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Assessing Quality of Boarding/Alighting Facility and Metro Stations Accessibility Incorporating Hybrid Cost Function

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Abstract: Mass Rapid Transit (MRT) systems play a critical role in promoting sustainable development, particularly in megacities. This study assesses the quality of boarding/alighting facilities along with accessibility of MRT, as integrated system components which is vital for maintaining a safe, efficient and user-friendly transit system, in the context of built-up cities. A robust questionnaire form is designed using 29 selected variables derived from pilot survey which was administerd to 1,397 respondents across nine operational stations of MRT in Dhaka, a developing megacity of Southeast Asia. Using the collected data, Gini Index and ANOVA are employed for variable prioritization. Machine Learning Algorithms, i.e., Random Forest (RF) Classifier, Support Vector Machine (SVM) and Classification and Regression Trees (CART), are compared to assess predictive performance where RF demonstrated better performance based on accuracy. Additionally, feature selection identified critical factors related to MRT trip performance, such as switching cost comparison, feeder service cost, inclusive service performance, customer loyalty, lighting near stations, overall comfort, security. This study, further, incorporates two most crucial factor, switching cost comparison and feeder service cost to a hybrid function, assessing system components and user transferability, utilizing a novel matrix-based approach. The study's conclusions provide insights into boarding/alighting facility and accessibility as system components incorporating hybrid cost function (HCF) to enhance the efficiency of MRT services in built-up cities across the world.

Keywords: Boarding/alighting quality; Accessibility; Cost function; Machine learning; Mass Rapid Transit

1 Introduction

Public transportation is essential for urban transportation systems, offering significant benefits that enhance the functionality, sustainability, and livability of cities. Mass Rapid Transit (MRT) systems are a key element of urban public transportation in megacities. However, strategic planning for integrating MRT with existing transportation networks differs between built-up and developing cities. The adaptability of metro systems in built-up areas varies due to differences in infrastructure, urban density, stakeholder engagement, and other factors. Traditionally, service quality analysis evaluates the overall performance of a transit journey. This study, however, focuses on assessing the quality of boarding/alighting facilities and accessibility as integral aspects of MRT systems in built-up areas. The quality of these facilities encompasses all user interactions from entering to exiting metro stations. Investing in high-quality boarding and alighting facilities is crucial for MRT systems' success, as these aspects directly affect safety, efficiency, accessibility, and passenger satisfaction, making this a preferred mode of urban travel and also contributing to the economic growth of the society [1]. Accessibility is defined as the ease with which individuals can reach destinations, activities, and services within a specified timeframe [2], is vital for engaging passengers in newly introduced public transportation systems and increasing ridership. In densely populated built-up areas, where space is limited, the quality of boarding and alighting facilities and accessibility to the transportation system play a decisive role in ensuring reliable and efficient MRT operations. When these two aspects are addressed together, they enhance user convenience, reduce travel time, and create a smoother commuting experience, forming the foundation for long-term system sustainability. Integrating accessibility with well-designed boarding and alighting facilities encourages commuters to shift from private and informal modes to MRT, increasing trust and ridership, thereby promoting a reliable and sustainable transport network within constrained urban environments.

Traditional service quality models primarily assess comfort, safety, and reliability to determine public transport efficiency but often overlook aspects, i.e., quality of boarding/alighting facility, accessibility; essential for the sustainability and adaptability of new transit systems. Addressing these limitations requires an expanded focus on factors like accessibility, political economy, and social equity [3]. This research aligns goal with SDG 11, target 11.2; providing access to safe, affordable, accessible and sustainable transport systems for all including persons with disabilities. Evaluating the accessibility of the stations and overall facilities related to boarding/alighting, will help the policymakers to ensure sustainable modal shift to MRT. Additionally, this study introduces a cost analysis, unique to this field, that considers the influence of boarding/alighting facilities and accessibility on passenger satisfaction, enhancing understanding of system reliability and efficiency in dense urban settings.

Previous studies on boarding/alighting quality have focused on relevant infrastructure and design improvements aimed at increasing efficiency and reducing dwell time, such as the application of social force models for passenger behavior [4] and the serviceability of public transit considering dwell time and headway [5]. While transit agencies have addressed metro accessibility influencing passenger experience [6], there is limited understanding of the factors affecting the boarding and alighting process. However, to the best of authors' knowledge, there's a significant research gap regarding these two service quality parameters being evaluated as system components in built-up areas. In this study, boarding/alighting facilities and accessibility are assessed as overall components of MRT service as this involves several aspects like- land use, urban structure, and mobility behavior [7] as well as adaptation strategy in built-up environments, especially from the perspective of stakeholders. Here, system component refers to overall integration of MRT systems including metro network, station locations, service frequency, fare and the transfer facilities in and around metro stations.

Furthermore, in developing areas, the integration of MRT systems within the existing transportation sector is achieved through step-by-step policy planning. In built-up cities like Dhaka, the quality of boarding/alighting facilities, along with accessibility, are critical factors for sustainable development. When an MRT system is introduced in a built-up city, many users make the transition from other transportation modes to the MRT, making transferability an influential parameter for assessing the system's reliability. In addition, evaluating the patterns of factors impacting public transit ridership surrounding a newly launched service is important to make it attractive to the users [8–10]. This is essential for creating an integrated and efficient urban transportation network, as accessibility concerns the convenience of accomplishing specific activities by transit, focusing highly on feeder service cost determining the affordability, reliability, and safety of MRT [11].

In this research, the quality of boarding/alighting facilities is evaluated as a system component along with accessibility, using a machine learning approach. The study identifies the most influential features related to MRT service performance, providing practical insights for policymakers to enhance overall service performance and passenger satisfaction. Additionally, a hybrid cost function (HCF) is developed by combining switching cost comparison and feeder service cost which emerged as the two most crucial factors for ensuring transferability among existing users. These factors are integral to the overall performance, reliability, and customer loyalty of the MRT system in built-up cities, related to transferability to the metro system. This study's findings of MRT's boarding/alighting quality and accessibility will provide valuable insights that apply to MRT systems worldwide as high population density and traffic congestion are similar to many other urban cities as well. These findings provide a framework for developing MRT systems that meet the needs of urban populations while addressing the unique challenges faced by cities in different parts of the world. This however, plays a vital role in operational efficiency affecting various aspects of the system's affordability.

2 Literature Review

The rapid expansion of metro systems in many major cities worldwide is leading more people to choose metro as their daily mode of transport, enhancing urban mobility. Therefore, it is essential to accurately evaluate the development conditions of urban metro systems to ensure service sustainability, as factors such as density, utility, efficiency, and financial resources significantly impact overall metro service [12, 13]. To maintain adaptability of metro service and increasing ridership in densely populated built-up areas, the quality of boarding and alighting facilities, along with overall system accessibility, is crucial [14]. However, despite the recognition of these aspects, while assessing metro performance systematic integration of these service quality parameters remains limited.

The process of passengers disembarking and boarding at metro stations has garnered increasing research interest due to its impact on passenger distribution on platforms and train stop durations. Numerous studies have aimed to understand passenger alighting and boarding characteristics, which reflect real passenger behaviors. These include modeling and simulation of passenger boarding and alighting to study the effects of different group sizes on efficiency in the Beijing metro [15], measuring boarding and alighting times for various train types [16], and investigating factors affecting passengers in Dutch stations, like platform distribution, station type, vehicle characteristics, and time of day [17], impacts of urban rail boarding and alighting factors using large datasets [18] and introduction of Social Force Model to simulate passenger actions in Hong Kong [19]. Studies have also investigated the impact of the ratio of boarding to alighting passengers on passenger behavior at metro stations, with the aim of improving crowd control, platform density, and timing [20]. These studies collectively enhance understanding of operational and behavioral dynamics in station environments; however, they primarily emphasize physical flow efficiency rather than users' perceived service quality or comfort during boarding and alighting.

Extending beyond platform-level operations, the flexibility of MRT systems depends on factors such as network size, station placement, service frequency, fare structure, and the quality of transfer facilities. Poor connectivity between residences and transit points reduces accessibility and transfer convenience [21, 22]. Previous studies have explored pedestrian accessibility to metro stations using models like the KLP to assess walking preferences [23], structural equation modeling to analyze satisfaction factors [24, 25], and evaluations of walking comfort, road networks, and crossing facilities [26]. While the importance of transferability has been acknowledged in multimodal interchanges and transit-oriented development [27, 28], very few studies have integrated it to ensure accessibility as a system component for newly launched MRT services. This lack of integration restricts the understanding of how accessibility interacts with overall metro service performance.

Sustainable urban development encompasses not just economic growth, but also environmental protection, social equity, and efficient land use. Metro systems have been widely evaluated as sustainable transit solutions. Studies have examined their impacts on congestion reduction [29], land-use optimization [30], and energy and emission performance compared to other modes [31], freight movement, such as simulating track usage in Newcastle [32] or exploring delivery use in Rome [33]. While these studies affirm the sustainability benefits of metro systems, they often emphasize environmental or economic indicators while neglecting service attributes of passengers such as accessibility and boarding/alighting experience. Consequently, the quality of boarding/alighting facilities and overall accessibility remain underrepresented in sustainability assessments, despite being vital for maintaining long-term metro service effectiveness.

Furthermore, cost is a critical determinant of service quality perception for a newly introduced metro system in a densely populated developing city, where public transport facilities are often inadequate and multimodal integration remains limited. In such contexts, passengers' perceived accessibility is influenced not only by fare or travel time but also by the perceived burdens of mode switching and last-mile connectivity. Previous research has emphasized switching or transfer cost as a major deterrent to multimodal usage [34], while others have highlighted the significance of feeder service cost in shaping last-mile accessibility and ridership [35]. To the best of the authors' knowledge, no existing study has integrated two cost functions into a single variable to assess service quality for newly introduced systems. Specifically, the perceived costs of switching between modes and using feeder services remain independently modeled in most prior works. The present study bridges this gap by proposing a perception-based HCF that jointly represents switching and feeder service costs, thus reflecting users' holistic cost experience during multimodal travel. This approach extends the generalized cost framework toward perception-driven modeling suitable for emerging MRT systems in developing cities.

Recent advancements in machine learning and statistical modeling have enhanced the evaluation of public transport service quality and user satisfaction. Techniques such as Random Forest (RF), Gradient Boosting Model (GBM), and Decision Trees have been employed to predict metro ridership based on built environment characteristics [36, 37], while RF has been widely used to assess system efficiency and user perceptions [38–41]. Hybrid variable selection methods combining filter techniques with wrapper approaches like RFE have been used to improve feature selection, using classifiers such as RF and Support Vector Machine-Random Feature Elimination (SVM-RFE) [42, 43]. These analytical developments demonstrate the growing use of data-driven models in transportation studies, yet limited work applies such techniques to perception-based MRT accessibility assessment. Addressing these limitations, this study applies three widely used machine learning models, RF, Support Vector Machine (SVM), and Classification and Regression Trees (CART) to evaluate boarding/alighting quality and accessibility as integrated components of MRT service, ensuring robust and accurate prediction of key service parameters. Hence, this study bridges existing gaps by analyzing boarding/alighting facility quality, accessibility, and a perception-based hybrid cost framework using advanced machine-learning models to provide an integrated evaluation of MRT service performance.

3 Methodology

The methodological workflow outlines the systematic approach used to conduct the research, detailing each step from initial planning to final analysis. A diagram of methodological workflow of this study is depicted in Figure 1.

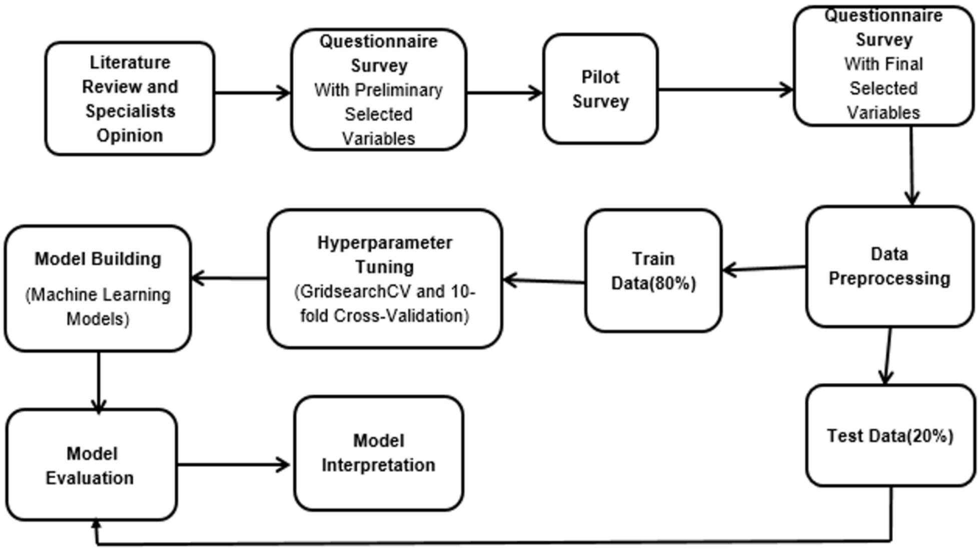

Figure 1. Methodological workflow

The study corridor for this research focuses on the operational MRT Line 6 in Dhaka. Initially, preliminary variables for the questionnaire survey are selected based on an extensive literature review and expert opinions. This is followed by a pilot survey to refine these variables for the final data collection. Once the questionnaire form is finalized, data is collected from nine operational metro stations. Data preprocessing is then conducted to prepare the data for analysis. Subsequently, descriptive statistics are performed based on respondents' perceptions. The dataset consists of train and test data ratio of 80:20. In the modeling phase, ANOVA and RF are used to select the most influential variables which was followed by grid search cross-validation for hyperparameter tuning to enhance model performance. Machine learning models, i.e., RF, SVM and CART, are used for data analysis, with the models run using the selected variables. The best model, based on accuracy, is then identified and thoroughly interpreted. Simultaneously, the model is evaluated to determine if the selected variables adequately explain it using the train data.

3.1 Questionnaire Design

The survey's questionnaire is divided into two sections. The first section aims to gather general information about the passenger, including the demographics, and the travel characteristics, i.e., purpose of travelling, reason behind choosing MRT, previous mode of transportation etc. The second segment focused on gathering rider's feedback regarding the perceived value of the chosen service characteristics on a Likert scale (Very poor, Poor, Average, Good, and Excellent). Each indicator was measured through a single rating item, where respondents selected one of five ordered response categories presented as tick-box options. For example, the respondents were asked several questions: what do they feel about on time performance, frequency, seat availability, safety, cleanliness of MRT; does the MRT significantly reduce their travel time; do they think the integration of feeder service is adequate etc. in order to learn how passengers felt about them. The questionnaire was provided in both English and Bangla to ensure clarity for all users.

3.2 Data Collection

The study investigates the performance characteristics of the MRT service operating along Line 6, spanning from Agargaon to Uttara North Metro Station, within Dhaka, Bangladesh. Data collection commenced with a custom-designed questionnaire survey administered through the KOBO Toolbox software, conducted both online and offline interviewing passengers traveling on MRT and those are waiting for departure at concourse and platform area. During data collection, efforts were made to avoid gender and profession biasness.

3.3 Data Preparation and Resampling

A grand total of 1397 samples of 29 indicator variables are prepared for the final modelling stage. The dataset exhibits positive skewness in its distribution. Users are highly content with the service initially, taking into account the quality of service and the performance of the trips. Consequently, a significant proportion of users provided favorable ratings for these trip performances, highlighting the necessity for recategorization of the dataset to enhance the model's performance which can act as a potential source of error in model's performance. The dataset represents population with p-value greater than 0.05 indicating no significant deviation.

Linacre [44] conducted research about the importance of uniformity in observing and recording data across different categories or steps. It's stated that if there's irregularity or imbalance within each category, it could suggest problems with how those categories are being used or interpreted. As a result, to facilitate model construction from this data, recategorization is conducted to mitigate anomalies during subsequent analysis.

3.4 Descriptive Statistics of Respondents

Table 1 represents traveller information, about the socio-demographic aspects of the respondents using MRT line 6, including information on gender, age, income, purpose of travel, and previously used mode of transportation etc. Among the 1397 data collected, 58.91% were provided by males, while 40.73% were provided by females [45]. Thus, the result highlights a gender disparity among responders, with a higher proportion of males compared to females, indicating that transit in Dhaka is predominantly male-dominated. The data table indicates the largest proportion, accounting for 47.6% of participants, belong to the age group of 25 to 45 years, while an additional 43.5% fell within the age range of 10 to 25 years. This trend can be attributed to the high usage of MRT by students and individuals in the workforce for educational and professional purposes. Conversely, only 0.5% of users are aged over 65 years, likely due to discomfort or inconvenience associated with public transportation for older individuals.

Table 1. Summary of data collection

Traveler Information		
Variable	**Category**	**%**
Gender	Male	58.91
	Female	40.73
	Others	0.36
Travelling purpose	Returning home	36.79
	Study	10.16
	Recreation	8.73
	Business	7.02
	Shopping	6.94
	Office trip	5.80
	Others	24.55
Age	10–25 years	43.52
	25–45 years	47.60
	45–65 years	8.38
	>65 years	0.50
Previously used mode	Bus	59.41
	CNG	14.96
	Motorcycle	6.80
	Rickshaw	5.30
	Car	4.51
	Ride sharing (Motorcycle)	3.65
	Ride sharing (Car)	2.43
	Others	2.93
Reason	Comfortable	94.27
	Available	67.43
	Reliable	9.95
	Cheaper	3.65
Income (in BDT)	<20,000	21.22
	20,000–50,000	31.57
	50,000–80,000	29.43
	80,000–100,000	14.92
	>100,000	4.02

Table 1 demonstrates that most respondents had an income between 20,000 and 50,000 BDT, indicating that this public transport service is predominantly utilized by individuals belonging to the middle class. Conversely, the lowest income range, accounting for only 4% of respondents, is above 100,000 BDT, suggesting a potential correlation with car ownership, which may discourage individuals in this group from utilizing the MRT service. Around 36.79% of individuals stated that they commute from employment, whereas 10.16% use it for educational purposes. The statistics suggest that the use of MRT for travelling between work and home is at its highest, because of its dependable service.

The result also demonstrates that the MRT is favored due to its exceptional comfort in comparison to other available forms of transportation in the city. The findings indicate that a substantial percentage of MRT users (94.27%) perceive it as quite comfortable, whereas 67.43% regard its accessibility as a crucial aspect. In addition, 9.95% of consumers prioritize the dependability of the MRT. Moreover, about 60% of present MRT users formerly preferred buses for their commuting requirements, suggesting a notable pattern of shifting between various modes of public transportation. Essentially, this indicates a phenomenon of replacing one kind of public transport with another, where people are transitioning from buses to the MRT.

3.5 Variable Selection

A total of 29 independent variables and 2 dependent variables are selected for analysis. The description of variables is given below in Table 2.

In this study, beyond traditional service quality analysis, two key output variables, i.e., boarding/alighting facility quality, accessibility, and a HCF are selected for machine learning model analysis. The boarding/alighting quality and accessibility variables capture the full user experience, from station access to the boarding process. These factors are critical for boosting ridership and enhancing inclusivity, especially for new users. While transit agencies have long prioritized accessibility, the specific factors influencing boarding and alighting remain less understood and can impact overall commuter accessibility [46]. So, both these variables have been taken as output variables in ML models.

3.6 Formation of Hybrid Cost Function

Two most influential variables are identified namely switching cost comparison and feeder service cost from two step approach of influential variable selection using Analysis of Variance (ANOVA) and RF Gini index. These individual variables have significant influence on overall performance of MRT in Dhaka. These variables are then further merged to assess their collective impact on service parameters. In most of the study a hybrid short-term forecasting approach for prediction of passenger flows is proposed by combining the modified gravity model and deep learning models, SVM-RFE etc. Whereas in our study, we proposed a matrix-based approach for combining two individual variables into one hybrid variable, a novel contribution of this research. The methodology of matrix-based approach is given in Table 3.

Let SCi denote the Switching Cost Comparison score and FCi denote the Feeder Service Cost score for respondent or station i. Both variables were measured on an ordinal perception scale as:

$$SCi, FCi \in \{1, 2, 3\}$$

where, 1, 2, and 3 correspond to low, moderate, and high perceived cost, respectively.

The HCF was formulated to represent the joint perceived burden of these two components through an additive composite structure as follows:

$$HCF_i = f\left(SC_i, FC_i\right) = \alpha SC_i + \beta FCi \tag{1}$$

where, HCF_i = hybrid cost index for observation i, SC_i = perceived switching-cost comparison score (1–3), FC_i = perceived feeder-service-cost score (1–3) and α, β = weighting coefficients denoting the relative influence of each component.

Based on preliminary ANOVA and Random-Forest-based variable importance analyses, both factors exhibited comparable significance. Therefore, equal weights were assigned (α = β = 1). The additive formulation preserves ordinal consistency across observations and ensures that each cost component contributes linearly and proportionally to the overall perceived hybrid cost.This approach is consistent with linear composite structures commonly applied in perception-based transport service quality modeling [47, 48].

Given $SCi, FCi \in \{1, 2, 3\}$, the resulting $HCFi$ values range from 2 to 6, indicating progressively higher combined perceived cost burdens. This relationship can be expressed in a two-dimensional matrix, where each cell represents a unique cost combination. For general ordinal levels $SC \in \{1, \ldots, m\}$ and $FC \in \{1, \ldots, n\}$, the hybrid cost corresponding to cell (j, k) is given by:

$$HCF(j, k) = \alpha j + \beta k \tag{2}$$

Each matrix cell (j, k) thus maps directly to a distinct hybrid-cost value, allowing a structured visualization of the joint perception of switching and feeder costs, such as high-switching/high-feeder conditions. This matrix-based interpretation, as illustrated in Table 3, complements the additive formulation by depicting the gradation of perceived hybrid costs, while the single-index HCF variable enables seamless integration into subsequent machine-learning-based models for analyzing boarding/alighting quality and station accessibility.

Table 2. Definition of variables

Traveler Information		
Sl. No	**Variables**	**Description**
1	Boarding/alighting facility quality	Passenger perception of the adequacy and convenience of boarding and alighting facilities, including platform design, alignment with coach doors, signage, crowd flow management, ticket system management and ease of moving from entry to exit.
2	Accessibility to metro station	Perceived ease of reaching the metro station, considering access-egress distance, feeder service availability, footpath quality, pedestrian safety, and integration with other transport modes.
3	On time performance	Perception of MRT trains arriving and departing according to schedule, minimizing delays and ensuring reliability.
4	Frequency of MRT coaches	Passenger perception of service intervals and how frequently MRT trains are available to reduce waiting time.
5	Dwelling time MRT coach	Perceived waiting time incurred during passenger's boarding and alighting at stations, reflecting efficiency of station operations.
6	Seat availability	Passenger perception of the likelihood of securing a seat during the journey, directly linked to comfort and service adequacy.
7	Travel time reduction by MRT	Passenger evaluation of travel time savings compared to other modes of transport due to MRT operation.
8	Switching cost comparison	Passenger perception of monetary costs involved in transfers between feeder modes and MRT compared to other modes.
9	Security against rain/storm	Passenger perception of weather protection facilities (shelters, covered walkways, waiting areas) ensuring protection from rain or storm.
10	Air-conditioning and Ventilation	Perceived adequacy of thermal comfort inside coaches and at stations, including air conditioning, ventilation, and temperature regulation.
11	Waiting place condition	Passenger perception of the adequacy, comfort, cleanliness, and availability of waiting areas at concourse and platforms.
12	Toilet facility	Passenger perception of the availability, accessibility, and cleanliness of toilet facilities at stations.
13	Noise problem	Passenger perception of disturbance due to noise inside coaches, at concourse, or on platforms.
14	Display of necessary Information	Perceived effectiveness of information displays and signage regarding train timings, delays, directions, and passenger guidance.
15	Crowd management	Passenger perception of how effectively crowds are managed in concourse and platforms, including physical arrangements.
16	Staff behavior	Passenger perception of the courtesy, helpfulness, and responsiveness of MRT staff during travel and at stations.
17	Women safety	Female passengers' perception of safety from harassment, intimidation, or insecurity while traveling in MRT coaches or at stations.
18	Overall security	Passenger perception of overall safety and security in concourses, platforms, and coaches, including presence of surveillance and security staff.
19	Cleanliness of concourse	Passenger evaluation of the cleanliness and hygiene of concourses, platforms, and public spaces within stations.
20	Regular maintenance	Passenger perception of the adequacy of regular upkeep and maintenance of station facilities and train coaches.
21	Overall comfort	Passenger's overall assessment of comfort during MRT travel, considering seating, space, riding smoothness, and ambient conditions.
22	Performance of ATS	Passenger perception of the efficiency, reliability, and ease of use of the Automated Ticketing System (ATS).
23	Performance of MTS	Passenger perception of the efficiency and reliability of the Manual Ticketing System (MTS) for those who use it.
24	Adequacy of feeder service	Passenger perception of feeder service availability, sufficiency, and integration to ensure last-mile connectivity with MRT stations.
25	Feeder service cost	Passenger perception of the affordability and fairness of feeder service fares in relation to MRT usage.
26	Footpath condition near MRT	Passenger perception of the quality, continuity, and safety of footpaths near MRT stations for access and egress.
27	Lighting near MRT station	Passenger perception of the adequacy of lighting in and around MRT stations for visibility, comfort, and safety.
28	Access control	Passenger perception of the efficiency and reliability of access control measures at entry and exit gates.
29	MRT ticket fare	Passenger perception of MRT ticket affordability, value for money, and fairness of pricing.
30	Customer loyalty	Passenger willingness to recommend MRT to others (word-of-mouth) based on satisfaction and service quality experience.
31	Inclusive service performance	Passenger perception of how inclusive MRT services are for vulnerable groups, including elderly, disabled, and low-income commuters.

Table 3. Matrix based approach for hybrid variable formation

		Switching Cost Comparison						
		1	2	3	4	5	...	m
	1	(1,1)	(2,1)	(3,1)	(4,1)	(5,1)	...	(m,1)
	2	(1,2)	(2,2)	(3,2)	(4,2)	(5,2)	...	(m,2)
	3	(1,3)	(2,3)	(3,3)	(4,3)	(5,3)	...	(m,3)
Feeder Service Cost	4	(1,4)	(2,4)	(3,4)	(4,4)	(5,4)	...	(m,4)
	5	(1,5)	(2,5)	(3,5)	(4,5)	(5,5)	...	(m,5)
	...	...	...	...	...	...	...	...
	n	(1,n)	(2,n)	(3,n)	(4,n)	(5,n)	...	(m,n)

3.7 Machine Learning Algorithms

Three machine learning algorithm, i.e., RF, SVM, CART have been developed for model assessment.

4 Results

4.1 Model Development

4.1.1 Most influential variable selection

In this research, two important service parameters: quality of boarding/alighting facilities, accessibility have been assessed based on passenger perception. A two-step approach has been used for selection of influential variable using ANOVA and RF Gini Index algorithms.

The dataset for this study consisted of twenty-nine (29) input features related to MRT service aspects, such as on-time performance, dwelling time, seat availability, security measures, overall comfort etc. The output variable, "Quality of boarding alighting facility", represents the perceived overall qualities of the facilities available from entering to departing metro stations. Cutoff point selection of variables from using K-best selection based on ANOVA and RF feature importance based on Gini Index are shown by red dash line below.

Additionally, same dataset is used for accessibility model assessment. Here, the output variable is "Accessibility" which refers to the ease where all the individuals can access the metro service. Cutoff point selection according to the feature importance score based on ANOVA and RF Gini index are shown by blue dash line for accessibility.

The prior task before building the models is to determine the optimized parameters by tuning each of the 3 models (RF, SVM and CART) with different combinations of hyperparameters on the data. A grid search with 10-fold cross-validation technique has been used for hyperparameter tuning.

For Quality of Boarding/Alighting Facility, RF model's best hyperparameters are found: "n_estimators": 100, "criterion": gini, "max_depth": 15, "min_samples_leaf": 2, "min_samples_split": 2. Best hyperparameters for SVM are "C": 10, "kernel": rbf, "gamma": auto and for CART: "criterion": gini, "max_depth": 5, "min_samples_leaf": 5, "min_samples_split": 5.

Similarly, gridsearch cross validation is performed for assessing accessibility. The best hyperparameters for RF model: "n_estimators": 100, "criterion": gini, "max_depth": 15, "min_samples_leaf": 2, "min_samples_split": 2; for SVM model: "C": 0.1, "kernel": rbf, "gamma": auto; for CART: "criterion": "gini", "max_depth": 5, "min_samples_leaf": 3, "min_samples_split": 5.

After combining the top most variables from cutoff point of ANOVA and RF as mentioned in Figure 2, influential variables are selected and shown in Table 4.

4.2 Model Evaluation

Accuracy of the three models is shown in Figure 3 and RF emerges as the most significant model.

Among the three models, RF achieved the highest accuracy for predicting boarding/alighting facility quality, with 85.35%, compared to SVM at 83.57% and CART at 82.86%. RF also performed best for accessibility predictions, reaching 77.14% accuracy, followed by SVM with 76.78% and CART with 75.35%. Thus, RF is identified as the most effective model for predicting both boarding/alighting quality and accessibility. Besides, recall and F1 score for boarding/alighting facility quality are found 85% and 83% whereas for accessibility it is found 74% and 77% respectively.

As RF combines multiple decision trees and reduce overfitting along with handling varied dataset with interdependent variables, it gives better accuracy than the other models. The confusion matrix of RF models for boarding/alighting quality and accessibility is shown in Figure 4.

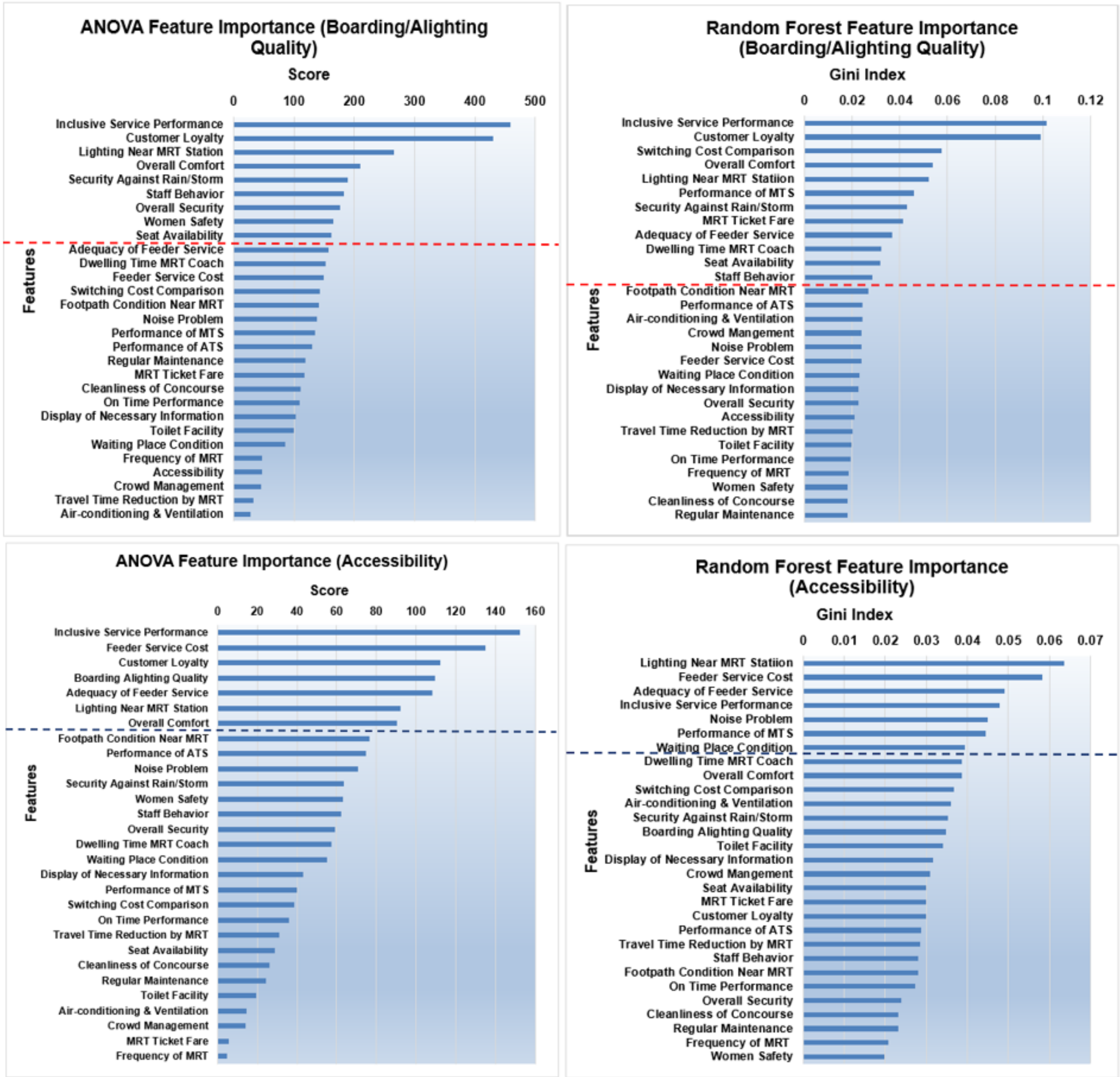

Figure 2. Cutoff point selection for quality of boarding/alighting facility (red line) and accessibility (blue line)

Table 4. Selected variables for quality of boarding/alighting facility and accessibility

Rank	Influential Variable for Quality of Boarding/Alighting Facility	Influential Variable for Accessibility
1	Inclusive Service Performance	Inclusive Service Performance
2	Customer Loyalty	Feeder Service Cost
3	Lighting Near MRT Station	Customer Loyalty
4	Overall Comfort	Adequacy of Feeder Service
5	Security Against Rain/Storm	Lighting Near MRT Station
6	Staff Behavior	Overall Comfort
7	Seat Availability	Footpath Condition Near MRT
8	Adequacy of Feeder Service	Noise Problem
9	Dwelling Time MRT Coach	Security Against Rain/Storm
10	Feeder Service Cost	Dwelling Time MRT Coach
11	Switching Cost Comparison	Waiting Place Condition
12	Performance of MTS (Manual Ticketing System)	Performance of MTS
13	MRT Ticket Fare	Switching Cost Comparison
14	-	Air-conditioning & Ventilation

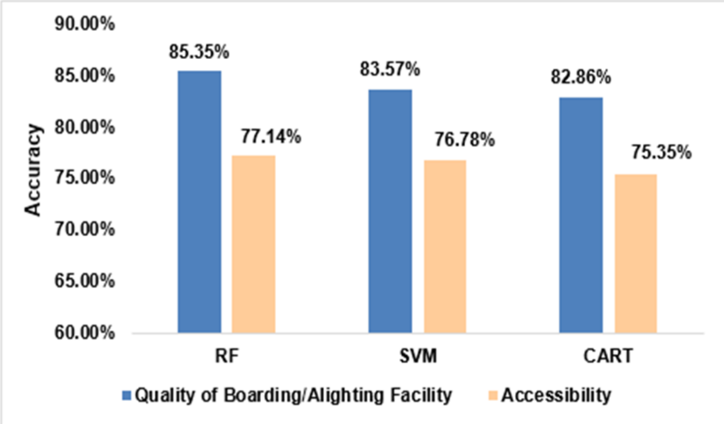

Figure 3. Accuracy of 3 machine learning models

		Confusion Matrix of Quality of Boarding/Alighting Facility					Confusion Matrix of Accessibility		
		1	2	3			1	2	3
Actual	1	3	22	0	Actual	1	37	34	1
	2	2	204	2		2	6	180	1
	3	0	16	31		3	5	15	31
		Predicted					Predicted		

Figure 4. Confusion matrix of Random Forest (RF) models for quality of boarding/alighting facility & accessibility

4.3 Model Interpretation

Figure 5 depicts the feature contribution. As RF was chosen as the best model, variable ranking was done using it. According to the best model, feature important score of the variables are shown below:

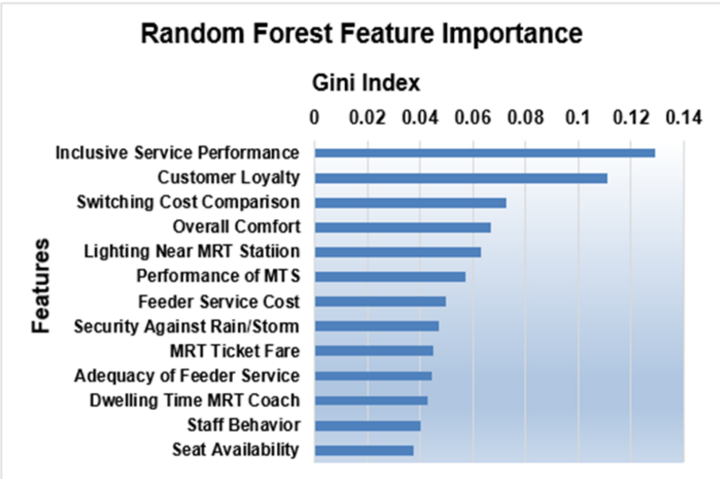

Figure 5. Feature importance of variables based on best model for quality of boarding / alighting facility

Figure 5 displays the significance of several factors based on the Gini index, which is obtained from a RF model. By summing the significance scores of the features, we determine that these variables can explain 98.6% of the model's performance. The model's performance using influential variables is excellent, suggesting that the chosen cutoff threshold from ANOVA and RF is accurate.

Furthermore, "Inclusive Service Performance" holds the utmost significance, indicating that it is the most prominent predictor for quality of boarding/alighting facility. As boarding and alighting are among the most critical points in a transit journey, ensuring these facilities are accessible and affordable for all age groups, individuals with physical challenges, and people across different income levels can encourage a wider range of users to choose MRT services. Ensuring all the amenities related to boarding and alighting are suitable to all the users will increase sustainability of the service. Following this, “Customer Loyalty”, a key indicator to describe how satisfied and loyal are the users to the service, plays a significant role in providing and maintaining better facilities at stations. “Switching Cost Comparison” which indicates travel cost of metro compared to other modes, is vital as people are willing to pay higher fares and switch to metro services for time-saving and other benefits. Features such as “Staff Behavior” which indicates behavior of the officials and “Seat Availability” indicating the percentage of getting a seat while travelling are considered less important in the model’s estimates of boarding/alighting facility quality. Feature importance scores for accessibility are shown below:

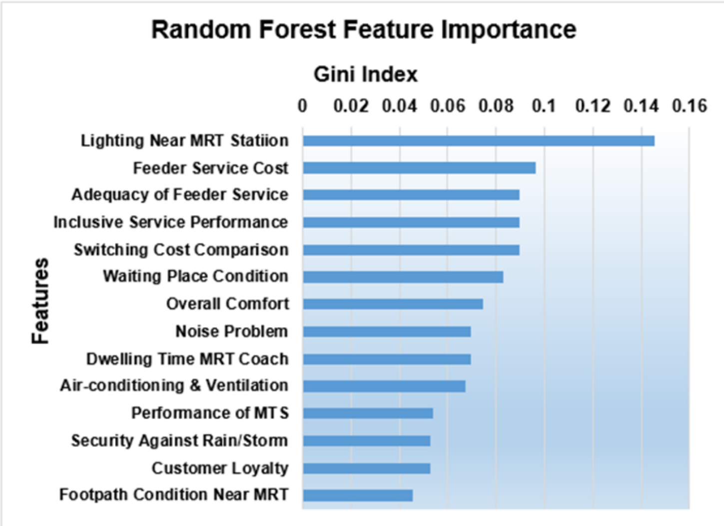

Figure 6. Feature importance of variables based on best model for accessibility

By summing the significance scores of the features, we determine that these variables account for 98% of the model’s explanation. The model has excellent performance when utilising the most influential variables obtained from ANOVA and Random Forest.

Based on Figure 6, it is evident that “Lighting Near MRT Station” is the most critical factor, as it facilitates easier access for users by ensuring safe entry and exit into metro stations. This directly influences passengers’ sense of safety, comfort, particularly important for specific user group such as women and elderly individuals. Next, there are two other factors that are of significant importance: “Feeder Service Cost” and “Adequacy of Feeder Service”. These two factors play a crucial role for motivating users to make a transition from other modes to metro. “Switching Cost Comparison” is a significant variable in the model influencing transit ridership associated with feeder modes and cost being a major consideration for users. Features such as “Customer Loyalty” and “Footpath Condition Near MRT” are considered less important in the model’s predictions on accessibility, as they have a lesser level of influence.

The data presented in Figure 5 and Figure 6 offers significant insights for transportation authorities to identify areas for development and customize their services to enhance customer satisfaction.

After analyzing service quality factors, particularly the quality of boarding/alighting facility and accessibility, we have identified the two influential variables: switching cost comparison and feeder service cost. The two distinct variables have been merged into a hybrid variable referred to as “Cost Function”. The main goal is to assess the interdependency between two service parameters and cost function.

4.4 Hybrid Cost Function

For modeling the HCF, a method similar to the one used for the previous two parameters is employed. Using a two-step approach involving ANOVA and the RF Gini Index, the top 13 crucial features concerning the MRT cost function are identified. These features include inclusive service performance, boarding/alighting quality, MRT ticket fare, performance of ATS, overall comfort, customer loyalty, adequacy of feeder service, lighting near MRT stations, security against rain/storm, dwelling near MRT coaches, travel time reduction by MRT, footpath conditions near MRT and accessibility. Among these, inclusive service performance emerges as the most significant, indicating its highest importance in relation to the cost function of MRT as it ensures ridership of different age, disabled people to access the metro station. Boarding/Alighting Quality also has importance in cost function as ridership will depend on cost function. MRT ticket fare is significantly related to cost function. If riders are satisfied with ticket fare corresponding with other facilities, they would more likely switch from other transport facilities to MRT.

Like the previous machine learning models, a grid search with 10-fold cross validation is performed to determine the optimized parameters by tuning each of the 3 ML models. Therefore, best hyperparameters obtained from RF model: “n_estimators”: 100, “criterion”: gini, “max_depth”: 25, “min_samples_leaf”: 2, “min_samples_split”: 2; for SVM: C: 1, “kernel”: rbf, “gamma”: auto; for CART: “criterion”: gini, “max_depth”: 3, “min_samples_leaf”: 5,”min_samples_split”: 5. Using the best hyperparameters, model accuracy of RF, SVM, CART is found 76.2%, 68.7% and 71.6% respectively. Recall and F1 score are found 75% and 73%. The confusion matrix of cost function in shown in Figure 7.

		Confusion Matrix of Cost Function		
		1	2	3
Actual	1	39	40	6
	2	18	78	23
	3	5	35	36
		Predicted		

Figure 7. Confusion matrix of RF model for cost function

Comparing the three models, RF emerges as the best model for prediction of cost function. According to the best model, feature important score of the variables are shown in Figure 8.

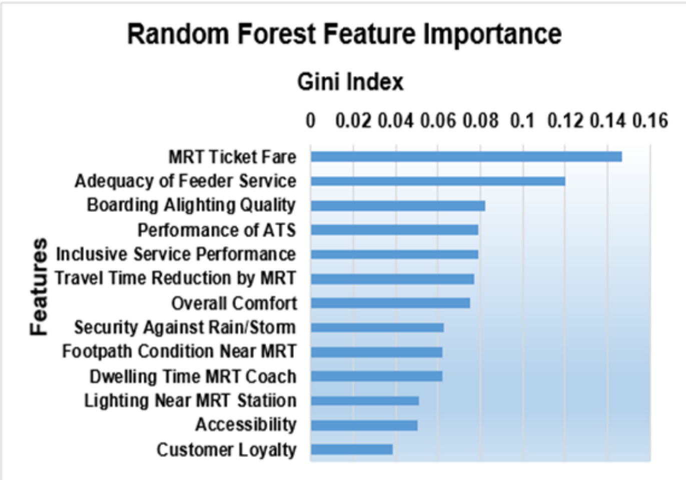

Figure 8. Feature importance of variables based on gini index on cost function

By summing the significance scores of the features, we determine that these variables account for 98.2% of the model’s explanation which represents the model’s effectiveness using those 13 factors. So, cutoff point selection of these variables is accurate.

The Figure 8 demonstrates that the “MRT Ticket Fare” holds the greatest significance and shows an important correlation with the hybrid target variable, underscoring its crucial role in predicting the model’s outcome. This factor influences users’ perception, attracting them to use the service even at a higher fare due to reliability and time savings of MRT. The attributes of “Adequacy of Feeder Service” also influences cost function significantly as feeder service is highly important for ensuring transferability of users. “Boarding/Alighting Quality” suggests that people will choose metro services for better boarding and alighting facilities, thus impacting the cost function. Additionally, “Performance of ATS,” and “Inclusive Service Performance” are consistently important factors. Therefore, service quality factors have a substantial impact on the cost function. In contrast, attributes such as “Dwelling Time MRT Coach,” “Lighting Near MRT Station,” and “Customer Loyalty” are deemed less significant in the model’s cost function analysis, indicating that they have smaller influence on the model’s predictions. The insights provided by the Figure 8 offer valuable information to transport authorities, helping them identify areas for improvement for sustainable development of city areas and tailor services to increase passengers’ satisfaction levels.

5 Conclusions and Policy Implications

The research focused on assessing the quality of boarding and alighting facilities as a system component along with accessibility in built-up environment ensuring sustainable mode of transport and transferability of existing users from stakeholders' perspective. Additionally, a HCF was developed, integrating switching cost and feeder service cost identified as two critical factors influencing overall performance, reliability, and customer loyalty in high-density urban contexts.

The most influential variables, ranked by priority from the HCF model according to major analysis using the RF Classifier, are critical for sustainable urban growth. Ensuring the adequacy of feeder services is essential for seamless and efficient transportation and to facilitate transferability, cities like Shanghai and Hong Kong in East Asia often encourage bus use (i.e., feeder buses and public buses), while Washington promotes bike-sharing, and Europe favors cycling to connect to the metro. In Dhaka, integrating both motorized and non-motorized feeder modes, including rickshaws and paratransit, can enhance affordability and accessibility. Furthermore, the MRT system can be effectively integrated with other public transport modes, such as buses and BRT, to enhance overall accessibility. The study also indicates that the condition of footpaths, pedestrian-friendly infrastructure, and adequate lighting around MRT stations play a crucial role in encouraging ridership. Promoting active travel modes, i.e., walking and cycling for first- and last-mile connectivity can substantially improve the modal shift toward MRT and strengthen users' confidence in its reliability. These insights provide valuable guidance for policymakers to strategically plan and coordinate transport infrastructure, ensuring that MRT functions as a comprehensive mobility solution for highly congested urban environments like Dhaka.

The study interestingly reveals that the cost of MRT is not the sole determinant influencing ridership; rather, travel time savings compared to other conventional transport modes serve as a major motivating factor for users to choose MRT services. The performance of both ATS and MTS systems also emerges as a critical component in enhancing operational efficiency, minimizing waiting times, and boosting overall ridership. Expanding the MRT and Rapid Pass systems, with the inclusion of online ticketing and recharge facilities would further improve accessibility and optimize crowd management. Additionally, reducing headways during peak hours and enhancing security, particularly for women, are essential measures to encourage greater metro use in dense urban environments such as Dhaka. Considering the significance of safety, increasing women-only compartments and strengthening administrative policing can foster a sense of security and attract a wider segment of road users. These insights provide practical guidance for policymakers to incorporate into future MRT expansion plans, especially as five additional routes are currently under construction and policy formulation in Dhaka. The authors expect to develop more sophisticated models for MRT service quality parmeters, which would be beyond the scope of this argument. Besides the survey was conducted from Agargaon to Uttara North but MRT Line-6 extends from Uttara North to Kamalapur. So the factors influencing boarding/alighting facility quality, accessibility, cost function may differ during the full operational phase of MRT Line-6 which would be a scope for future research which can be insightful for built-up cities all over the world. Ultimately, consistent monitoring and improvement of these elements alongside the enhancement of boarding and alighting facilities will be vital to ensuring accessibility, reliability, and the long-term sustainability of MRT systems in built-up cities worldwide.

Author Contributions

The authors confirm contribution to the paper as follows: study conception and design: M.A.R. and M.H.; data collection: F.A.P., T.A., and A.F.S.A.R.K.; analysis and interpretation of results: T.A., F.A.P., A.F.S.A.R.K., N.T., M.A.R., and M.H.; draft manuscript preparation: F.A.P., T.A., N.T., and M.A.R. All authors reviewed the results and approved the final version of the manuscript.

Data Availability

The data used to support the findings of this study are available from the corresponding author upon request.

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Conflicts of Interest

The authors declare that they have no conflicts of interest.

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Nomenclature

MRT	Mass Rapid Transit
RF	Random Forest
SVM	Support Vector Machine
CART	Classification and Regression Tree
HCF	Hybrid Cost Function
SVM	Support Vector Machine
RFE	Random Forest Elimination
GBM	Gradient Boosting Model