithm for the electromagnetic actuator system has been developed. The steady-state conditions have been utilized to create the reference actuator position, actuator velocity, and coil current profiles. The sliding mode control was employed to design the closed-loop coil voltage with steady-state actuator position dispersions and moving piston mass deviations. A thousand simulations using Monte-Carlo method were propagated to validate the effectiveness of the sliding control law. Despite the wide range of actuator position and mass deviations, the proposed system is able to reach steady-state conditions with fast response, excellent overshoot, and outstanding performance.

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2021 5th Annual Systems Modelling Conference (SMC) | 978-1-6654-3815-5/21/$31.00 ©2021 IEEE | DOI: 10.1109/SMC53803.2021.9569926

ISBN: 978-1-6654-3815-5