A Study on the Relation between Spatial Configuration, Spatial Design, and Staying Behaviors in Underground Public Spaces in Tokyo

1X18DS02-4 Shuntaro Umetsu*

There are factors affecting pedestrians' staying behaviors regardless of their awareness of such factors. In this study, through the analysis and creation of logistic regression models, factors affecting the occurrences of staying behaviors in public spaces located on the underground floor of buildings are investigated and the effectiveness of predicting the occurrences of staying behaviors by the logistic regression model is evaluated. The results showed that the existence of Advertisement_Exhibit, Bench_Chair, and Floor_Guide_Map are primary factors affecting the occurrences of staying behaviors, and VGA indexes are secondary factors in the public underground spaces. The general availability of the prediction by logistic regression models remains unclear but an example in which a logistic regression model that was created based on the other underground spaces' data of pedestrian locations and results of VGA can be used for predictions of the occurrence of staying behavior in a certain space was demonstrated.

Key Words: *Public Underground Spaces, Staying Behaviors, Spatial Design, Spatial Configuration, Visibility Graph Analysis, Prediction Model*

1. INTRODUCTION

(1) Research Background

Development of underground space has been attracting the attention of local governments, railway companies, and real estate developers especially in urban areas since developments aboveground are limited by high land prices and poor space for the construction of new roads and buildings[1)]. While there exists several types of underground space developments, this paper only focuses on the development of connecting public underground walkways to the public spaces located on the underground floor of buildings, because such kind of development is common in Japan[2)] and adopted in many buildings in Japanese urban area when buildings are reconstructed[3)] due to the existence of urban renewal measures which raise the limits of the floor area ratio of buildings or loosen the restrictions of the Building Standards Act if the development would contribute to the improvement of urban renewal and environment[4)].

Since the spatial configuration of underground space is different from that of aboveground due to the low ceiling and poor visibility by the existence of pillars, people behave differently[5)], and careful attention to the pedestrian environment is required for creating liveliness in the connected space[6)].

For real estate developers, although connecting the underground floor of their buildings to public underground walkways is an institutional, technical, and financial burden to a certain degree, it contributes to the increase in the number of visitors and sales, enhancement of the building's asset value, and improvement of accessibility and connectivity of pedestrians.

As the pedestrian flow and the existence of staying people are related to the liveliness of the space, factors affecting them in open spaces, stations, and shopping complexes have been investigated by various approaches such as observations, questionnaires, and space syntax theory. Since the increase in pedestrian flow and staying people lead to the increase in the sales of stores and revenue of real estate developers[6)], investigating factors affecting the occurrence of staying people and attracting pedestrians in underground public spaces of buildings seems to be important for realizing the creation of underground spaces which are ideal for real estate developers.

(2) Research Objective

The purpose of this study is to investigate the factors affecting the occurrence of pedestrians' staying behaviors in underground public spaces of buildings connected to public underground walkways in Tokyo from the viewpoint of spatial configuration, spatial design, and recording of pedestrians' staying behavior locations. At the same time, the effectiveness of the logistic regression model predicting the occurrence of staying behaviors based on the information on spatial configuration and

*Department of Social and Environmental Engineering, School of Creative Science and Engineering, Waseda University

Landscape and Design Yoh Sasaki Laboratory 4th year

spatial design will be evaluated.

Specified factors and the prediction model are presumed to be supplementary information for controlling and predicting the occurrence of pedestrians' staying behaviors in underground public spaces of buildings. Therefore, the findings of this study will assist real estate developers and designers to consider and create the layout of furniture and spatial configurations of ideal underground spaces for them.

2. LITERATURE REVIEWS

Studies on factor analysis of pedestrian flow, pedestrian density, and pedestrians' staying behaviors are reviewed here to understand the factors affecting the pedestrians' staying behaviors above ground.

(1) Factor Analysis of Pedestrians' Staying Behaviors

There exist various studies analyzing the factors of pedestrians' staying behaviors.

Matsumoto[7] classified pedestrians' staying behaviors into stop with purpose and stop without purpose. Through observations of pedestrians' staying behaviors and investigation on space conditions of the underground shopping arcade in Nagoya, they proved that actions of stop with purpose are often observed in open spaces and actions of stop without purpose in gateway spaces.

Shimada[8] focused on staying behaviors in public open spaces and tried to demonstrate the relation between the number of staying people and spatial configurations of public open spaces. As a result of quantification method 1, spatial configurations namely, area of effective open space, number of benches, number of entrances to the parking lot, number of convenience stores located on the first floor of buildings, the existence of offices in the first floor of buildings, the existence of art, and the existence of vending machines are extracted as factors affecting the number of staying people in public open spaces.

Sakai[9][10] executed questionaries to sitting staying people in open spaces to investigate the factors affecting their stay location selections. Through the analysis of collected questionaries and actual observations, it was demonstrated that accessibility, more specifically the distance from entrances and the number of pedestrian flow around staying locations, is the primary factor for stay location selection, and comfortability, the existence of other sitting staying people, and the existence of equipment like walls or pillars are the secondary factors.

Kamino[11] implied that the existence of space to spare allowing pedestrians to stop anytime is important in terms of the comfort of the space. In addition, he indicated the necessity of equipment and space in urban public spaces allowing pedestrians to take a breather and relax, and it is desirable that such space is located a bit far from the pedestrian flows but not segregated, and being able to gaze pedestrian flows. According to the author, pedestrians' staying behaviors are supposed to occur if such space exists.

(2) Factor Analysis of Pedestrian Flow and Pedestrian Density with VGA

In various target spaces and sites, studies adopting Visibility Graph Analysis (VGA) to specify factors affecting pedestrian flow and density have been done.

Ueno[12] defined a complicated three-dimensional space like Shibuya station as a multilevel complex and analyzed the factors affecting the number of pedestrian flow in the multilevel complex with Visibility Graph Analysis and multiple regression analysis. He concluded that Connectivity, minimum Visual Step Depth (VSD) from ticket gates, and average Metric Shortest Path Length (MSP) are the key factors for pedestrian flow in the space.

Fujitani[13] selected two commercial buildings (A and B) as the target sites. Building A is extending in the horizontal direction, and B is extending in the vertical direction. Fujitani conducted multiple regression analysis with the data of pedestrian density and results of VGA. According to his analysis, the impact of the store was the influential factor for pedestrian density in Building A, and connection with the entrances was the influential factor in Building B.

Saruyama[14] analyzed the relation between the shopper's distribution in the multi-layered shopping complex and spatial configurations represented by VGA. As a result, they showed two things. Walker's density in the circulation space can be explained by Global Integration and VSD from ESC. Shopper's density in retail stores can be explained by Connectivity and the length of the shop window.

Okamoto[15] investigated the factor of pedestrian flows with the measures of VGA. He chose the underground mall complex of Nagoya Station as a research target site and concluded that MSP and VSD from the closest ticket gates are primary factors for pedestrian flows while Visual Integration can work as the secondary factor.

(3) Characterization of Research

This study has three features. First, studies focusing on staying behaviors in underground public spaces of buildings connected to underground public walkways are scarce while many studies on staying behaviors and pedestrian flow select stations,

shopping complexes, and open spaces as research target sites. Second, it executes multivariable analyses based on the data of Visibility Graph Analysis and staying people. The influence of pedestrian flow will be reflected in the analyses through VGA values, and pedestrian flow itself will not be used in the analyses. Finally, it provides meaningful data and expertise for the management and control of pedestrians in underground spaces of buildings connected to public underground walkways by the creation and evaluation of a logistic model predicting the occurrence of staying behaviors and by clarifying the relation among spatial configuration, spatial design, and the staying behaviors of people.

3. RESEARCH FLOW AND SITE

(1) Research Flow

Fig.1 shows the flow of the research process. After the introduction, the preceding studies and selection of research target sites are introduced and discussed. Then, the results of recording of staying behavior locations and VGA will be demonstrated. Next, the logistic regression analysis will be conducted to specify factors affecting the occurrences of pedestrians' staying behaviors. After that, a logistic regression model predicting the occurrence of staying behaviors will be built, and its effectiveness will be evaluated.

(2) Selection of Research Target Site

Research target sites in this study were selected based on the following criteria:

1. An underground space of a building is seamlessly connected to public underground walkways
2. An underground space has the capability of allowing a certain number of people to stay without being uncomfortable at the same time
3. Availability of getting a floor plan of the target site
4. A certain number of people actually stop with/without purpose on the target site

As a result of selection, 5 sites (6 patterns) were selected as research target sites in this study. **Fig.2-7** are the photos of target spaces.

(3) Overview of Target Sites

Basic information like names of the buildings, year of completion of the buildings, their use, owners, and connected railways are summarized in **Table 1**.

4. RECORDING OF STAYING BEHAVIOR LOCATIONS AND VGA

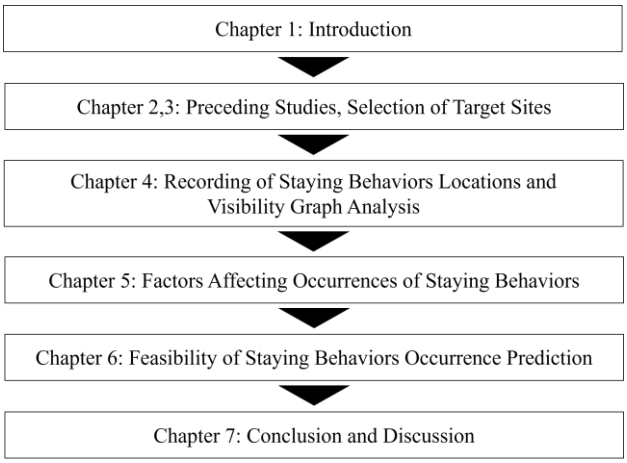

Fig.1 Research Flow

Fig.2 Kyobashi Edogrand

Fig.3 Tokyo Square Garden

Fig.4 Midtown Hibiya#1

Fig.5 Midtown Hibiya#2

Fig.6 Takashimaya Mitsui Bldg.

Fig.7 Metro Hat

Table 1 Overview of Target Sites

Target Site	Date of Observation	Weather	Year of Completion	Use	Owner	Railway Lines
Kyobashi Edogrand	Oct. 2nd 12:00-13:00	cloudy	2016	office, restraunts, stores, public facility	urban redevelopment association	Ginza Line
Tokyo Square Garden	Oct. 2nd 13:20-14:20	cloudy	2013	office, stores, medical facility	multiple corporations	Ginza Line
Tokyo Midtown Hibiya	#1 Oct. 15th 10:50-11:50 #2 Nov. 13rd 11:40-12:40	#1 cloudy #2 cloudy	2018	office, stores, cultural exchange facility, industry support facility, theatre, DHC	Mitsui Fudosan	Chiyoda Line Hibiya Line Mita Line
Nihonbashi Takashimaya Mitsui Building	Oct. 15th 13:15-14:15	cloudy	2018	office, stores, restaurants	urban redevelopment association	Ginza Line Tozai Line Asakusa Line
Roppongi Hills Metro Hat	Nov. 20th 10:50-11:50	sunny	2003	office, stores, residence, hotel, theatre	urban redevelopment association	Hibiya Line

(1) Recording of Staying Behavior Locations

An investigator visually recorded locations of furniture, staying people, and their gender to floor plans in each target site.

At the time of recording, staying people were classified into stop with purpose and stop without purpose based on their behavior. This classification is based on the definition of prior research[7]. To minimize the influence of the investigator's existence on staying people in target sites, an investigator did not remain in the same place for over 5 minutes when recording. The recording duration was one hour for each site. All observations and recordings were conducted on holidays between October and November when the weather condition is relatively static. The date and weather of the recording days are summarized in **Table 1**.

(2) Visibility Graph Analysis

In this study, Visibility Graph Analysis, which is one of the analysis approaches in Space Syntax Theory, is adopted to quantitatively analyze spatial configurations in research target sites.

Bill Hillier, a professor at the University of London, and his colleagues developed the Space Syntax Theory based on graph theory in the 1980s. Among several approaches in Space Syntax Theory, Visibility Graph Analysis (VGA) is more suitable for the analysis of closed spaces like underground spaces[16]. The basic concept of VGA is illustrated in **Fig.8**. Spatial configurations of target spaces are evaluated by six measures obtained by this analysis. Those six VGA measures used in this study are summarized in **Table 2**.

Fig.9 shown below represents the results of pedestrian location recording and VGA in the case of Kyobashi Edogrand. Regarding the result of VGA in the figure, a result of Through Vision is picked as an example and overlayed as heatmaps. Data on pedestrian locations and VGA results in each target space will be used in logistic regression analysis.

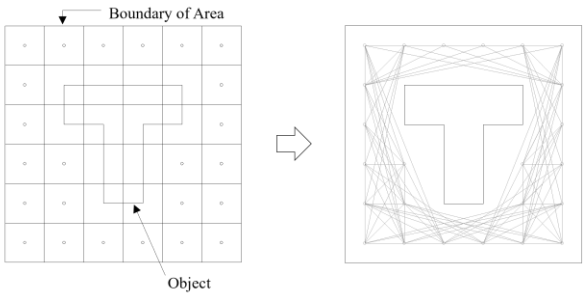

Fig.8 Basic Concept of VGA[*1] (Left: Division by Grid Right: Generation of Lines)

Table 2 Summaries of VGA measures used in this study

1) Visual Entropy
Visual Entropy in VGA is the application of Shannon's entropy of information to the distribution of depths to any other cell. Visual Entropy for a cell increases if the whole space is to be traversed[17].
2) Visual Integration (Global)
Visual Integration represents the visibility of the space. The calculation process for Visual Integration is the same as that of Global Integration Value used in Axial Analysis. Visual Integration correlates with pedestrian flow[18].
3) Through Vision
For each cell in the grid, it is the number of times it is crossed by lines drawn between the centroids of all other inter-visible cells. Through Vision can be used to pinpoint locations most likely to be traveled, given that they are "in the way" to get from one position to another. It correlates with potential to move[17].
4) Isovist Drift Magnitude (IDM)
Isovist Drift Magnitude is the magnitude of a vector from the generating point to the center of gravity of the polygon. Isovist drift magnitude measures the potential of space to explore[17]. If the value is high, it might imply a strong 'draw', pulling a person through a space[19].
5)6) Metric Shortest Path Length (MSP) from entrances / from stores
MSP represents the Euclidean distance from a specific centroid to another centroid[12].

Fig.9 Pedestrian Locations and VGA (Through Vision) Results in the case of Kyobashi Edogrand

5. FACTORS AFFECTING OCCURENCES OF STAYING BEHAVIORS

Using location recording data of pedestrians stopping with/without purpose and results of Visibility Graph Analysis, logistic regression analyses are conducted to quantitatively specify factors affecting the occurrences of staying behaviors.

(1) Logistic Regression Analysis Methods

Details of conducted logistic regression analyses are summarized in **Table 3**. Three dummy variables were decided to be used in the analyses since they are presumed to have a large influence on pedestrians' staying locations based on observations in target spaces. Explaining variables used for the analyses were carefully selected considering the existence of multicollinearity.

As staying behaviors are classified into stop with/without purpose in this study, factors affecting them are investigated separately. Thus, two regression models are derived for each target space.

(2) Logistic Regression Analysis Results

The results of all 12 analyses (6 analyses for stop with purpose, and 6 analyses for stop without purpose) are summarized in **Table 4**. In **Table 4**, the partial regression coefficient of statistically significant variables ($p<0.05$) and marginally significant variables ($p<0.1$) are listed. Note that the results of the omnibus test for all models were statistically significant.

a) Difference between the Models of Stop with Purpose and without Purpose

As the differences between the statistically significant variables in models for stop with purpose and models for stop without purpose, the following two tendencies are demonstrated in **Table 4**.

First, the number of statistically significant variables in a model of stop without purpose tends to be equal or greater than that of stop with purpose in any target space. This implies that controlling and predicting the occurrences of stop without purpose is more difficult than that of stop with purpose since relatively more factors are expected to have a significant influence on the occurrences of staying behaviors.

Second, Bench_Chair is considered to be the explaining variable having the definitive impact on the occurrence of stop with purpose in underground public spaces as the variable is statistically significant in all regression models for stop with purpose. At the same time, Floor_Guide_Map is also presumed to have a significant influence on the occurrence of stop without purpose as the variable is

Table 3 Details of logistic regression analyses

Purpose of the Analysis
To reveal significant factors affecting the location selection of pedestrian in the reseacrh target spaces
Applied Multivariavle Analysis Method
Logistic Regression Analysis (bootstrapped)
Used Software
SPSS
Method of Setting Explaining Variavles in Models
Forced entry method
Explanining Variavbles
Visual Entropy, Visual Integration, Through Vision, Isovist Drift Magnitude, MSP from Entrances, MSP from Stores, Dummy Variables (Advertisement_Exhibit, Bench_Chair, Floor_Guide_Map)
Purpose Variable
Occurrence of stop with purpose in 1 hour / Occurrence of stop without purpose in 1 hour
Samples used in the analysis
Target spaces are devided into cells (2m*2m or 2.5m*2.5m, depending on the target spaces' area). Based on the recording of pedestrians locations and VGA results, each cell has following data: values of six VGA indexes, existence of dummy variables in a cell, existence of pedestrians stopping with purpose in a cell, and existence of pedestrians stopping without purpose in a cell.

Table 4 Summaries of logistic regression analyses results

		Kyobashi Edogrand		Tokyo Square Garden		Tokyo Midtown Hibiya with exhibits #1		Tokyo Midtown Hibiya with tables #2		Nihonbashi Takashimaya Mitsui building		Roppogi Hills Metro Hat	
		w/ p	wo/p	w/ p	wo/p	w/ p	wo/p	w/ p	wo/p	w/ p	wo/p	w/ p	wo/p
Model	Hosmer and Lemeshow Test	0.817	0.469	0.389	0.615	0.194	0.695	0.514	0.665	0.097	0.141	0.938	0.699
	% of Correct Classifications	92.3	88.2	95.2	89.7	87.3	87.3	89.8	89.1	87.0	82.1	92.8	88.5
	Constant	-3.864	3.719	-16.97	-23.22	-2.807	3.550	-5.669	-14.55	0.163	-1.503	-13.13	-1.602
VGA Indexes	VE				15.79								
	VI				0.292			0.148	0.239				
	TV_adjusted							-0.029		-0.085			
	IDM											0.229	
	MSP_E		-0.073			0.101	0.078		-0.053		-0.281		
	MSP_S		-0.135						-0.133	-0.133	-0.178		
Dummy Variables	Advertisement_Exhibit		3.414	-18.05	4.621		4.128					3.444	
	Bench_Chair	3.725		8.736		23.27	-19.14	3.701	-18.07	23.61	-18.89	8.077	-18.09
	Floor_Guide_Map	3.962	23.07	4.637	1.934	2.212	3.189		23.12	1.879		2.654	3.554

Note: TV_adjusted = 1/10,000 of calculated Through Vision value

Note: Only significant variables ($p<0.05$) are colored

statistically or marginally significant in most of the regression models for stop without purpose.

b) Difference between Target Spaces

For the influence of dummy variables, significant differences could not be observed between target spaces. While for the influence of VGA indexes, regression models of target spaces could be divided into the models of Tokyo Square Garden and Roppongi Hills Metro Hat, and the models of the other four target spaces depending on the significance of MSP_E and MSP_S. This implies the tendency that MSP_E and MSP_S tend to be significant for the occurrence of staying behavior when the shape of the target space is close to a vertically or horizontally long rectangle.

The difference of significant VGA indexes between Tokyo Midtown Hibiya with exhibits #1 and Tokyo Midtown Hibiya with tables #2 suggests that the statistical significance of VGA indexes on the occurrence of staying behavior in underground public spaces changes depending on the abundance of furniture in space since the target space of #1 and #2 are only different in the existence of furniture.

c) Comparison with Preceding Studies

In preceding studies using VGA[12)13)14)15)], Connectivity (CNT) is used in multivariable analysis together with Visual Integration. However, in this study, CNT was excluded from VGA indexes applied in the logistic regression model because there was a strong correlation (VIF>10) between CNT and VI, and that correlation caused the multicollinearity in all target spaces. The main differences between preceding studies and this study are the complexity of the target space and the size of the space. This implies the existence of a strong correlation between the values of Connectivity and Visual Integration when the shape of the target space is simple and the area of Visibility Graph Analysis is not so large.

The fact that Visual Integration and MSP_E were derived as significant factors affecting the occurrence of staying behaviors in underground public spaces agrees with the preceding studies[12)13)14)15)] conducted on stations, commercial buildings, and shopping complexes. In addition, the fact that the existence of Advertisement_Exhibit, Bench_Chair, and Floor_Guide_Map are significant factors affecting the occurrence of staying behaviors also agrees with the study of Shimada[8)]. The main difference from preceding studies is that the existence of dummy variables is the primary factor affecting the occurrence of staying behaviors and VGA indexes are secondary factors in public spaces located on the underground floor of buildings.

d) Comparison of 12 Regression Models

The grand VGA index which has a statistically strong influence on the occurrences of stop with or without purpose in any underground public space located on the underground floor of a building was not found in this study. Each VGA index is derived as a statistically or marginally significant explaining variable among at least one of six target spaces, but statistically significant VGA indexes are limited to the following four indexes: Visual Integration, Through Vision, MSP from entrances, and MSP from stores. In addition, the existence of dummy variables is statistically significant in any underground public space while the statistical significance of VGA indexes is dependent on target spaces.

6. FEASIBILITY OF STAYING BEHAVIOR OCCURRENCE PREDICTION

To consider the validity of predicting the occurrences of staying behaviors in any underground public space by the logistic regression model which was created based on the other underground spaces' data of pedestrian locations and results of VGA, logistic regression models are created and evaluated.

(1) Creation of Logistic Regression Model

In this paper, prediction logistic regression models for the occurrences of stop with purpose and the occurrences of stop without purpose are created based on the mixed data of Tokyo Midtown Hibiya (#1 and #2), in a total of 516 cells. Detailed conditions for creating the prediction logistic models are almost same as conditions used when creating 12 regression models, and summarized in **Table 3**. The only difference is the fact that Through Vision values are weighted.

Since the results of VGA and shapes of Tokyo Midtown Hibiya (#1 and #2) and Kyobashi Edogrand were relatively similar to each other among six target spaces, created models are applied to Kyobashi Edogrand (220 cells), that is, values of VGA indexes and the existence of dummy variables in Kyobashi Edogrand are substituted in the models, and prediction results are compared with actual pedestrian location recording data.

Eq.1 represents the prediction model, and **Table 5** shows the partial regression coefficients of created prediction models.

(2) Evaluation of Prediction Model

The goodness of fit of prediction models will be evaluated by confusion matrix and AUC.

a) Confusion Matrix

Prediction results are summarized in the confusion matrix. From the confusion matrix, the following information about the prediction model has been obtained: Accuracy (the ratio of correctly predicted cases to all cases), Precision (the ratio of actual

occurrence cases to all cases predicted as occurrence), Sensitivity (the ratio of correctly predicted as occurrence to all actual occurrence cases), and Specificity (the ratio of correctly predicted as non-occurrence to all actual non-occurrence cases).

Table 6 and **7** are confusion matrices for the model of stop with purpose and stop without purpose. And **Table 8** summarizes the accuracy, precision, sensitivity, and specificity of both models. "Cut off 50%" means that a cell is judged as "occurrence" when the probability of the occurrence calculated by the prediction model is equal to or greater than 50%.

From **Table 8**, it is presumed that prediction models are good at predicting the non-occurrence of pedestrians' stop with/without purpose while models are poor at predicting the occurrence of stop with/without purpose, although the accuracy of both models is high.

b) AUC (Area Under the Curve)

AUC is the area under the ROC curve, which is drawn by the prediction model taking sensitivity as the y-axis and 1-specificity as the x-axis. AUC is used to evaluate the effectiveness of prediction models. AUC ranges from 0 to 1. When AUC=1, the accuracy of the prediction model is perfect, while the random prediction model is considered to take 0.5 as AUC. Generally, the model is considered to be low accurate when AUC=0.5~0.7, moderately accurate when AUC=0.7~0.9, and highly accurate when AUC=0.9~1.0.

Fig.10 illustrates the ROC curves for the model of stop with purpose and the model for stop without purpose. From the ROC curve, AUC of the model predicting the occurrence of stop with purpose was calculated as 0.72, and that of stop without purpose was calculated as 0.66. Therefore, both prediction models are effective if not highly accurate, more accurate than the random prediction model at least.

7. CONCLUSION AND DISCUSSION

(1) Conclusion

1) Factor analysis of pedestrians' staying behaviors

Investigations on the causal association between pedestrians' staying behavior, spatial configurations, and spatial designs clarified the fact that both pedestrians stopping with purpose and without purpose are influenced by the existence of furniture like signboards, floor guides, exhibits, and spatial configurations represented by VGA indexes, but the existence of furniture is a more common influential factor than VGA indexes in underground public spaces. Besides, results showed the tendency that the occurrence of stop without purpose is affected by more factors than the occurrence of stop with purpose. Bench_Chair and Floor_Guide_Map have a significant impact on the occurrence of stop with purpose and the occurrence of stop without purpose in almost all target spaces, but other factors affecting the occurrences of staying behaviors were different in each space.

$$P = \frac{1}{1+exp\{-(Constant+VE\times x_1+VI\times x_2+\cdots+Floor\_Guide\_Map\times x_9)\}} \quad \textbf{(Eq.1)}$$

Table 5 Partial regression coefficients for the models

	stop with purpose	stop without purpose
VE	-0.044	-3.987
VI	-0.021	0.036
TV_weighted	-0.014	0.005
IDM	0.036	0.004
MSP_E	0.078	0.016
MSP_S	0.018	-0.095
Advertisement_Exhibit	-0.728	4.61
Bench_Chair	3.883	-19.272
Floor_Guide_Map	1.26	3.617
Constant	-2.856	1.159

Table 6 Confusion matrix for the model of stop with purpose

stop with purpose (cut off 50%)		Prediction Model	
		occurrence	non-occurrence
Actual Observation	occurrence	6	13
	non-occurrence	4	197

Table 7 Confusion matrix for the model of stop without purpose

stop without purpose (cut off 50%)		Prediction Model	
		occurrence	non-occurrence
Actual Observation	occurrence	14	23
	non-occurrence	5	178

Table 8 Information from confusion matrix

	Accuracy	Precision	Sensitivity	Specificity
stop with purpose	92.30%	60.00%	31.60%	98.00%
stop without purpose	87.30%	73.70%	37.80%	97.30%

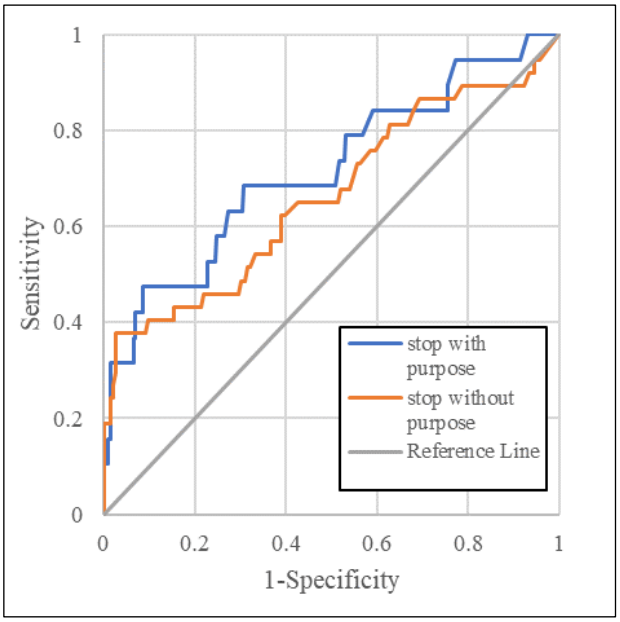

Fig.10 ROC curve of prediction model

2) Feasibility of prediction models

The evaluations demonstrated the existence of an example in which a logistic regression model that was created based on the other underground spaces' data of pedestrian locations and results of VGA can be used for predictions of the occurrence of staying behavior in a certain space. However, the general availability of prediction models remains unclear.

(2) Discussion

This study quantitatively investigated the factors affecting the occurrence of staying behaviors in public spaces located on the underground floor of buildings and considered the effectiveness of prediction models. The findings of this study are expected to be used as factual and supplementary information when designers or real estate developers, who tend to rely on beliefs and experiences[20], consider the floor plan and layout of the underground space, and create a space that is ideal for them.

Visibility Graph Analysis is often used for the factor analysis of pedestrian flow, density, and the occurrence of staying behaviors as indexes of VGA are considered to be related to the pedestrian flow and the occurrence of staying behavior. However, the significance of VGA indexes on the occurrence of staying behavior changes depending on the spatial conditions such as the shape of the target space, distribution of stores, and locations of entrances, and the VGA indexes could be just one of many factors affecting the occurrence of staying behaviors in underground public spaces. Therefore, it is necessary to carefully consider the characteristics of a target space and results obtained from VGA when using the findings of this study.

NOTES

*1. This figure was created referring to the figure in the paper of Ueno[12].

REFERENCES

1) Okumura, T: 最新の地下施設と将来展望, 建設の施工企画, No.734, pp.16-23, 2011.
2) Yanase, N. et al: The annual report on the planning subcommittee, committee on underground space research: Recent trend on urban renovation projects and underground pedestrian network, Proceedings of the Symposium on Underground Space, pp.23-30, 2014.
3) Yajima, K. et al: 再開発事業における開放的な地下鉄接続通路の設計手法, 土木建設技術発表会 概要集, pp.60-65, 2012.
4) Murakami, K. et al: Study on the feature of buildings with entrances of underground stations and introduction of entrance facilities of buildings by applying urban development systems, Journal of the City Planning Institute of Japan, Vol.53 No.3, pp.1369-1376, 2022.
5) Matsuo, K. et al: 地下公共空間における歩行者行動による駅施設の特性把握, Proceedings of The City Planning Institute of Japan, Kansai Branch, Vol.12, pp.117-120, 2014.
6) 札幌市: 都心の地下歩行ネットワーク拡充手法に関する基本方針(案), 2020.
7) Matsumoto, N. et al: Relationship between foot passengers' actions of stop without purpose and stop with purpose in an underground shopping arcade, J. Archit. Plann., AIJ, Vol.76, No.660, pp.321-326, 2011.
8) Shimada, K. et al: 公開空地における滞留行動と空間構成要素, 景観・デザイン研究講演集, No.5, pp.206-209, 2009.
9) Sakai, T. et al: A Basic Study an openspace structure and Sitting Stationary People -Part1-, Summaries of technical papers of Annual Meeting Architectural Institute of Japan. F-1, Urban planning, building economics and housing problems, Vol.2006, pp.145-146, 2006.
10) Sakai, T. et al: A Basic Study an openspace structure and Sitting Stationary People -Part2-, Summaries of technical papers of Annual Meeting Architectural Institute of Japan. F-1, Urban planning, building economics and housing problems, Vol.2006, pp.147-148, 2006.
11) Kamino Keijin: 人間都市論, 学芸出版社, pp.28-33, 1990.
12) Ueno, J. et al: An analysis of pedestrian movement in multilevel complex by Space Syntax theory In the case of Shibuya station, Proceedings of the 7th International Space Syntax Symposium, Ref 118, 2009.
13) Fujitani, M. et al: A study about the pedestrian distribution in the commercial buildings by the location of stores and the structure of the walking space, Proceedings of the 8th International Space Syntax Symposium, Ref 8094, 2012.
14) Saruyama, N. et al: Distribution of shoppers in multi-layered shopping complex: Estimation of shopper density considering escalators, elevators, stairs, Proceedings of the 10th International Space Syntax Symposium, Ref 35, 2015.
15) Okamoto, K. et al: Correlation analyses between underground spatial configuration and pedestrian flows by space syntax measures: a case study of underground mall complex in Nagoya Station, Urban Form at the Edge: Proceedings of ISUF, Volume 1, pp.116-128, 2013.
16) Takamatsu, S.: How can we simulate spatial configuration in public spaces?, Journal of the Japanese Institute of Landscape Architecture, Vol.74 No.3, pp.206-209, 2010.
17) Koustsolampros, P. et al: Dissecting visibility graph analysis: The metrics and their role in understanding workplace human behavior, Proceedings of the 12th Space Syntax Symposium, Ref191, 2019.
18) 黛崇仁: 図書館の空間分析に基づく館内サインの改善, 医学図書館, 63巻2号, pp.157-162, 2016.
19) Yu, R. et al: The mathematics of spatial transparency and mystery: using syntactical data to visualize and analyze the properties of the Yuyuan Garden, Visualization in Engineering, Vol.4 No.4, 2016.
20) Robert, B. et al: Evidence-based landscape architecture: The maturing of a profession, Landscape and Urban Planning, Vol.100, pp.327-329, 2011.