




## Analysis of Pedestrian Performance by Integrating both Quantitative and Qualitative Factors

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### Abstract

The importance of non-motorized movements, explicitly walking, and its corresponding impact on social, economic, and environmental aspects has always been overlooked due to the convenience brought by motorized vehicles. An automobile-dependent society mirrors the rise and worsening of several transportation problems, such as road-wide traffic congestion, massive fuel consumption, and excessive CO<sub>2</sub> emissions. In response to these aggravating situations and in support of various national and international calls, the main objective of this study was to extract the significant factors influencing the pedestrian level of service and walkability and to subsequently develop a predictive mathematical model for evaluating pedestrian conditions. Factors influencing the pedestrian level of service and walkability were initially identified through an extensive review and evaluation of existing studies, literature, and other relevant resources. A cause-and-effect analysis was used to develop an Ishikawa Diagram tackling pedestrian performance. The finalized factors were incorporated into the development of the Pedestrian Performance Assessment Questionnaire (PPAQ), which was utilized for data acquisition. Survey responses were then subjected to factor analysis after satisfying several tests for assumptions and suitability to extract the root causes influencing pedestrian performance. The validated root causes were then integrated to form the Pedestrian Performance Audit Tool (PPAT), a tool used in evaluating pedestrian areas in Tarlac City, Philippines. Data was analyzed through ordinal regression analysis to develop the multi-objective pedestrian performance prediction model. Results showed that there are six critical predictors of pedestrian performance unified in the final mathematical model: Pedestrian Space (PS), Official's Intervention (OI), Ambiance (A), Vibrance (V), Street Vendors (SV), and Trash Bins (TB), and is the most significant contribution of the study. The model's validity was ascertained through a confusion matrix, which resulted in an acceptable rating. The comparison between calculated and perceived values together with the use of odds ratios served as the basis for the interpretation of some of the key results and findings. Finally, recommendations were also presented which can be a basis for the development of sustainable programs and interventions for the improvement of the pedestrian system.

*Keywords:* Pedestrian Level of Service; Walkability; Ishikawa Diagram; Multivariate Factorial Analysis; Ordinal Regression Analysis.

### 1. Introduction

The efficiency and convenience brought by motorized vehicles have always been incomparable. Since most of the people living today already considered those as a necessity more than a want, the immeasurable number of motorized vehicles actively existing has brought a variety of harmful consequences, including road wide traffic congestion, massive fuel consumption, tremendous increase in accident rates, and excessive CO<sub>2</sub> emission. The drastic deterioration of the quality of life brought by these occurrences has led civil societies to identify and implement a more sustainable mobility approach [1]. An integral approach, which starts by shifting from car-centric planning to more sustainable-oriented strategies that can provide simultaneous societal, economic, and environmental gains [2].

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Nowadays, non-motorized movement, specifically walking, has always been envisioned to be a long-term sustainable solution to alleviate the transportation problems mentioned earlier [2, 3]. Several studies have shown how walking can improve the quality of life by exploring the potential impacts of improved pedestrian facilities and levels of service [2]. Pedestrian Level of Service (PLOS) has been widely used in the prioritization of these improvement modifications as it measures the level of safety and comfort given by a pedestrian facility [4]. Generally, several methodologies are used in evaluating PLOS, specifically depending on the context but mainly focused on the objective calculation of quantitative components including pedestrian flow, pedestrian space, and pedestrian density [1, 5]. However, contrary to the improved facilities and infrastructure, it is still a challenge for the transportation industry to encourage people to walk due to inconsistencies and lack of prioritization of the actual needs of the pedestrian system [6].

Traditional transportation planning tends to undervalue the importance of considering walkability, precisely the qualitative characteristics of walking as perceived by pedestrians [7, 8]. In fact, several studies proved that those factors could also contribute to the pedestrian level of service [8], and can actually be the key answer that may potentially encourage individuals to use it [9]. In the analysis of Amprasi et al. (2022), comparing micro-simulated PLOS to user perception, the study led to an interesting result: contrary to the high level of service calculated through simulation models, a significant number of pedestrian users still feel uncomfortable and unsafe. Thus, improving pedestrian safety with synchronous consideration of walkability can play a significant role since PLOS can also be characterized by several subjective indicators [1, 10]. Furthermore, an increase in walkability can encourage individuals, including the vulnerable, to use pedestrian facilities, particularly for shorter-distance travel, and can also increase the use of public transportation for longer-distance travel [11].

Existing literature and studies have revealed a wide range of influencing factors when the objective and subjective dimensions of the pedestrian level of service being calculated and perceived are taken into account [12, 13]. Apparently, few studies on pedestrian performance analysis have considered dealing with techniques that delineate and condense those numerous factors before developing mathematical models. Likewise, the majority of the improvement interventions only focused on the factors associated with facility development and geometric design without an explicit attempt to thoroughly consider the factors aligned with its governing policies and management provisions, the interaction between the road and pedestrian users, and the natural and built environment. Thus, those approaches' improvement measures may somehow have insignificant effects, especially in encouraging people to walk.

The results of these studies can vary among developed and developing countries as one of the general considerations is the geographic location and the perception of its constituents [9]. The Philippines, as a third-world country that focuses mainly on its developmental perspective, has been lacking published studies that tackle the significance of non-motorized transport and its potential contribution to the national and local context. Authorities of several first-class component cities in the country, including Tarlac City, now make efforts to provide sustainable solutions as they severely experience a variety of the afore-mentioned problems. Tarlac City is located in Central Luzon, Philippines with an overall population of 342,493 across all 76 barangays based on the 2015 survey of PSA [14]. From the past years, Tarlac City has been focusing more on car-centric planning since the area is considered as a transportation hub connecting the northern and southern portions of the island.

In support to several national and international callings, this research study also aims to recognize the significant role of pedestrian mobility, particularly in addressing the world's pressing issues. This study provided a holistic and multi-objective approach in tackling the pedestrian level of service and walkability by integrating walking's social, economic, environmental, and political role as general influencing factors under consideration. Above all, the main focus of this study was to develop a multi-objective pedestrian performance prediction model for evaluating existing pedestrian conditions that incorporates both the quantitative and qualitative factors that directly and indirectly influence the pedestrian level of service and walkability. Since there is a need to consider numerous underlying factors explicitly, the study also provided a comprehensive and systematic approach by applying combinations of statistical techniques and several validation and reliability tests. Identified influencing factors were categorized into four major aspects – Infrastructure and Facilities, Management and Policies, User Interaction and Movement, and the Environment. In order to develop the model, several assessment and audit tools were devised and validated for the data acquisition. The acquired information was subjected to two-fold statistical tests through factor analysis and ordinal regression analysis. The developed predictive mathematical model not only predicts the performance of the pedestrian system, but also provides an avenue to identify the key predictors that profoundly influence its performance. Lastly, this study's results and findings can help authorities to determine the priority of actions and establish long-term policies and initiatives for their respective governing areas.

## **2. Statement of the Problem**

The main objective of this research study is to develop a multi-objective pedestrian performance prediction model in evaluating pedestrian performance utilizing multivariate factorial analysis and ordinal regression analysis. Specifically, this study aims to address the following:

- Identify factors affecting pedestrian level of service and walkability through the evaluation of various published research literatures, studies, guidebooks, manuals, and other established concepts.
- Develop an Ishikawa Diagram in classifying factors influencing pedestrian performance categorized in terms of the following major aspect: Infrastructure & Facilities, Management & Policies, User’s Interaction & Movement, and Environment.
- Analyze assessment survey results to extract the significant factors (root causes) influencing pedestrian performance utilizing multivariate factorial analysis.
- Develop a multi-objective pedestrian performance prediction model in evaluating pedestrian performance utilizing ordinal regression analysis.
- Assess the effectiveness of the developed predictive mathematical model by evaluating existing pedestrian system of Tarlac City, Philippines.
- Provide recommendations and improvement measures to the Local Government of Tarlac to potentially and significantly increase the performance level of the city’s existing pedestrian condition.

### 3. Materials and Methods

This section chronologically presents the study's methodology, illustrating the different phases and their corresponding steps to provide a detailed discussion on the procedures of gathering and analyzing pertinent data to fulfill each research objective. The study engaged in a five (5) phased method covering a fifteen (15) step process in extracting the root causes that significantly influence pedestrian performance and subsequently developing a predictive mathematical model. This approach allowed the study to have a deeper understanding of the underlying causes that significantly influences pedestrian performance, leading to the identification of critical-to-quality parameters that may elevate the performance of its current state. The study's conceptual framework is presented by the diagram shown in Figure 1.

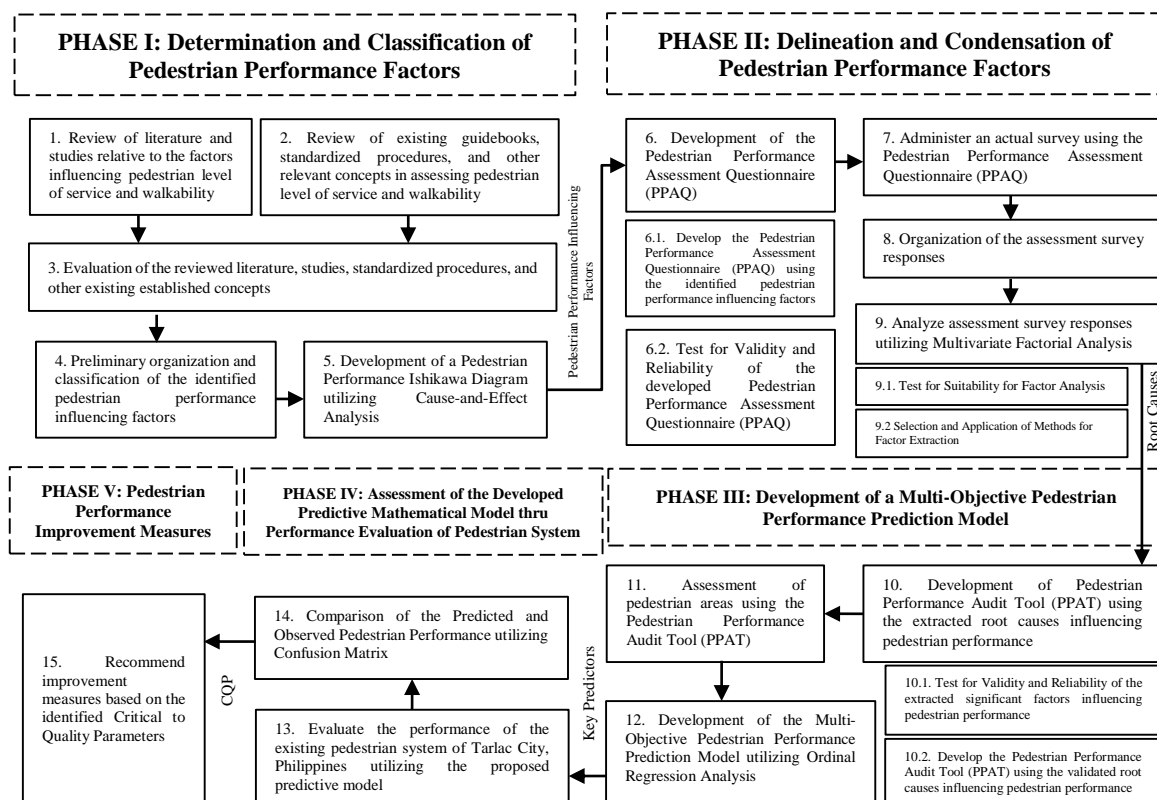


Figure 1. The Conceptual Framework

The first phase of the study's methodology focused on determining and classifying factors influencing the pedestrian level of service and walkability through a rigorous review and evaluation of published literature and studies, standardized procedures, and other relevant concepts. This specific phase outlined the concept of pedestrian performance to provide an overview of how pedestrian systems work and what factors influence its performance. An Ishikawa Diagram was then constructed through the application of cause-and-effect analysis to identify secondary and tertiary factors and subsequently classify all the identified factors based on the significant aspects of the study [15].

The second phase of this approach tackled the delineation and condensation of the identified factors. The Pedestrian Performance Assessment Questionnaire (PPAQ) was developed incorporating the identified factors and subsequently validated through face validity and internal consistency test. Factor analysis was employed in evaluating survey responses to extract the root causes affecting pedestrian performance. However, validation and assumption tests were conducted first before its application to see if the acquired data were suitable for factor analysis. This analysis is utilized in studies with large data sets to group various measures with common descriptions into a few components [16, 17].

The development of a multi-objective pedestrian performance prediction model was the focus of the third phase of the study. A Pedestrian Performance Audit Tool (PPAT) was devised to assess pedestrian areas, only incorporating the factors that passed the construct and composite reliability tests. Ordinal regression analysis was utilized to develop the predictive mathematical model. Through the application of this analysis, key predictors were extracted from the items involved in the PPAT and paved the way to generate the mathematical predictive model. For the study's fourth phase, the developed predictive mathematical model was validated using a confusion matrix by evaluating a new set of streets. Predicted values were then compared to the observed performance perceived by the respondents. Finally, the calculation of odds ratios served as the primary tool in interpreting several dimensions of the result. Recommendations were also laid out in the study's fifth phase based on the identified critical-to-quality parameters.

### 4. Results and Discussion

#### 4.1. Phase I: Determination and Classification of Pedestrian Performance Factors

The first two objectives of the study were the focus of Phase 1 which aimed to determine and classify factors influencing pedestrian performance. A total of 56 factors were initially listed after a thorough review and evaluation of several established and relevant concepts tackling the pedestrian level of service [3, 8, 18] and walkability [12, 19, 20]. Cause-and-Effect Analysis was then employed to explore further the underlying causes which affect pedestrian performance. After a series of brainstorming sessions, additional factors were added, and subcategories of the study's four major aspects were developed to further classify these identified factors. For the finalization, experts in pedestrian movement and facilities validated the list encompassing these factors. Factors that bear many similarities were enjoined, and factors that so far were not included in the list were also supplemented. With this, the study has now come up to the finalization of 81 pedestrian performance influencing factors broken down as follows: forty (40) factors under Infrastructure & Facilities, seventeen (17) under Management & Policies, sixteen (16) from User's Interaction & Movement, and eight (8) factors included under the Environment. Subsequently, this led to the development of an Ishikawa Diagram tackling pedestrian performance (Figure 2) and achievement of the study's first and second specific objectives.

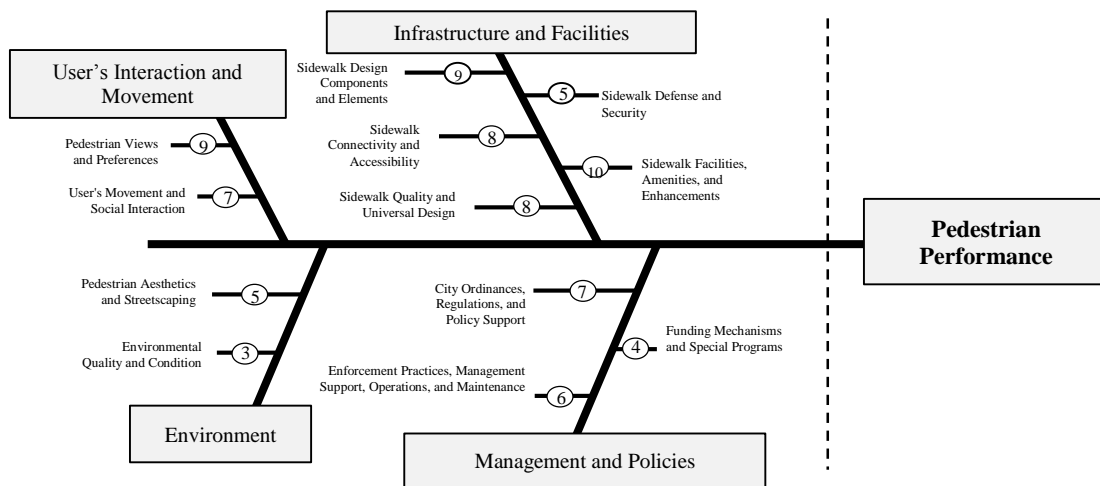


Figure 2. Ishikawa Diagram for Pedestrian Performance

#### 4.2. Phase II: Delineation and Condensation of Pedestrian Performance Factors

The PPAQ was subsequently developed utilizing the finalized factors and was crafted under a five-point Likert scale to measure the importance of the encrypted factors based on the objective and subjective views of the respondents. However, before its application, the PPAQ was first evaluated by experts in the context of transportation and experts in statistics through face validity test. These professionals focused on evaluating the questionnaire's content, especially on how those items were presented. A pilot study was also conducted to measure the reliability of the questionnaire, specifically its ability to measure the variable of interest through internal consistency test (Table 1). Cronbach's Alpha for each sub-group of the study was uncovered. Results of this calculation showed that all values were acceptable as these were above the 0.70 threshold value [16].

**Table 1. Internal Consistency Test**

Pedestrian Performance Influencing Factor	Cronbach's Alpha	Consistency
Infrastructure and Facilities	0.935	Excellent
Management and Policies	0.797	Acceptable
User's Interaction and Movement	0.888	Good
Environment	0.750	Acceptable
OVERALL	0.962	Excellent

The validated PPAQ was then evaluated by 100 pedestrians who considered walking as their primary means of transport. After tabulating responses, it was first checked if the obtained data were suitable for factor analysis by carefully checking if all assumptions under this analysis were met. The sampling adequacy was examined using the Kaiser-Meyer-Olkin (KMO) Measure of Sampling Adequacy. In the initial run of PCA in the data set, the KMO value is 0.694, a value above 0.50, which means that the samples are adequate. To check if the data should be suitable for reduction, Bartlett's Test of Sphericity was employed where the p-value was found to be at 0.00, a p-value lower than 0.05, which means that the correlation matrix of the variables is not an identity matrix; thus, PCA is justified (Table 2).

**Table 2. KMO and Bartlett's Test**

Kaiser-Meyer-Olkin Measure of Sampling Adequacy	0.694	
	Approx. Chi-Square	9758.443
Bartlett's Test of Sphericity	df.	3240
	Sig.	0

In this study, 81 items were accounted for the total variance. Each item has a corresponding eigenvalue of 1. However, after applying PCA as the extraction method, eigenvalues were redistributed to variables that carry the most variance in terms of the number of items. In the fourth and final rotation using Varimax with Kaiser Normalization as the rotation method, 21 items were eliminated. The study now was left with the 60 extracted factor items categorized into 13 components. These extracted components were then carefully named based on the shared concept of the items contained in those components. It must be noted that the 13 components can explain 79.242% of the total variance, a value higher than the acceptable threshold of 50% and reflects to the fulfillment of the study's third specific objective.

**4.3. Phase III: Development of a Multi-Objective Pedestrian Performance Prediction Model**

Before these extracted root causes were involved in developing a new audit tool, these extracted factors were subjected first to validity and reliability tests through Average Variance Extracted (AVE) and Composite Reliability (CR) tests, respectively. These values were calculated with the use of the following expressions:

$$AVE = \frac{\sum(f_i)^2}{\sum(f_i)^2 + \sum \varepsilon_i} \tag{1}$$

$$CR = \frac{\sum f_i^2}{(\sum f_i)^2 + \sum \varepsilon_i} \tag{2}$$

where  $f_i$  is the factor loading of each measurement item and  $\varepsilon_i$  is the error variance.

It was set that the minimum criterion to be satisfied for the AVE is 0.50 [16], while for CR is 0.65. Items starting with the lowest factor loading were deleted as long as the AVE and CR of that specific component did not reach the threshold value. Undergoing this process comes with simultaneous verification if all the assumptions and requirements of factor analysis were still satisfied. Thus, after these thorough procedures, a total of 11 components covering all 40 items remained significant (Table 3).

The 40 validated root causes as the independent variable and the 6-point performance rating as the dependent variable were incorporated in the development of the PPAT. This tool served as an audit and evaluation tool in assessing pedestrian areas in the City of Tarlac. Five (5) randomly selected local and collector streets in the City of Tarlac were assessed using the developed PPAT, namely (a) F-Tañedo Street, (b) Romulo Boulevard, (c) Zamora Street, (d) Hilario Street, and (e) J. Luna Street. All field-driven data were observed and measured onsite, while items under the assessment survey were answered by a pool of respondents online. Moreover, all five streets were monitored for seven consecutive days and were observed in the morning, noon, and evening time to capture the optimum and most probable value for the items involved in each component, especially peak hour values.

**Table 3. Extracted and Finalized Root Causes influencing Pedestrian Performance**

Component	Description	FL	AVE	CR	Component	Description	FL	AVE	CR
User's Movement (UM)	Pedestrian Space	0.774	0.512	0.840	Policy Support (PS)	Policy Guidelines	0.734	0.523	0.767
	Vehicle Speed	0.759				Local Street Design Standards	0.733		
	Sight Distance	0.697				Public Spaces	0.702		
	Vehicle Traffic Flow and Density	0.682			Sidewalk Accessibility to Less Essential Destinations (SALED)	Open Spaces and Nature Preserves	0.817		
	Intersection Waiting Time	0.660				Social and Leisure Spots	0.757		
Operations and Management (OM)	Staffing Levels	0.845	0.605	0.902	Tourist and Historic Sites (SAED)	Tourist and Historic Sites	0.746	0.514	0.839
	Street Sweeping	0.813				Street Vendors	0.667		
	Interagency Cooperation	0.773				Comfort Rooms	0.571		
	Traffic Enforcers	0.764			Sidewalk Accessibility to Essential Destinations (SAED)	Education and Employment	0.752	0.838	0.700
	Monitoring and Repair	0.760				Hospital and Essential Services	0.715		
	Official's Intervention	0.704				Air and Odor Quality	0.833		
Defense and Universal Accessibility (DUA)	Traffic Control & Calming Devices	0.762	0.510	0.838	Environmental Quality (EQ)	Traffic Noise	0.723	0.559	0.791
	Physical Borders	0.762				Natural Enclosure of Vegetation	0.679		
	Street Lights	0.723			Sidewalk Amenities (SAm)	Guide Signs	0.758	0.523	0.687
	Obstructions	0.708				Trash Bins	0.687		
	Handrails and Guardrails	0.604				Pedestrian Crossing (PC)	Crossing Facilities		
Pedestrian Aesthetics and Streetscaping (PAS)	Imageability & Visual Quality	0.800	0.502	0.833	Refuge Islands		0.686		
	Ambiance	0.725			Sidewalk Zone Width (SZW)	Furnishing Zone	0.789	0.563	0.720
	Infrastructures	0.695				Frontage Zone	0.709		
	Vibrance	0.691							
	Good Street Art	0.618							

Ordinal regression analysis was adopted as the primary statistical tool due to the ordinal nature of the variables [21]. Initially, the 11 established components were set as the main predictors. However, along with the conduct of different tests for assumptions, the test for Goodness of Fit and Parallel Lines were not satisfied. In response to this situation, it was redirected to use the contained items in each component as the main predictors. Verifications tests were re-run and consequently interpreted. A P-value of more than 0.05 indicates that the assumption for proportional odds is met; thus, having a p-value of 1.0 indicates that this assumption was met. In the likelihood ratio chi-square test, a p-value of less than 0.05 is anticipated; thus, a p-value of 0.00 for a chi-square value of 144.799 indicates a significant improvement in the fit of the final model over the null model. Both Pearson and Deviance chi-square tests were also significant as the p-values were more than 0.5. These suggest that the model fits the data well (Table 4).

Ordinal Regression Analysis was then utilized to generate the predictive mathematical model. Coefficients bearing a significant value of less than 0.05 confidence interval were retained, and those items exceeding this threshold were removed. From the table shown, six items remained and were deemed statistically significant and led to the development of the predictive mathematical model. The study's fourth specific objective, which aims to develop the multi-objective pedestrian performance prediction model (Table 5), was achieved.

**Table 4. Overall Fitting Indices**

Test of Parallel Odds					Goodness-of-Fit			
Model	-2 Log Likelihood	Chi-Square	df.	P-val.	Chi-Square	df.	P-val.	
Ho	152.549	-	-	-	Pearson	376.264	460	0.998
General	99.525b	53.024c	140	1				
Model Fitting Information					Deviance	152.549	460	1.00
Intercept	297.348	-	-	-				
Final	152.549	144.799	35	0.00				



**Table 5. Pedestrian Performance Predictive Model**

Predictor	Coef.	Sig.	Pedestrian Performance	Constant	Model
Pedestrian Space	1.122	0.009	Needs Massive Improvement	6.575	$P(Y \leq 1) = P(Y=1)$
Official's Intervention	-1.369	0.008	Very Poor	7.609	$P(Y=2) = P(Y \leq 2) - P(Y \leq 1)$
Ambiance	1.475	0.007	Poor	11.136	$P(Y=3) = P(Y \leq 3) - P(Y \leq 2)$
Vibrance	1.326	0.019	Good	16.517	$P(Y=4) = P(Y \leq 4) - P(Y \leq 3)$
Street Vendors	-1.342	0.004	Very Good	21.482	$P(Y=5) = 1 - P(Y \leq 4)$
Trash Bins	1.114	0.015	<b>The Logit</b>	$p(x) = \frac{e^{\beta_0 + \beta_1 X_1 + \beta_2 X_2 + \dots + \beta_k X_k}}{1 + e^{\beta_0 + \beta_1 X_1 + \beta_2 X_2 + \dots + \beta_k X_k}}$	

**4.4. Phase IV: Assessment of the Developed Predictive Mathematical Model thru Performance Evaluation of Pedestrian System**

The validation of the predictive model was accomplished by using a confusion matrix. The PPAT was reconstructed only incorporating the key predictors of the predictive model and was used to assess another set of pedestrian streets. It was noted from the previous phase that the highest rating (excellent) of pedestrian performance garnered an insignificant number of responses. Therefore, the model showed a minimal probability of this being selected, thus excluded from the rating list. Re-coding of the dependent variable was deemed necessary in response to these changes. The interval for LOS A-C suggests that this LOS range was acceptable to pedestrians, while the interval for LOS D-F indicates that the users were dissatisfied [9]. The recoded rating is presented in Table 6.

**Table 6. Re-Coded Pedestrian Performance Rating**

Initial Value	Final Value
LOS A-B	Very Good
LOS C	Good
LOS D	Poor
LOS E	Very Poor
LOS F	Needs Massive Improvement

The respondent's perceived pedestrian performance was then compared to the predicted pedestrian performance. All matching observed and predicted values were associated with the total number of observations to calculate the model's accuracy, thus generating an acceptable accuracy rating of 71.67%. This accuracy rating made the multi-objective pedestrian performance prediction model acceptable and valid (Table 7).

**Table 7. Matrix of Observed and Predicted Pedestrian Performance**

Predicted	Observed				
	NMP	VP	P	G	VG
Needs Massive Improvement	16	1	7	1	0
Very Poor	0	0	0	0	0
Poor	0	0	17	6	1
Good	0	0	0	10	1
Very Good	0	0	0	0	0

**4.5. Phase V: Pedestrian Performance Improvement Measures**

The interpretation of the developed predictive mathematical model was undertaken by calculating the odds ratios. It was applied and taken into consideration that the calculated odds ratios are covered by the statistically significant intervals of the response variable and its reference categories [5]. From the table shown, it can be interpreted that there is no association between gender and how they perceive pedestrian performance. Results also showed that pedestrians are more concerned with the qualitative factors of the pedestrian system rather than its quantitative counterparts. Street ambiance and vibrance are the leading positive contributor to a higher pedestrian performance. For instance, pedestrians who rated the system's ambiance as high are more likely to perceive a higher rating by approximately 15 times than pedestrians who rated the ambiance as low (Table 8). On the other hand, pedestrians who rated vibrance as high also possess a high probability of rating the pedestrian system high by approximately ten times than pedestrians who rated the system's vibrance as low.

**Table 8. Calculation of Odds Ratios**

Variable	Interval	Odds Ratios
Gender	Male (RC)/Female	1.042
Ambiance	Low/High (RC)	15.375
Vibrance	Low/High (RC)	10.286

To further ascertain all these claims, a comparison between the objective calculations of PLOS from the subjective evaluation of respondents was undertaken. Also, this comparison aimed to find potential differences and to acknowledge additional aspects that must be considered. There are several methodologies used for the calculated PLOS. However, this study utilized pedestrian space from the Highway Capacity Manual (2000) as the basis for the objective calculation of PLOS due to the following reasons: Pedestrian Space is considered one of the most widely used measurements in the context of PLOS [8], and Pedestrian Space is considered as one of the predictors of pedestrian performance as it is deemed statistically significant in the context of this study.

**Table 9. Calculated vs. Perceived Pedestrian Level of Service**

Area	Calculated PLOS				Perceived PLOS
	Before/After the Peak (m <sup>2</sup> /ped)	LOS	During the Peak (m <sup>2</sup> /ped)	LOS	
F-Tañedo Street	3.55	B	1.25	D	Good
Romulo Boulevard	3.72	B	3.00	C	Good
Zamora Street	3.64	B	3.40	C	Poor
Hilario Street	5.06	A	4.88	A	Very Poor
J. Luna Street	5.02	A	4.92	A	Poor
Macabulos Drive	4.08	B	3.32	C	Poor
MH. Del Pilar Street	3.92	B	2.67	C	Very Poor
Rizal Street	4.98	A	4.43	B	Poor

The calculated PLOS showed positive indications based on the presented information as it reached the acceptable service rating. However, most of the respondents were still not satisfied with the service given by these pedestrian areas. Also, even if F-Tañedo Street goes below the acceptable calculated level of service during its peak, pedestrian users are still satisfied with its service as they experience good street vibrance. From this, it is apparent that focusing more on heightening the system's ambience and vibrance may significantly improve the performance of the pedestrian system. These factors do not possess a numerical equivalence, but they may still be enhanced by meeting the things that provide ease, comfort, and lively spirit to pedestrians while walking in public places. Also, providing every street with trash bins not only contributes to improving pedestrian performance, but may also heighten the system's ambience. Sufficient pedestrian space can be maintained or enhanced by ensuring that pedestrians' density and flow are not being interrupted and do not go beyond the critical level.

On the other hand, two factors negatively impacted pedestrian performance. In relevant to those cases, it is highly recommended that the local government of the City of Tarlac invest more effort in studying and integrating empirical evidence in the development of sustainable programs, especially those which tackle the needs of pedestrians. Allotting street vendors with free space and relocating them to areas that may not obstruct pedestrian flow can help. Providing these interventions may result in a two-dimensional win as this may reset the mindset of pedestrians from the negative impression of OI and SV and may subsequently elevate the pedestrian's performance.

### 5. Summary and Conclusion

The main objective of this research study was to develop a multi-objective pedestrian performance prediction model for evaluating pedestrian performance by integrating both quantitative and qualitative factors. Eighty-one items were initially listed and classified after thorough evaluation, validation, and verification procedures. These items were then classified, which led to the development of an Ishikawa Diagram tackling pedestrian performance. After several validity and reliability tests, the PPAQ was employed and participated in by pedestrians in Tarlac City. Responses were then analyzed using factor analysis, incorporating various validity and reliability tests that led to the extraction and finalization of forty (40) root causes. Local and collector streets in Tarlac City were evaluated using the PPAT, which was developed based on the finalized root causes. After the application of ordinal regression, results showed that there were six key predictors in predicting pedestrian performance (PS, OI, A, V, SV, & TB), which became the most significant contribution of the study.



The findings of the study's analyses were somehow consistent with the previously presented studies. Based on the results and discussion, it is highly evident that pedestrian users are more concerned with the qualitative aspect of the pedestrian system. Although the evaluated streets were considered acceptable in the context of calculated PLOS, most of the respondents were still dissatisfied with its service. Street ambiance and vibrance were the leading factors that significantly influenced pedestrians' performance. The findings of this study specify the relevance of considering pedestrian perception, specifically in the development of sustainable programs and measures for improving the pedestrian system. It must also be noted that pedestrian space is also deemed statistically significant, an indicator under the objective calculation of PLOS. Thus, the calculated and perceived assessments should be integrated to establish a trustworthy evaluation of the pedestrian's performance.

The model also showed that both Street Vendors (SV) and Official's Intervention (OI) have a negative coefficient, which signifies an inverse relationship to pedestrian performance. Upon careful observation, evaluation, and proper consultation, the overwhelming number of street vendors obstructs the pathway intended for pedestrians, negatively impacting pedestrians' perception. On the other hand, it has been evident that the majority of the interventions of elected and appointed officials are still car-centric, specifically in terms of public budgeting and infrastructure development. Also, some of the pedestrian interventions do not maximize the allotted budget, effort, and time as they do not thoroughly address the needs of the pedestrians, which leads to a negative impact on the pedestrians' experience. Nonetheless, it must be noted that the negative effects of SV and OI do not permanently imply that these factors are negatively fixed and will continually degrade the system's performance. The irregularities brought by these instances may be resolved by re-running all the procedures in the development of the predictive model within a set of time intervals to be able to recalibrate the predictive mathematical model, especially if solutions were introduced and executed since people's views and opinions change.

### 5.1. Recommendations

The development of the ordinal regression mathematical model in predicting pedestrian performance was extensively undertaken. But still, several measures may further strengthen the integrity of the gathered data and supplementarily enhance several aspects of the development of this regression model. For instance, the data acquisition was restricted to a remote form of gathering responses due to the ongoing situation of the COVID-19 pandemic. The study opted to use a non-probability-based sampling technique to comply with the health restrictions and protocols imposed by the local government unit of Tarlac City and the national government of the Philippines. However, using a probability-based sampling technique can be of great help to ensure the normalization of all the gathered information. Also, several quantitative factors, such as traffic flow, pedestrian flow, space, etc., may be underestimated and may not take into account the real state of the pedestrian area because of how the pandemic has changed the way people drive and walk.

The study only focused on extracting the most significant factors that affect pedestrian performance and evaluating the differences between the calculated and perceived performance through the development of a predictive mathematical model. Regarding this concern, the study's model was only subjected to an average test to validate its performance. Thus, the use of high-caliber statistical validation measures such as cross-validation, evaluation metrics, and the like may further validate the accuracy of the developed model. However, these measures are far beyond the scope of the study.

It must also be noted that the multi-objective pedestrian performance prediction model is somehow relevant both to the time and geographic region where this model was developed. Thus, using this model in other places may not ensure the reliability and applicability of its generated results since this model was crafted from the perception and point of view of pedestrians residing in the City of Tarlac. Time can also be a factor relevant to the accuracy of the developed model. The irregularities brought by these instances may be resolved by re-running all the procedures undertaken in developing the predictive model within a set of time intervals and considering the geographic region of the area.

## 6. Declarations

### 6.1. Author Contributions

Conceptualization, N.A.I.M.; methodology, N.A.I.M. and J.S.B.; software, N.A.I.M.; validation, N.A.I.M. and J.S.B.; formal analysis, N.A.I.M. and J.S.B.; investigation, N.A.I.M.; resources, N.A.I.M.; data curation, N.A.I.M.; writing—original draft preparation, N.A.I.M.; writing—review and editing, N.A.I.M. and J.S.B.; visualization, N.A.I.M.; supervision, J.S.B.; project administration, N.A.I.M. and J.S.B.; funding acquisition, N.A.I.M. All authors have read and agreed to the published version of the manuscript.

### 6.2. Data Availability Statement

The data presented in this study are available on request from the corresponding author.

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#### 6.5. Conflicts of Interest

The authors declare no conflict of interest.

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## Appendix I

### Pedestrian Performance Assessment Questionnaire

Dear Respondent:

Greetings!

This is Neil Andrew I. Meneses currently conducting a research study entitled “Efficiency of Pedestrian Mobility: A Factor Analytic Approach in Developing a Multi-Objective Pedestrian Performance Prediction Model utilizing Regression Analysis” which aims to develop a multi-objective pedestrian performance prediction model in evaluating existing pedestrian condition and the quality of service it provides, the main purpose of this questionnaire is to examine and subsequently extract factors which potentially influences pedestrian performance based on pedestrians’ perspective focusing mainly in the City of Tarlac.

All information provided herein by the respondents will remain secured and confidential. The undersigned researcher, the only person with full authority to access the responses, fully commits to undertake technical and data protection measures as required by the Data Privacy Act of 2012 to ensure that the data are protected and safeguarded against unauthorized disclosure or any similar unlawful acts and will only be used for this research purpose only.

#### I. Respondent’s Profile

This section contains personal information regarding the respondent. The researcher is fully aware of the rights of his respondents under the Data Privacy Act including the right to review the data, the right to withdraw consent, the right to correct and/or update the data, the right to object to processing the data, the right to access the respondent’s data, the right to correct any inaccurate data, and the right to erasure and blocking of data. For requests to undertake the actions stated above or any similar acts as per indicated in the Data Privacy Act, please contact the researcher at “*naimeneses@mymail.mapua.edu.ph*”.

Name (Optional): Age:  
 Civil Status: Gender:  
 Address: Employment Status:  
 Highest Educational Attainment:  
 Are you a Person with Disability (PWD)? Yes/No  
 Do you have a Driver’s License? Yes/No

Which of the following means of land transportation you mostly utilize to go to your day-to-day destinations? (Private Transp., Public Transp., Walking, Cycling, others)

Do you consider Walking as one of your primary means of transportation? Yes/No  
 Estimate the average number of hours you accumulate walking in public places per day:

#### II. Assessment Questionnaire

This survey questionnaire contains a number of potential factors which may affect or influence the pedestrian performance that were properly validated with the help of some experts in the fields of transportation, research, and statistics. These potential factors are listed below which were initially categorized into four major components - (1) Infrastructure and Facilities, (2) Management and Policies, (3) User’s Interaction and Movement, and (4) Environment to provide a holistic approach in assessing the pedestrian facilities and environment, and its capability to accommodate and address the needs of its users.

This questionnaire hereby asks your personal beliefs and preferences on how important these items are relevant to the things you consider while walking in public places. These items may directly or indirectly affect the quality of service provided by pedestrian facilities as these factors may have significant correlation to pedestrian performance. Please carefully read and assess each item and indicate to what extent you feel the importance of each statement based on your own perspective.

##### A. Infrastructure and Facilities

Item No.	Potential Factor	Not Important	Slightly Important	Moderately Important	Important	Highly Important
		1	2	3	4	5
<b>1.0 Network Design Components and Elements</b>						
Assess the following items on how these are important being a part or an integral component of a pedestrian facility						
1.1	Furnishing Zone					
1.2	Pedestrian Zone					
1.3	Frontage Zone					

1.4	Functional Width					
1.5	Sidewalk Block Length					
1.6	Carriageway Width					
1.7	Corner Radius					
1.8	Efficient Drainage					
1.9	Land Use					
<b>2.0 Network Connectivity and Continuity</b>						
Evaluate the importance that the sidewalk must be continuous and provide accessibility to the following items						
2.1	Hospitals and Essential Services					
2.2	Education and Employment					
2.3	Private and Public Markets, Restaurants, and other Food Source					
2.4	Social and Leisure Spots					
2.5	Tourist and Historic Sites					
2.6	Open Spaces and Nature Preserves					
2.7	Public Transportation Terminals					
2.8	Comfort Rooms					
<b>3.0 Network Quality and Universal Design</b>						
Assess the importance of considering and/or incorporating the following items in pedestrian facilities relevant to the growing needs of its users specifically to cater the needs of people with disabilities and special needs						
3.1	Sidewalk Segment					
3.2	Surface Quality					
3.3	Grade					
3.4	Surface Markings					
3.5	Curb Cuts and Ramps					
3.6	Handrails and Guardrails					
3.7	Crossing Facilities					
3.8	Refuge Islands					
<b>4.0 Network Defense and Security</b>						
Evaluate the importance of the following items relevant to your safety and security while using the pedestrian facilities						
4.1	Physical Borders					
4.2	Streetlights					
4.3	Traffic Control and Calming Devices					
4.4	Obstructions					
4.5	Security Cameras					
<b>5.0 Network Facilities, Amenities, and Sidewalk Enhancements</b>						
Assess the importance of including the following amenities and sidewalk enhancements in pedestrian facilities relevant to your convenience and comfort						
5.1	Weather Protection					
5.2	Stations of Public Transportation					
5.3	Crossing Holding Areas					
5.4	Pedestrian Traffic Signals					
5.5	Pedestrian Signages					
5.6	Guide Signs					
5.7	Street Vendors					
5.8	Public Seats					
5.9	Portable Toilets					
5.10	Trash Bins					

**B. Management and Policies**

Item No.	Potential Factor	Not Important	Slightly Important	Moderately Important	Important	Highly Important
		1	2	3	4	5
<b>1.0 City Ordinances, Regulations, and Policy Support</b>						
Evaluate the significance of the following items if these items may directly or indirectly bear impact to pedestrian quality and performance						
1.1	Policy Guidelines					
1.2	Local Street Design Standards					
1.3	City Ordinances					
1.4	Public Spaces					
1.5	Speed Limits					
1.6	Vandalism and Littering					
1.7	Street Parking					
<b>2.0 Funding Mechanisms and Special Programs</b>						
Evaluate the significance of the following items if these items may directly or indirectly bear impact to pedestrian quality and performance						
2.1	Funding					
2.2	Campaigns					
2.3	Awareness Programs					
2.4	Community Outreach					
<b>3.0 Enforcement Practices, Management Support, Operations, and Maintenance</b>						
Evaluate the significance of the following items if these items may directly or indirectly bear impact to pedestrian quality and performance						
3.1	Official's Intervention					
3.2	Interagency Cooperation					
3.3	Staffing Levels					
3.4	Traffic Enforcers					
3.5	Monitoring and Repair					
3.6	Street Sweeping					

**C. User's Interaction and Movement**

Item No.	Potential Factor	Not Important	Slightly Important	Moderately Important	Important	Highly Important
		1	2	3	4	5
<b>1.0 Pedestrian Views and Preferences</b>						
Evaluate the significance of the following items relevant to the things you primarily consider while walking in public places						
1.1	Safety					
1.2	Security					
1.3	Convenience					
1.4	Pedestrian Visibility and Transparency					
1.5	Ambiance					
1.6	Comfortability					
1.7	Vibrance					
1.8	Social Acceptance					
1.9	User's Attitude and Behavior					
<b>2.0 User's Movement and Social Interaction</b>						
Evaluate the importance of the following items relevant to the things that affects or influences you as you use pedestrian facilities and walk in public places						
2.1	Pedestrian Walking Speed					
2.2	Pedestrian Volume to Capacity Ratio					
2.3	Vehicle Speed					
2.4	Vehicle Volume to Capacity Ratio					
2.5	Pedestrian Space					
2.6	Sight Distance					
2.7	Intersection Waiting Time					



**D. Environment**

Item No.	Potential Factor	Not Important	Slightly Important	Moderately Important	Important	Highly Important
		1	2	3	4	5
<b>1.0 Pedestrian Complexity and Streetscaping</b>						
Assess if the following items relevant to the surroundings is important and of relative significance in the quality of pedestrian area						
1.1	Cleanliness					
1.2	Image ability and Visual Quality					
1.3	Infrastructures					
1.4	Adequate Greening and Pleasing Vegetation					
1.5	Good Street Art					
<b>2.0 Environmental Quality and Condition</b>						
Assess if the following items relevant to the environment is important and of relative significance in the quality of pedestrian area						
2.1	Air and Odor Quality					
2.2	Traffic Noise					
2.3	Natural Enclosure of Vegetation					

Thank you for submitting your response!

We hope to continuously gain your support as we strive to raise awareness regarding the importance and benefits of using this indigenous mode of transport, and to unceasingly improve and develop its facilities.