sustainability

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Optimization Path of Metro Commercial Passageway Based on Computational Analysis

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Abstract: In this study, three key factors affecting the planning of metro commercial passageways are selected: the built environment of metro station, travel purposes of passenger flow and gate position of the station hall. The Pearson model, Logistic model and software simulation are combined to analyze passage passenger flow. In the study of metro passageways, most studies focus on the optimization of evacuation and transfer functions, with little research on metro commercial passageways. The purpose of this study is to improve the attractiveness of metro commercial passageways to passenger flow by improving the three key factors mentioned above, thereby improving the current situation of underground commerce. The analysis results show that in the built environment analysis, the four selected construction factors are highly correlated with the passenger flow, and the correlation degree is in the following order (from high to low): length of the passage, operation of the escalators, the distance from the passage exit to the bus stop and the passage width. In the passenger flow travel purpose analysis, based on the structure of passengers and the function of the surrounding land use, it can be divided into shopping, work and living purposes, and the result of model parameter comparison shows that "shopping trips" is the most significant purpose. According to the analysis of the location of the exit gates at the station concourse level, the passageway with a closer distance or linear pattern to the gate location is more attractive to the passenger flow.

Keywords: passenger flow; transportation planning; travel behavior model; metro commercial passageway; optimization path

Citation: Dai, P.; Han, S.; Fu, G.; Fu, H.; Wang, Y. Optimization Path of Metro Commercial Passageway Based on Computational Analysis. *Sustainability* **2023**, *15*, 11140. https://doi.org/10.3390/su151411140

Academic Editors: Zhiqing Zhao, Qinglian Wang and Bocheng Zhang

Received: 1 June 2023
Revised: 7 July 2023
Accepted: 14 July 2023
Published: 17 July 2023

1. Introduction

The three-dimensional commerce directly connected by subway channels has strong attraction and commercial operations with a wide variety, a wide range and a large scale. It can attract a large number of pedestrians whether they take the subway or not. At present, three-dimensional commerce is the mainstream mode of subway commercial development. In addition, subway commercial centers do not exist in the form of independent individuals but form a whole area connected with surrounding commercial centers through various corridors and underground passages, facilitating customers and tourists between various commercial centers. Tourists often can walk in the mall all day long, unaffected by various external conditions, which not only facilitates shopping for customers and tourists but also brings customers to various commercial centers continually.

The metro is the preferred element for the development and use of underground spaces in the city, and the metro station area of influence forms a number of individually developed and used underground spaces that need to be connected, most of which are commercial complexes with more than one passageway. To improve the attractiveness of the passageway between the metro and the underground commercial area, three key influencing factors, which are the metro station building environment, passenger flow purposes and exit gate position of station hall, were identified as the bases for the selection of the metro commercial passageway.

Since 2016, Qingdao Metro Line 2 and Line 3 have been put into operation successively. Compared with other cities, although the opening time of Qingdao Metro is relatively late and the number of metros is small, Qingdao Metro has still had a huge impact on the businesses and the change of business pattern in Qingdao. In December 2019, the west section of Qingdao Metro Line 2 was put into operation, which ended the period of no subways in Taidong trade area. In terms of trade area, Qingdao Metro Line 2 passes through three regions with rapid economic development in Qingdao, namely Shinan District, Licang District and Shibei District. Among them, Shinan district and Licang district are linked with the Licun trade area and Xianggang Middle Road trade area; Shibei district connects with the Taidong trade area; and the line passes through 17 commercial projects. At present, compared with other metro lines, Qingdao Metro Line 2 has the most commercial projects along the way.

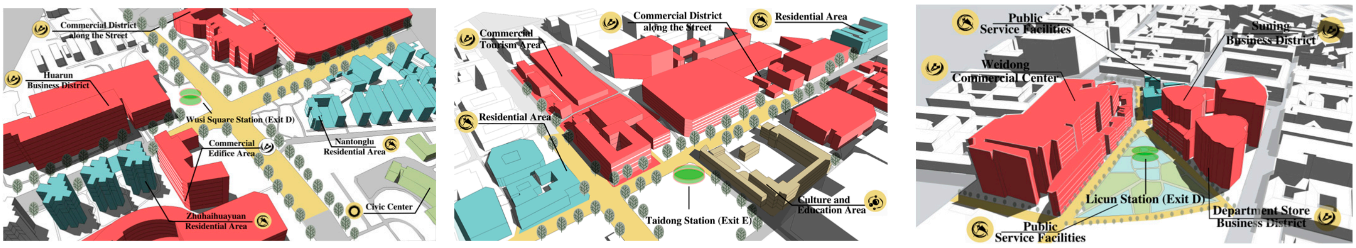
In order to explore the commerce along Qingdao Metro Line 2 more intuitively, we will analyze 14 commercial projects connected by the currently operating metro stations, which are shown in Table 1.

Table 1. Summary of commercial projects of Qingdao Metro Line 2.

Metro Station	Commercial Project	Whether to Use Metro Commercial Passageway for Connection
Licun	WeiKe Xing Cheng, Likelai Shopping Mall, Qingdao Harmony Plaza, Laoshan Department Store	Yes
Tonganlu	Thumb Plaza	No
Shilaorenyuchang	Liqun Plaza	Yes
Yanerdaolu	AEON MALL, Maikaile Shopping Plaza	No
Wusi square	Wanxiangcheng Shopping Center	Yes
Fushansuo	Yinzuo Business Center, Haixin Plaza	No
Miaolinglu	Lida Shopping Center	No
Taidong	Taitung Wanda Plaza, Taitung Liqun Commercial Center	Yes

It can be seen from Table 1 that the metro stations with underground commercial channels are Wusi Square station, Shilaoren Beach station, Taidong station and Licun station. In order to narrow the research scope, we start with the daily average passenger flow data of Qingdao Metro station. The top five subway stations with daily average passenger flow are Qingdaobei station (162,600 person times), Taidong station (155,700 person times), Qingdao station (137,800 person times), Wusi Square station (122,400 person times) and Licun station (86,100 person times), of which Qingdao station and Qingdaobei station belong to traffic center metro stations.

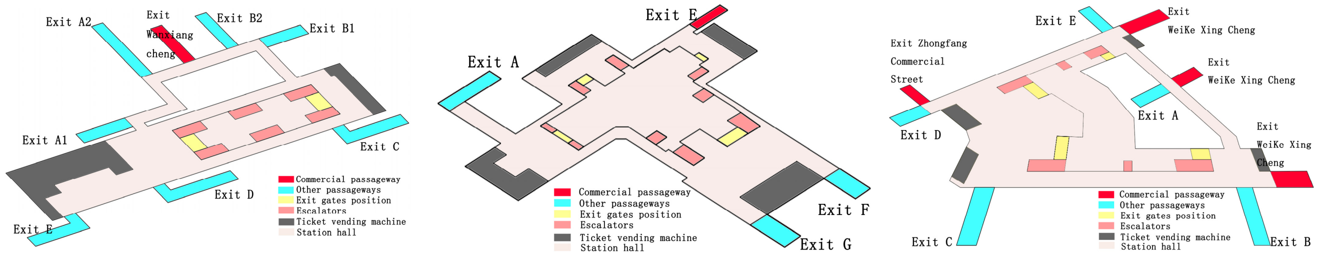
Combining the results in Table 1 with the average daily passenger flow of the subway, it can be found that Wusi Square station, Taidong station and Licun station not only have high passenger flow but also have many commercial projects around the subway station. On this basis, we use 3D diagrams to represent the location of the station in the surrounding urban environment and the types of commercial projects around it, which is shown in Figure 1.



(**a**) (**b**) (**c**)

Figure 1. 3D diagrams of metro station and surrounding environment: (**a**) Wusi Square Station; (**b**) Taidong Station; (**c**) Licun Station.

Therefore, the research objects of this study are Wusi Square station, Taidong station and Licun station. Meanwhile, we take the current situation of underground commerce as an entry point. Several technical methods, including field research, logic and axial methods, are applied to select the key elements for improving passenger flow of the metro commercial passageway, and this is used to determine the basis for enhancing the value of the commercial metro passageway. The hall floor plans of Wusi Square station, Taidong station and Licun station of Qingdao Metro are shown in Figure 2.



(**a**) (**b**) (**c**)

Figure 2. Layout of Qingdao Metro: (**a**) Wusi Square Station; (**b**) Taidong Station; (**c**) Licun Station.

2. Literature Review

On the relationship between metro and urban development, Ye believes that the expansion of underground urbanism opens up an added and concerning dimension to the privatization and class separation that has threatened the character of urban public life in recent decades [1]. Lin indicates that the use of urban underground space (UUS) has contributed to new town developments in many cities in the world. This offers an opportunity to map out and systematically describe the potential contributions of UUS for transport, land use, economic, environmental and social development in new towns for planners, designers and policy-makers to consider [2]. By conducting research on underground commerce in the city center, Seo maintains that the guarantee that security in underground commercial space plays a vital important role in the urban sustainable development and the research into safe escape from underground commercial spaces is of great theoretical significance and practical value [3]. Yuan uses the comprehensive compactness formula to extract influencing factors and to explore the interaction mechanism between underground space utilization and urban compact development [4]. Ahn studied the relationship between the actual transaction prices of condominiums in four metropolitan areas of South Korea and the accessibility of subway networks by examining the economic impact of subway networks in these areas [5]. Gallo's results show that the impacts on real estate values of the metro system in Naples are significant, with corresponding external benefits estimated at about 7.2 billion euros or about 8.5% of the total value of real estate assets [6].

On the relationship between underground urban planning and transport networks, Behrends explores the relevance of local policies for sustainable modal shift strategies by conceptualizing the links between urban planning and rail freight. The results indicate that urban transport has a significant role to play in underground urban planning [7]. Yang investigated the spatial characteristics of an urban bus service system by using the complex network approach. The empirical findings can provide insights into the statistical laws and distinct convenient areas in a bus service network and consequently aid in optimizing the allocation of bus stops and routes [8]. Kujala has published a curated collection of 25 cities' public transport networks in multiple easy-to-use formats. This collection promotes the study of how PT is organized across the globe and also provides a testbed for developing tools for PT network analysis and PT routing algorithms [9].

In the development of the underground metro, Majumdar conducted a survey on metro infrastructure, facility and service quality investigation based on commuter perception to explore and prioritize the key attributes influencing overall metro service quality in a typical Indian context [10]. Melo found the metro patronage is relatively more responsive to changes in the fare than to changes in service level, with long-run elasticity values ranging between -0.45 and -0.84 for metro travel card and between 0.45 and 0.50 for service level [11]. Wu provided a valuable reference for further comfort research and environmental control in metro station, and his conclusions may guide the further underground space design of metro transfer stations [12]. Wu proposed that the exit width, seat layout, visibility, speed and reaction capabilities were crucial to the evacuation process [13].

In a research on passenger satisfaction questionnaire survey in metro stations, Reveau presented a route choice model for metro networks that considers different time components as well as variables related to the transferring experience, train crowding, network topology and socio-demographic characteristics [14]. Rocio investigates the relationship between perceived service quality, customer satisfaction and behavioral intentions for the metro of Seville [15]. Juan seeks to summarize the evolution of research and current thinking, analyzing customer satisfaction with the quality of public transportation services. Han selected six subway stations in Seoul for physical environmental measurements and conducted a survey of 5282 passengers. The questionnaire addressed thermal, air, light, acoustic and overall comfort [16]. Sui designed a survey questionnaire to investigate the panic related psychology and behaviors of evacuation crowds in subway emergencies [17].

Property rights determine the development of the of under- (and over-) ground space as well as metro station design and overall need for expropriation. In the development of metro property rights, Zheng found that a new subway station positively contributes to the quantity, diversity and consumer demand of nearby food and beverage services [18]. Currently, the subsurface is often utilized according to the "first-come-first-served" principle, which hinders optimization of competing subsurface use. Volchko studied underground as a multifunctional resource from five key points from a broad international perspective [19]. Pagliara proposed an ex-ante analysis by measuring retailers' views on the completion ceremony of the new subway station. The main findings show that the increase of accessibility brought by new interventions in the transit system increases the attractiveness of the area for retailers and shops location choice [20].

The property rights of underground subway cover a wide range of underground uses, transportation and infrastructures networks; water and energy storage facilities; municipal spaces, housing, business and manufacturing facilities; and overall exploitation of Urban Underground Space (UUS). Among them, Perperidou introduced the idea that with the need for the exploitation of UUS rising, detailed documentation of 3D underground property rights in transportation networks is crucial [21]. The method proposed by Zhang can effectively solve the dispute of property rights against problems rising with unclear contract and lags in the legislation of urban underground space [22]. Hamor-Vido has established a harmonized public authority scheme of permitting and sustainable resource management, supported by the development of 3D (and 4D) information, and indicated that underground metro space utilization can also be assessed in the criticality context [23]. Jillella proposed a four step participatory strategic value capture (PSVC) framework. The PSVC framework, applied to the sub-urban rail project in India, has demonstrated the importance of stakeholder engagement using deliberated participatory approaches from a win–win perspective [24].

Currently, research on subway passageways is mainly aimed at meeting the transfer needs of passenger flow, but there is still insufficient research on commercial functions. Zhou assessed the congestion level of pedestrians in metro stations. Twelve hours of video data were collected in the channel, stairway and platform in a metro station in the city of Ningbo, China. As a proposition for the management of pedestrians in metro stations [25]. Peng emphasized the relationship between the layout of commercial centers and the layout of metro station centers, emphasized the smooth transfer of personnel between transportation modes and also emphasized the importance of metro commercial passageways [26]. In an underground subway station, passageways play an important role in the capacity design of service facilities. Chen collected an inter-arrival time of passengers at existing service facilities in three underground subway stations of a metropolitan city, Chengdu, China. Results showed that the width of the passageway plays an important determining role in passenger flow [27].

In a recent literature research on the Pearson model, logistic model and space syntax, Dong studied the influencing factors of the “cause nodes”, and then a pre-selection “cause nodes” procedure which utilizes the Pearson correlation coefficient to evaluate the relevancy of the traffic data was introduced [28]. Djordjevic aims to have the indicators be grouped according to sustainability themes and pillars, while the new approach to assess their impact is based on a two-stage process—correlation analysis and a DEA model [29]. Sarkar calibrated the binary logic models using crash data from 1998 to 2006 maintained by the Accident Research Institute of Bangladesh to identify the factors associated with the probability of a fatal outcome [30]. Space syntax is a theory developed to reveal the hidden interrelationships between spaces using architectural diagrams. Frank uses fuzzy theory and uses field observations, engineering personnel interviews and questionnaires designed to utilize “fuzzy syntax” [31]. The limitations of previous studies and the improvements made in this study are shown in Table 2.

Table 2. Comparison of research gaps.

Limitations of Previous Studies	Improvements of This Study
Scholars’ research on metro station passageways mostly focuses on passenger evacuation, passenger transfer and other aspects, with little research exploring the relationship between passenger flow and surrounding underground commerce. Based on previous research, it can be found that there are some areas for improvement in the analysis of metro station passageways, such as that the selection of influencing factors is too few, the technical methods are too single and the scope of research objects is too small.	Due to the fact that the attractiveness of the connecting passage between the metro and surrounding underground commerce for passenger flow has not met the expected requirements, we will focus our research on the metro commercial passageway. In this study, we selected three key influencing factors and adopted various technical methods such as Pearson model, logistic model and software simulation to study the three most commercial metro stations in Qingdao.

3. Methods

Combining with the results of questionnaire, this study adopts two methods: the Pearson model and logistic model. A series of questions was designed to obtain the purpose of passenger flow, travel time and subway construction factors that affect passenger flow travel. This is to understand the demand for passenger flow and channel construction at three subway stations. Finally, the basic data support is summarized from the survey data through software such as Excel and SPSS.

In existing research conclusions, quantitative analysis mainly focuses on the application of logistic and Pearson models in research and questionnaire survey results, without further analysis of the hierarchical relationships and functional logic of different influencing factors. This may lead to insufficient in-depth research results, resulting in insufficient refinement and specificity of specific public policies and administrative measures. On the premise of using logistic and Pearson models for preliminary empirical analysis, this paper further uses space syntax to explain the structure model, stratifying the levels of the influencing factors, and explores the interaction between the influencing factors. The specific technical flowchart is shown in Figure 3.

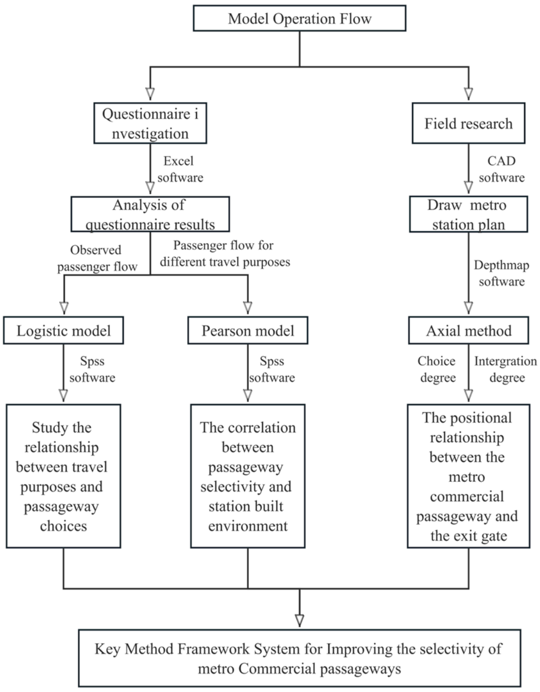


Figure 3. Technical flowchart.

3.1. Questionnaire Survey Method

The questionnaire survey method is a method of conducting a survey on the opinions of the target audience, with the aim of obtaining first-hand data for statistical and survey purposes. The main implementation process is to present a table of questions in the form of questions, making controlling measurement methods more scientific and efficient. The reasons for adopting a questionnaire survey in this study are as follows:

1. Questionnaire surveys are widely used because their biggest advantage is their easy operation and cost savings. When investigating the purpose of passenger flow in metro stations, verbal questioning is not only inefficient but also causes certain difficulties for pedestrian traffic. Instead, paper questionnaires can be filled out after on-site distribution, or QR codes for electronic questionnaires can be provided. This can not only survey many people in a short period of time but also process the data of the questionnaire survey results through computers, saving analysis costs and time.
2. As respondents generally complete the questionnaire survey anonymously, they can freely express their views.
3. The questionnaire survey has consistency. The questionnaire survey uses the same questionnaire for all respondents, which is beneficial for comparative analysis of respondents in the same situation. During our research and investigation, it is necessary to obtain the travel purposes of passenger flow in different channels of metro stations, so the questionnaire survey method should be the preferred one.

Due to the high passenger flow of metro stations, distributing paper questionnaires in the passageways can cause congestion in passenger flow. Therefore, this study adopted two survey methods, namely paper questionnaires and electronic questionnaires, by inviting pedestrians to fill out a paper questionnaire without affecting pedestrian traffic and, in the case of poor traffic, providing electronic questionnaires for pedestrians and providing small gifts to pedestrians who fill out the questionnaires.

The questions in both types of questionnaires are the same, and the questionnaire consists of 10 multiple-choice questions. Among them, 5 questions ask about the passageway chosen by the passenger flow and the purpose of this trip, and the other 5 questions ask about the satisfaction of the passenger flow with the infrastructure of the metro station and provide the reasons for dissatisfaction. A screening method is adopted to process the questionnaire results.

3.2. Logistic Model and Route Selection Models

Logistic regression is a probabilistic nonlinear model that can be classified as binary or multivariate according to the type of dependent variable. A binary logistic model was chosen when the dependent variable had only two fetched outcomes. A multivariate logistic model was chosen when the dependent variable was an extension of the binary variable and had multiple fetched outcomes. When conducting logistic regression analysis in SPSS 24.0 software, there are usually three steps involved, namely data processing, chi-squared test and impact relationship research.

The first step is data processing. When studying the impact of travel purpose on whether passengers choose metro commercial channels, travel purpose is the influencing factor, and it is obvious that this factor belongs to categorical data, so dummy variables need to be set.

The second step is chi-squared test or ANOVA. Through this step, we can tentatively understand the impact relationship between each influencing factor X and Y. Before studying the impact relationship, we need to perform a differential analysis on X and screen out X that is different from Y. If X is categorical data, then we use the chi-squared test to analyze the differences. If X is quantitative data, then ANOVA can be used to study the differences between X and Y.

The third step is logistic model analysis. After determining the influencing factors in the previous step, this step directly performs logistic regression analysis. When conducting logistic regression analysis, the first step is to determine whether a factor exhibits significance (if the p-value is less than 0.05, it indicates significance at the 0.05 level; if the p-value is less than 0.01, it indicates significance at the 0.01 level). If significance is present, it indicates that the factor has an impact on Y, and whether it has a positive or negative impact needs to be explained in conjunction with the corresponding regression coefficient value. If the regression coefficient value is greater than 0, then it indicates a positive impact. On the contrary, if the regression value is not greater than 0, it indicates a negative impact. In addition, logistic regression analysis also involves Exp(B), which is equal to the exponential power of the regression coefficients.

In addition, a discrete choice model must be constructed to assume pedestrian path selection in terms of path utility maximization theory. The path utility function is [32]:

$$U_{ni} = V_{ni} + \varepsilon_{ni} \tag{1}$$

where U_{ni} is the usefulness, n is the passenger flow out of the station, i is the choice of the travel mode and V_{ni} and ε_{ni} are the effect of observable and unobservable factors on utility, respectively.

Regarding the distribution of passenger flow in the survey results, the use of logistic regression models and route selection models can effectively study the relationship between passengers' travel purposes and channel choices.

3.3. Pearson Correlation Coefficient Model

Correlation is the most commonly used statistical measure, which uses a number to describe the degree of correlation between two variables. The correlation coefficient ranges from -1 to 1, with a negative value indicating that as the value of one variable increases, the other decreases. A positive value indicates that as one variable's value increases, the other also increases. A value of 0 indicates that the increase or decrease of one variable has no effect on the value of the other. In correlation analysis, the most commonly used is the Pearson correlation, named after Karl Pearson, and this correlation coefficient is also called "Pearson Product-Moment Correlation". The Pearson correlation coefficient is usually represented by the letter "r", which measures the linear relationship between two random variables.

The Pearson correlation coefficient of the population between two variables is defined as the quotient of the product of covariance and standard deviation between the two variables, usually expressed as follows:

$$\rho_{\mathrm{xy}} = \frac{\mathrm{cov}(X, Y)}{\sigma_{\mathrm{x}}\sigma_{\mathrm{y}}} = \frac{E[(X - \mu_X)(Y - \mu_Y)]}{\sqrt{\sigma_X^2 \sigma_Y^2}} \tag{2}$$

By estimating the covariance and standard deviation of the sample, the Pearson correlation coefficient can be obtained, represented by the letter "r", and expressed as follows:

$$\mathrm{r} = \frac{\sum_{i=1}^{n}(x_i - \overline{X})(y_i - \overline{Y})}{\sqrt{\sum_{i=1}^{n}(x_i - \overline{X})^2}\sqrt{\sum_{i=1}^{n}(x_i - \overline{Y})^2}} \tag{3}$$

when conducting Pearson correlation coefficient analysis in SPSS 24.0 software, the first step is to prepare the data and classify the variables in Excel 2019 software. The second step is to process and operate the data in SPSS. By selecting "Simple Scatter Plot", we move variable 1 to the *Y*-axis, move variable 2 to the *X*-axis and then click "OK". After completing the above steps, we will output the required scatter plot. The third step is to conduct correlation analysis. We select "Analysis, Correlate and Bivariate", move the two variables to the "Variable Box" and then click "OK" to obtain the results of the correlation analysis.

In addition, to measure the correlation between channel selectivity and the station building environment, this study adopts the Pearson correlation coefficient model. Based on the correlation coefficient results, four factors are classified in the building environment of the selected station: length of the passage, operation of the escalators, the distance from the passage exit to the bus stop and the passage width.

3.4. Space Syntax

Space syntax is a computational language about space, which can deeply explain the spatial essence and function of buildings and cities. "Space" is the essence of syntax research and is a multi-dimensional concept. There are three main analysis methods of space syntax, namely convex polygon analysis, axis method analysis and visual graph analysis. However, the first two of the three methods have different problems in axis drawing and convex space drawing methods. For the same space, model drawings drawn by different people will lead to different analysis results. Subsequently, with the continuous improvement of theory, methods such as overlapping convex spaces, all line methods and view area integration analysis emerged.

In this study, we chose the axis method for analysis, which captures a series of processes in which observers perceive space during self-movement. Taking the application of urban planning and design as an example, the axis method is determined as the axis by observing the main path of pedestrian movement in urban space and the apogee that the line of sight can reach in the travel process. The axis method can accurately reflect the drawing principle of the longest and smallest street coverage in the syntactic axis. By using the axis method to quantify and graphically represent the axis, analysts can conduct extensive analysis on large-scale space types, such as centrality analysis, integrated core area analysis, global and local relationship analysis and identification analysis, of cities or scenic spots.

When conducting axis method analysis in Depthmap 1.0 software, the first step is to import the drawn subway station hall floor plan (AUTOCAD format) into Depthmap 1.0 software and click "Axial map" to obtain all passenger flow routes within the plan.

Step 2 involves clicking “Tools, Axia/Convey/Mesh, Reduce to west line map” in order to delete the routes that have no research significance. The third step is to click “Tools, Axis/Convey/Mesh, Run graph analysis” in order to obtain the axis selection and integration values we need. Finally, we obtain the integration degree and choice degree of the remaining routes. The degree of integration is a quantitative measure at the core of spatial syntax theory, assessing the potential of a space to attract pedestrians and indicating the extent to which it connects or disperses with other spaces. The degree of choice refers to the frequency of a specific element within the spatial system, measured as the shortest topological distance between two nodes.

A higher degree of choice indicates a greater likelihood of human traffic passing through that space. By calculating the values of integration and choice degrees, numerical ranges can be established to evaluate the channel index, ultimately determining the positional relationship between the commercial passageway and the exit gate.

4. Results

4.1. Passenger Flow Survey and Questionnaire

Considering the practicality of the research content and the implementation of the research method, the survey was conducted during the peak hours of weekdays from July to September in 2022. The peak hours were divided into two time periods: morning peak hours (7–9 a.m.) and evening peak hours (5–7 p.m.), as well as two time periods during rest days: morning peak hours (9–11 a.m.) and evening peak hours (7–9 p.m.). The total passenger flow obtained during these four time periods was averaged to obtain the daily average passenger flow, and the research location was the passageway of each entrance and exit.

For the measurement of passenger flow, our research team has sent a total of 20 members, who can freely form a team to record at the entrance and exit of the metro commercial passageways, but each team must contain no fewer than two people. When conducting measurements, it is difficult to obtain data due to the extremely high peak passenger flow. Therefore, only one person is selected from each small team for statistics, while the rest are used for observation, which can better reduce errors, as shown in Figure 4. In addition, monitoring equipment inside the subway station was used to capture and filter out the outbound passenger flow of each channel through video capture, achieving more accurate passenger flow statistics.

Figure 4. Site commercial passageway site.

There are eight observation points at Wusi Square Station, including seven entrance/exit passageways and a commercial passageway for Wanxiangcheng. A total of 2808 passenger flows were obtained in four time periods, as shown in Figure 5a. There are four observation points at Taidong Station, including Passageway E, which is a commercial passageway connected to the underground pedestrian street, and a total of 3107 passenger flows were obtained in four time periods, as shown in Figure 5b. There are nine observation points at Licun Station, including five entrance/exit passageways and four commercial passageways, and a total of 3648 passenger flows were obtained in four time periods, as shown in Figure 5c.

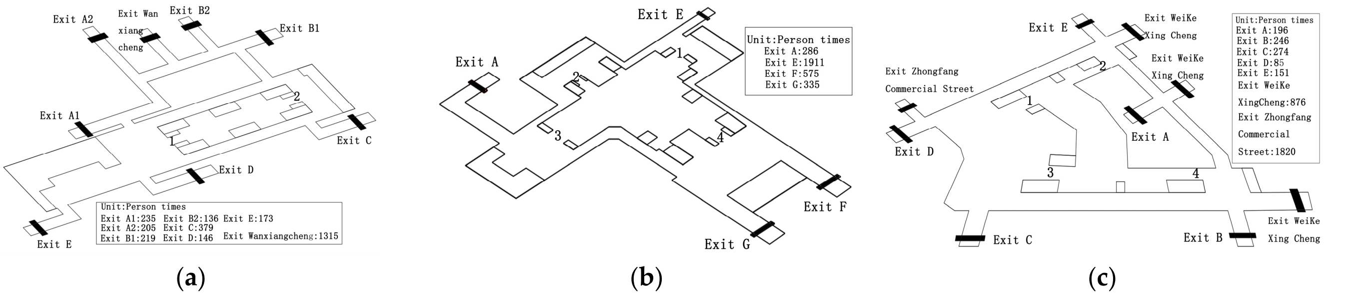


Figure 5. Passenger flow distribution map of each passageway of the site: (**a**) Wusi Square Station; (**b**) Taidong Station; (**c**) Licun Station.

The outbound passenger flow during peak hours was selected for the travel purpose questionnaire. The questionnaires were collected at the entrances and exits of each passageway and were conducted through a combination of WeChat mini-app and paper questionnaires. For the mini-app questionnaire, a QR code was provided for passage passengers to scan and fill in, while passengers were invited to fill in the site for the paper questionnaire.

Here, 2168, 2398 and 2873 questionnaires were collected from Wusi Square Station, Taidong Station and Licun Station, respectively. The questionnaire results were classified based on "commercial passageway" and "other passageways", as shown in Table 3.

Table 3. Passenger traffic by purpose of travel (trips).

Purpose of the Trip	Wusi Square Station		Taidong Station		Licun Station	
	Other Access	Commercial Access	Other Access	Commercial Access	Other Access	Commercial Access
Shopping	292	734	356	744	318	1018
Working	308	394	194	337	216	488
Housing	294	146	298	469	191	642

4.2. Analysis of the Impact of Passengers Travel Purposes

The area around the metro station has a high concentration of various social and economic activities, and there are obvious differences in the land-use structure and passenger commuting of different station types. Based on the different travel needs of passengers at different time periods, the questionnaire results were imported into the regression model for parameter comparison to obtain the choice of commercial passageways by passengers under the conditions of three travel purposes: shopping, work and living [33].

4.2.1. Comparison Analysis of Parameter Estimation between Logistic Model and Route Selection Models

Logistic regression and route selection models were chosen to investigate the relationship between passenger flow purposes and the passageway choice in response to the distribution of passenger flow in the passageways in the questionnaire results.

Based on the independent variables incorporated in the logistic regression model, the V_{ni} function in the path utility Function (4) is as follows:

$$V_{ni} = \sum_{k=1}^{K} \theta_k X_{ink} \tag{4}$$

A logistic model of the three travel purposes (i.e., work, shopping and living) that influence the choice of metro commercial passageways by passenger flows is developed, and the determined term of the path utility function is expressed as follows:

$$V_{ni} = \theta_0 + \theta_1 X_1 + \theta_2 X_2 + \theta_3 X_3 \tag{5}$$

where θ_0 is a constant term, $\theta_1 X_1$ is the utility of shopping to influence passageway choices, $\theta_2 X_2$ is the utility of work to influence passageway choices and $\theta_3 X_3$ is the utility of the residential to influence passageway choices.

Before the calculation, the "purpose of the travel" (1 = shopping, 2 = work and 3 = living) was defined as the independent variable, and the choice of passageway by passenger flow was defined as the dependent variable. However, the dependent variables were selected differently, with "whether to choose commercial passageway" (0 = no and 1 = yes) as the dependent variable for Taidong Station and Wusi Square Station, and we built a binary logistic regression model in SPSS 22.0 software, with "three categorical variables" (1 = WeiKe Xing Cheng, 2 = Zhongfang Commercial Street and 3 = Other Passageways) as the dependent variables of LiCun Station, and built a multivariate logistic regression model in SPSS 22.0 software.

To make the purpose of travel more significant, the "living purposes", "work purposes" and "other passageways" group were used as a control during the morning peak hours, during evening peak hours and in the choice of route, respectively. In addition, none of the three passenger flow purposes captured during the morning peak hours on weekends showed significant effects, and the following model excluded this time period from the calibration process. In the table, '\' is a non-significant (significance > 0.05) independent variable factor, for which no parametric analysis was performed, and a comparison of the estimated parameters of the commercial passageway model for the three sites is shown in Tables 4 and 5, respectively.

Table 4. Comparison of parameter estimation of commercial passageway models for Wusi Square and Taitung Station.

	Wusi Square Station				Taidong Station		
Purpose of the Trip	**B**	**Statistical Significance**	**Exp(B)**	**Purpose of the Trip**	**B**	**Statistical Significance**	**Exp(B)**
			Weekday morning peak				
1	\	\	\	1	\	\	\
2	2.863	0.001	14.182	2	1.404	0.004	4.071
Constants	−2.015	0.007	0.133	Constants	−0.539	0.257	0.583
			Weekday evening peak				
1	2.688	0.000	14.696	1	1.700	0.000	5.475
3	\	\	\	3	1.602	0.000	4.963
Constants	−1.715	0.000	0.180	Constants	−0.747	0.065	0.474
			Weekend evening peak				
1	2.864	0.000	17.539	1	2.338	0.000	10.361
3	\	\	\	3	1.758	0.009	5.801
Constants	−1.914	0.000	0.149	Constants	−1.609	0.011	0.200

Table 5. Comparison of parameter estimation of commercial passageway models for LiCun Station.

Chosen Path	**Purpose of the Trip**	**B**	**Statistical Significance**	**Exp(B)**
		Weekday morning peak		
	1	\	\	\
1	2	\	\	\
	Intercept distance	\	\	\
	1	\	\	\
2	2	1.212	0.003	3.360
	Intercept distance	−0.894	0.024	\

Table 5. *Cont.*

Chosen Path	Purpose of the Trip	B	Statistical Significance	Exp(B)
		Weekday evening peak		
1	1	1.143	0.000	3.135
	3	1.280	0.000	3.597
	Intercept distance	0.174	0.556	\
2	1	1.534	0.000	4.638
	3	1.375	0.002	3.957
	Intercept distance	−0.847	0.033	\
		Weekend evening peak		
1	1	2.270	0.000	9.682
	3	1.344	0.007	3.833
	Intercept distance	−2.001	0.000	\
2	1	3.013	0.000	20.350
	3	2.402	0.000	11.047
	Intercept distance	−1.819	0.000	\

Based on the constants and intercepts in Tables 4 and 5, the utility functions that can be chosen for the commercial passageways at the three sites are shown in Table 6.

Table 6. Subway commercial passageway utility function.

Time Period / Commercial Access	Weekday Morning Peak	Weekday Evening Peak	Weekend Evening Peak
Business passageway of Wanxiangcheng	$V = -2.015 + 2.863X_2$	$V = -1.715 + 2.688X_1$	$V = -1.904 + 2.864X_1$
E passageway of Taidong Station	$V = -0.539 + 1.404X_2$	$V = -0.747 + 1.700X_1 + 1.602X_3$	$V = -1.609 + 2.338X_1 + 1.758X_3$
WeiKe Xing Cheng	\	$V = 0.714 + 1.143X_1 + 1.280X_3$	$V = -2.001 + 2.270X_1 + 1.344X_3$
Zhongfang Commercial Street	$V = -0.849 + 1.212X_2$	$V = -0.847 + 1.534X_1 + 1.375X_3$	$V = -1.819 + 3.013X_1 + 2.402X_3$

4.2.2. Interpretation of Parameter Estimation Comparison Results

The results of the comparison of the commercial passageway parameters in the three sites show that during the weekday morning peak hours, "work purposes" has a significant impact on the three passageways of Wanxiangcheng, Taidong Pedestrian Street and Zhongfang Commercial Street but not on the WeiKe Xing Cheng, mainly due to the complex space of the underground mall of WeiKe Xing Cheng, the cluttered guidance signs and the long passageways, which result in very little flow.

During the evening peak hours of the working day, there is a surge of passenger flow for "shopping purposes" and "living purposes", and the passenger flow for "shopping purposes" has a significant impact on the commercial passageways of all three stations. However, because of the different proportions of residential land around the exit of the commercial passageways, the passenger flow for "living purposes" is significant in the Taidong Station Exit E passageway, WeiKe Xing Cheng passageway and Zhongfang Commercial Street passageway, and it is not significant in the Wanxiangcheng passageway. In LiCun Station, which has several commercial passageways, although the passenger numbers for "shopping purpose" and "living purpose" are significant in the passageways, the Exp(B) of the Zhongfang Commercial Street passageway is higher than that of the WeiKe Xing Cheng passageway for both purposes.

The impact on the commercial passageway is similar to the weekday evening peak during the weekend evening peak, but with an increase in Exp(B) for travel purposes due to the surge in passenger traffic. In addition, the "shopping purpose" is much higher than the other two purposes when comparing the Exp(B) for travel purpose between different time periods, demonstrating that the commercial passageway has a greater preference for shopping passenger flow.

4.3. Analysis of the Impact of Build Environment

The metro station building environment includes the main building environment of the station and the building environment around the station. Only the main building environment of the station was analyzed in this study. The main building environment of the station can be divided into four construction factors: entrances and exits, passageways, escalators and the distance from the station to the bus stop. The passenger flow collected from the metro passageway was analyzed through. The Pearson correlation with four construction factors in the main building environment of the station is used separately to determine the relationship between the main built environment of the station and the selectivity of the commercial passageway [34].

Among them, in Taidong Station, there are escalators available at all entrances/exits. The "escalator operation status" factor is classified based on the ascending time in the channel. In Li Cun Station, there are entrances/exits without escalators. The "escalator operation status" factor is classified based on the ascending time and the absence of escalators in the passageway. The "distance between entrances/exits and bus stations" is defined as follows: close range is within 50 meters; moderate range is between 50 and 70 m; and the long range is between 70 and 100 m. The collected data of subway channel passenger flow and the four factors in the station's building environment are subjected to Pearson correlation analysis to determine the relationship between the station's built environment and the selectivity of commercial channels.

4.3.1. The Correlation between the Building Environment of a Metro Station and Passenger Flow

Figure 5a shows the passenger flow of each passageway in Wusi Square Station. The main building environment of the Wusi Square Station selected three construction factors, including the passageway width, passageway length and distance between the entrance and exit of the passageway and the bus station for the test analysis of the correlation coefficient. The distance between the entrance and exit and the bus station can be divided into three levels (1 = near, 2 = far and 3 = farther), as shown in Tables 7 and 8.

Table 7. Statistics of elements for the construction of Wusi Square Station.

Factors of Influence	Description and Statistical Results		
Passage width (m)	1 = 4.5–5.5	2 = 5.5–6.5	3 = 6.5–7.5
	A2, D	A1, C	B1, B2, E, Wanxiangcheng
Passage length (m)	1 = 20–25	2 = 25–30	3 = 30–35
	A2, B1, Wanxiangcheng	B2, C, D	A1, E
Degree of distance to bus stops	1 = Near	2 = Middle	3 = Far
	B1, C, Wanxiangcheng	A1, B2, D	A2, E

Table 8. Pearson correlation coefficient test results of Wusi Square Station.

Variables	The Statistics on the Completed Elements of Station Hall		
	Passage Width	Passage Length	Subway Station Distance from Bus Stops
Pearson's chi-squared	0.88	−0.96	−0.95
Statistical significance	0.000	0.000	0.000

Figure 5b shows the passenger flow of each passageway in TaiDong Station. The three construction factors of the passageway width, passageway length and escalator operation were selected for the test analysis of correlation coefficients at TaiDong Station and are listed in Tables 9 and 10.

Table 9. Statistics of elements for the construction of Taidong Station.

Factors of Influence	Description and Statistical Results		
Passage width (m)	1 = 5–5.5 A, E	2 = 5.5–6.0 F	3 = 6.0–6.5 G
Passage length (m)	1 = 10–15 E	2 = 15–20 F, G	3 = 20–25 A
Operation of the escalators (s)	1 = 50–55 G, F	2 = 55–60 E	3 = 60–65 A

Table 10. Pearson correlation coefficient test results of Taidong Station.

Variables	Statistics on the Completed Elements of Station Hall		
	Passage Width	Passage Length	Operation of the Escalators
Pearson's chi-squared Statistical significance	0.93 0.000	−0.97 0.000	−0.94 0.000

Figure 5c shows the passenger flow of each passageway in LiCun Station. The following statistical and correlation coefficients were tested for the four construction factors (i.e., passageway, passageway length, distance from the passages exit to the bus stop and operation of the escalators for LiCun Station) to verify whether these factors selected for the two stations of Wusi square Station and Taidong Station are equally applicable to other metro stations in commercial areas, as shown in Tables 11 and 12.

Table 11. Statistics of elements for the construction of Licun Station.

Factors of Influence	Description and Statistical Results		
Passage width (m)	1 = 5–6 C	2 = 6–7 E, B, D	3 = 7–8 WeiKe Xing Cheng, Zhongfang Commercial Street, A
Passage length (m)	1 = 25–30 Zhongfang Commercial Street, B, C	2 = 30–35 WeiKe Xing Cheng, A	3 = 35–40 D, E
Degree of distance to bus stops	1 = Near WeiKe Xing Cheng, Zhongfang Commercial Street, D	2 = Middle E, C, B	3 = Far A
Operation of the escalators (s)	1 = 35–40 Zhongfang Commercial Street	2 = 40–45 WeiKe Xing Cheng, C, B, A	3 = No escalators D, E

Table 12. Pearson correlation coefficient test results of Licun Station.

Variables	Statistics on the Completed Elements of the Station Hall			
	Passage Width	Passage Length	Subway Station Distance from Bus Stops	Operation of the Escalators
Pearson's chi-squared Statistical significance	0.70 0.000	−0.94 0.000	−0.77 0.000	−0.86 0.000

4.3.2. Comparative Analysis of Correlation Coefficients

According to the results of the Pearson correlation coefficient test for the three stations, the four construction factors of the main building environment of the selected stations significantly impact the choice of passageway by passengers in the commercial area of the metro station. The most significant factor is the length of the passage, followed by the operation of the escalators, the distance from the passages exit to the bus stop and the passage width. It is also clear from the results that a long passageway may cause passengers to abandon the aisle when making their choice. The absence of escalators or the distance between the metro stations and the bus stop has a slightly weaker effect on the choice of passageway. In contrast, passengers are more receptive to the fact that the aisle width is narrow.

4.4. Analysis of the Impact of the Exit Gates Position

4.4.1. Axial Method

In this study, metro station hall-level gates refer to exit gates, excluding entrance gates. The exit gates are used as a corresponding supporting measure on the station hall level, and their location affects the convenience of passengers reaching the commercial passageway, which is more appropriately analyzed using the axial method in the Space Syntax [35]. Depthmap Bate 1.0 software was also applied to construct the axial models of the hall level and the connected passageways at Wusi Square Station, Taidong Station and Licun Station (Figures 6 and 7) to calculate the different values of the integration degree (r = 3) and the selection degree of the passageways, with the size of the values differentiated by the chromatogram from red to blue, and to evaluate the indices of the passageways based on the divided value groups, as shown in Table 13.

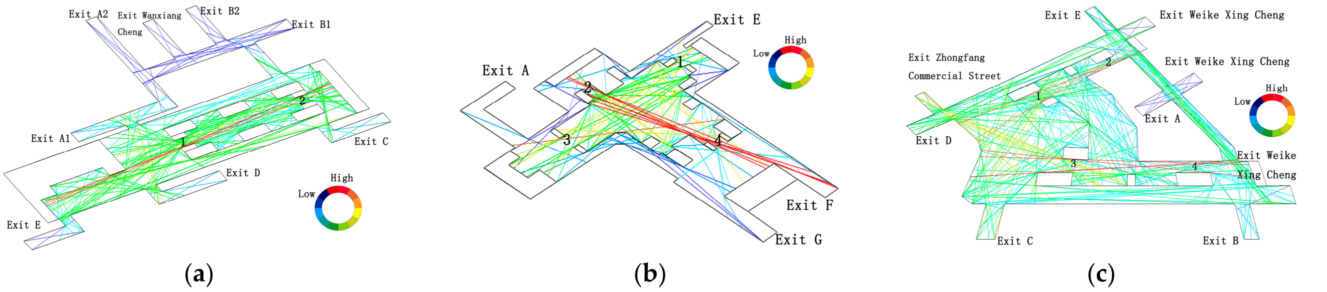


Figure 6. Integration degree model analysis: (**a**) Wusi Square Station; (**b**) Taidong Station; (**c**) Licun Station.

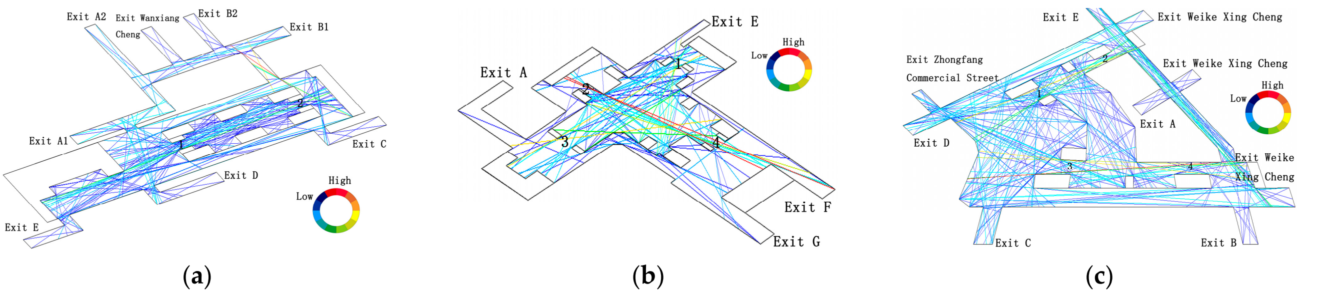


Figure 7. Choice degree model analysis: (**a**) Wusi Square Station; (**b**) Taidong Station; (**c**) Licun Station.

Table 13. Classification and evaluation of model results indicators.

Integration	Choice	Wusi Square Station	Taidong Station	Licun Station	Evaluation of Indicators
2–5	0–200	Wanxiangcheng, A2, B1, B2	/	WeiKe Xing Cheng	Poor
5–8	200–400	E	G	A, B	Fair
8–11	400–600	C, D	A	C, D, E	Good
11–14	600–800	/	E, F	Zhongfang Commercial Street	Excellent

4.4.2. Analysis of the Range of Integration and Choice

Comparing the results of the software simulation with the number of passengers in the investigated passageways, it was found that the higher the value of the indicator, the higher the passenger flow in the passageway. This indicates that the manner in which the exit gates are laid out is also crucial to improve the selectivity of commercial passageways.

The passageway location is considerably far from the gate when the passageway integration degree is in the range of 2–8 and the choice degree is in the range of 0–400, resulting in poor accessibility to the passageway. When the passageway integration degree is in the range of 8–11 and the choice degree is in the range of 400–600, the passageway location is close to the gate, and the accessibility to the passageway is good. On the other hand, when the passageway integration degree is in the range of 11–14 and the choice degree is in the range of 600–800, the relationship between the passageway and exit gates is characterized by a linear pattern, and passengers have the best accessibility to the passageway.

The commercial passageways of the three stations were divided into index evaluations based on the location of exit gate. Those with poor evaluation are Wusi Square station's Wanxiangcheng passageway and Licun Station's Weike Xing Cheng passageway, while those with excellent evaluation are Taidong Station's E-exit passageway and Licun Station's Zhongfang Commercial Street passageway. In summary, the positional relationship between the commercial passageway and exit gate determines the integration and selection degrees of the passageway. The passageway that is close to the gate or in a linear mode has a high index value, which is more conducive to the commercial passageway to attract passenger flow.

5. Discussion

5.1. The Relationship between the Construction of Metro Commercial Passageways and Urban Planning

The design of metro commercial passageways as connecting spaces is not only about creating architectural spaces but also involves conducting multi-dimensional and interdisciplinary research based on the theories of urban planning, transportation and architectural layout. Due to the influence of rapid industrialization, China's urban planning and construction still lack in-depth thinking, resulting in many problems.

Metro commerce should be planned and designed based on the public facility construction zoning in urban zoning planning, with a focus on the number and scale of network points, commercial structure and owner characteristics. Fully consider the layout of traditional street markets, emerging businesses and tourist attractions near the station, taking into account the characteristics of each residential area into account. The planning of commercial facilities along the metro line should be based on the planning of the subway line. Due to the different regions along the subway, the economic development status and urban functions undertaken by different regions are also different. This often leads to different development intensities at various stations along the line, resulting in significant differences between stations, which has a significant impact on subway commerce. Therefore, it is necessary to analyze the construction of subway station commercial channel infrastructure and the location selection of subway commercial channels based on different functions and locations.

5.2. Stimulating the Vitality of Underground Commerce to Improve the Efficiency of Metro Commercial Passageways

The optimization path of subway commercial channels aims to stimulate the vitality of underground commerce within the metro system, ultimately improving the efficiency of metro commercial channels. The positioning of underground commerce should be considered in terms of the composition structure of passenger flow and the function of the station, with the aim of attracting passenger flow for consumption. Additionally, the planning and design of underground commerce should align with the commercial characteristics of the area. Attention should be given to the proper allocation of large, medium and small commercial areas within the commercial space [36]. Furthermore, the layout of the stations should be fully integrated with the addition of parking lots, public services and other facilities. Moreover, underground commerce should not exist in isolation but rather form a cohesive unit with the surrounding underground commerce centered around the site. This facilitates the movement of customers among various commercial centers. To prevent direct competition among similar businesses, stores of the same type can be placed on different floors according to customers' psychology.

5.3. Zoning and Facility Construction to Improve the Selectivity of Subway Commercial Channels

The development of underground space itself possesses characteristics of a long cycle, high difficulty and poor feasibility. Undertaking an overall development at once will result in significant challenges in underground space planning. Therefore, zoning and facility construction have become the primary choice for underground space development, with priority given to key development areas and addressing site construction environments.

Utilizing the Pearson model and evaluating the correlation between the four elements of metro commercial channels and the built environment can serve as a basis for prioritizing the zoning and facility planning of commercial stations. Moreover, for commercial stations with excessively long metro commercial passageways and a distance of more than 50 m between the entrance and the bus station, a portion of the channel can be transformed into a sunken square. By integrating the design of the sunken square and introducing the underground bus transfer point for same-station transfers, not only can the intersection of two-way passenger flows be avoided and the efficiency of passenger flow in and out be enhanced, but the transfer distance for passengers can also be reduced, thus further promoting the development of underground commerce.

The installation of escalators as vertical transportation facilities and their placement are of great importance. When there is a significant height difference between the commercial passage and the above-ground entrance of the subway, we can draw upon the successful experience of the commercial passageways at Exit E of Taidong Station. The "escalator-underground commercial-escalator-above ground entrances" approach used there can serve as a reference. However, there is no escalator in the commercial channel at Exit D of Li Cun Station, leading to frequent congestion and slippery conditions for passenger flow, particularly on rainy days.

5.4. The Optimal Relationship between the Location of Metro Exit Gates and Commercial Channels

For commercial center metro stations, the majority of passenger flow is primarily focused on shopping, food and popular internet celebrity streets. As a result, when leaving the station, passengers typically prioritize the exit gate that is closest to these destinations. Simultaneously, in order to attract passenger flow at the exit gate, it is essential to quantitatively analyze the positional relationship between the gate and the commercial channel [37].

The integration and choice degrees of the metro station hall level were calculated using the axis method. Based on the analysis of the calculation results, it was determined that the location of the exit gates has an influence on the passenger flow of the commercial passageway. Therefore, when planning for metro commercial passageways, it is advisable to maintain a linear pattern between the exit gate and the passageway position, whenever possible.

5.5. The Limitations of the Study's Models and Methods

In this research, the logistics model used in this study has limitations in terms of independent variables (shopping, work and life). There are too few factors to choose independent variables, and there is no more detailed division of the travel purpose of passenger flow.

The Pearson model used in this research has a small difference in the numerical range of independent variables (passage width, passage length, distance from the passage exit to the bus stop and operation of the escalators), resulting in Pearson correlation coefficient test results that are close. At the same time, there is a certain degree of error in the data obtained from artificial measurements in the independent variables of the Pearson model.

The exit gate has varying degrees and quantities of damage, and the "other channels" in the layout have a certain height difference from the subway station hall floor. These factors can affect the results of the axis method analysis.

1. By reading the relevant literature, identify more factors that have an impact on passenger flow travel and further classify these factors to improve the computational accuracy of the logistic model.
2. Contact the subway company to obtain more accurate data to avoid errors caused by manual measurements. At the same time, increase research cases and expand the numerical range of independent variables in the Pearson model.
3. Calculate the passenger flow at the exit gates (excluding unused exit gates), and then combine this data with the axis method for analysis.

6. Conclusions

Wusi Square Station, Taidong Station and Licun Station are all important urban traffic transferring hubs in Qingdao. They meet the travel needs of the public and meanwhile undertake the function of converting passenger flow into the commercial passenger flow. The passenger flow of the commercial passageway station shows a large difference from that of other passageways. As a link between the metro station and the underground commercial, it is necessary to focus on the influence of three key factors (i.e., metro station building environment, passenger flow purpose and gate position of station hall) to enhance its attraction to passenger flow in future planning and construction and identify potential avenues for future research:

1. Change the construction sequence of the four elements in the building environment of the station, and what impact it will have on the underground commerce connected with the metro commercial passageway.
2. If the position of the metro exit gate is adjusted, will the effectiveness of optimizing passenger flow change?

At the same time, we also need to briefly introduce the contributions of this study:

1. After our research, we have summarized the drawbacks of commercial channels at three subway stations (Wusi Square Station, Taidong Station and Licun Station). Therefore, Qingdao Metro Co., Ltd. (Qingdao, China) can propose corresponding optimization paths according to our research conclusions.
2. The process, methods and models of this study can be referenced in the planning of other subway commercial channels in the future. And based on comprehensive consideration of multiple factors, a design plan will be proposed that can make underground commerce more dynamic.

Author Contributions: Conceptualization, P.D.; Data curation, S.H., H.F., Y.W. and G.F.; Formal analysis, Y.W.; Funding acquisition, P.D.; Investigation, S.H.; Methodology, S.H.; Writing—original draft, H.F. and G.F.; Writing—review and editing, P.D. and G.F. All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding.

Conflicts of Interest: The authors declared that they have no conflict of interest related to this work.

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