Hindawi
Journal of Advanced Transportation
Volume 2024, Article ID 6613603, 13 pages
https://doi.org/10.1155/2024/6613603

Research Article

Analysis of Hotspots in and outside School Zones: A Case Study of Seoul

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Received 29 July 2023; Revised 16 January 2024; Accepted 28 February 2024; Published 15 March 2024

Academic Editor: Chris Lee

With growing social concern on pedestrian accidents involving children, the Korean government announced a plan to decrease the number of child deaths due to traffic accidents by 2026. Therefore, policymakers should consider various measures for school zones because a safe school walkway is essential for preventing traffic accidents around schools. Some parts of the roads within a radius of 300 m from elementary school and kindergarten entrances are designated as school zones. Certain roads experience frequent accidents within the school zone, while others experience frequent accidents outside the school zone. Hence, this study aimed to provide school zone types in Seoul by noting different occurrence accidents within and outside each school zone and suggest proper countermeasure by type. After selecting a 300 m radius analysis unit from the school zones, a distinction was made between the school zones and outside for each analysis unit. After verifying the spatial autocorrelation in each unit, hotspot analysis identified four types based on the presence or absence of hotspots in each unit. Types were defined as follows: Type A—no hotspots in school zones or outside the school zones; Type B—hotspots only outside the school zones; Type C—hotspots only the school zones; and Type D—hotspots both in school zones and outside the school zones. Subsequently, a case study was conducted to validate the types. For Types B and C, the results revealed differences in the installation of traffic safety facilities and the environment between within and outside the school zones. Therefore, Type B requires improving safety outside the school zones by expanding school zones to match the safety level within. For Type C, it implies the need to strengthen safety measures in the school zones. Lastly, for Type D, improvement projects for a safe walking environment should be implemented in primarily by conducting separate inspections.

1. Introduction

Traffic accidents are a major threat among children and adolescents worldwide. According to UNICEF, traffic accidents rank as the second leading cause of mortality in the age groups of 5–9 and 10–14, while claiming the top position as the leading cause of death in the 15–19 age groups. Global Burden of Disease Collaborative Network announced that among children aged 0–14 years, 93,700 children died, and 8 million disability-adjusted life years were lost because of road traffic injuries in 2019 worldwide, accounting for nearly a quarter of the burden of injuries. In order to solve this issue effectively, a crucial part involves extracting and investigating factors that exert significant influence on accidents involving children. Some studies on accidents for children focused on the correlation between the increase in accidents involving children and the increase in exposure variables in all traffic accidents. Typically, higher population density [1–3], increased traffic volume [1, 3–5], and rush hour time [1, 6] have been reported to amplify the risk of injury in children. Furthermore, previous studies have examined the correlation between traffic accidents and spatial and temporal characteristics of children's commutes. School travel times [1, 7], seasons [3, 7], school neighbourhood characteristics [2], spatial arrangements [2], and several schools [3] in an area have all been associated with collisions

near schools. Certain studies in the field of ergonomics, human factors, and human physics examined the relationship between traffic accidents and pedestrian behaviors of children. Some of the children's pedestrian behaviors include being unaware of their surroundings, having a low cognitive ability to recognize dangerous situations, and poorly observing traffic rules. This indicates that walking requires a cognitive process such as execution and attention functions [8–10]. Based on these studies, caregivers of children (parents, teachers) need to educate children to pay more attention and enhance perceptual skills while walking. However, this type of educational effectiveness is inconsistent; therefore, different approaches must be taken to implement a pedestrian environment that fits the characteristics of children [11–14]. Children are exposed to dangerous pedestrian environments during their commute to school. Considering their insufficient concentration during walking, many countries worldwide have adopted the use of school zones in areas where children commute to school. It is deemed essential to establish these zones around elementary schools, given the increased risk of collisions between children and vehicles during school commuting hours [15]. Japan, which introduced school zones in 1972, operates them within a radius of 500 meters from designated school facilities along commuting routes. The country ensures safety by implementing policies such as installing crosswalks and reflectors, expanding sidewalks, implementing one-way traffic and speed limits, and prohibiting vehicle passage [16]. Safety in school zones in Australian is ensured through regulations on speed limits within school zones, improvements in road facilities, and strengthened penalties for illegal activities [17]. In the Victoria, one of the Australia regions, the implementation of speed control measures around schools resulted in a 23 percent decrease in casualty crashes and a 24 percent reduction in all pedestrian and bicyclist crashes outside schools [18]. Various facilities for traffic safety are installed once an area is designated as a school zone. These facilities commonly include pavement markings (speeds, crossing lines, and stop bars), watch your speed boards, flashing beacons, speed humps, color pavement, road signs (speeds, school zone, and pedestrian caution), as well as cameras for speed monitoring and parking violations. Previous studies have proved that these types of facilities aid in reducing vehicle speed [19–22] and lowering reckless driving [19, 23, 24], thereby effectively decreasing the number of traffic accidents [25]. In Korea, certain sections of roads within a 300 m radius of main entrances of school zone-designated institutions are designated as school zones in accordance with "Rules for Designation and Management of Children, the Elderly, and the Disabled Protection Zones." A total of 16,759 school zones (6,261 elementary schools, 6,988 kindergartens, 3,233 daycare centers, 190 special-education schools, and 87 private academies) have been designated throughout Korea. Twenty-eight children have died within school zones in Korea over the past five years (2017–2021), accounting for approximately 13.5% of child deaths due to traffic accidents. This study began with the interpretation that the fact that children traffic accident fatalities within school zones account for 13.5% can be seen as including both positive and negative aspects. In other words, designating a school zone has a positive effect in protecting the safety of children; however, there is also a negative aspect that the remaining 86.5% of child fatalities occur on roads without designated school zones. Our society realistically faces limitations in setting up school zones on all roads that children use for commuting. This is because school zones require a significant budget and have negative implications in terms of mobility, and many roads near schools need to allow curbside parking depending on land use. Therefore, during the introduction phase of a school zone, it is inevitable to establish the installation zones with the consensus of local traffic safety authorities based on rough criteria. There are severe studies that serve as the basis for criteria [26–28]. A study showed that an area within 150 meters of schools had the highest proportion of child pedestrian-vehicle crashes and fatalities compared to areas 300 meters or more away from schools [26]. The New Jersey Department of Transportation provides a guideline for the length of school zones [27]. School speed limit zones in urban areas, 30 mph or less, can have school zones as short as 400 feet (150 m). School speed limit zones in rural areas, where posted speeds are typically 55 mph or more, tend to be longer. The suggested length of school zones in rural areas is 1,000 feet (300 m). However, research has shown that speeds are approximately 1 mph higher for every 500 feet driven within a school zone; therefore, longer school zones are associated with greater speed variability within the zone [28]. The purpose of this study is to develop methods that can be applied when considering improvements during the operation phase of school zones for children's protection. Policymakers in children's safety need to determine whether the points where children traffic accidents continue to occur, despite the operation of school zones, require an expansion of school zones or if there are facility problems within the school zones. Korean parents argue that the designation of school zones is very short compared to their children's commute distance. However, expanding school zones does not guarantee the prevention of children traffic accidents. For example, installing regulatory facilities such as surveillance cameras at certain points can reduce accidents, but the effectiveness of these facilities might diminish, and there might be an increase in accidents in the surrounding areas. On the contrary, in areas where school zones are operating but traffic safety facilities are improperly installed or compliance with speed limits is lacking, children traffic accidents may still occur. Because the operation of school zones has these dual aspects, policymakers need to continuously monitor traffic accidents occurring on children's commuting routes and evaluate whether to improve or expand currently operating school zones based on the conditions around schools. In this study, an evaluation method for the operation of school zones using hotspot analysis was presented. The most crucial theoretical basis for hotspot analysis is that traffic accidents have spatial correlation. Therefore, in this study, it was assumed that there would be spatial autocorrelation within the school zone since road facilities, speed limits, signal operations are installed and conducted by similar administrator in each region. Conversely, for the

external space not operated as a school zone, it was assumed that there would be spatial autocorrelation because it is within a 300 m radius of the school and shares similar characteristics with the surroundings of the school zone. According to Moran's Index analysis results, spatial correlation was found both inside and outside the school zone. As there is spatial correlation between traffic accidents that occurred inside and outside the school zone, a hotspot analysis was conducted to propose categorization method for traffic safety within and outside the school zone for each school. The analysis results allowed the categorization of school zones into four types, each suggesting directions for traffic safety improvements for policymakers based on the respective types.

2. Materials and Methods

2.1. Data. For hotspot analysis, it is necessary to indicate the need for the improvement and expansion of existing school zones. To do this, data that can distinguish between the in and outside of school zones is required, along with data that can distinguish pedestrian traffic accidents involving children occurring in and outside of school zones. Data encompass the years 2018 to 2020, as this time frame allows for feasible data collection. During the data construction process, terminology ambiguity may arise. For hotspot analysis, it is necessary to indicate the need for the improvement and expansion of existing school zones. To do this, data that can distinguish between the in and outside of school zones is required, along with data that can distinguish pedestrian traffic accidents involving children occurring in and outside of school zones. Data encompass the years 2018 to 2020, as this time frame allows for feasible data collection. During the data construction process, terminology ambiguity may arise. Therefore, this study aims to minimize confusion by initially defining the data to be used as presented in Table 1.

2.1.1. School-Zone Institutions and School Zones Data. In this study, for a spatial analysis of traffic accidents occurring near school-zone institutions (e.g., schools, kindergartens, and private institutions), we collected the school-zone institution data and school zone data provided by Smart Seoul Map (https://map.seoul.go.kr/smgis2/). Both data are characterized in shapefile which includes spatial information such as location, shape, and area. School zone institution data has a form of point data, while school zone data has a form of polygon data, as shown in Figure 1 (ArcGIS Pro 2.8 setting). As of 2020, the number of school-zone institutions was 1,750 in Seoul, and 1,658 institutions were subject to spatial analysis.

2.1.2. Preprocessing of School-Zone Institutions and School Zones Data. Provided school-zone data had two significant problems. First, the information regarding which institution designated the school zone is missing. The provided school zone data does not contain information about the authority responsible for designating the school zones. When the government requests safety measures from the school zone management authorities to improve safety, if the identification of the responsible institution is not possible, the situation will prevent the effective implementation of measures aimed at enhancing the safety of school zones. Therefore, it is necessary to propose the specific designated institutions for each school zone to address this concern. Next, certain school-zone institutions were either removed or newly established during the analysis period (`18~`20). The possibility of biased results exists when it comes to school-zone institutions that were either removed or newly established during the period, as they may record relatively fewer traffic accidents compared to the previously school-zone institutions that operated for the full three years. To overcome these drawbacks, this study matched the nearest institutions with school zones by using the "Near" tool provided by ArcGIS. However, in some school zones, they were not installed by a single institution but took the form of "integrated school zones" operated by multiple institutions. Therefore, the "Near" tool, which defines one school zone and the nearest institution in one-on-one matching, was inappropriate for certain school zones. Hence, as a solution, the matching data of institutions and school zones provided by the Traffic Accident Analysis System (TAAS) of the Korea Road Traffic Authority were additionally conducted using the "Aggregate" tool of ArcGIS, as shown in Figure 2.

Furthermore, to match the year when the school-zone shapefile was generated with the reference year for the accident data, in this study, we additionally collected data on school-zone institutions that were removed or newly established between 2018 and 2020, as provided by the official website in Seoul (https://www.seoul.go.kr/). By deleting the some school zones that were removed or newly established school-zone institutions during the period, 1,247 school zones and a school zone area of 8.23 km^2 were ultimately constructed as the school zone data in this study.

2.1.3. Data of Children Traffic Accidents in Seoul. Traffic accident data provided by TAAS were used for analysing the spatial characteristics of children's traffic accidents. The accident data used in this study consisted of 3,896 traffic accident cases that occurred in Seoul for three years (`18~`20) and contained the accident type and location information. The 3,896 traffic accidents used in this study refer to pedestrian accidents involving children aged 12 or younger. A spatial analysis (selected by location) was performed using the school-zone data generated previously to identify traffic accidents involving children, both in and outside a school zone. For the analysis, accidents were distinguished into those that occurred in and outside a school zone. As a result of performing the analysis, 3,328 accident cases (85.42%) involving children were found to occur outside the school zone, whereas 568 cases (14.58%) were found to occur in the school zone. Figure 3 illustrates pedestrian accidents involving children in and outside a school zone in Seoul. Also, the figure at the bottom of Figure 3 shows the part of the shape of the school zone used in this study. The polygon shape marked in yellow is the actual designation status of the school zone of Nonhyeon

Table 1: Definition terminology in this study.

Type	Definition
School zone institution	(i) Institution that lead to the designation of school zones (`18~`20)
School zone (children protection area)	(ii) Roads designated as school zones within a 300 meter radius centered around school-zone institutions
Outside school zone	(iii) Roads not designated as school zones within a 300 meter radius centered around school-zone institutions
Traffic accidents in school zone	(iv) Pedestrian traffic accidents involving children that occurred in school zone (`18~`20)
Traffic accidents outside school zone	(v) Pedestrian traffic accidents involving children that occurred in outside school zone (`18~`20)

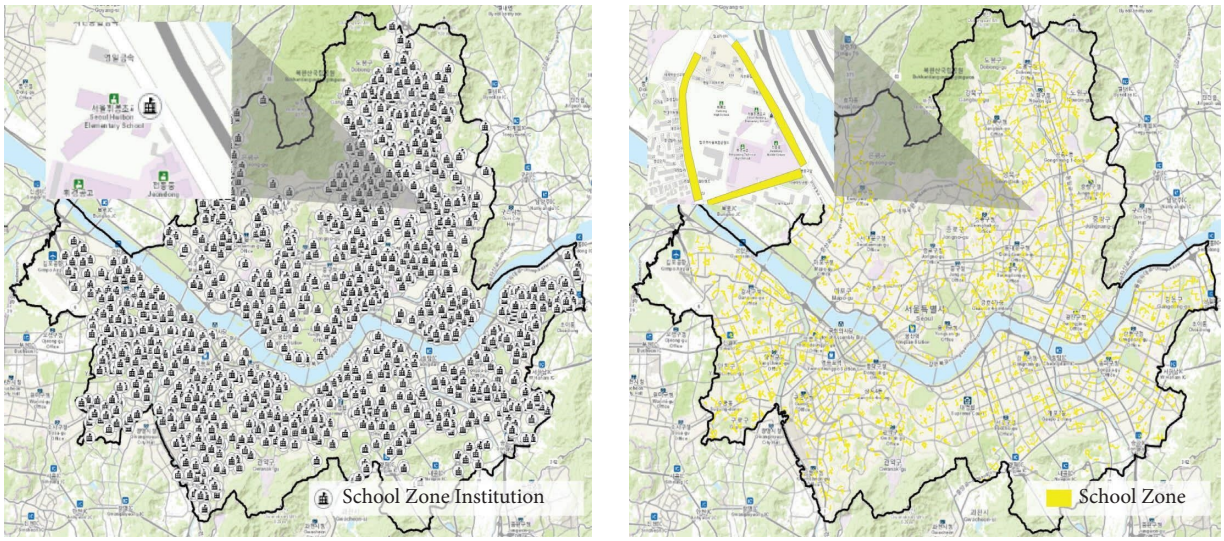


Figure 1: Distribution of school-zone institutions and school zones in Seoul city.

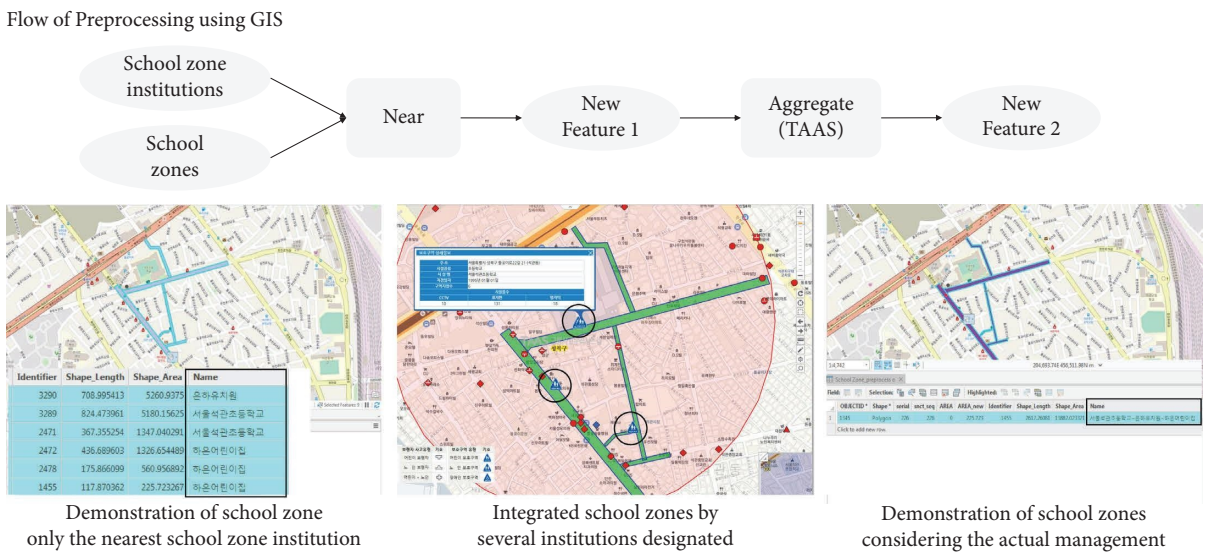


Figure 2: Preprocessing of school zone using ArcGIS and TAAS.

Elementary School, and the orange points located in the zone indicate children's traffic accident that occurred in the zone.

2.2. Methods. In this study, we applied a hotspot analysis method into areas in and outside for classifying school zones, considering spatial autocorrelation. If spatial autocorrelation is analysed without distinguishing between the areas in and outside school zone boundaries, the analysis would be integrated accidents from both areas. Furthermore, in this study, we analysed whether spatial patterns exist in traffic accidents that occurred in and outside school zones located within a 300 m radius of school-zone institutions. Instead of examining spatial autocorrelation solely based on the number of accidents as in numerous studies, in this study, we analysed spatial patterns based on road area and school zone area. This is because the larger the area of the school zone or the road surface within the school zone, the higher the likelihood of children being involved in accidents. To verify the presence of spatial autocorrelation as a process before hotspot analysis, we examined clustering patterns of traffic accidents per unit area of traffic accidents that occurred outside and in of a school zone. Then, the suitability of a hotspot analysis was reviewed based on the spatial autocorrelation analysis results before applying the hotspot analysis results. Figure 4 shows general flow of this study using by spatial analysis.

2.2.1. Spatial Autocorrelation. Spatial autocorrelation occurs when the values of variables sampled at nearby locations are dependent on each other [29]. It implies that the correlation is higher as spaces are located closer to each other. Spatial autocorrelation is classified into global spatial autocorrelation or local spatial autocorrelation. Global spatial autocorrelation computes a series of results from a single analysis, and the results are uniformly applied to the entire research, denoting an average of measurements. Therefore, a global spatial autocorrelation index is a quantitative value based on an equation (equation (1)), which represents the degree of the similarity of the attributes of unit areas within the research region to those of adjacent regions.

$$\text{Moran's I} = \frac{N\sum_i^N \sum_j^N w_{ij}(X_i - \overline{X})(X_j - \overline{X})}{\sum_i^N \sum_j^N (w_{ij}) \sum_i^N (X_i - \overline{X})^2}, \quad (1)$$

X_j denotes the attributes of j region, w_{ij} denotes the spatial weight between i and j regions, and N denotes the number of spatial units. Moran's I is a typical global autocorrelation index between −1 and 1. A value closer to −1 indicates a negative correlation between neighboring spaces, whereas a value closer to +1 indicates a positive correlation between neighboring spaces. Spatial autocorrelation is computed using Moran's I and the p value. There is no reference value of Moran's I that indicate autocorrelation, but a significant p value indicates the relevance of autocorrelation. Several previous studies reported a moderately high Moran's I of 0.32 [30] or 0.30 [31] at the significance level of 1%, but some studies reported a low Moran's I in the range of 0.1–0.2 [32] or less than 0.1 [33, 34]. Global spatial autocorrelation is useful when identifying the overall spatial correlation of certain areas presented within the research scope, but there are also limitations. First, spatial autocorrelation of large-scale regions or regions with an unstable spatial structure has a high risk of inducing errors in judgment for statistical inference or effectiveness of statistical models [35]. Second, it is difficult to clarify local correlations in the analysis region [36]. Local spatial autocorrelation is analysed to overcome these limitations and thoroughly examine the results deduced from global spatial autocorrelation. Local spatial autocorrelation is analysed through local indicators of spatial association (LISA) or Getis-Ord Gi∗, where both methods form clusters based on spatial patterns. Specifically, Getis-Ord Gi∗ is also well-known for hotspot analysis and is frequently used for its ability to intuitively distinguish hotspots and cold spots from G_i^* statistics.

$$G_i^* = \frac{\sum_j^N w_{ij} X_j - \overline{X} \sum_j^N w_{ij}}{\sqrt{\left(\sum_j^N X_j^2 / N\right) - (\overline{X})^2} \sqrt{\left(N \sum_j^N w_{ij}^2 w_j - \left(\sum_j^N w_{ij}\right)^2\right) / (N-1)}}, \quad (2)$$

X_j denotes the attributes of j region, w_{ij} denotes the spatial weight between i and j regions, and N denotes the number of spatial units. Previous studies that analysed spatial autocorrelation of school zone accidents can generally be divided into two categories. As a first method, the number of school zones and accident data are input data according to administrative district boundaries. Then, spatial autocorrelation is analysed by the administrative district. It allows decision-makers to propose directionality and implications for securing traffic safety per administrative district. However, the data characteristics cannot be identified on a small scale, and there is a negative influence on reliability because only the aggregated data are used [37]. Another method involves a specific space, which is divided into grids of a certain length, and then accident data are input into the grids to analyze the spatial autocorrelation. In a grid unit-based analysis, the size of grids used in the spatial analysis is adjusted to lower the workload, while statistical data for an administrative district are converted to a grid unit and, thereby, are unaffected by the changes in the boundary of administration districts [38]. This study divides data into a grid unit of a certain length to analyze the spatial autocorrelation of children's traffic accidents that occurred outside a school zone. Then, indices reflecting the number of

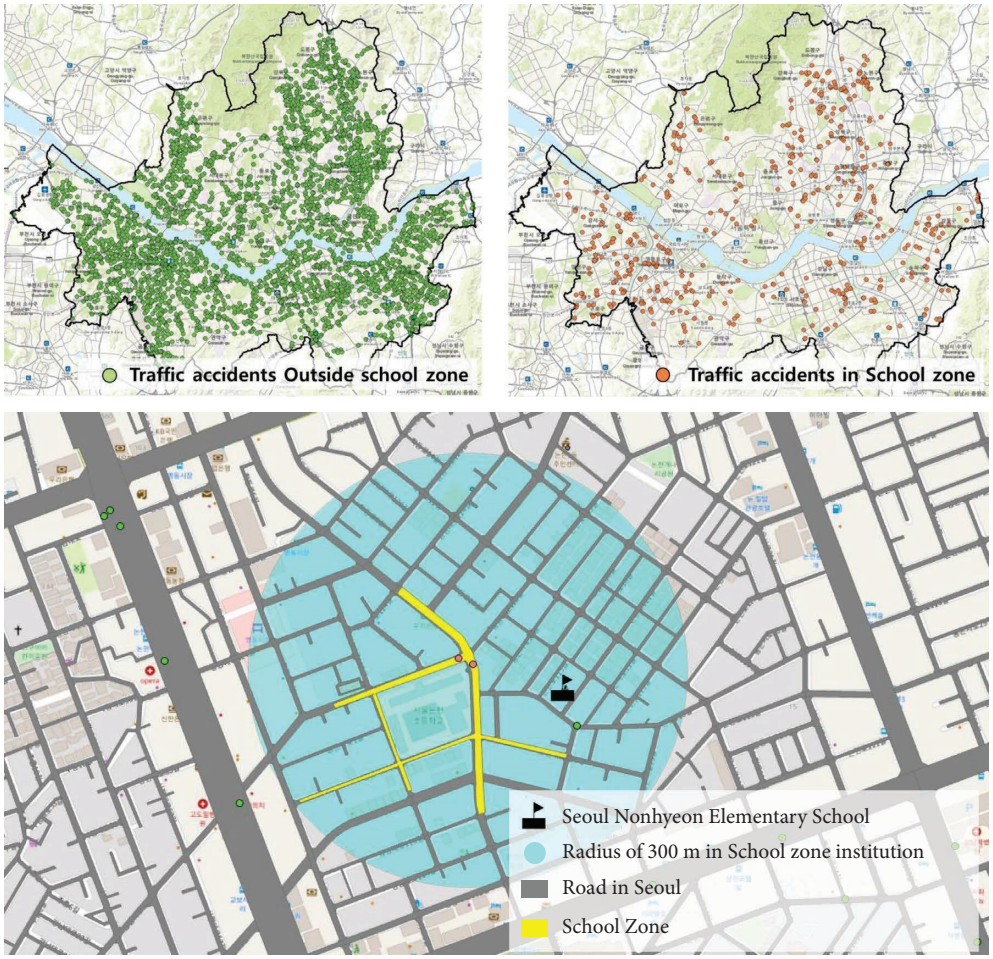


Figure 3: Distribution of children accidents in Seoul city.

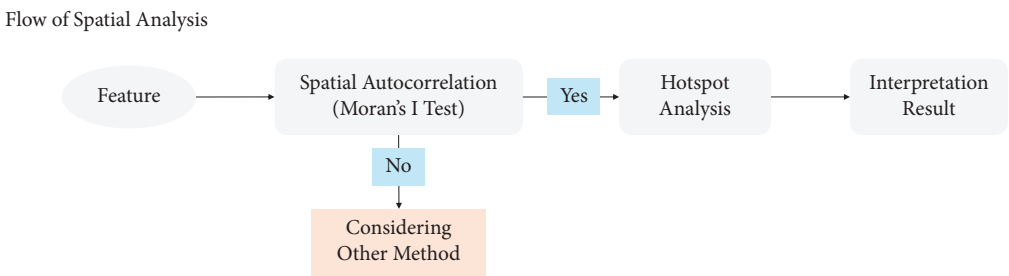


Figure 4: General flow of method by using by spatial analysis.

accidents and actual road area were used in the analysis. Previous studies mostly utilized the aggregated data of the number of school zones per administrative district because it was challenging to collect the shape data of each school zone. However, in this study, we analysed spatial autocorrelation in school zones by using the distance between school zones based on the acquired shape data of each school zone. Since spatial autocorrelation is calculated based on the distance between objects, space autocorrelation can be examined based on the distance between center points of individual school zones. Moran's I of accidents for children that occurred in a school zone were analysed using the spatial-autocorrelation tool provided in ArcGIS Pro 2.8. The methodology used in this study can discern between a school zone with a relatively higher risk of accidents and the outside of a school zone with a relatively higher risk of accidents. This is a fundamental analysis for identifying the regions where school zones should be expanded or the existing ones should be improved.

2.2.2. Classifying Types of School Zones. Several projects are underway to heighten the safety of school zones, such as improving accident-prone areas of school zones and

installing traffic safety institutions in school zones. However, it is not advisable to implement projects simply based on the number of traffic accidents. Currently, improvement projects only focus on accidents occurring within school zones, neglecting those outside these areas. If spatial patterns are considered, school zones can be divided based on the detailed location of accidents and institutions in addition to the number of accidents. Therefore, in this study, we performed a hotspot analysis based on global spatial autocorrelation and aimed to discern the regions requiring improvements in a school zone and those requiring an expansion of school zones based on spatial patterns of accidents. Based on the hotspot results in and outside the school zones, four types of spaces were classified in this study (Figure 5). Type A is a space where both in and outside the school zones are not hotspots, Type B is a space where only outside the school zone is a hotspot, Type C is a space where only in the school zone is a hotspot, and finally, Type D is defined as a space where both in and outside the school zones are hotspots.

3. Results

3.1. Spatial Analysis Results of Accidents in School Zones. 568 accidents involving children occurred in a school zone in Seoul. However, this study does not simply perform a hotspot analysis considering only the number of traffic accidents that occurred within the school zone or the number of traffic accidents that occurred outside the school zone, but rather conducts a hotspot analysis that reflects the number of traffic accidents by considering the road area within each school zone and grid. Several factors justify this choice of number of traffic accidents considering area than a simple number of traffic accidents.

First, Figure 6 illustrates the comparison of the number of traffic accidents in school zone and the number of traffic accidents in school zone but considering area (10,000 m^2). In the case considering area, numbers were rounded to make integer. As a result, there is a difference between the case where the area of the school zone is considered and the case where it is not. Second, traffic accidents tend to increase as the exposure variables (e.g., traffic volume and section length) increase. Therefore, the results can be distorted if spatial autocorrelation is analyzed solely based on the number of traffic accidents. A higher number of roads designated as school zones can more likely lead to a higher number of traffic accidents. In used data in this study, out of the 12 regions in which five or more accidents occurred in a school zone over three years, 8 were integrated school zones (66.7%), where school-zone institutions are highly concentrated in a larger area than other school zones. Also, there is a positive coefficient with school zones area with traffic accidents in school zone. The statistically verified correlation between the two variables indicates a positive correlation, as evident from Table 2.

Therefore, we used the number of traffic accidents per the area of school zones as opposed to simply the number of traffic accidents. Afterward, in order to determine the presence or absence of spatial autocorrelation for the number of accidents and spatially clustered school zones, we conducted a Moran's I test. Table 3 presents the results of analyzing global spatial autocorrelation based on inverse distance using the number of traffic accidents per school zone area. Moran's I was 0.04, there are spatial autocorrelation in analysis target.

3.2. Spatial Analysis Results of Accidents outside School Zones. In the context of geographical analysis, it is of paramount importance to set an appropriate grid size when analyzing spatial autocorrelation based on specific geographic units, such as grids. Generally, larger grid sizes tend to result in a greater degree of spatial autocorrelation. When grid sizes are large, there is a concern of obtaining overestimated results due to increased spatial autocorrelation. Conversely, very small grid sizes may lead to reduced spatial autocorrelation, potentially failing to reveal existing spatial autocorrelation. This issue, where analysis results vary depending on the defined spatial unit for geographical data collection and construction, is known as the Modifiable Areal Unit Problem (MAUP). When conducting spatial analysis considering spatial influence, there is a concern regarding MAUP, and the selection of spatial aggregation units is crucial, as spatial characteristics can significantly impact the analysis. Previous research has proposed four solutions to minimize the MAUP problem and argued that choosing an appropriate spatial scale for analysis can mitigate the effects of MAUP [39]. In this study, Seoul's road network at 100 meter intervals was divided, ranging from 100 meters to 500 meters. A noteworthy aspect is that, when conducting an analysis outside school zones, we did not simply segment the analysis targets into a basic grid unit. Instead, we performed grid analysis by considering the road network, as opposed to a simplistic grid-based approach. Initially, Seoul was subdivided into grid units. These grids were used to divide the city's road network data, establishing an analytical unit at the road-grid level. Following this, traffic accident data were spatially integrated, and accident counts, accounting for road area within each road grid unit, were determined. Subsequently, we conducted Moran's I tests to determine the presence or absence of spatial autocorrelation for child pedestrian traffic accidents within each unit. The results of analyzing global spatial autocorrelation based on the number of accidents in the grids are listed in Table 4. It revealed the existence of spatial autocorrelation in grids larger than 100 meters. To establish an appropriate analytical unit (grid), we considered the current guidelines for school zone designation in Seoul and statistical validity. According to existing regulations, school zones are designated within a 300 meter radius around designated institutions. Additionally, based on spatial autocorrelation verification using a 300 meter road grid unit, we found spatial autocorrelation within a 99% confidence level. Therefore, we selected the 300 meter unit for hotspot analysis.

3.3. Types of School Zones. Children traffic accidents in and outside school zones in Seoul exhibit spatial dependency. Therefore, a hotspot analysis using ArcGIS Pro 2.8 was conducted for such accidents. Considering the school zone

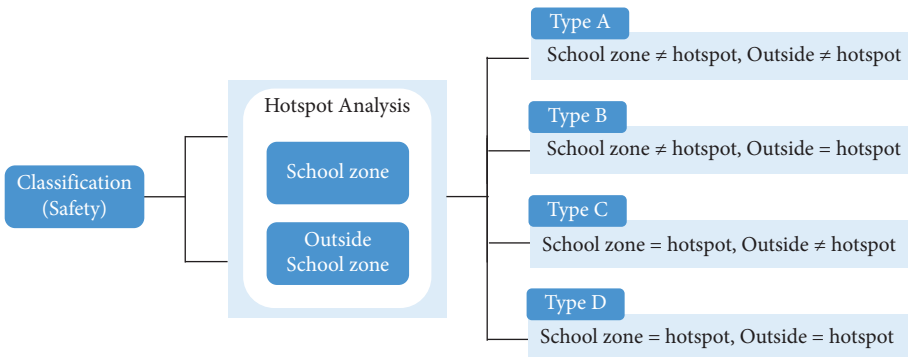


Figure 5: School zone classification flow based on hotspot analysis.

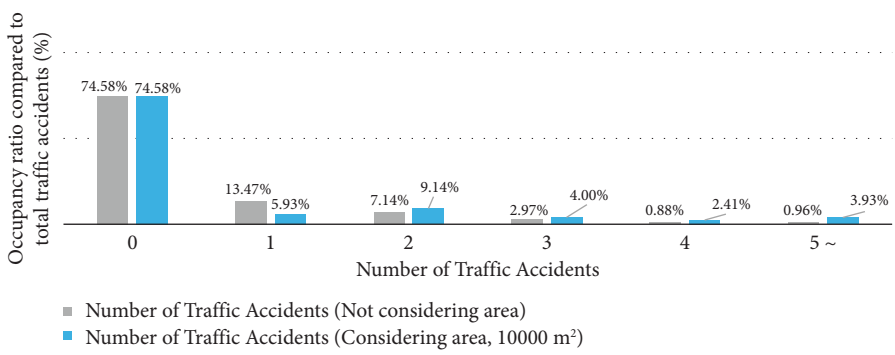


Figure 6: Distribution of the number of traffic accidents in a school zone by area.

Table 2: Result of correlation analysis.

(Pearson)	Coefficient	T value	p value
Correlation analysis	0.51	20.89	0.001***

***Significant at the 99% confidence level.

Table 3: Spatial autocorrelation in school zones (10,000 m^2).

	Moran's I	Z score	p value
School zone (10,000 m^2)	0.04	4.011	0.001***

***Significant at the 99% confidence level.

Table 4: Spatial autocorrelation outside a school zone.

	Moran's I	Z score	p value
100 m grid	0.00	−0.03	0.98
200 m grid	0.04	7.67	0.001***
300 m grid	0.02	3.34	0.001***
400 m grid	0.06	5.21	0.001***
500 m grid	0.10	6.78	0.001***

***Significant at the 99% confidence level.

range specified in the "Rules for Designation and Management of Children, the Elderly, and the Disabled Protection Zones," is analysis regions within a radius of 300 meters from the center of 1,658 school-zone-designated institutions were treated. Figure 7 represents partial results of hotspot analysis conducted for 1,658 analysis areas, and Table 5 analyzes whether the in and outside school zones within a 300 meters radius of school-zone-designated institutions in Seoul are hotspots. Based on this analysis, it categorizes the analysis areas into four types. In Type A, school zones have no hotspots within the 300 meters radius of a designated institution. It is highly likely that accidents did not occur in and outside the nearby school zone, and even if accidents occurred, they are likely independent with no correlation to the spatial patterns of near regions. This suggests that it cannot be considered a hotspot, considering the spatial autocorrelation of nearby schools, residential areas, and commute routes. For Type B, the school zone itself is not a hotspot, but the outside is a hotspot due to the correlation of surrounding spatial patterns. Designating this type as a school zone can significantly impact reducing the number of current hotspots outside the school zone. Safety measures implemented due to school zone have an effect in reducing traffic accidents [19–22]. In addition, since Type B school zones did not emerge as hotspots internally, it implies that they are relatively accident-free, and adjacent school zones are not identified as accident-prone areas. Therefore, when implementing safety measures for the identified external areas as hotspots, it is necessary to review the facilities and operational systems applied to nearby school zones before introducing them.

Type C represents a school zone classified as a hotspot, but the outside is not. Improvement is needed for management of institutions within the school zone or their operational system, considering the hotspot within the school zone in terms of spatial patterns. In order to enhance the safety of Type C school zones, improvements should be made by comparing them with Type A and Type B school

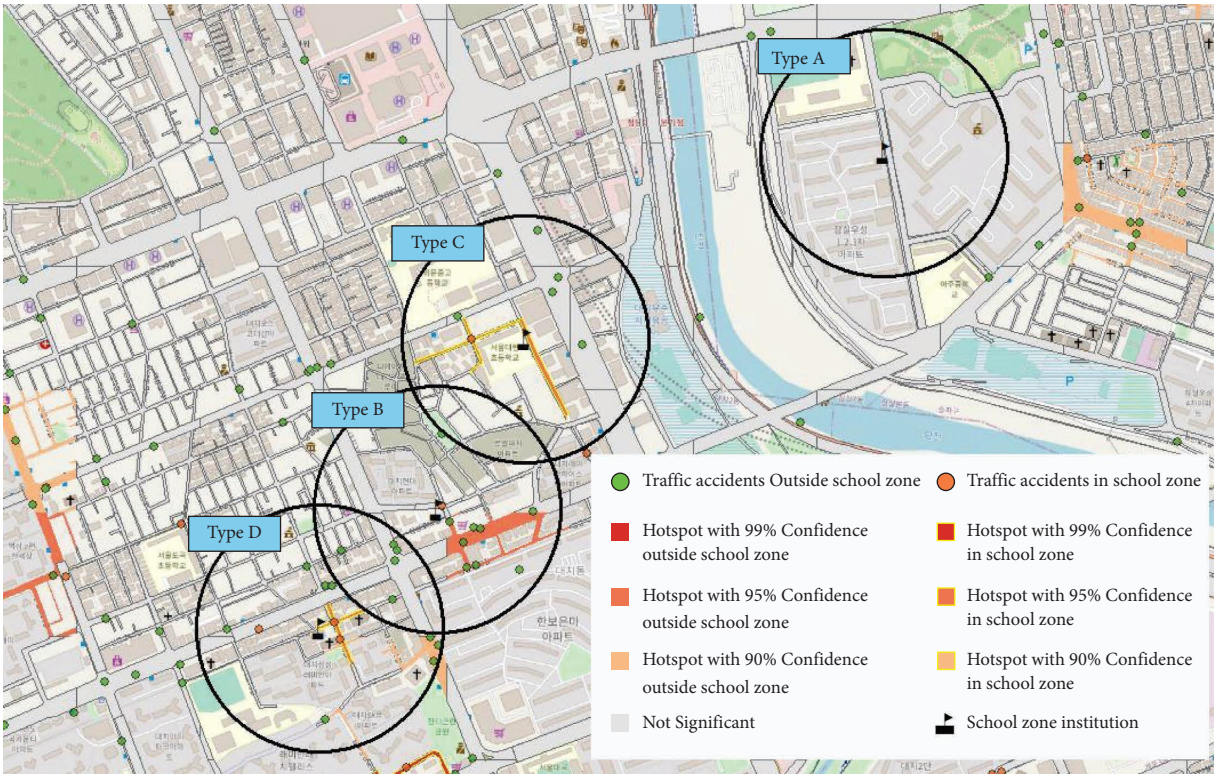


Figure 7: Results of a hotspot analysis in a school within a radius of 300 m.

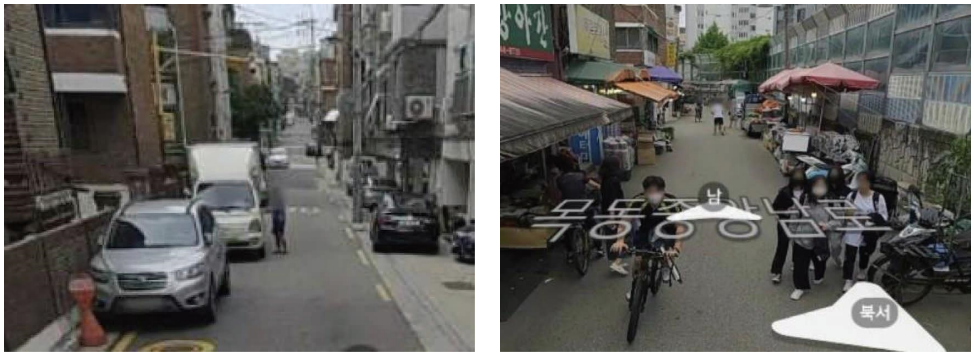
Table 5: Ratio of hotspots in and outside a school zone.

	School zone	Outside school zone	Counts	Ratio (%)
Type A	Hotspot X	Hotspot X	1,228	74.07
Type B	Hotspot X	Hotspot O	259	15.62
Type C	Hotspot O	Hotspot X	152	9.17
Type D	Hotspot O	Hotspot O	19	1.14
Total			1,658	100.0

zones. Finally, for Type D, both in and outside of a school zone within the 300 meters radius of the institution have been categorized as hotspots. These school zones are considered the most hazardous, as they have a high likelihood of accidents based on spatial autocorrelation, even if accidents have not occurred in and outside the school zone. This suggests potential issues both in and outside Type D school zones. Case study was conducted for Type B, Type C, and Type D to validate the results of this study.

4. Case Study

Hotspot analysis is characterized not only by relying on the number of accidents to identify high-risk roads or areas but also by considering spatial interactions and accident counts together to select risk groups. When performing a conventional analysis based solely on the number of accidents, improvement measures are prioritized for areas where accidents frequently occur. However, consideration is not given to school zones and areas outside school zones where accidents have not occurred but there is a risk of occurrence. In the case of hotspot analysis, the fact that school zones located near school zones where accidents have occurred also have a high likelihood of accidents due to geographical similarity implies that this is equally applicable to areas outside school zones. Among the four types, the institution classified as Type B and Type C were compared, and the validity of the results was verified. The Ministry of Education and the Ministry of the Interior and Safety are conducting joint safety inspections of children's commutes to schools to prevent traffic accidents involving children. The Korea Transportation Safety Authority (TS) has inspected a total of 31 school zones in Seoul, one of the road safety inspection institutions in Korea, over the past two years (2021-2022). They were classified into four types based on the proposed methodology. Jeongmok Elementary School (Type B) is surrounded by a small apartment complex and low-rise residential buildings. In Korea, the roads around low-rise residential buildings are narrower compared to apartment complexes. The separation between sidewalks and roadways is not well defined, and there are often illegal parking issues, making it difficult to have clear visibility. If these road areas are designated as children's school zones, the number of accidents within those areas would decrease. However, in areas that are not designated as school zones, the road environment is not favorable for pedestrians, resulting in a relatively high occurrence of accidents. This is a typical example of a Type B hotspot, which is not a hotspot within a school zone but outside of it. Figure 8 shows a significant commute route 200 m from a school, but it is not designated as a school zone, with frequent pedestrian accidents. The road in front of low-rise residential buildings in Figure 8(a)



(a) (b)

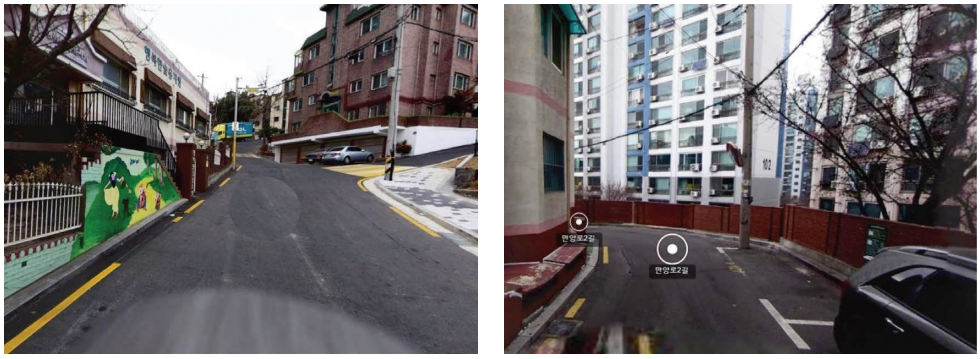
Figure 8: Within 200 m of an elementary school (a) cars parked in the low-rise residential building town and (b) in front of a market. Source: https://map.kakao.com street view.

(a) (b)

Figure 9: Anpyeong Elementary's School zone status (a) July 2018 and (b) July 2021. Source: https://map.kakao.com street view around Anpyeong Elem. school.

requires more parking spaces, whereas the road in front of a market in Figure 8(b) is not designated as a school zone for cars visiting the market. This road is a significant commute route located 300 m from the front entrance of a school, but it has not been designated as a school zone because of its surroundings, which poses a serious accident risk. Risk factors must be removed by overhauling nearby school institutions and designating the area as a school zone.

Conversely, Anpyeong Elementary School, classified as Type C, is located within a large apartment complex. The school zone around Anpyeong Elementary School was classified as a hotspot, but there were several risk factors in the school zone. For example, during our study period in July 2018, Anpyeong Elementary School did not have visually noticeable road surfacing, partially allowed curbside parking, red road surfacing for a school zone was applied only to one side of the road, did not have a reflector at the



(a) (b)

Figure 10: Happy Kindergarten's School zone status in 2019 (a) in and (b) outside. Source: https://map.naver.com street view around happy kindergarten.

intersection without a traffic light, and had limited visibility due to tree shadows as shown in Figure 9(a).

Improvements were made after the TS inspected children's commute routes in 2021. Figure 9(b) shows the school zone in July 2021. Red road surfacing has been applied throughout the school zone, and double yellow lines were added to prohibit curbside parking. Furthermore, the height of the fence for preventing jaywalking was also raised. Moreover, trees causing reduced visibility were partly removed, and a reflector and speed limit signboard were added to the intersection without a traffic light. These results imply spatial autocorrelation of the surrounding regions. The neighborhoods of Anpyeong Elementary School have large-scale apartment complexes in which school commute routes are limited and have all been designated as school zones. Thus, accidents do not occur outside a school zone and only occur in areas with insufficient institutions or inadequate operation. This study can be offered perspective in proactive prevention of traffic accidents. Type D is a classification of hotspots that includes both the interior and exterior of school zones, with the Happy Forest Kindergarten being a representative facility. Although this facility opened in August 2015, appropriate measures were not implemented until the nearby apartment redevelopment took place in 2020. While no accidents occurred in this school zone for the actual three-year period, hotspot analysis based on spatial autocorrelation revealed potential risk factors for accidents both in and outside the school zone, as depicted in Figure 10. Figure 10(a) represents the interior of the school zone, where safety signs and road markings were absent despite being a school zone. In addition, Figure 10(b) pertains to the outside the school zone, where some road sections were used as parking spaces due to a shortage. It results in insufficient pedestrian space. Moreover, the limited visibility in curved sections posed a potential conflict between vehicles and pedestrians. In such areas, priority measures should include installing safety signs and road markings in school zone. Subsequently, measures like installing public parking lots and clearing sightlines for pedestrian safety outside the school zone should be implemented.

5. Conclusions

After performing preprocessing on a total of 1,658 school zones in Seoul, a spatial analysis was conducted using traffic accident data. Subsequently, analysis units were selected by establishing a 300 m radius around school-zone institutions. Spatial autocorrelation was examined for both school zones and outside school zones. This suggests a correlation between traffic accidents involving children and the operation of school zones with their nearby surroundings. It was indicated that the occurrence of accidents in school zones adjacent to each other is associated within a 99% confidence level. Similarly, outside school zones, accidents were found to be associated with neighboring areas. Based on the derived spatial autocorrelation results, hotspot analysis was further conducted to categorize types according to the presence of hotspots school zones and outside school zones. Subsequently, case study was performed for each type to validate the results and derived validity. The results presented in this study could assist in determining whether there is a need for improvements in safety measures and speed limit operations within existing school zones or if expansion to areas outside school zones is necessary. Moreover, these results can be utilized by policymakers to establish criteria for prioritizing improvement measures in specific school zones. For instance, Type B (the school zone itself is not a hotspot, but the outside is a hotspot) school zones may demonstrate sufficient accident prevention effects, but outside school zones, the accident prevention effect may be lower compared to within school zones. In such cases, proposing measures like expanding school zones could be recommended to ensure a similar level of safety both inside and outside school zones. Type C school zones, on the other hand, may indicate that the measures implemented within the zones are not adequately preventing accidents. Therefore, for Type C (school zone classified as a hotspot, but the outside is not) school zones, applying safety measures used in Type A (school zones have no hotspots within the 300 meters radius) and Type B zones (the school zone itself is not a hotspot, but the outside is a hotspot) might be necessary. Type D school zones (both in

and outside of a school zone within the 300 meters radius of the institution), identified as requiring the most immediate improvements compared to other school zones, should undergo separate inspection, and safety measures should be implemented with the highest priority. However, it is important to note that while this study can identify specific institutions requiring school zone expansion or prioritize targets for improvement projects, it has not thoroughly examined the facilities or operational systems that could effectively prevent accidents. Future research should incorporate spatial modeling into data with existing spatial interactions to identify variables significantly impacting accident prevention. Nevertheless, these study findings could contribute to informed decision-making, preventing excessive budget expenditure on expanding school zones solely based on parental requests and enhancing safety management for children commuting to school.

Data Availability

The school-zone institution and zone data that support the findings of this study are available from the website https://map.seoul.go.kr/smgis2/short/6ODrL, but crash data are not publicly available due to privacy policy restrictions.

Conflicts of Interest

The authors declare that there are no conflicts of interest regarding the publication of this paper.

Acknowledgments

The Korea Transportation Safety Authority has advised and provided support for the details on traffic safety inspections on children's commute routes.

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