# Assessing Frictional Performance of Heavy Brake Pad Compounds Through Manta Ray Foraging Optimized Ensemble Tree Approach

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The compound of braking pads has a vital role in predicting frictional performances. For efficient brakes, the design has to combine excessive friction with longevity to survive extended use. Creating brakes formulations which can deliver steady and dependable resistive efficiency under a variety of operational environments, such as severe levels and high loads is an obstacle. To overcome those issues, we explore a Manta Ray Foraging Optimized Ensemble Tree Approach (MRFO-ETA) as a novel method. At the initial stage, the data's are collected and the collected data's are undergoing for preprocessing stage using min-max normalizations. Through comprehensive experimentation and analysis, we evaluate the proposed ensemble tree approach against traditional methods, showcasing its superiority in accurately predicting the frictional behavior of heavy brake pad compounds. This innovative methodology not only contributes to advancements in automotive safety but also highlights the potential of bio-inspired optimization in engineering applications. The findings provide valuable insights for optimizing brake pad formulations, contributing to the enhancement of vehicle safety and performance. MRFO-ETA performance that obtained 97% of accuracy, 95% of recall, 94% of F1 score and 1.25 in RMSE. The research aims to identify optimal formulations that balance high frictional performance with wear resistance.

**Keywords:** Manta Ray Foraging Optimized Ensemble Tree Approach (MRFO-ETA), Disc, Brake Pad, Environments, Friction.

## 1. Introduction

In every car brake structure, the stopping pads with discs are a crucial tribo-pair. The structure has to possess the proper heat conductance, steady coefficients for abrasion and small attrition (Hendre and Bachchhav 2021). Frictional modifications, binding agents, additives and stabilizers constitute the main components of frictional compounds; the exact mix of these components varies depending on the needs of the entire structure (Sagiroglu and Akdogan 2023). Despite its outstanding tribo-mechanical as well as thermo qualities, mesothelioma is deemed dangerous for human beings according to multiple environmental bodies. Modern substances that are free of asbestos fibers, tin, copper and arsenic have been suggested to reduce adverse ecological consequences (Sethupathi et al 2021). It creates a sustainable friction-reducing substance comprised of materials from nature that don't include mesothelioma. Employing a conventional disc configuration and simulations test conditions, the properties of newly discovered friction-reducing compounds were assessed, in addition to characteristics including wear as well as tear, heat conductivity, indices of dispute and stiffness to enlargement, among hardness (Yanar et al 2022). An essential component to guarantee the effectiveness, as well as security of the brake mechanism on trucks and buses, is the evaluation of resistive effectiveness with compositions of large braking pads. Transit systems and factories require a lot of halting force and hefty friction pads are essential to supply the braking force. Braking effectiveness is greatly impacted by the changing features of the padding structure, which affect factors like temperature emitted, placement prevention and overall reliability (Chandradass 2021;Irawan et al 2022). The transportation and manufacturing sectors insist on more efficiency and dependability of regarding brakes. In addition to assisting in the creation of sophisticated pads, it guarantees that trucks and buses can confirm strict security rules and legal constraints (Varriale et al 2022;Motta et al 2023). The objective of the study is to assess the grip efficiency in pad substances that pay particular attention to the composition of materials, heat conduct and general efficacy in high-duty vehicle brakes. The area of powerful vehicles brakes technologies that offer knowledge regarding the optimization of brake pad compositions towards increased security, resilience and effectiveness.

Kumar and Kumaran (2019) explored the significance of advancement in brake frictional materials. The primary goals of these improvements were to lessen the ecological damage by the dangerous compounds included in braking pads to improve the efficiency of brakes. The lack of information regarding the fundamental kinds of pad formulations gives fresh investigators a basic comprehension of the subject and educates users on the impacts of different ingredients used in friction-free pad components. Elzayady and Elsoeudy (2021) showed improved friction-wear characteristics compared to the lubricant's designed substance. The outermost examination shows that the actual pads of post-service scratched stages. The actual pads of wearing mechanisms include abrasion application, severe contact cracking from heat exhaustion, corroded coatings, metallic oxides and glazing surfaces as a result of the two-way interactions. Hesse et al(2021) examined the particulate emissions production of various braking systems and frictional components were assessed and distinctive traits were determined. An inertial device with an ongoing sample mechanism was used for the results. The brake wear granular ratios for different disc layouts in different dimensions were computed for comparison using grey cast-iron discs, silica carbide-coated discs and carbon-based ceramic discs. Manoj et al(2023) discovered that the development of braking coatings evolved significantly. They enhanced the stopping power and reduced the harm that breaks patches' harmful chemicals caused to the surroundings were the most important goals of development. Tavangar et al(2020) analyzed the industries that have to identify a suitable substitute with copper as the application of silver for frictional components was restricted due to increasing environmental issues. Pair retail displays into two types, first type is minimal metal-containing with copper fibers and the other type is dim metal-based thermal graphite. Pai et al(2020) demonstrated that elastic compounds had possibilities as brake line micro-fillers. In sudden and sporadic collision operations like brakes, these can offer acoustical benefits along with vibration dampening. Reusing products that normally end up in dumps was made possible through the ability to recover the elasticity component in non-renewable wheels. Mulani et al(2022) performed the wearing detritus that gets generated by an extreme abrasion and sticky wear process in the brake pad-disc systems. This process creates small particles of waste due to the continuous scratching, which was undoubtedly harmful to the natural world. Gray iron casting in the mineral pearlite state containing laminated grapheme stages constitutes the typical materials utilized in braking discs. They offer an excellent melting point and they were electrically reactive. Moreover, it possesses a strong propensity to corrode and significant materials were worn over time. LS (2020) presented the structures of flakes-shaped iron-aluminum alloys based frictional materials have consistent fading coupled with rebound capabilities along a strong chemical, physiological, heat and biomechanical capabilities.

## 2. Materials and methods

The abrasion functionality of heavyweight pad composition was a crucial factor in guaranteeing the effectiveness as well as security of the brakes. Automobiles like buses, pickups and any other bigger cars that maneuver beneath significant weight and difficult circumstances utilize thick pads for brakes. Figure 1 illustrates the flow of the suggested methodology.

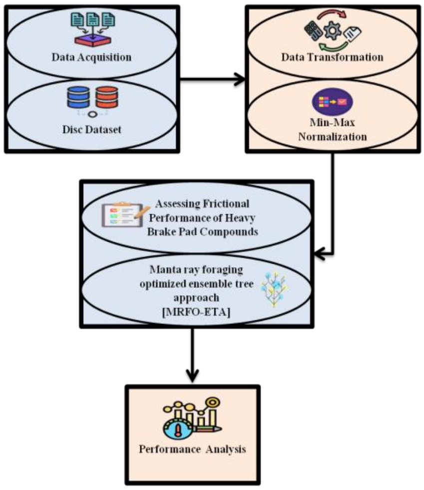


Figure 1Flow of Methodology

[Source: Author]

2.1 Dataset

The research utilized a typical, easily bought kind of disc and padding: the disc itself is composed of normal black cast iron. The pads and the aforementioned disc worked on the frame of the dynamos. This halting device was delivered inside a container that included an inlet and a discharge allowing dispensing parts, allowing for real-time particulate quantity measurement and particulate collection during the experiments. The testing cycles employed include the state master period, which is implemented through car designers and brakes manufacturers to assess brake pad materials regarding technical advancements, reliability, with auto security, incorporating requirements (Dimopoulos et al 2022).

2.2 Data preprocessing using min-max normalization

Min-Mix Normalization is a method that applies a linear change to the initial set of information. The term Min-Mix Normalization refers to a method that preserves the relationships between the initial information. An easy method called min-max normalization allows information to be fitted in a predetermined border that has a predetermined border. Using the Min-Max normalization method as shown in equation (1);

$$B' = \left(\frac{B - min\ value\ of\ B}{max\ value\ of\ B - min\ value\ of\ B}\right) * (C - D) + D \qquad (1)$$

Whereby B' contains one of the Min-Max normalized pieces of data. If [C,D] is predetermined as borders if B is an initial information area. ThereforeB is newly translated information.

Manta ray foraging optimized ensemble tree approach (MRFO-ETA)

2.3.1 Manta ray foraging optimized (MRFO)

Manta ray foraging optimization (MRFO) offers an engrossing insight through the intricate forage tactics such magnificent fish have evolved to effectively dine in their undersea environments. MRFO are renowned for their elegant motions and remarkable shoulder fins which resemble wings. They possess special hunting tactics that allow them to consume the most power possible when slicing through wide oceans. MRFO research explores the efficient ways in which these creatures find, hunt and catch food, providing insights into the ecological factors along with adaptive behaviors that affect their effectiveness. This study advances our understanding of marine ecosystems and can have ramifications for bio-mimicry and the creation of novel approaches to the assets of optimization in a range of technical and situational circumstances as shown in Algorithm 1.

MRFO shares similarities with several meta-heuristic methods however; its starting stage is determined by randomness as shown in equation (2);

$$W_{ji}\left(\dot{.}\right) = Ka_{ji} + q\left(\dot{.}\right).\left(Ga_{ji} - Ka_{ji}\right)\forall j \in M_{pop,} i \in M_{var} \quad (2)$$

The chaining strategies are used in equation (3) and equation (4);

$$Q_{h,u}(a+1) = \begin{cases} Q_{h,u}(r) + (Q_{best,u}(a) - Q_{h,u}(a)).(w\left(\dot{.}\right) - \lambda)\,\Delta\forall h = 1, u \in N_{var} \\ Q_{h,u}(a) + (Q_{h-1,u}(a) - Q_{h,u}(a)).(w\left(\dot{.}\right) - \lambda)\,\Delta\forall h > 1, u \in N_{pop} \end{cases} \quad (3)$$

$$\varphi = 2.w\left(\dot{.}\right).\sqrt{\left|log\left(q\left(\dot{.}\right)\right)\right|} \quad (4)$$

MRFO is modified utilizing the equation given to revolve about the optimal point in this operating design as shown in equation (5);

$$Q_{h,u}(a+1) = X_{h,u}(a) + SF.\left(w_2 Q_{best.u} - w_3 Q_{h,u}(a)\right)\Delta\forall h \in N_{pop} \quad (5)$$

$Q_{best,u}$ is the best location of concentration

$$Q_{h,u}(a+1) = \begin{cases} Q_{best,u}\Delta Q_{h,u}.(w - \beta)\Delta\forall h = 1, u \in N_{var} \\ Q_{best,u} + r.\left(q_{h-1,j}(a) - Q_{h,u}(a)\right)\beta.\Delta Q_{h,u}\Delta\forall h > 1: N_{pop} \end{cases}$$

Where $\Delta W_{j,i} = W_{best,i}(s) - W_{j,i}(s)$ (6)

$$\beta = 2.exp\left(q_1.\frac{s_{max} - s + 1}{s_{max}}\right).sin\,(2\pi q_1 \quad (7)$$

$$Q_{h,u}(t+1) = \begin{cases} Q_{rand}\Delta Q_{h,u}.(w - \beta)\Delta\forall h = 1, u \in N_{var} \\ Q_{best,u} + w.\left(q_{h-1,u}(a) - q_{h,u}(a)\right)\beta.\Delta Q_{h,u}\Delta\forall h > 1 : N_{pop} \\ Where \quad \Delta Q_{h,u} = Q_{rand} - Q_{h,u}(a) \end{cases} \quad (8)$$

$$W_{rand}\left(\dot{.}\right) = Ka + q\left(\dot{.}\right).(Ga - Ka) \quad (9)$$

***Algorithm 1: The Manta ray foraging optimization***

*Initialize search agents (manta ray) populations* $j = 1, \ldots, m$
*while the Stop condition is not met do*
*for* $j = 1$ *to* $M$ *do*
*if rand* $< 0.5$ *then* ⊳*Cyclone foraging*

$$Q_{rand} = q_i + rand \,.\, (Q_c - Q_j)$$

$$q_h(t+1) = \begin{cases} q_{rand} + a\,.\,(q_{rand} - q_h(a)) + \beta.\,(q_{rand} - Q_h(a)) h = 1 \\ q_{rand} + a\,.\,(q_{l-1}(a) - q_h(a)) + \beta.\,(q_{rand} - Q_h(a)) h = 2, \ldots, N \end{cases}$$

*else*

$$q_h(a+1) = \begin{cases} q_{best} + a\,.\,(q_{best} - q_h(a)) + \beta.\,(q_{best} - q_h(a)) \quad h = 1 \\ q_{best} + a\,.\,(q_{h-1}(a) - q_h(a)) + \beta.\,(q_{best} - q_h(a)) h = 2, \ldots, N \end{cases}$$

*end if*
*else* ⊳ *Chain foraging*

$$q_h(a+1) = \begin{cases} q_h(a) + a\,.\,(q_{best} - q_h(a)) + \alpha.\,(q_{best} - q_h(a)) \quad h = 1 \\ q_h(a) + a\,.\,(q_{h-1}(a) - q_h(a)) + \alpha.\,(q_{best} - q_h(a)) h = 2, \ldots, N \end{cases}$$

*end if*
*Update the value of* $Q_{best}$
*Compute the fitness of each* $w(q_h(a+1))$.
*If* $w(q_j(a+1)) < w(q_{best})$ *then*

$$q_{best} = q_h(a+1)$$

*end if*
*for* $i = 1$ *TO* $M$ *do* ⊳ *Somersault foraging*

$$q_h(a+1) = q_h(a) + r.\,(a_2\,.\,q_{best} - q_3\,.\,q_h(a))$$

*Compute the fitness of each individual* $w(q_h(a+1))$
*If* $w(q_h(a+1)) < w(q_{best})$ *then*

$$q_{best} = q_h(a+1)$$

*end if*
*end for*
*end for*
*end while*

2.3.2 Ensemble tree approach (ETA)

An Ensemble Tree Approach (ETA) constitutes an effective and visually appealing utilization that provides an organized depiction of potential results and the choice routes that lead to them. It is employed for data assessment and choice-making. Especially useful in disciplines like company analytics and neural networks was this simple approach. Figure 2 depicts the flow of ETA. An ETA is conceptualized as having roots that represent the original selection or beginning points and branching outward across multiple points at every stage of ETA making to indicate other options or possible results.

The twigs keep growing, creating something such as a living thing that assists in clearly and methodically illustrating the process of making choices. The membership values are taken as a sample as shown in equation (10);

$$E(H\left(d_{n_j}(w)\right) = \sum_{j=1}^{i=o} d_{n_l}^{i}(w) \quad (10)$$

Consequently, it is possible to determine the energy of the data level nodes on levels using the equation provided below in equation (11):

$$FH\ (H) = \sum_{n=J}^{n=l} \frac{E\left(H\left(d_{n_j}(w)\right)\right)}{\sum_{n=1}^{n=l}(EH(d_n(w))} log_2 \frac{E\left(H\left(d_{n_j}(w)\right)\right)}{\sum_{n=1}^{n=l}(EH(d_n(w))} \quad (11)$$

The following is the flexible segmented of feature trees and the characteristic node-specific computation equation (12):

$$FH\left(\frac{H_j}{B}\right) = -\sum_{n=1}^{n=l} \frac{E\left(B_j(d_n(w)\right) \cap E(d_n(w)))}{\sum_{n=1}^{n=l} E(B_j(d_n(w))}\ FH\ (H \cap B_j) \quad (12)$$

Lastly, the relevant data is obtained as follows in equation (13):

$$Egain\ \left(B_j, H\right) = FH(H) - FH(\frac{H}{B_j}) \quad (13)$$

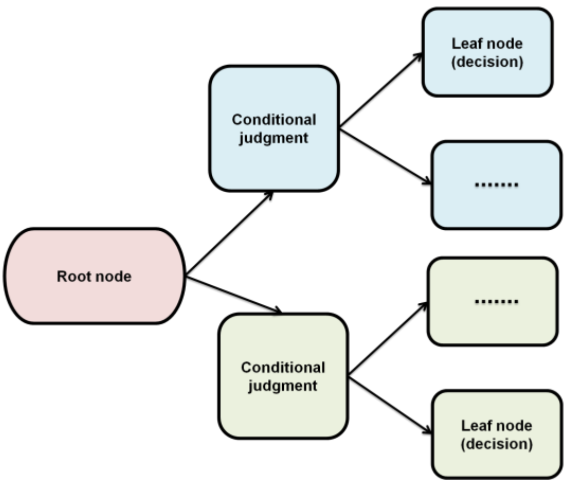


Figure 2 Flow of ensemble tree structure [Source: Author]

## 3. Results

The braking patch's longevity of heat conductivity and braking effectiveness are influenced by their contact efficiency. Compared with their smaller equivalents, tough vehicles as well as corporate vehicles face more weight and harder situations while driving. In this paper, we have taken MRFO-ETA as a proposed method and existing methods are modified convolutional neural network-support vector machine (MCNN-SVM), artificial neural network(ANN) and convolutional neural network-long short-term memory (CNN-LSTM).

### 3.1 Accuracy

Accuracy ensures that the selected brake components meet or exceed company norms for lifetime as well as effectiveness; hence, accurate and reliable testing needs to be accomplished. Precise evaluations need thorough procedures, like exacting device tests across a range of settings, involving temperatures, pressures, as well as velocity. Table 1 and Figure 3 illustrate the value of accuracy of MRFO-ETA at 97% which is higher than the CNN-LSTM obtained at 70%, MCNN-SVM occurred at 85% and ANN obtained at 80%.

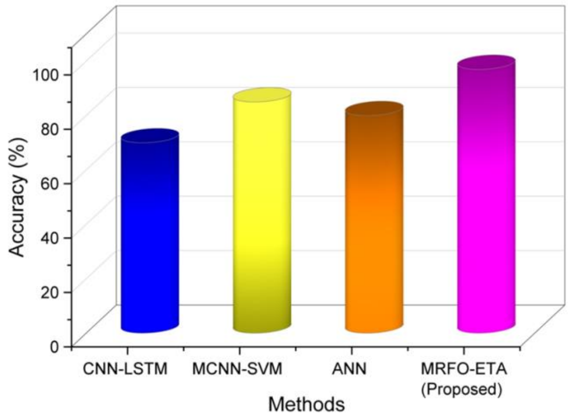


Figure 3Performance of accuracy [Source: Author]

Table 1Numerical values of accuracy [Source: Author]

| Methods | Accuracy (%) |
|---|---|
| CNN-LSTM (Wang et al 2023) | 70 |
| MCNN-SVM (Zhang et al 2021) | 85 |
| ANN (Hong and Ha 2023) | 80 |
| MRFO-ETA (Proposed Method) | 97 |

### 3.2 Recall

Recall is the braking effectiveness of large braking substances; recollection pertains to the capacity to get crucial facts and figures for the assessment of those combinations. Retrieval is essential in the complex world of pedal design because it ensures that all relevant factors influencing mechanical effectiveness are given account. This includes gathering real-world information from earlier research, analyzing the characteristics of the materials and figuring out the physical circumstances whereby those massive braking compositions should operate. A comprehensive recalls approach could assist in making educated choices that aid with the enhancement and refinement of robust padding formulations. Table 2 and Figure 4 depict the value of recall in MRFO-ETA at 95% which is higher than the CNN-LSTM obtained at 85%, MCNN-SVM occurred at 70% and ANN obtained at 90%.

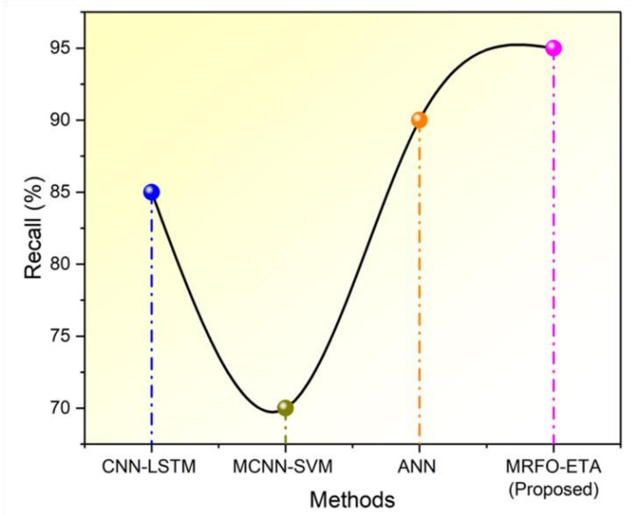


Figure 4Performance of recall[Source: Author]

Table 2Numerical values of recall[Source: Author]

| Methods | Recall (%) |
|---|---|
| CNN-LSTM (Wang et al., 2023) | 85 |
| MCNN-SVM (Zhang et al 2021) | 70 |
| ANN (Hong and Ha 2023) | 90 |
| MRFO-ETA (Proposed Method) | 95 |

### 3.3 F1 - score

F1 score is a measure that applied to problems with binary categorization and can be modified to evaluate the contact effectiveness of substances employed in braking pads. When it comes to evaluating braking pads, splitting between the two types can allow distinguishing between materials that work well and those don't work well based on friction qualities. Combining recall and accuracy, the F1 score offers a fair assessment of strategy efficiency. Recall measures the capacity of the model to catch the pertinent occurrences, whereas sharpness evaluates the reliability of its favorable forecasts. The score of F1 provides a thorough assessment that strikes equilibrium between recollection and accuracy by taking into account the two types of mistakes and fraudulent negatives. An elevated F1 score in the context of thick pad compositions suggests a fair evaluation of the thermal efficiency, considering the detection of efficiency. Table 3 and Figure 5 show the value of the F1 score in MRFO-ETA presented at 94%, CNN-LSTM performed at 90%, MCNN-SVM obtained 80% and ANN occurred at 85%.

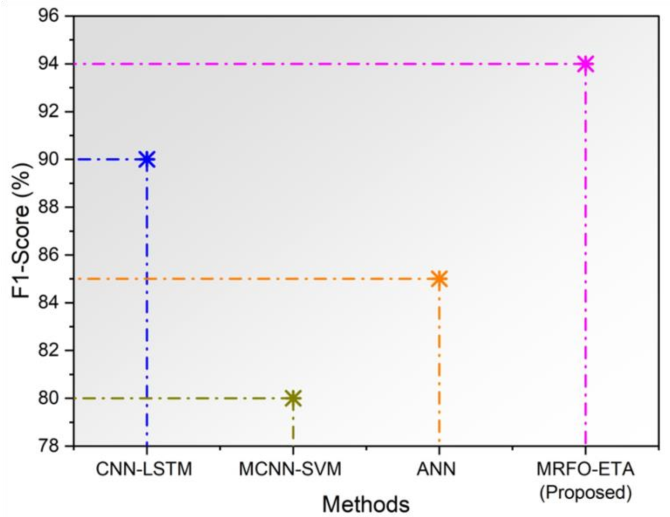


Figure 5Performance of F1 score [Source: Author]

Table 3Numerical values of F1 score [Source: Author]

| Methods | F1-Score (%) |
|---|---|
| CNN-LSTM (Wang et al., 2023) | 90 |
| MCNN-SVM (Zhang et al 2021) | 80 |
| ANN (Hong and Ha 2023) | 85 |
| MRFO-ETA (Proposed Method) | 94 |

## 3.4 RMSE

Root mean square error (RMSE) is an analytical indicator that measures the discrepancies between actual and expected quantities to evaluate the exactness and reliability of observations or forecasts. RMSE is a crucial instrument to evaluate the prediction algorithms' or empirical findings' efficacy to gauge the braking efficiency of heavier braking pads materials. It computes the inverse of the square base of the mean of the proportional discrepancies among the frictionless effectiveness levels that are anticipated. A smaller RMSE suggests an improved interpretation of the mechanical actions of the brake pad's composition as it shows that forecasts roughly correspond to the observations. Table 4 and Figure 6 illustrate the value of RMSE as MRFO-ETA obtained 1.25 which is lower than the CNN-LSTM occurred 1.4, MCNN-SVM performed 2.1 and ANN performed 1.8.

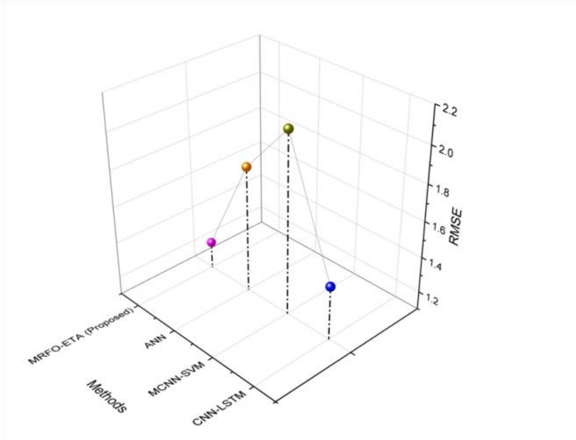


Figure 6Performance of RMSE [Source: Author]

Table 4Numerical values of RMSE [Source: Author]

| Methods | RMSE |
|---|---|
| CNN-LSTM (Wang et al 2023) | 1.4 |
| MCNN-SVM (Zhang et al 2021) | 2.1 |
| ANN (Hong and Ha 2023) | 1.8 |
| MRFO-ETA (Proposed Method) | 1.25 |

## 4. Conclusions

The evaluation of dynamic characteristics of powerful pad compositions serves as crucial to enhance the halting equipment's security and efficacy in large, commercial vehicles. An in-depth examination of the various pad materials provides valuable insight into ways that can withstand the challenging conditions resulting from larger loads and increasingly demanding operating conditions. The proposed method MRFO-ETA performs better values than the other existing methods, MRFO-ETA obtained 97% accuracy, observed 95% recall, revealed a 94% F1 score and has a lower value in RMSE of 1.25 which is more efficient. The evaluation technique yields data on thermal resilience, wear tolerance and coefficients of controversy, which are useful in selecting brake pad compositions that provide adequate longevity with powerful stopped force. It might advance heavier brake compositions, which will eventually end up resulting in better restraining effectiveness, a lesser burden on brake elements and more general automotive security through the frictional attributes of materials.

### 4.1 Limitations and Future Scope

The abrasive effectiveness of high brake pads with different compositions plays a critical role in the optimization of stopping devices on trucks and buses, it's essential to recognize that the procedure has some intrinsic limits. Several variables might affect the efficiency of brake pad substances, including the environment, carloads and road surfaces. Even though research in laboratories is useful, the model was unable to capture the complexity and unpredictable nature of any of the external factors.Gradual damage that happens to the robustness and efficiency of powerful braking pad compositions can show themselves in many ways.

To examine novel substances and nanotechnology in the manufacture of brake pads. Efficiency could be increased of nanoparticles by improving durability against wear and mechanical characteristics in the future.To analyze braking effectiveness information using artificial intelligence techniques along with analysis. Improved comprehension of wearing trends, ideal operational circumstances and predicted braking pad lifetime modeling may result in the future.

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