The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences, Volume L-4/W1-2026
Free and Open Source Software for Geospatial (FOSS4G) 2026 – Academic Track "Bridging Geospatial Technology and Humanity",
30 August–5 September 2026, Hiroshima, Japan

How Does Walkability for Elderly People Differ between Hilly and Flat Urban Areas? A Case Study of Shin-Yurigaoka Station and Nagareyama-Otakanomori Station

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Keywords: Walkability, Elderly People, Space Syntax, Angular Segment Analysis, Slope Analysis, Suburban Railway Station Areas

Abstract

This study evaluates station-area environments that enable elderly people to walk comfortably in their daily lives. Conventional walkability assessments often emphasize street connectivity and proximity to destinations, but they do not fully capture walking burdens specific to elderly people, such as slopes and elevation differences. Therefore, this study examines whether some streets evaluated as central by Space Syntax within a street network are also streets that elderly people can walk on comfortably. The study areas are Shin-Yurigaoka Station, located in a hilly suburban area, and Nagareyama-Otakanomori Station, located in a relatively flat suburban area. A pedestrian network was extracted using OpenStreetMap road data, and Normalized Angular Integration and Normalized Angular Choice were calculated through Angular Segment Analysis in Space Syntax. The layer of high-centrality roads is overlaid on the layer of 5% or less slope roads, and that of 8% or less slope roads. In addition, field observation, pedestrian counts, interviews, and Mapillary photography were conducted to examine whether the central streets identified in the Space Syntax analysis corresponded to actual walking environments. This comparison shows that around Shin-Yurigaoka, some of the highly central streets include steeper slopes and may impose burdens on elderly people. By contrast, around Nagareyama-Otakanomori, low-slope streets are distributed more widely, suggesting a more comfortable walking environment. In conclusion, this study demonstrates both the usefulness and limitations of walkability assessments for elderly people by combining Space Syntax, slope analysis, and field survey. It also provides a workflow using open data and open-source GIS tools.

1. Introduction

Japan is experiencing rapid population aging, and the importance of urban environments that allow elderly people to continue walking in daily life is increasing. According to the Cabinet Office, Japan's aging rate has reached 29.3%, and the proportion of elderly people is expected to remain high in the future (Cabinet Office, 2025). The World Health Organization also notes that the health and quality of life of elderly people are influenced not only by individual physical capacity but also by housing and community environments (WHO, 2025). Walking is a fundamental mode of mobility that supports shopping, medical visits, access to public facilities, and social participation. Therefore, how to evaluate and improve urban environments that are easy for elderly people to walk in is an important issue shared by health, welfare, and urban planning.

In relation to this issue, walkability assessment has become important in urban planning as a way to create pedestrian-oriented urban spaces. The Ministry of Land, Infrastructure, Transport and Tourism promotes the creation of city centers that are comfortable and encourage walking in response to population decline, population aging, and the decline of local vitality (MLIT, 2024). Previous studies have also shown that walking behavior is associated with built-environment factors such as land use, density, street connectivity, proximity to destinations, and safety (Saelens and Handy, 2008). However, when walking by elderly people is the focus, conventional walkability indicators may be insufficient. Their walking behavior is affected by physical function, walking speed, slope burden, perceived security, and subjective ease of walking (Barnett et al., 2017; Zhao et al., 2024). Recent reviews have also suggested that the relationship between walking among elderly people and the built environment may include nonlinearity and thresholds, making evaluation at a finer spatial scale necessary (Shen et al., 2025).

When evaluating walking environments for elderly people at a fine spatial scale, topographical conditions are particularly important in suburban areas of Japan's large metropolitan regions. Since the period of rapid economic growth, large-scale housing estates and new towns have been developed to respond to population concentration and housing shortages. In particular, since the 1960s, many large planned housing estates have been developed on hillsides and other suburban landforms around major cities (Hayashi, 2010). In such hilly suburban residential areas, slopes and elevation differences may become walking burdens even when the distance to stations or commercial facilities is short. In Japanese urban transport planning, the need to evaluate topographical conditions has also been pointed out, and sloped urban areas may affect outing behavior and transport mode choice because of the mobility burden created by gradients (Hayauchi et al., 2021). Therefore, evaluating walking environments for elderly people around hilly suburban stations requires consideration not only of planar distance and proximity to facilities but also of slopes and elevation differences.

However, slopes and elevation differences alone cannot fully capture the overall walking environment around a station. Walking environments are influenced not only by individual road conditions but also by the structure of the entire street network. Space Syntax has been developed as a method for quantitatively analyzing the configurational structure of urban space and understanding its relationship with human movement and space use. Hillier et al. (1993) showed that street configuration is related to pedestrian movement patterns, and Hillier and Iida (2005) showed that urban movement is affected not only by simple shortest distance but also by geometric and topological elements such as angular change and direction change. Space Syntax is therefore an effective analytical method for identifying which streets around a station are structurally central and which streets are likely to be used as through routes.

Thus, evaluating walking environments for elderly people requires an integrated understanding of the built environment, topographical conditions, and street-network structure. Recent studies have combined Space Syntax and GIS to evaluate walkable streets by integrating street-network structure and slope (Şahin Körmeçli, 2023). However, many previous studies focus on general walkable street networks, and studies that integrate walking catchments based on elderly people's walking speed, hilly suburban station areas in Japan, and field verification remain limited. This study therefore combines Space Syntax-based street-network analysis with slope analysis derived from DEM data to identify streets that may be easy for elderly people to walk on in hilly suburban station areas. In addition to Shin-Yurigaoka Station, this study compares Nagareyama-Otakanomori Station, which differs in its topographical condition and urban development process, and examines the relationship between GIS-based results and actual walking environments through field observation and interviews. The contribution of this study is to apply the existing Space Syntax and GIS framework to the assessment of walkability for elderly people and to demonstrate the usefulness and limitations of slope-aware walkability assessment through comparison of different suburban station areas.

2. Study Area

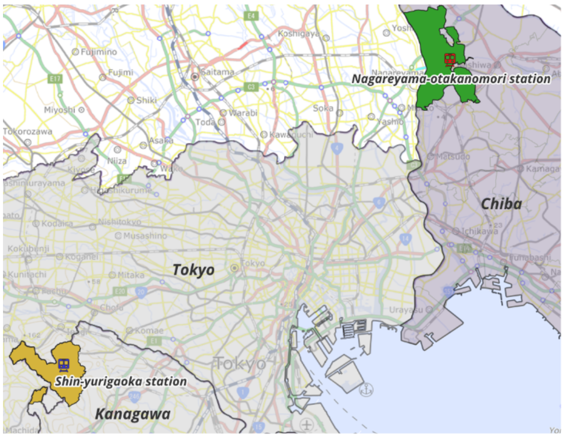


Figure 1. Location of the study areas

This study examines the areas around two suburban railway stations in the Tokyo metropolitan region: Shin-Yurigaoka Station in Asao Ward, Kawasaki City, Kanagawa Prefecture, and Nagareyama-Otakanomori Station in Nagareyama City, Chiba Prefecture. Both areas are suburban centers where residential districts, commercial facilities, and public spaces have formed around railway stations, but they differ in topographical conditions, development period, and station-front spatial planning. By comparing these differences, this study examines how street-network centrality and slope conditions affect walking environments for elderly people.

The area around Shin-Yurigaoka Station is positioned as a regional center in northern Kawasaki City, with commercial facilities, administrative facilities, cultural facilities, and residential areas concentrated around the station. According to Kawasaki City materials, land readjustment was implemented around the north side of the station after the station opened, but about 40 years have passed with limited renewal of major facilities and functions, and improvement of the traffic environment and reorganization of urban functions are now recognized as issues (Kawasaki City, 2026). The same materials note that, in addition to population growth caused by residential development in surrounding areas, the hilly topography has led to substantial car use around the station, and safe and smooth traffic environments for pedestrians and vehicles are required (Kawasaki City, 2026). Furthermore, the topographic map of Asao Ward indicates elevation differences of roughly 10 m to 120 m in the legend, suggesting that hilly terrain with elevation variation on the order of 100 m extends across the ward (Kawasaki City, 2019). Such topographical conditions may create walking burdens for elderly people that cannot be captured by distance alone.

By contrast, Nagareyama-Otakanomori Station is a transport node where the Tsukuba Express and Tobu Noda Line intersect. Around the approximately 30 ha station-front center district, townscape development has been promoted through integrated design of station-front spaces, roadside spaces, and green spaces (Nagareyama City, 2017). The district emphasizes the concept of a forest town closest to central Tokyo, with attention to coordination between the station plaza and lower floors of buildings, characterization of individual streets, creation of pedestrian spaces through public-private collaboration, and networks connected to surrounding greenery (Nagareyama City, 2017). According to preliminary results of the 2025 Population Census, Nagareyama City had the highest population growth rate in Chiba Prefecture, increasing by 15,281 people, or 7.65%, from 2020 to 2025 (Chiba Prefecture, 2026). Therefore, the area around Nagareyama-Otakanomori Station can be characterized as a newly planned suburban station area developed against the background of population growth.

Based on these characteristics, this study compares Shin-Yurigaoka Station, which has hilly terrain and features of an established urban area, with Nagareyama-Otakanomori Station, which is relatively new and planned. Through this comparison, the study examines the effectiveness of overlaying slope conditions on Space Syntax-based street-network evaluation under different urban conditions.

3. Methods

3.1 Data

To understand road spaces around stations that are easy for elderly people to walk on, this study used OpenStreetMap (OSM) road data, the 5 m mesh Digital Elevation Model (DEM) of the Fundamental Geospatial Data provided by the Geospatial Information Authority of Japan, station center points, and field-survey data. OSM road data were obtained using the QuickOSM plugin in QGIS and were used to create the pedestrian network, conduct Space Syntax analysis, and summarize road length. The DEM was used to calculate the longitudinal slope of each road segment. Station center points were set as origins for 15-minute walking-catchment analysis around Shin-Yurigaoka Station and Nagareyama-Otakanomori Station. Field-survey data were collected to verify the actual conditions of road segments extracted by GIS analysis, including observation of walking environments, pedestrian counts, interviews, and pedestrian-view image records using Mapillary.

The analysis was based on QGIS. QuickOSM was used to obtain OSM road data, QNEAT3 was used for walking-catchment analysis, and Space Syntax Toolkit and depthmapXnet were used for Space Syntax analysis. By combining geospatial data such as OSM, DEM, and Mapillary with open-source GIS tools related to QGIS, this study was designed as a practical workflow for evaluating walking environments around stations.

3.2 Analytical Settings

The analysis area was defined as the area reachable within 15 minutes from each station center point, assuming station access on foot by elderly people. Walking speed was set at 47 m/min for people aged 65 years or older, and the walking distance for 15 minutes was standardized as 705 m. This setting was used to define a practical walking catchment around each station, based on previous research examining accessibility to community facilities in relation to topographical conditions for elderly people (Satoh and Yoshikawa, 2005). In the QNEAT3 Iso-Area function, the prepared pedestrian network was used as the Network layer, the station center point was used as the Start point, and catchments based on walking speed were extracted. In the Space Syn-

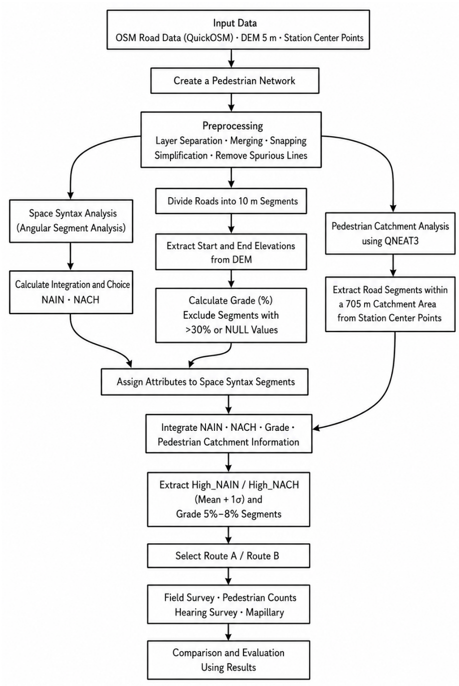


Figure 2. Analytical workflow of this study

tax analysis, the Metric Radius was also set to 705 m to maintain consistency with the walking catchment.

For slope conditions, roads with slopes of 5% or less were defined as relatively easy-to-walk low-slope roads, and roads with slopes of 8% or less were defined as a broader tolerance condition. These thresholds were based on sidewalk longitudinal-gradient standards, in which the standard value is 5% or less and 8% or less is allowed when unavoidable because of topographical conditions or other constraints (MLIT, 2005). In this study, these standards were not used as direct criteria for barrier-free compliance, but as analytical conditions for evaluating topographical walking burden for elderly people in stages.

3.3 Space Syntax and Angular Segment Analysis

Space Syntax (SS) is a method for treating streets as a network and quantitatively evaluating to-movement potential and through-movement potential within urban space. Hillier et al. (1993) proposed the theory of natural movement, which argues that pedestrian movement is generated more by the configuration of the street network itself than by the distribution of destinations. Spatial configuration is the primary factor shaping flows of people, while destinations amplify those flows. Space Syntax theory was originally based on axial analysis, which models space using the longest lines of sight and movement, known as axial lines.

However, axial analysis has the limitation that curvilinear roads may be divided in ways that do not adequately represent them. It has also been shown that people consider not only the number of turns but also the angle of each turn when choosing routes (Hillier and Iida, 2005). Therefore, this study adopted Angular Segment Analysis, which can more accurately reflect the cognitive mechanisms of human route choice. This method divides roads at intersections and evaluates movement cost by the cumulative angle of turns, or angular distance. Routes close to straight movement have lower cost, while routes with larger direction changes have higher cost.

The main indicators of centrality are Integration and Choice. Integration indicates to-movement potential, or the tendency of a space to be reached from the whole system with small angular change. Choice indicates through-movement potential, or the extent to which a road is included in shortest paths (van Nes and Yamu, 2021). This study also used NAIN and NACH, normalized versions of these indicators, to objectively compare areas of different sizes (Hillier et al., 2012). In this study, NAIN is interpreted as normalized to-movement potential and NACH as normalized through-movement potential. However, SS indicators show only network-structural potential and do not directly reflect microscopic environmental factors such as slope or sidewalk width. Therefore, comprehensive evaluation of walking environments for elderly people requires combining macro-scale SS analysis with micro-scale evaluations such as slope analysis and field surveys.

3.4 Street Network Analysis

Based on OSM road data, a road network that pedestrians can actually use was created. Around station-front spaces, not only ground-level roads but also pedestrian decks, stairs, ramps, crosswalks, and sidewalks were included to reproduce actual pedestrian routes as closely as possible. By contrast, roads not normally used by general pedestrians, such as roads within private sites, roads in parking lots, private roads, indoor roads, and roads with private access, were excluded. On major roads, sidewalks were retained as separate lines, while on smaller roads, the network was adjusted to avoid duplicate parallel representation of sidewalks and carriageways. Crossings were connected in principle where crosswalks existed, but on small roads of about one lane, crossing was treated as possible regardless of the presence or absence of a marked crosswalk.

In preprocessing the road network, ground-level layers, grade-separated layers, and stair layers were separated based on OSM attributes and then integrated into an analytical network. Intersections were split, duplicate geometries were removed, snapping was applied, line simplification was performed using the Douglas-Peucker method, invalid geometries were repaired, and isolated lines were removed. Because preprocessing and line simplification can affect analysis results when road center lines are used for Angular Segment Analysis, the road center line simplification principles proposed by Kolovou et al. (2017) were used as a reference.

Using the prepared pedestrian network, Angular Segment Analysis was performed in QGIS with the Space Syntax Toolkit plugin and depthmapXnet. The calculated indicators were Integration, Choice, NAIN, and NACH. In this study, NAIN was treated as an indicator of to-movement potential around the station, while NACH was treated as an indicator of through-movement potential, and the two indicators were analyzed separately.

3.5 Slope Analysis

To evaluate walking burden on roads, the longitudinal slope of each road segment was calculated using the DEM. First, the prepared pedestrian network was divided into segments of up to 10 m, and a unique ID was assigned to each 10 m segment. Next, the start and end points of each segment were extracted, and elevation values were obtained from the 5 m mesh DEM. Letting the start-point elevation be Z_{start}, the end-point elevation be Z_{end}, and the actual segment length be length, slope was calculated as $\text{grade}(\%) = |Z_{\text{end}} - Z_{\text{start}}| / \text{length} \times 100$. This calculation follows the general method for obtaining percent slope by dividing elevation difference by horizontal distance and multiplying by 100 (U.S. Geological Survey, n.d.). Because the denominator used the actual length of each segment rather than a fixed 10 m value, terminal segments shorter than 10 m could also be handled. The 10 m segment length corresponds to about two cells of the 5 m mesh DEM and was set as a unit that can capture short-distance slope changes felt by pedestrians while reducing the effect of local elevation errors.

Because DEM effects and features such as bridges or grade-separated structures may produce unnaturally high values for actual walking slope, slope values exceeding 30% were treated as outliers and converted to NULL, while the road features themselves were not deleted. OSM steps were included in the pedestrian network, but the main purpose of this study was not to evaluate the slope of stairs themselves, but to understand the continuous longitudinal slope of roads and sidewalks.

3.6 Integration of Space Syntax Metrics and Slope

Road segments obtained from Space Syntax analysis and the 10 m road segments created to calculate slopes from the DEM have different spatial units. Therefore, slope values calculated at 10 m intervals were aggregated to the Space Syntax segments. As a result, NAIN, NACH, mean slope, and slope values after outlier processing were assigned to each Space Syntax segment.

To extract road segments with high to-movement potential or high through-movement potential, High_NAIN and High_NACH were defined as NAIN and NACH values at or above the mean plus one standard deviation. This threshold was used to identify road segments with distinctly high centrality relative to the distribution within each station-area network. High_NAIN roads with slopes of 5% or less were treated as roads with high to-movement potential and relatively low topographical burden, while High_NACH roads with slopes of 5% or less were treated as roads with high through-movement potential and relatively low topographical burden. The same overlay was also conducted using a slope threshold of 8% or less to examine how the identified road segments expanded when the slope condition was relaxed. This procedure evaluated walking environments around stations by combining to-movement and through-movement potentials with topographical walking burden.

3.7 Field Observation and Interview Survey

To verify the actual conditions of road segments extracted through GIS analysis, field observation, pedestrian counts, interview surveys, and Mapillary photography were conducted around Shin-Yurigaoka Station and Nagareyama-Otakanomori Station. The survey dates were 11 May 2026 for Shin-Yurigaoka Station and 18 May 2026 for Nagareyama-Otakanomori Station, and the weather was sunny on both days. Pedestrian counts were conducted from 10:30 to 10:45, and interview surveys were conducted from 10:45 to 11:30 by two surveyors. Pedestrian counts were recorded every five minutes for 15 minutes at the interview-survey locations.

The interviews targeted pedestrians aged 65 years or older who were walking toward the station. Responses were obtained from 13 people in total on Routes A and B at Shin-Yurigaoka Station and from 4 people in total on Routes A and B at Nagareyama-Otakanomori Station. Observation items included sidewalk width, impression of slope, steps or level differences, benches and resting places, shade, proximity to cars, risk of contact with bicycles, ease of signals and crossings, and pedestrian volume. The design of walking-environment checklist items and five-point evaluation in the field survey referred to previous research that collected subjective evaluations by road segment using five-point Likert scales for items such as ease and enjoyment of walking in walkability assessment (Oba et al., 2025). Interview-survey points were selected from roads that provide access to the station and have similar distances at each station, focusing on sections with different slope conditions. Route A was defined as a High_NAIN road with a slope of 5% or less, and Route B was defined as a High_NACH road with a slope of 5% or less that did not overlap with Route A.

Mapillary routes were set to supplement the verification of interview-survey points. Routes 1 and 2 corresponded to Routes A and B, respectively, and were photographed because updates or pedestrian-view images were insufficient. Routes 3 and 4 were set to record roads where existing Mapillary data were insufficient or unavailable.

Route	Corresponding GIS condition	Distance	Mean slope	Max. slope	Respondents	Ped. count
Shin-Yurigaoka						
A	High_NAIN ∩ slope ≤ 5%	152.0 m	2.06%	4.57%	8	159
B	High_NACH ∩ slope ≤ 5%, not overlapping Route A	131.2 m	4.61%	11.97%	5	143
Nagareyama-Otakanomori						
A	High_NAIN ∩ slope ≤ 5%	83.7 m	3.32%	4.26%	3	20
B	High_NACH ∩ slope ≤ 5%, not overlapping Route A	94.9 m	2.25%	2.25%	1	131

Table 1. Overview of interview-survey points

4. Results

4.1 Walkable Catchment and Street Network Characteristics

For Shin-Yurigaoka Station and Nagareyama-Otakanomori Station, this study set a 15-minute walking catchment centered on each station and used the walkable roads within that area as the analysis target. The 15-minute walking catchment of Shin-Yurigaoka Station covered 89.36 ha, the target road length was 34,176.87 m, and road density was 382.6 m/ha. By contrast, the 15-minute walking catchment of Nagareyama-Otakanomori Station covered 94.74 ha, the target road length was 33,153.94 m, and road density was 350.0 m/ha. The target road lengths at the two stations did not differ greatly, but the area around Shin-Yurigaoka Station showed slightly higher road density. This confirms that, although the two stations have walking catchments of similar scale, their street-network densities differ to some extent.

4.2 Space Syntax Results

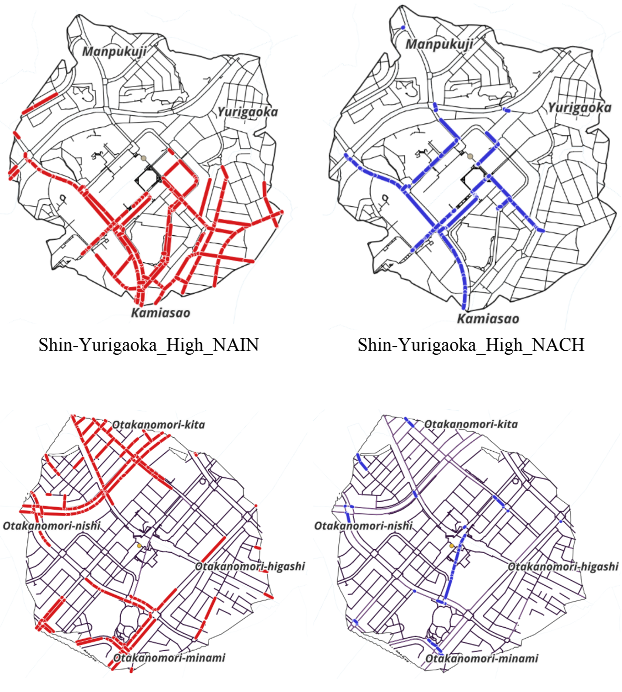
In the Space Syntax analysis, NAIN and NACH were calculated for each road segment through Angular Segment Analysis. NAIN was used as an indicator of roads that are easy to reach as destinations around the station, while NACH was used as an indicator of roads likely to be passed through as routes. In this study, roads whose values were equal to or greater than the mean plus one standard deviation among the target roads at each station were extracted as High_NAIN roads and High_NACH roads, respectively, and treated as central roads around the station.

In terms of road length, High_NAIN roads measured 6,280.75 m at Shin-Yurigaoka Station and 6,411.01 m at Nagareyama-Otakanomori Station, showing almost the same level at both stations. By contrast, High_NACH roads measured 2,275.61 m at Shin-Yurigaoka Station and 798.16 m at Nagareyama-Otakanomori Station, with Shin-Yurigaoka greatly exceeding Nagareyama-Otakanomori. This indicates that, although the length of roads with high to-movement potential was similar between the two stations, the distribution of roads with high through-movement potential differed.

The spatial overlap between High_NAIN and High_NACH also differed. At Shin-Yurigaoka, the Jaccard Index was 22.80%, which was higher than the 5.67% at Nagareyama-Otakanomori (Table 2). At Shin-Yurigaoka, 69.82% of High_NACH overlapped with High_NAIN, indicating that many roads with high through-movement potential were also roads with high to-movement potential. However, only 25.30% of High_NAIN overlapped with High_NACH, meaning that not all roads with high to-movement potential were major through-movement routes. At Nagareyama-Otakanomori, the share of High_NAIN overlapping High_NACH was low at 6.03%, confirming that only part of the road network with high to-movement potential functions as through routes.

Indicator	Shin-Yurigaoka	Nagareyama-Otakanomori
Jaccard Index (%)	**22.80%**	**5.67%**
Share of High_NACH overlapping High_NAIN (%)	**69.82%**	**48.44%**
Share of High_NAIN overlapping High_NACH (%)	**25.30%**	**6.03%**

Table 2. Spatial overlap between High_NAIN and High_NACH roads



Shin-Yurigaoka_High_NAIN Shin-Yurigaoka_High_NACH

Nagareyama-Otakanomori_High_NAIN Nagareyama-Otakanomori_High_NACH

Figure 3. Distribution maps of NAIN and NACH

4.3 Slope Analysis Results

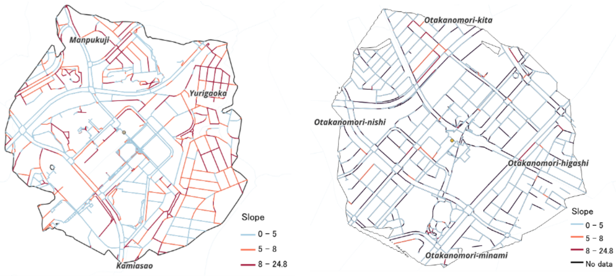
Next, road slope was calculated using the DEM, and topographical conditions related to walking burden were compared. Slopes were classified into three categories: 5% or less, 5–8%, and greater than 8%. Roads with slopes of 5% or less were treated as relatively easy-to-walk low-slope roads, roads with slopes of 5–8% as moderate-slope roads that may impose some burden on elderly people, and roads with slopes greater than 8% as roads that may impose substantial walking burden.

At Shin-Yurigaoka Station, roads with slopes of 5% or less measured 18,540.7 m and accounted for 54.2% of the total, roads with slopes of 5–8% measured 8,375.5 m and accounted for 24.5%, and roads with slopes greater than 8% measured 7,260.68 m and accounted for 21.2%. Roads with slopes of 8% or less measured 26,916.2 m, accounting for 78.7% of the total. At Nagareyama-Otakanomori Station, roads with slopes of 5% or less measured 22,733.3 m and accounted for 68.6% of the total, roads with slopes of 5–8% measured 897.2 m and accounted for 2.7%, and roads with slopes greater than 8% measured 810.0 m and accounted for 2.4%. NULL sections without assigned slope values measured 8,709.61 m and accounted for 26.2% of the total (Table 3, Figure 4).

At Shin-Yurigaoka Station, slope data were assigned to almost all roads, and roads with slopes greater than 8% accounted for about 20% of the total. By contrast, although NULL sections must be considered at Nagareyama-Otakanomori Station, among roads that could be classified, many were low-slope roads of 5% or less, and steep roads greater than 8% were limited. Therefore, in terms of topographical conditions, roads with smaller walking burden were more widely distributed around Nagareyama-Otakanomori Station.

Slope category	Shin-Yurigaoka (m)	Share	Nagareyama-Otakanomori (m)	Share
≤ 5%	18,540.7	**54.2%**	22,733.3	**68.6%**
≤ 8%	26,916.2	**78.7%**	23,630.5	**71.3%**
> 8%	7,260.68	**21.2%**	810	**2.4%**
No data	0	0%	8709.61	26.2%
5–8% (increase)	**8,375.5 m**	**24.5%**	**897.2 m**	**2.7%**
Target road length (denominator)	**34,176.87 m**	—	**33,153.94 m**	—

Table 3. Road length and share by slope category



Shin-Yurigaoka Nagareyama-Otakanomori

Figure 4. Slope classification maps

4.4 Combined Results of Network Centrality and Slope

The overlap between central roads extracted by Space Syntax and low-slope roads was then analyzed. This analysis examined whether roads that are important in the street network also satisfy conditions of low walking burden.

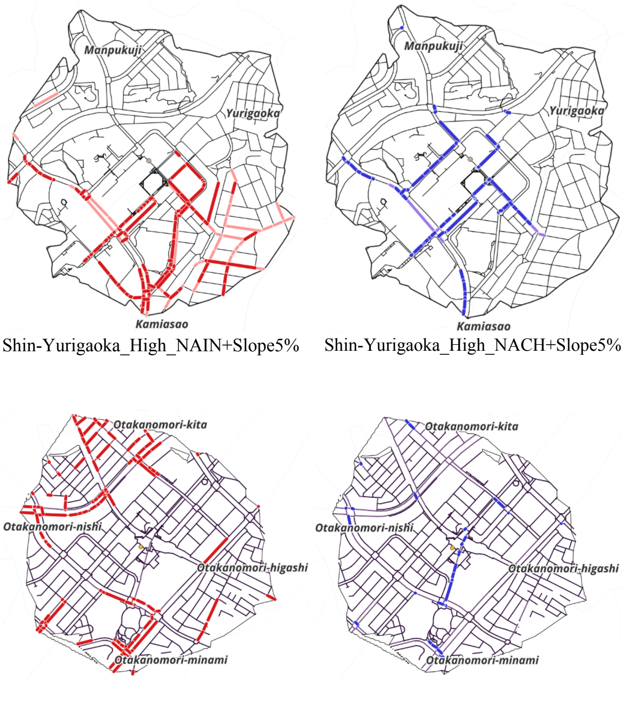
The overlapping length of High_NAIN roads and roads with slopes of 5% or less was 3,362.77 m at Shin-Yurigaoka Station and 4,018.36 m at Nagareyama-Otakanomori Station. Their shares of the total road length were 9.84% and 12.12%, respectively, meaning that under the low-slope condition of 5% or less, Nagareyama-Otakanomori Station showed a longer length. When the condition was expanded to slopes of 8% or less, the length increased to 5,253.47 m at Shin-Yurigaoka Station and 4,166.33 m at Nagareyama-Otakanomori Station. At Shin-Yurigaoka Station in particular, the increase from the 5% or less condition to the 8% or less condition was large, at 1,890.70 m, confirming that many High_NAIN roads include moderate slopes of 5–8%. At Nagareyama-Otakanomori Station, the increase under the same condition was only 147.97 m (Table 4, Figure 5).

For High_NACH roads, the overlapping length with slopes of 5% or less was 1,746.52 m at Shin-Yurigaoka Station and 607.21 m at Nagareyama-Otakanomori Station. When the condition was expanded to slopes of 8% or less, the length at Shin-Yurigaoka Station increased to 2,050.53 m, while it remained 607.21 m at Nagareyama-Otakanomori Station. This indicates that, although High_NACH roads are limited at Nagareyama-Otakanomori Station, many of them are already included in the low-slope condition of 5% or less.

These results show that, at Shin-Yurigaoka Station, central roads, especially High_NACH roads, have relatively large lengths, but some include roads with moderate or steeper slopes. In other words, even major movement routes around the station may impose walking burden because of topographical conditions. At Nagareyama-Otakanomori Station, by contrast, although the length of High_NACH roads is limited, low-slope roads are widely distributed and central roads also overlap with relatively flat conditions. This suggests that a pedestrian network with low physical burden has been formed around Nagareyama-Otakanomori Station.

Condition	Length (m)	Total share	Increase (m)	Increase share
Shin-Yurigaoka				
High NAIN ∩ slope ≤ 5%	3,362.77	9.84%	—	—
High NAIN ∩ slope ≤ 8%	5,253.47	15.37%	1,890.70	5.53%
High NACH ∩ slope ≤ 5%	1,746.52	5.11%	—	—
High NACH ∩ slope ≤ 8%	2,050.53	6.00%	304.01	0.89%
Nagareyama				
High NAIN ∩ slope ≤ 5%	4,018.36	12.12%	—	—
High NAIN ∩ slope ≤ 8%	4,166.33	12.57%	147.97	0.45%
High NACH ∩ slope ≤ 5%	607.21	1.83%	—	—
High NACH ∩ slope ≤ 8%	607.21	1.83%	0	0%

Table 4. Overlay results of High_NAIN/High_NACH and low-slope roads



Shin-Yurigaoka_High_NAIN+Slope5% Shin-Yurigaoka_High_NACH+Slope5%

Nagareyama-Otakanomori_High_NAIN+Slope5% Nagareyama-Otakanomori_High_NACH+Slope5%

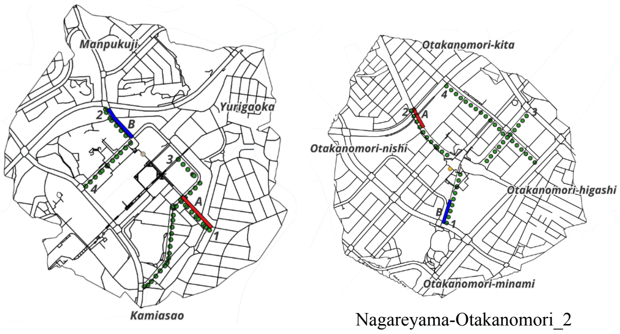
Figure 5. Overlay maps of High_NAIN/High_NACH and low-slope roads

4.5 Field Observation and Interview Results

Finally, to confirm the correspondence between road conditions indicated by GIS analysis and actual walking environments, field observation, pedestrian counts, and interviews were conducted around each station. The survey routes were set as pedestrian routes that actually provide station access, while referring to central roads and low-slope conditions extracted by GIS analysis (Figure 6).

At Shin-Yurigaoka Station, Route A had a mean slope of 2.06% and a maximum slope of 4.57%, making it a relatively flat section. By contrast, Route B had a mean slope of 4.61% and a maximum slope of 11.97%, including locally steep slopes. In the five-point interview evaluation, Route A received high scores for ease of walking (mean 4.25), perceived security (5.00), and comfort (4.38), whereas Route B received lower scores for ease of walking (2.60) and comfort (3.60). Free responses evaluated greenery and safety on Route A, while slopes, narrow sidewalks, and lack of shade were raised as dissatisfactions on Route B. Pedestrian counts were high on both routes, with 159 people on Route A and 143 people on Route B, and the shares of elderly people were 37.7% and 36.4%, respectively. Around Shin-Yurigaoka Station, routes were frequently used as daily-life movement paths, but evaluations of the walking environment differed by route.

At Nagareyama-Otakanomori Station, Route A had a mean slope of 3.32% and a maximum slope of 4.26%, while both the mean and maximum slopes of Route B were 2.25%, indicating that both routes were relatively flat. In the interviews, the mean ease-of-walking score was 5.00 for both Route A and Route B, and respondents positively evaluated wide sidewalks, straight and easy-to-understand routes, and the presence of greenery and shade. However, because the number of respondents was small, with 3 people on Route A and 1 person on Route B, the interpretation of these evaluation results requires caution. Pedestrian counts were 20 people on Route A and 131 people on Route B, indicating that Route B, which connects the station-front plaza and the park, was used more heavily. These field-survey results show that a low-slope and comfortable walking environment has been formed around Nagareyama-Otakanomori Station, while around Shin-Yurigaoka Station, even central roads and highly used routes are affected by slopes and sidewalk conditions.



Shin-Yurigaoka_1 Nagareyama-Otakanomori_2

Figure 6. Field-survey points (red and blue) and Mapillary routes (green)

5. Discussion

This study examined whether central roads around stations are easy for elderly people to walk on by overlaying Space Syntax-based street-network analysis with slope analysis. First, the High_NAIN and High_NACH results revealed network characteristics around each station. At Shin-Yurigaoka, many High_NACH roads overlapped with High_NAIN roads, suggesting that a certain set of roads has high network potential where both intentional visits and through movement are concentrated. At Nagareyama-Otakanomori, by contrast, High_NAIN roads were distributed relatively widely, while High_NACH roads were concentrated on some streets.

However, High_NAIN and High_NACH are indicators of centrality within the road network and do not directly reflect walking-environment factors such as slope, sidewalk width, level differences, or traffic volume. At Shin-Yurigaoka, highly central roads are important pedestrian routes, but automobile traffic and pedestrian flows may also concentrate on them. Kawasaki City's town-development policy also points out that, around the station, conflicts between pedestrian and vehicle flows and elevation differences can become walking burdens for elderly people and others. Therefore, being theoretically central does not necessarily mean that a road is easy for elderly people to walk on.

By contrast, the broad distribution of High_NAIN and the concentration of High_NACH on some roads at Nagareyama-Otakanomori indicate a network structure in which through movement is consolidated on selected roads while circulation within the living sphere is maintained. High_NAIN and High_NACH were extracted only in limited parts of the station-front center, but this does not mean that the walking environment is weak. Rather, this result is consistent with the planning intention of the area's Townscape Guidelines, such as routes for liveliness and circulation. Road improvement projects have also reorganized pedestrian-priority spaces through measures such as sidewalk widening by one-way conversion and speed reduction by slalom-like street design. Therefore, at Nagareyama-Otakanomori, major through routes and spaces for pedestrian circulation and staying may be functionally separated, and this separation and improvement of pedestrian spaces can be interpreted as consistent with the direction of walkable city-center development promoted by MLIT.

The main significance of this study lies in overlaying slope conditions on network centrality. Even when a road is central, a large slope increases physical burden for elderly people. At Shin-Yurigaoka, when the low-slope condition was relaxed from 5% or less to 8% or less, the number of applicable central roads increased substantially. This indicates that many central roads at Shin-Yurigaoka include moderate-slope sections above 5%. At Nagareyama-Otakanomori, by contrast, the change between the

5% and 8% conditions was small, suggesting that many central roads were already low-slope roads.

Comparing GIS analysis with field surveys suggests that even central and low-slope roads cannot be fully explained by GIS indicators alone in terms of actual ease of walking. Walking environments for elderly people may be influenced not only by slope but also by sidewalk width, level differences, traffic volume, resting places, shade, and crossing environments. Therefore, GIS analysis is effective for extracting roads that should be investigated in detail, but evaluation of actual walkability for elderly people requires combination with field observation and interview surveys.

These findings indicate that walkability assessment for elderly people should integrate not only walking catchments and street centrality but also slopes and the quality of pedestrian spaces. Especially in hilly suburban residential areas, practical station access may be reduced by slope even when a location is close to a station. The practical significance of this study is that its method can identify roads that satisfy High_NAIN or High_NACH but impose large slope burdens as priority targets for improvement.

Another feature of this study is that it combines geospatial data such as OpenStreetMap, Fundamental Geospatial Data DEM, and Mapillary with open-source GIS tools such as QGIS, QuickOSM, QNEAT3, Space Syntax Toolkit, and depthmapXnet. This makes it possible to organize walking-catchment extraction, street-network analysis, slope analysis, and field verification as a single analytical workflow and to present an evaluation procedure applicable to other station areas.

This study also has several limitations. The number of field-survey respondents and the observation time were limited, and the results may be affected by survey date, weather, and time of day. DEM data cannot fully represent three-dimensional pedestrian spaces such as bridges, decks, stairs, and grade-separated crossings, and OSM data have limitations in the accuracy of road classification and sidewalk information. Moreover, as Oba et al. (2025) indicate, nonlinear relationships may exist between physical indicators and pedestrians’ subjective evaluations. Future research should use street-level images such as 3D city models and Mapillary, and introduce participatory evaluation using GeoAI and related methods, to integrate the sensory evaluations and tacit knowledge of elderly people and develop evaluation models closer to actual walking experience.

6. Conclusions

This study combined Space Syntax-based street-network analysis with DEM-based slope analysis to compare the areas around Shin-Yurigaoka Station and Nagareyama-Otakanomori Station, with the aim of understanding station-area environments that are easy for elderly people to walk in. In particular, the study focused on the possibility that roads central within the street network are not necessarily roads that are easy for elderly people to walk on, and evaluated them by overlaying NAIN, NACH, and multiple slope conditions.

The analysis extracted High_NAIN roads to some extent at both stations, but the distribution of High_NACH roads differed. At Shin-Yurigaoka, relatively many roads showed overlap between High_NAIN and High_NACH, indicating that major roads around the station have both to-movement and through-movement potentials. However, Shin-Yurigaoka is located in hilly terrain, and even central roads are affected by slopes and elevation differences. Therefore, roads with high importance in the street network may not necessarily be easy for elderly people to walk on.

At Nagareyama-Otakanomori, by contrast, High_NAIN roads were widely distributed, while High_NACH roads were concentrated in some areas. This suggests that through movement may be organized on specific roads while to-movement potential within the living sphere is maintained. In the station-front district, pedestrian-priority spatial improvements such as sidewalk widening and speed reduction have also been promoted, and the analytical results of this study are considered to correspond to this urban-design direction to some extent.

By combining field observation and interviews, this study also supplemented the ways walking environments are used and perceived by users, which are difficult to capture through numerical analysis alone. Therefore, evaluating walkability around stations requires considering not only central roads in the street network but also slope, the condition of pedestrian-space improvements, and actual use. The significance of this study lies in visualizing the relationship between structurally central roads in the urban network and roads that are easy for elderly people to walk on by combining Space Syntax and slope analysis. Because the method uses open data and open-source GIS tools, it can also be applied to the evaluation of station-area environments in other regions.

At the same time, this study is limited to two station areas, and the number of field-survey respondents and survey time periods are constrained, which limits the generalizability of the results. Future research should increase the number of target stations and add factors such as sidewalk width, traffic signals, crosswalks, stairs, decks, and land use to enable walking-environment evaluation that is closer to actual conditions. In addition, the use of 3D city models and detailed pedestrian-space data may allow more precise evaluation of three-dimensional urban spaces, including slopes, stairs, and level differences.

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Appendix: Data and Software

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