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ORIGINAL SCHOLARSHIP

Preference-based jogging route selection in downtown Tokyo

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ABSTRACT

Jogging has become a popular urban outdoor recreational activity because it is inexpensive and easy. Although there are positive responses to leisure-route planning from many regions, the routes with features preferred by joggers are not commonly considered in urban planning. This article explores and evaluates methods for determining optimal urban jogging routes while considering joggers' preferences. This study combines information about road width, green space, riverbank scenery, and various points of interest with jogging heat map data and uses a decision tree analysis to study joggers' preferences. Next, routes with high potential considering three different patterns of points of interest and road width are selected using the vehicle routing problem analysis in ArcGIS. This method for preference-based route selection can be used to identify which links in urban road networks are attractive to runners and provide policymakers with useful information for designing built environments.

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KEYWORDS
Jogger preferences; jogging route selection; urban outdoor recreation; vehicle routing problem

Introduction

Regular physical activity is widely recognized as a protective factor in preventing and managing non-communicable diseases (World Health Organization 2020). Outdoor recreational activities such as bicycling, walking, and jogging positively impact people's emotional well-being and psychological resilience (Buchecker and Degenhardt 2015, Shuvo *et al.* 2021). Jogging, in particular, has seen a surge in popularity due to its benefits for both physical and mental health. According to statistics from the physical activity-recording website STRAVA, 1 million new members registered every month in 2019, and data for an average of 19 million physical activities were uploaded every week. Among these kinds of activities, endurance jogging is becoming popular worldwide, and the biggest increase is in Japan (STRAVA 2018). This is because running and jogging have a low technical threshold, low cost, and are not restricted by venues (Latham 2015).

The World Health Organization recommends that all countries develop and implement appropriate national or subnational policies and programs to enable people of all ages and abilities to be physically active and improve their health (World Health Organization 2020). In this context, many countries have implemented related policies. For example, The Ministry of Health, Labour and Welfare of Japan (2000) set a goal of increasing awareness of physical activity, as well as the number of people participating in daily physical activity by 10%. The United States has also published physical activity guidelines to help people improve their health through regular physical activity (U.S. Department of Health and Human Services 2018).

Policymakers are increasingly recognizing the importance of built environments as a key condition for active living (Deelen *et al.* 2019). Holland Village in the U.S. state of Michigan installed a snow melting system under its sidewalks. This act, featured in *Runner's World* magazine for attracting a large number of runners, captured national attention (Streets Division of Transportation Services Department of Holland Village Michigan City 2016, Meschke 2019). In Atlanta, the BeltLine, which connects various parts of the community through transformed abandoned railway lines and multi-use trails, provides citizens with open spaces for leisure and sports to encourage healthy lifestyles (Atlanta City Council 2010). In Japan, many local governments in Tokyo published recommended routes for walking and jogging that connect famous sites in the city and dining spots (Bureau of Social Welfare and Public Health, & Tokyo Metropolitan Government 2016).

Despite the abundance of jogging routes, key questions about their selection remain: What kind of road is suitable for jogging? Which urban conditions contribute to higher satisfaction with jogging routes? Furthermore, considering the limited budgets of local governments, which streets should be prioritized for jogging routes? Even though there are many police officers in the city to maintain law and order, it is

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also very difficult to protect the safety of joggers in real time (Allen 2018). Thus, selecting jogging routes requires balancing safety with satisfaction.

In addressing the preferences of joggers and necessary conditions for jogging, various studies have examined urban spaces where physical activities, particularly walking and cycling, occur. For instance, Frank *et al.* (2005) found that community design elements like land-use mix, street connectivity, and residential density are significantly linked to moderate levels of physical activity. Borst *et al.* (2008) identified sections of streets between intersections, noting that features such as tree-lined paths, front gardens, bus or tram stops, shops, business buildings, catering establishments, and routes through parks are especially appealing to elderly walkers. Additionally, Coombes *et al.* (2010) explored the relationship between access to green spaces, their use frequency, physical activity, and obesity risk using GIS. They discovered that the use of green spaces decreases as their distance increases, indicating that easily accessible green areas in cities encourage more physical activity. However, research specifically focusing on joggers is not as extensive as that for pedestrians and cyclists. Some studies have investigated how the running environment influences joggers' satisfaction and frequency of jogging (Ettema 2016, Deelen *et al.* 2019, Schuurman *et al.* 2021). While these studies highlight a significant link between the built environment and jogging, their conclusions are somewhat constrained by limited data and analysis units, as they rely primarily on surveys.

Social media platforms designed for outdoor activities offer significant opportunities to collect data rich in geospatial information, enhancing our understanding of these activities (Norman and Pickering 2019). A prime example is STRAVA, a widely-used social fitness network that tracks activities like walking, running, cycling, and hiking using GPS on mobile phones. The data captured includes distance, time, average speed, and the GPS trajectory of each activity. With over 100 million athletes using its services, STRAVA has become a valuable resource for researchers analyzing the popularity and quality of different locations (Santos *et al.* 2016, Hochmair *et al.* 2019, Dong *et al.* 2023, Huang *et al.* 2023).

Utilizing data from these sources enables a detailed quantification of joggers' preferences within various built environments. It led to an increased number of studies exploring the relationship between jogging activities and environmental features (Dong *et al.* 2023, Huang *et al.* 2023, Liu *et al.* 2023, Yang *et al.* 2023, Zhang *et al.* 2023). For instance, Yang *et al.* (2024) analyzed how built environment factors like intersection density, population density, and the number of tracks, as well as visual landscape features such as greening and sky view, affect jogging volume. They particularly emphasized the significant impact of these built environment factors at the Traffic Analysis Zone level. Additionally, several studies have focused on street-level features related to jogging intensity. Huang *et al.* (2023), for example, examined how greenery, urban density, and traffic influence running density in Helsinki using Strava data. Similarly, Dong *et al.* (2023) combined objective street environment data with subjective perception analysis, uncovering notable correlations between these factors and jogging activity in Boston, transforming Strava Heatmap data into a street-level intensity analysis.

These findings significantly advance our understanding of joggers' preferences and the suitable street-level conditions for jogging. However, a gap remains in the existing research: it does not address which streets should be prioritized for jogging routes, especially considering the constrained budgets of local governments. While there are studies on route planning for active mobility like walking and cycling (Novack *et al.* 2018, Gao *et al.* 2022, Ribeiro *et al.* 2022), these primarily focus on generating routes between specific origin and destination points, taking into account factors such as pollution, traffic, noise, and green spaces, with the goal of minimizing the increase in travel distance. For instance, Ribeiro *et al.* (2022) developed a method to plan urban routes that enhance public health and promote sustainable urban mobility, offering pedestrians and cyclists routes with less pollution and noise. Similarly, Novack *et al.* (2018) introduced a system for customizing pedestrian routes by considering elements like greenery, social spaces, and tranquility, thus allowing users to prioritize these features in route planning, aiming to create more enjoyable and personalized experiences in urban settings.

When it comes to planning and designating routes, several studies have focused on creating routes within constraints like budget and length (Ospina *et al.* 2022, Folco *et al.* 2023, Paulsen and Rich 2023). For example, Ospina *et al.* (2022) introduced an optimization model for developing connected, safe, and efficient bicycle networks, balancing cost against cyclist coverage. Folco *et al.* (2023) proposed a network development model that underscores the trade-off between demand-based and safety-based development, demonstrating how data can streamline and enhance urban route planning processes. Even though previous studies on the relationship between built environment and jogging activities emphasized the importance of built environment for joggers' pleasure and safety, these studies primarily concentrate on micromobility networks, such as bike and e-scooter paths, and do not encompass jogging. Willamowski *et al.* (2019) presented a methodology to generate pleasant running tour but considered only elevation. Hence, the route selection based on joggers' preference have the potential to secure the suitable route for jogging under the constraints such as available budget and space.

Building upon previous research, this study aims to develop methods for selecting urban jogging routes that specifically consider the preferences of joggers. It makes two primary contributions to the existing body of literature. Firstly, it focuses on joggers' preferences utilizing big data, considering factors such as road condition, points of interest (POIs), and green and riverside areas. Previous research has already highlighted joggers' preference for green and riverside areas, considering factors like proximity and street view (Huang *et al.* 2022, Yang *et al.* 2023). Uniquely, this study delves into both the quantity and types of POIs, which are associated with aspects like traffic volume, nighttime safety, and amenities. In terms of practical application, the study employs variables that are readily measurable and implementable. Secondly, the study proposes a method for jogging route selecting that takes into account both the current usage and potential of road links, based on data-driven route analysis. While previous studies have uncovered joggers' preferences and the suitable conditions at street level for jogging, urban planners still need insights on which streets should be maintained or designed as jogging routes for effective practical planning. In this study, a 'link' is defined as a segment of a street between two intersections, and a 'route' as a series of links that connect a jogger's starting point and destination.

The remainder of the work is organized into three sections. The following section begins by explaining the methodology for investigating joggers' preferences and the process of route selection, along with a description of the study area and data. This is followed by presenting the results of the joggers' preference analysis and the selection of routes based on these preferences. The work concludes with a discussion of the potential applications of this research and suggestions for future studies.

Method

Our proposed method for planning jogging routes in urbanized areas consists of two steps illustrated in Figure 1: (1) analysis of joggers' preferences and (2) selection of links preferable for jogging using the vehicle routing problem (VRP) analysis of ArcGIS.

Joggers' preferences analysis

For the joggers' preference analysis, first, we classified the route popularity based on the heat map color using the ISO cluster unsupervised classification of ArcMap. Second, we extracted preference factors using a decision support method based on a tree-like model of decisions. The growing method for the decision tree was set as the chi-squared automatic interaction detection method (CHAID) because there are more than two branches for some nodes. Decision tree generates a set of rules for prediction through the repetitive process of splitting (Tso and Yau 2007). We selected the decision tree because 1) it is simple to understand by human experts, 2) provides the solution and the reason for a given case, and 3) is easy to construct a model is simple and efficient compared to other classifiers, such as neural network (Desarkar and Das 2018).

Selection of jogging routes

Assigning value to links considering jogger's preferences

To select a route considering joggers' preferences, we assigned a value (v_i) to each link to represent its attractiveness to joggers according to the results of the preference analysis. This value was determined by the width of the road, the number of POIs, and whether the link was close to green spaces and rivers.

$$v_i = W_i + POI_i + R_i + G_i \qquad (1)$$

The highways and links with a width of fewer than 3 m were excluded because they are not suitable for jogging route planning. In addition, v_i of links within the park were not considered because most of them

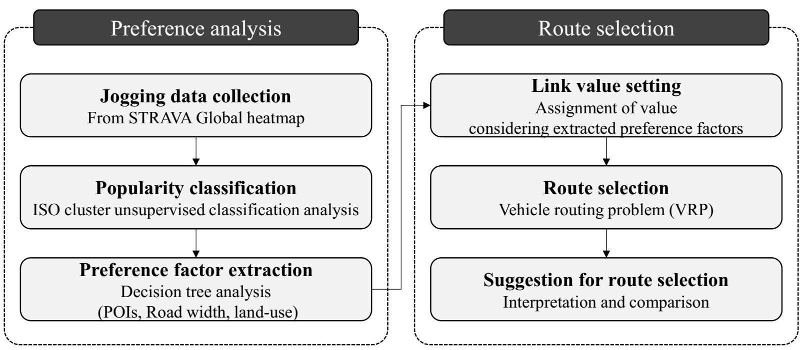


Figure 1. Flow of route selection. POI: point of interest.

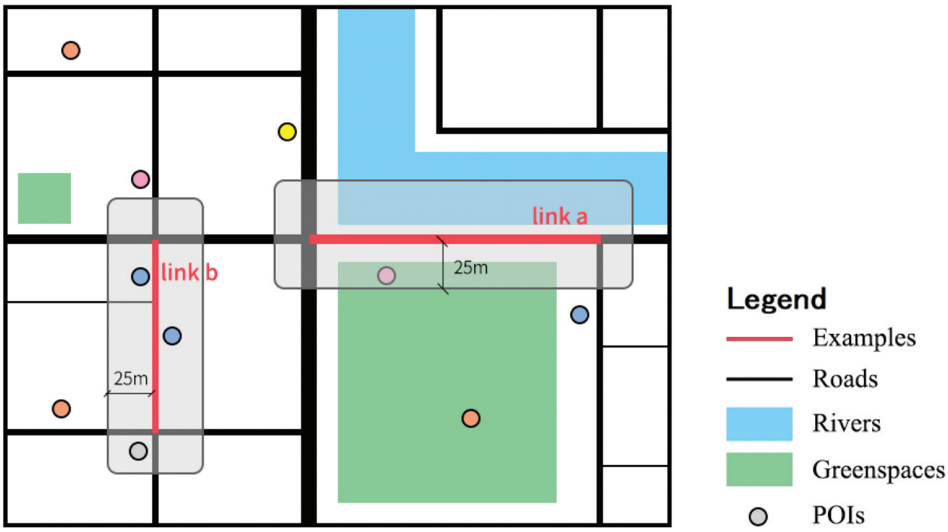


Figure 2. Schematic diagram of the value calculation process. POI: point of interest.

already have good conditions for jogging. Figure 2 illustrates an example of assigning value to links.

Route selection

VRP analysis was utilized to identify routes that align with joggers' preferences within a given limitation of total round-trip time. The original VRP involves devising multiple routes for a vehicle, each starting and ending at the depot and encompassing all necessary destinations. As an extension of the original VRP, the VRP with Profits shifts its focus to maximizing profit by strategically choosing the most beneficial sites to visit, taking into account resource limitations, instead of ensuring visits to all sites (Lee and Ahn 2019). VRP with profits has been thoroughly studied and applied to a variety of contexts such as home fuel delivery, tourist trip planning, patrols, and taxi routing (Stavropoulou *et al.* 2019, Lee and Jeong 2024).

Jogging routes are typically categorized into four types: round-trip, loop, lollipop (P-shaped), and one-way (Cook *et al.* 2016). With the exception of the one-way course, these types ensure the jogger returns to the starting point. Consequently, our jogging route model for VRP analysis incorporates the first three types. This analysis typically involves depots, delivery points, and networks. In our model, the starting and ending points of jogging are designated as depots, the central point of links as delivery points, and the urban road network serves as the network. This value (v_i) is also the profit in the VRP and is assigned to the central point of each link. As Figure 3 shows, Jogging route consists of an Origin and Destination (OD) point, several continuous links, several POIs, and a turning point. The OD points are the centroids of residential districts. The turning point consists of green space areas. To simulate a real jogging trajectory as much as possible, we prohibit U-turns in any position.

To calculate the route by considering actual joggers' behavior, we set the maximum travel time of a route according to the data from *the 2018 SSF National Sports-Life Survey* (Sasakawa Sports Foundation 2019) and the suggestion that all adults should undertake 150-300 min of moderate-intensity activity per week by the World Health Organization (World Health Organization 2020). According to *the 2018 SSF National Sports-Life Survey*, joggers often jog for 30 minutes (5 km). To consider joggers who run shorter distances and inexperienced joggers, we also calculated routes that take 18 minutes (3 km). In addition, we employed the population of residential districts to identify the potential of each link based on the number of joggers.

Since the turning point can vary according to individuals, it is necessary to select routes that visit

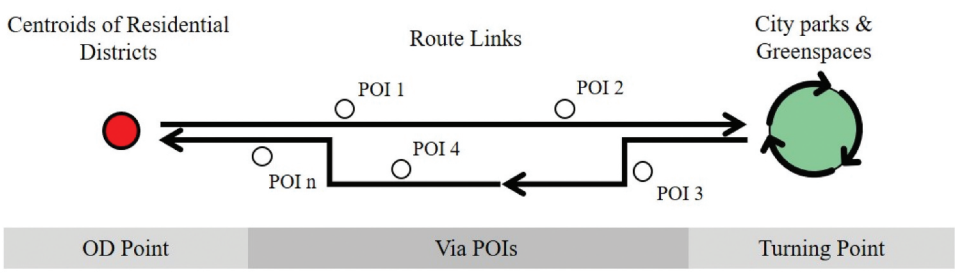


Figure 3. Designed jogging route model for the vehicle routing problem. OD: origin and destination; POI: point of interest.

different parks. We ran the VRP analysis repeatedly with the assumption that joggers in the same district select different green spaces. The number of routes for each residential district was the same as the number of green spaces within the given limitation of total round-trip time from the boundary of the ward area.

Figure 4 shows an example of route selection. There are two green areas that can be reached within maximum travel time. The orange number represents the value of the link calculated based on road width, the number of POIs, green area, and rivers. Because there are two possible destinations in the given district in Figure 4(a), we ran the VRP analysis twice by adding 100 to a green area per run. In the first run, we added a value of 100 to links surrounding green area A. In the next run, we added 100 to links surrounding green area B. Such a large value was assigned to ensure that all routes generated by running VRP in this round used this green space as a turning point. In each run, we considered links within 500 m from the straight line between residential district and given green space.

To accommodate diverse preferences, we developed three distinct routing patterns for the VRP model: the POI Priority Pattern, the Road-Width Priority Pattern, and the Mixed Priority Pattern. The POI Priority Pattern is based on the assumption that joggers prefer routes that offer liveliness and safety. Deelen *et al.* (2019) have demonstrated that liveliness enhances the appeal of a jogging environment. Additionally, the presence of POIs is positively associated with safety at night, due to increased surveillance or 'eyes on the street' (Jacobs 1961). The second pattern, the Road-Width Priority Pattern, posits that joggers favor wider roads irrespective of POI presence. Wider roads

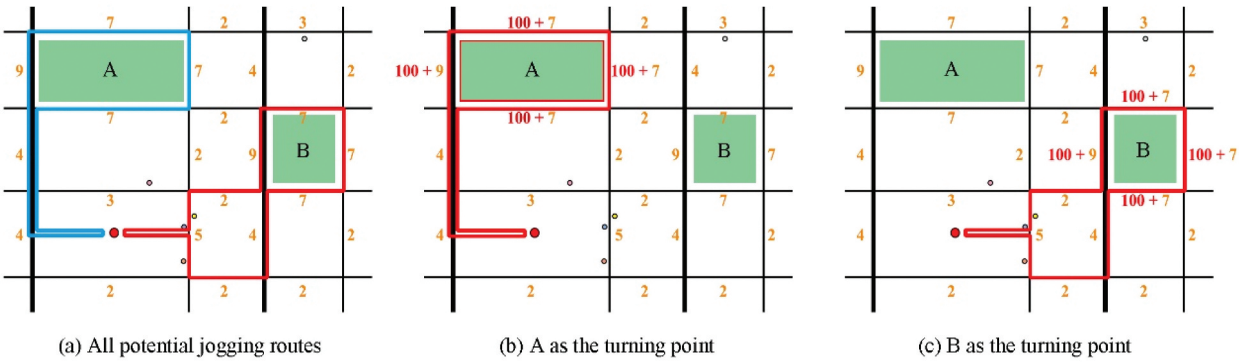


Figure 4. Vehicle routing problem analysis process.

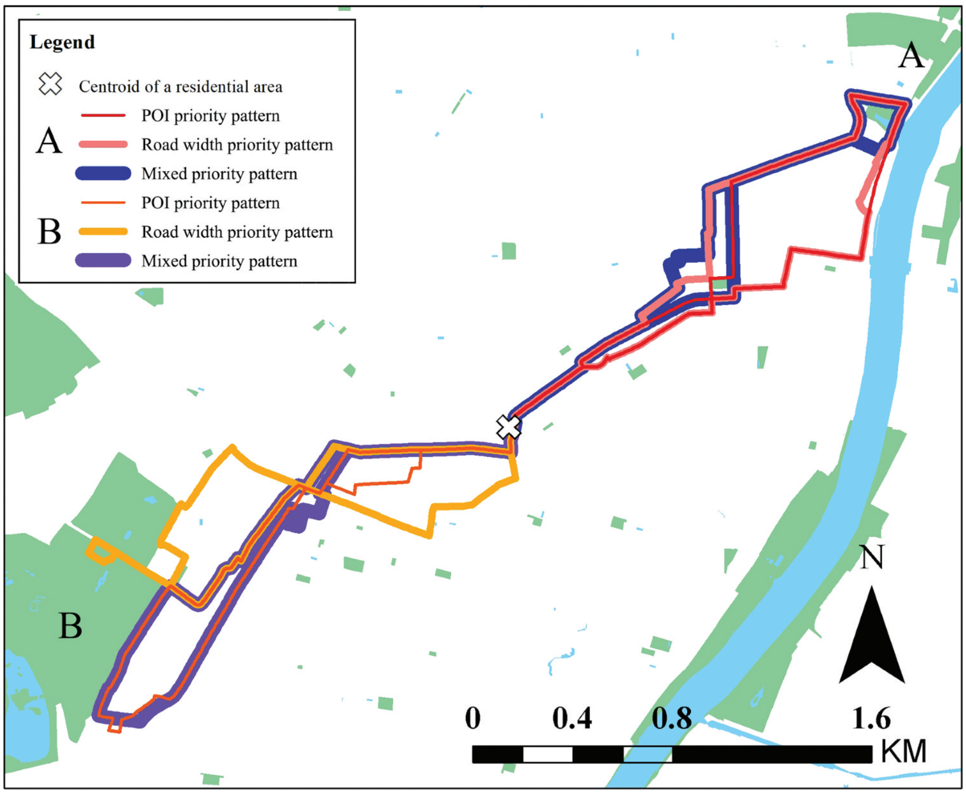


Figure 5. Example of the vehicle routing problem analysis results of the three patterns. POI: point of interest.

typically provide sidewalks and sufficient space, which are crucial for avoiding crowding, as emphasized in previous studies (Morelle *et al.* 2019, Xue *et al.* 2022, Normark 2023). The final pattern, the Mixed Priority Pattern, involves joggers considering both POIs and road width when selecting jogging routes. Figure 5 illustrates a sample route for each pattern.

The limitation of the total round-trip distance was set to 18 mins and 30 mins for the VRP analysis, which was conducted for each ward area. The number of VRP for each ward was the same as the number of green spaces within 9 mins and 15 mins from the boundary of each ward. Then, we combined all possible routes and calculated a weight to estimate possible road usage (E_i) by considering the jogging population. The jogging population of each route was calculated by multiplying the population of the residential area by the proportion of joggers from the Time Use and Leisure Activity Survey of the Bureau of Statistics of Japan (2017). The proportion of male joggers in Tokyo was approximately 21.94%, and the proportion of female joggers was approximately 19.68%. To adjust the difference in the number of green spaces of each ward, E_i was calculated by the following equation:

$$E_i = \sum_{i,j,k} \frac{\left(\alpha P_j^m + \beta P_j^f\right) x_{ijk}}{N}, \qquad (2)$$

where, x_{ijk}take takes a value of 1 if link i is included in the route from district j to green space k, P_j^m and P_j^f denote the population of men and women of district j respectively, α and β are the proportion of male and female joggers respectively, and N is the number of green spaces of a given ward.

Study area and data collection

Study area

The 23 special wards of Tokyo, Japan, were selected as the study area for preference analysis due to their rich array of Points of Interest (POIs), green spaces, rivers, and residential zones. Serving as Japan's political, economic, and cultural center, these wards cover an area of 627 km^2 and had a combined population of 9,733,276 as of 2020. Despite the high population density, access to public resources for leisure activities such as jogging was limited. Annear *et al.* (2022) advocated for the removal of restrictions on jogging and cycling in larger urban green spaces or the creation of shared pedestrian pathways within or linking major open areas. Subsequently, six special wards (Arakawa, Taito, Bunkyo, Sumida, Adachi, and Katsushika) were chosen for route selection, considering factors like the number of parks and rivers, and the diverse population distribution. Notably, the northernmost wards (Adachi and Katsushika) only partially encompass these features. Areas outside the boundary of the 23 wards of Tokyo were excluded from the data set. The selected wards are home to nearly 1.2 million permanent residents, with approximately 20% identified as joggers (Survey on Time Use and Leisure Activities of the Statistics Bureau of Japan 2017). The case study of Tokyo's ward area provides valuable insights, specifically: 1) it offers information to tackle the issue of limited jogging access in Tokyo, and 2) the methods proposed for jogging route selection can be adapted by other metropolitan cities to enhance the built environment for outdoor jogging.

Joggers' data

To investigate joggers' preferences, the number of joggers for each link should be investigated. We used the jogging heat map in Figure 6 from STRAVA (San Francisco, CA, USA) as a basis for determining preferences. The brighter the color, the more the path is used by joggers. It is important to note that while this data indicates the relative intensity of joggers, it does not provide the exact number of individuals engaged in jogging. Many studies have used these data to investigate certain aspects of outdoor activities (Selala and Musakwa 2016, Sun *et al.* 2017, Hochmair *et al.* 2019). For example, Sun *et al.* (2017) used STRAVA cycling data to investigate the correlation between cycling behavior and environmental characteristics (population density, road length, land use structure, traffic accidents). These previous studies show the usefulness of STRAVA data for quantifying the popularity of locations and obtaining evidence for policymaking. STRAVA heat data can, therefore, be trusted for use in studying jogging preferences.

Data on road and preference factors

Several factors affect a jogger's route choice. Multiple studies have shown that joggers prefer green and natural environments because they are visually appealing and offer more health benefits (Bodin and Hartig 2003, Deelen *et al.* 2019). In addition, lively routes in vibrant environments where other people are present and activities are occurring are popular (Deelen *et al.* 2019). Space is also an important factor due to the tightness of passages and the need to evade obstacles in certain areas (Cook *et al.* 2016). To conduct preference analysis, we selected road width to consider space, POIs to consider the liveliness of the route, and green and riverside areas based on the findings of previous studies that show a preference for these environments. POIs denote destinations or places of activity that someone may find useful or interesting, such as police stations, convenience stores, or stadiums (Wang *et al.* 2018).

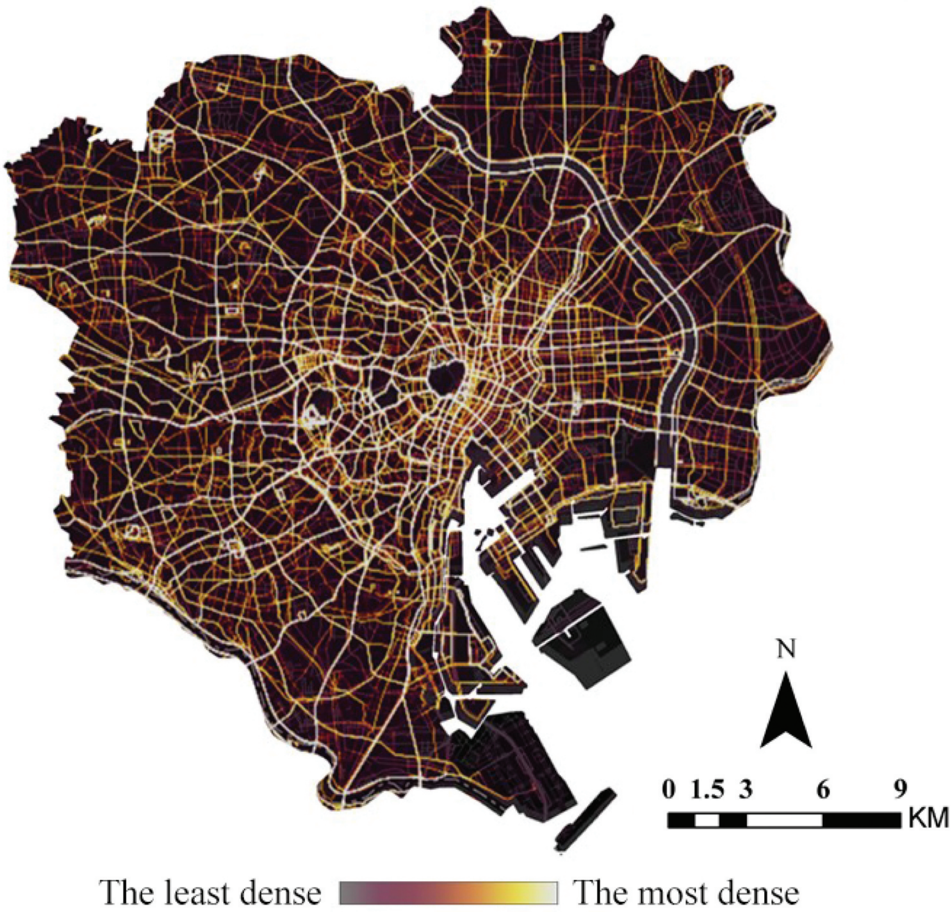


Figure 6. Jogging heatmap of Tokyo from STRAVA.

Table 1. Data sources.

Factor	Source	Year
Road width	Map and Survey Results of Geospatial Information Authority of Japan	2017
Land use	Map and Survey Results of Geospatial Information Authority of Japan	2016
Point of interest	Phonebook Database with Coordinates (including convenient store, supermarket, coffee shop, department store, snack bar, discount store, grocery store, educational institution, stadium, gas station, parking lot, and police station data.)	2018
Urban green spaces	Urban Planning Geographic Information System in Tokyo	2018
Jogging population	Time Use and Leisure Activity Survey of the Bureau of Statistics of Japan	2017

Table 1 shows the data sources and years examined in this study. Road width is classified into four categories: 3 m–5.5 m, 5.5 m–13 m, 13 m–19.5 m, and over 19.5 m. Regarding POIs, joggers are interested in commercial facilities that can provide supplies (water, food, etc.), facilities that ensure environmental safety (good lighting, guard-on-duty, community supervision) (Jacobs 1961), facilities with an atmosphere of physical activities (other people doing physical activities, such as in stadiums, athletic fields, etc.) (Deelen *et al.* 2019), and facilities with motor vehicle entrances and exits (parking lots, gas stations, etc.). Here, we selected 12 kinds of facilities related to jogging (Table 1). It is worth noting that to meet the basic sports space requirements for jogging, we selected green areas with an area of more than four hectares as the analysis factors. Finally, the population will be used as a weight to assign a value to the generated jogging route to calculate an accurate expected value.

Results

Jogging popularity and joggers' preferences

Jogging popularity analysis

Based on the STRAVA heat map, we set three groups to classify urban roads according to their jogging usage after trial and adjustment. Figure 7 illustrates the result of this grouping. The gray part describes group-level I, which are roads with the lowest density of joggers; the total length within 23 special wards of Tokyo is about 8,885 km (69.3%) and 1,465 km (70.8%) in six ward areas, respectively. The blue part describes group-level II. This group comprises roads

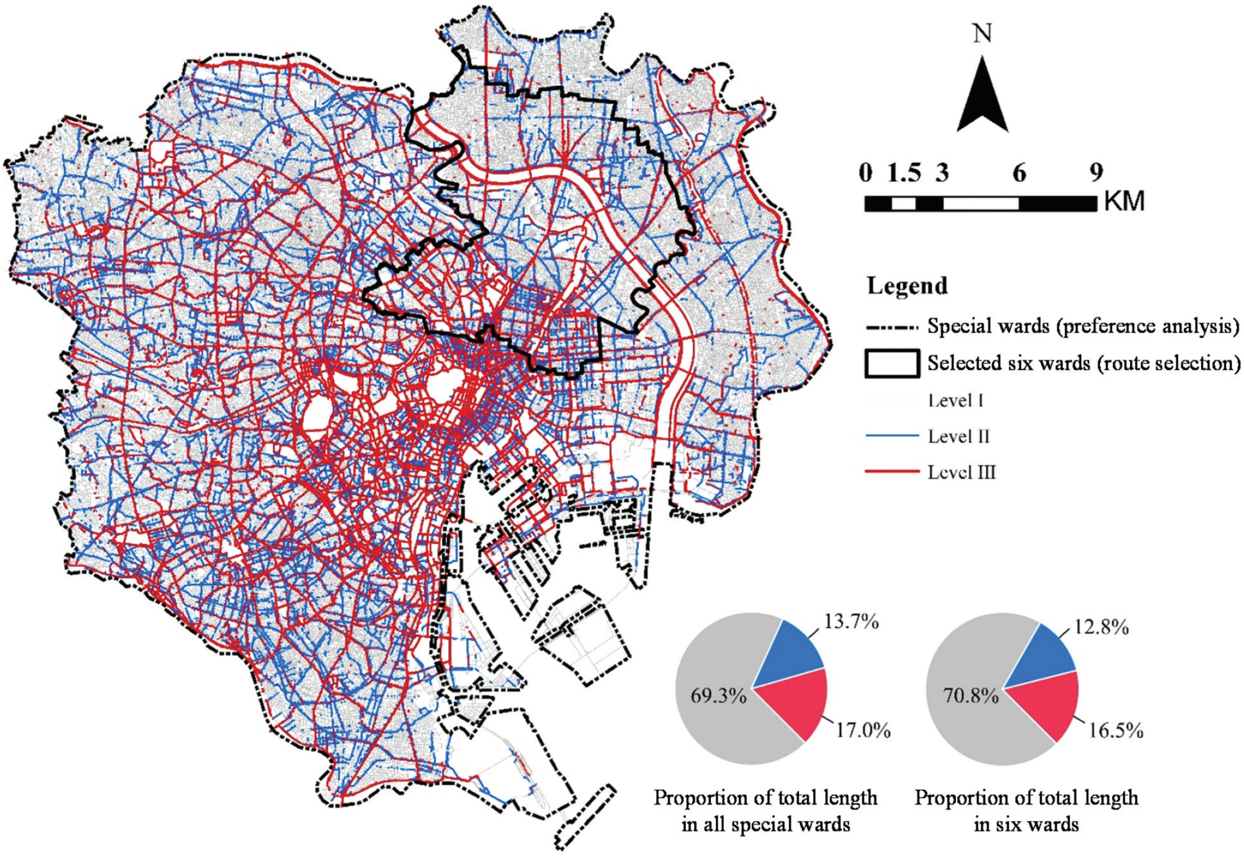


Figure 7. Result of ISO cluster unsupervised classification analysis.

with a medium jogging density; the total length is nearly 1,763 km (13.7%) and 264 km (12.8%) for total ward area and six ward areas, respectively. Finally, the red part describes the third group of routes, which have high popularity, level III; The total length is about 2,174 km (17.0%) and 341 km (16.5%) for total ward area and six ward areas, respectively.

Joggers' preference analysis

To conduct the decision tree analysis based on jogging use, all links were divided into popular (level II and III) and unpopular (level I). Road width, POIs, and green and riverside areas were included as independent variables. Table 2 shows the classification results of the decision tree analysis. The result of the best decision tree was achieved through several rounds of trial and error. The final decision tree correctly predicted 77.8% of all cases, with a higher correct classification percentage for unpopular links. It indicates that independent variables are strongly related to popularity of links. Even though the correct classification percentage of popular links is relatively low, it implies that there are links with high potential for a jogging route, but they are not used by joggers currently. The final tree structure involved eight splitting variables: road width, green space, river, coffee shop, stadium, snack bar, convenience store, and police station.

Table 2. Classification results of the decision tree analysis.

Classification of links			
	Predicted		
Observed	UNPOPULAR	POPULAR	Correct (Percentage)
UNPOPULAR	181,164	18,249	90.8%
POPULAR	45,216	41,884	48.1%
Overall Percentage	79.0%	21.0%	77.8%

Growing method: CHAID; dependent variable: Popularity.

From the analysis results in Figure 8, the root node was first split according to the road width at the first level of the tree. The wider the road, the higher the popularity. Figure 9 shows that wider roads are the most popular with joggers. In the roads with a width greater than 19.5 m, level III links account for over 70% of the total length. In contrast, for roads with a width of fewer than 5.5 m, level III links account for 10% of the total length.

The second and the third nodes are mainly composed of river area, green spaces, coffee shops, and convenience stores. Figure 10 shows the relationship between land use and jogging popularity as measured in three levels. It indicates that city parks, green spaces, river and lake banks, forests, and urban roads are highly popular with joggers. This emphasis on jogging in green environments is consistent with the findings of previous studies that show the physical and mental health benefits of exercising in green spaces (Gladwell *et al.* 2013, Deelen *et al.* 2019, Sasakawa Sports Foundation 2019).

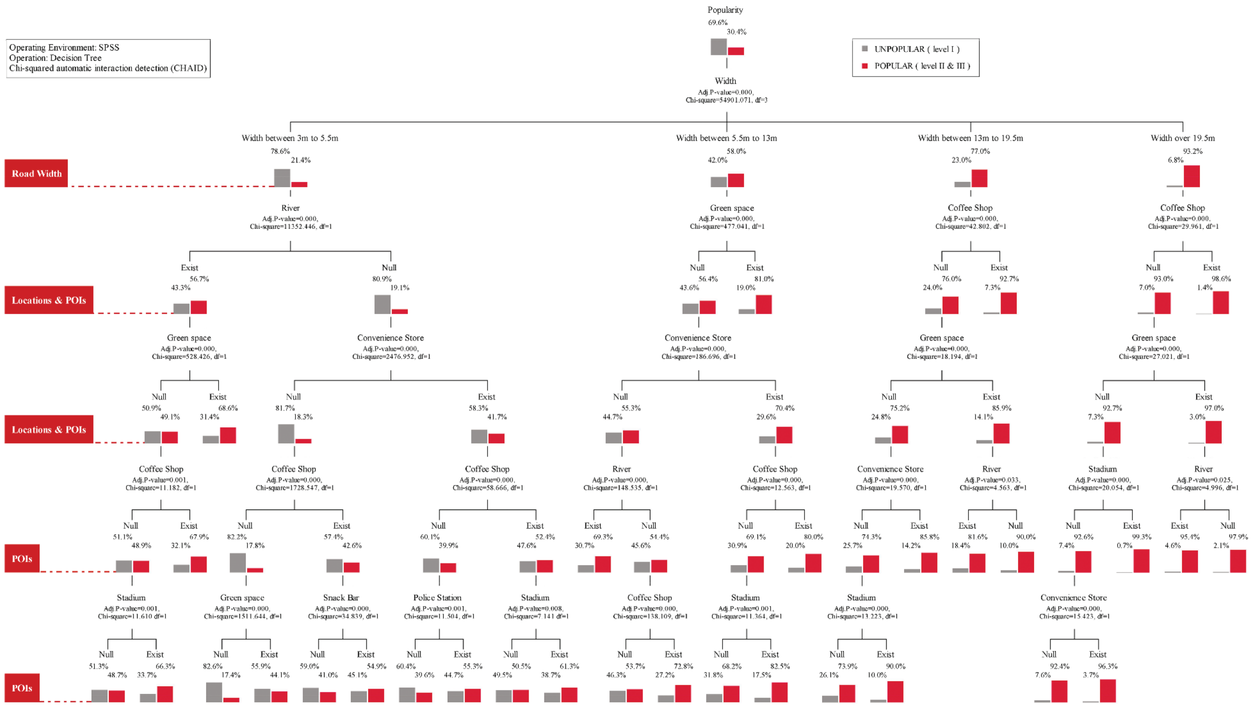


Figure 8. Result of the decision tree analysis.

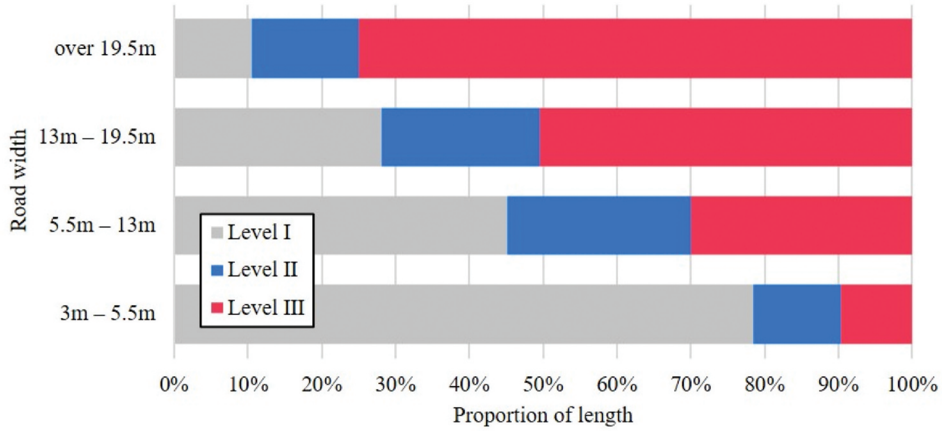


Figure 9. Relationship between jogging popularity and road width.

The fourth and fifth nodes are almost all POIs. Links with convenience stores, coffee shops, stadiums, snack bars, or police stations show especially high popularity. Deelen *et al.* (2019) showed that liveliness has a positive effect on the attractiveness of the jogging environment, and our result confirms this. The existence of POIs, such as stadiums, can let people see others who are implementing physical activities and shape the atmosphere of street activities (Deelen *et al.* 2019). Others such as convenience stores, coffee shops, and snack bars attract consumers who may become natural safety supervisors of streets, while the police station provides the most security (Jacobs 1961). Although pedestrians may be obstacles for joggers (Cook *et al.* 2016), they have a positive effect on joggers' perception of a route (Deelen *et al.* 2019). Therefore, it indicates that joggers prefer green spaces but also choose to pass POIs to balance the security risk. The decision tree clarified the relevant facility types that affect the popularity of various links.

Result of jogging route selection

Assigning values to links

Based on the preference analysis and the three patterns, the value of each link was calculated according to Table 3. The roads were divided into four levels according to their width and assigned W_i values of 2, 3, 4, and 5. The wider the road, the higher the value. Each POI was assigned a one-point value, and the POI_i value for each link was the sum of the POIs within 25 m of the road.

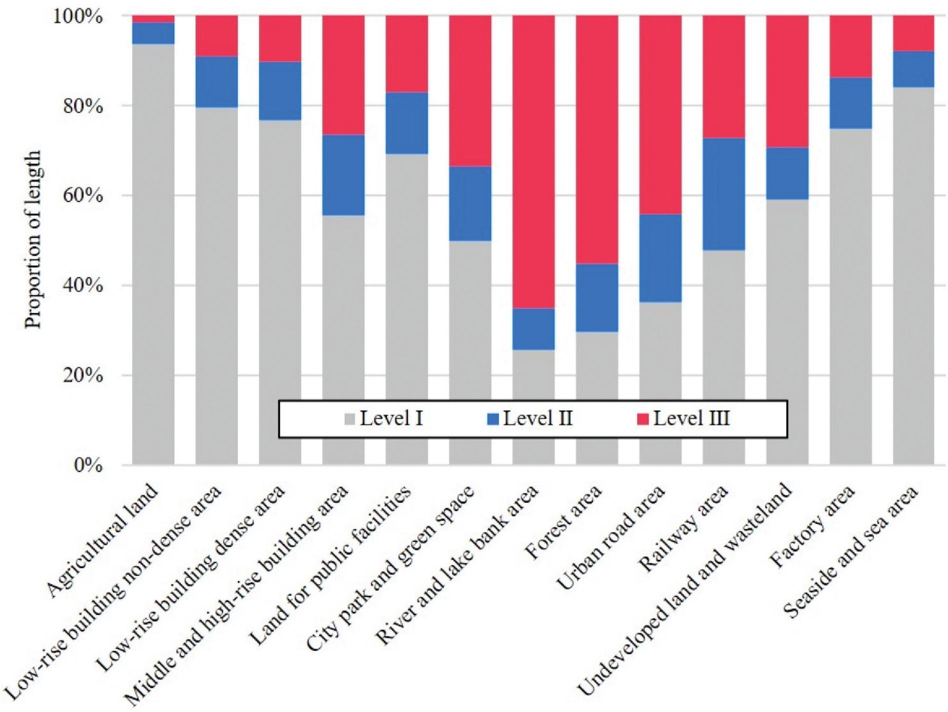


Figure 10. Relationship between land use and jogging popularity as measured in three levels.

Table 3. Parameter settings of the vehicle routing problem.

	Patterns			
Factors	Point of interest (POI) priority pattern	Road-width priority pattern	Mixed priority pattern	Remarks
Road Width (W_i)	/	2,3,4,5	2,3,4,5	2 = 3 *m*–5.5 m; 3 = 5.5 *m*–13 m; 4 = 13 *m*–19.5 m; 5 = over 19.5 m
Green Spaces (G_i)	5	5	5	
Riverbank (R_i)	3	3	3	
POIs (POI_i)	1	/	1	Police stations; Convenience stores; Stadiums; Coffee shops; Snack bars
Links Selection	Value ≥ 1	Value ≥ 3	Value ≥ 3	

Results of route selection

Figure 11 shows the E_i distribution of the three patterns. The darker the color, the higher the expected value. The lengths of the selected route for the POI priority pattern, road-width priority pattern, and mixed priority pattern were 1,920 km, 1,906 km, and 1,940 km, respectively.

To select links with a high potential for jogging, we considered the top links within the 200 km and 400 km extended length range after sorting their E_i in

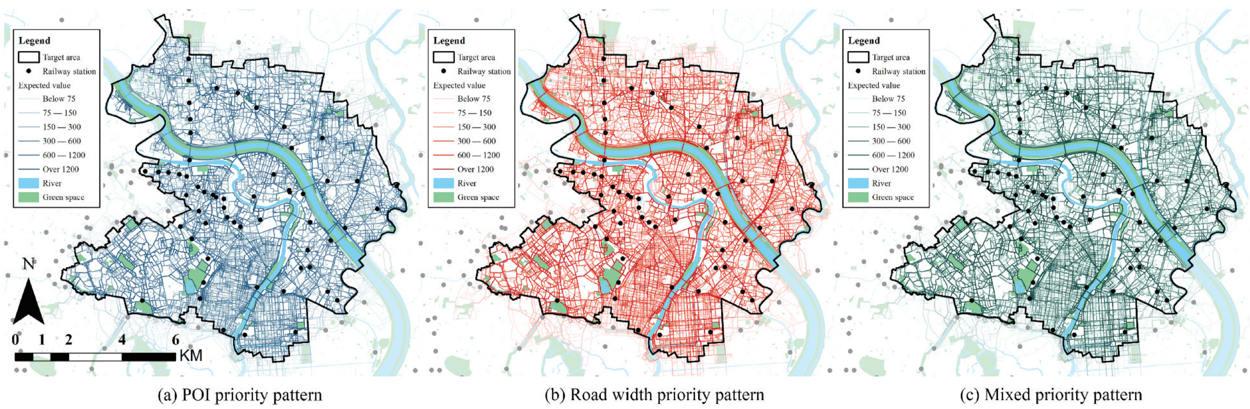


Figure 11. Jogging-route selection results (E_i). POI: point of interest.

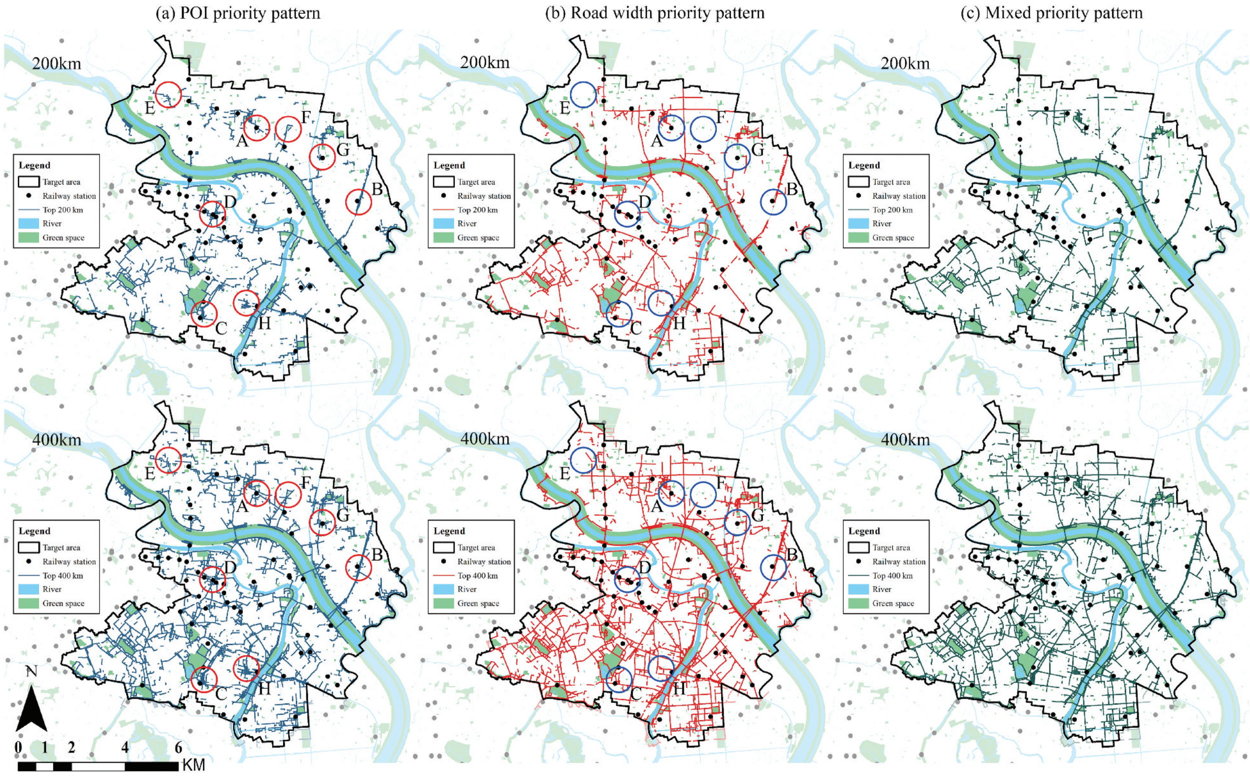


Figure 12. Cumulative length within the top 400 km of E_i ranking. POI: point of interest.

descending order in Figure 12. The links related to POI priority pattern were mostly clustered near the railway stations (A, B, C, D, and G in Figure 12) and several areas (E, F, and H in Figure 12), while arterial roads were mainly selected in the road-width priority pattern.

Next, we compared the number of POIs for selected links. The POI priority pattern and mixed priority pattern show a high concentration of links with many POIs. On the other hand, in the road-width priority pattern, the jogger load decreased as the number of POIs increased. This result implies that the mixed priority pattern can maximize the use of both POIs and road width.

Comparison of the three patterns

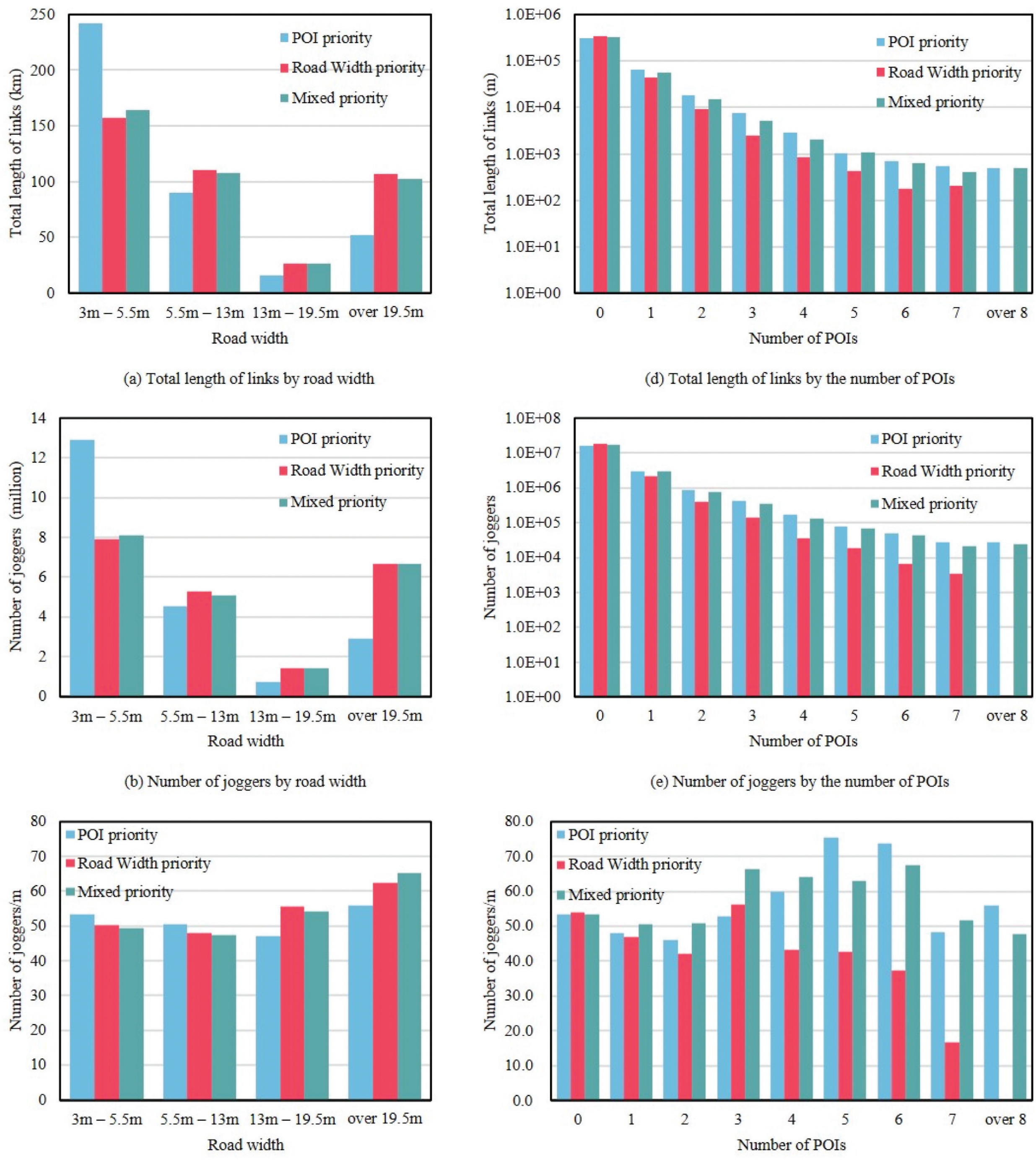
We merged the links within the top 400 km of the three patterns. Figure 13 compares the road width and the number of POIs of the three patterns. As expected, the POI priority pattern included narrower roads, while the road-width priority pattern and mixed priority pattern included wider roads. The mixed priority pattern shows similar results to the road-width priority pattern. Even though the number of joggers in narrow roads is high due to the long distance, the average number of joggers per unit distance is highest in the widest road. The wider the road, the higher the jogger load on a link. Links with high jogger load deserve more attention.

Figure 14 illustrates their spatial distribution. The cumulative total length of the links selected by the three patterns is 572 km. The total length of links selected by all three patterns at the same time reaches 233 km (40.7%). These links have the preferred jogging route design; they are mainly distributed around parks and riversides. It should be noted that the routes that connect residential areas and parks are commonly selected by the three patterns. These links selected by the three patterns all have a high potential use for joggers, and the planning and design of these links must be prioritized to improve their service level.

In Figure 7, the southern half of the route selection area contains many popular roads, while the northern half does not have as many based on the STRAVA heatmap. On the other hand, the attractive jogging links obtained by VRP analysis are evenly distributed, which effectively determined the preferred and potential jogging links.

Discussion and conclusion

Jogging has become more popular in recent times thanks to its physical and mental health and well-being benefits. Because of this popularity, jogging route selection for engaging and comfortable jogging is important. The main goal of this study was to investigate joggers' route preferences and suggest a model for jogging route selection based on joggers' preferences regarding road width, green spaces, and POIs. We selected specific Tokyo ward areas because they contain many attractive factors for joggers such as



(a) Total length of links by road width

(d) Total length of links by the number of POIs

(b) Number of joggers by road width

(e) Number of joggers by the number of POIs

(c) Number of joggers per unit length by road width

(f) Number of joggers per unit length by the number of POIs

Figure 13. Comparison of selected links. POI: point of interest.

parks, rivers, and POIs. Our case study analysis of these areas suggests three main findings.

First, road width, green spaces, and POIs show a significant relationship with the popularity of routes from the STRAVA data. According to the decision tree analysis, the road width and existence of POIs and green spaces have positive effects on route popularity. Regarding POIs, coffee shops, convenience stores, snack bars, stadiums, and police stations show a significant relationship with route popularity. The positive relationship concerning green spaces and wide roads is consistent with the findings of previous studies (Bodin and Hartig 2003, Cook *et al.* 2016, Deelen *et al.* 2019). A larger number of POIs, police stations, and 24-hour convenience stores can play the role of community supervision, just like the 'eyes on the streets' mentioned in Jane Jacobs's (1961) book, *The Death and Life of Big Cities in the United States*. In addition, these POIs can also provide joggers with supplies, such as food and water, and bathrooms, making long-distance jogging routes more convenient and comfortable. These findings suggest the necessity of considering surrounding facilities for jogging route design.

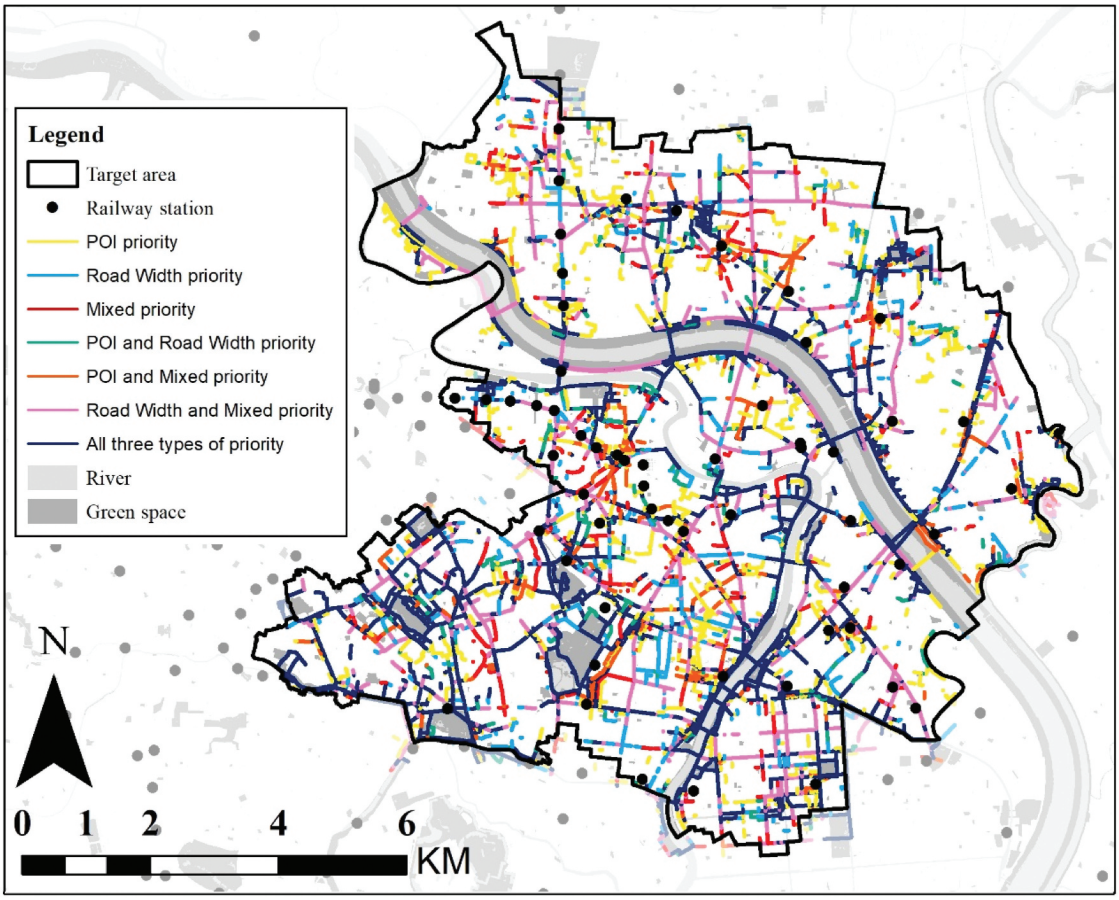


Figure 14. Comparing the selection results of the three patterns within 400 km. POI: point of interest.

Second, our VRP analysis clarified the important links with high potential for jogging. We set three patterns: POI priority, road-width priority, and mixed priority. Comparison of the three patterns showed that mixed priority pattern maximizes the best of both POI and road width factors. Simultaneous consideration of attractive factors including road width, POIs, and green spaces can contribute to designing safe and vibrant jogging routes. We applied our route selection method to the specific case of the Tokyo ward area, but our suggested method is not dependent on the specific city under study. It can be easily extended to other cities, allowing decision-makers to plan jogging routes.

Third, the expected number of joggers can give useful information for designing jogging routes. Even though our results are limited to the selection of links, they can help narrow down the candidates for jogging routes. When we selected the 400 km range with a high expected number of joggers, 233 km of links were selected according to the three patterns. These links can satisfy many types of joggers and have a high priority for route design. In addition, planners can vary the level of maintenance according to the expected number of joggers. Links with a small number of joggers may necessitate minor changes in street elements such as signs for jogger safety, while for links with a large number of joggers, more major physical improvements, such as separate lanes or friendlier road surfaces, can be considered. In addition, some links do not have obvious advantages in terms of their road width or number of POIs. However, from a geographical perspective, they are mainly connected to other well-received links and thus cannot be ignored because they may affect the overall service level of the planned road network.

This study investigated jogger's preferences and determined potential routes while considering road width, POIs, green spaces, and rivers. Preference-based route selection can identify which links in urban road networks are attractive to joggers and provide policymakers with useful information for built environment design such as developing urban jogging trails and improving street design for comfortable outdoor activities in an attractive environment. However, substantial room still exists for further reflection and improvement. First, employing detailed joggers' data such as trajectories, age, and gender can enhance our understanding the specific needs and preferences of different jogger groups. Second, even though our analysis of joggers' preferences primarily focused on POIs and road width for practical applications, considering other factors such as street view and pollution levels can further enhance the accuracy of route estimation. Third, the comparison of preferences with different activities such as cycling and walking is a possible direction for future work.

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References

Allen, K., 20 June 2018. *Massachusetts jogger details how she escaped terrifying abduction attempt*. ABC News Internet Ventures. Available from: https://abcnews.go.com/GMA/News/massachusetts-jogger-details-escaped-terrifying-abduction-attempt/story?id=56021660 .

Annear, M., *et al.*, 2022. Constructing legacy: walking audits of the leisure time physical activity potential of Tokyo Olympic venues and their urban milieu. *Annals of leisure research*, 25 (1), 23–47. doi:10.1080/11745398.2020.1867591.

Atlanta City Council, 2010. *The blueprint for the Atlanta BeltLine*. Available from: https://beltline.org/the-project/grant-application/master-planning/.

Bodin, M. and Hartig, T., 2003. Does the outdoor environment matter for psychological restoration gained through running? *Psychology of sport and exercise*, 4 (2), 141–153. doi:10.1016/S1469-0292(01)00038-3.

Borst, H.C., *et al.*, 2008. Relationships between street characteristics and perceived attractiveness for walking reported by elderly people. *Journal of environmental psychology*, 28 (4), 353–361. doi:10.1016/j.jenvp.2008.02.010.

Buchecker, M. and Degenhardt, B., 2015. The effects of urban inhabitants' nearby outdoor recreation on their well-being and their psychological resilience. *Journal of outdoor recreation and tourism*, 10, 55–62. doi:10.1016/j.jort.2015.06.007.

Bureau of Social Welfare and Public Health, Tokyo Metropolitan Government, 2016. *Tokyo walking map*. Available from: https://www.hokeniryo.metro.tokyo.lg.jp/walkmap/en/index.html.

Cook, S., Shaw, J., and Simpson, P., 2016. Jography: exploring meanings, experiences and spatialities of recreational road-running. *Mobilities*, 11 (5), 744–769. doi:10.1080/17450101.2015.1034455.

Coombes, E., Jones, A.P., and Hillsdon, M., 2010. The relationship of physical activity and overweight to objectively measured green space accessibility and use. *Social science and medicine*, 70 (6), 816–822. doi:10.1016/j.socscimed.2009.11.020.

Deelen, I., *et al.*, 2019. Attractive running environments for all? A cross-sectional study on physical environmental characteristics and runners' motives and attitudes, in relation to the experience of the running environment. *BMC public health*, 19 (1), 1–15. doi:10.1186/s12889-019-6676-6.

Desarkar, A. and Das, A., 2018. Implementing decision tree in air pollution reduction framework. *Smart innovation, systems and technologies*, 77, 105–113. doi:10.1007/978-981-10-5544-7_11.

Dong, L., *et al.*, 2023. Assessing impacts of objective features and subjective perceptions of street environment on running amount: a case study of Boston. *Landscape and urban planning*, 235 (June 2022), 104756. doi:10.1016/j.landurbplan.2023.104756.

Ettema, D., 2016. Runnable cities: how does the running environment influence perceived attractiveness, restorativeness, and running frequency? *Environment and behavior*, 48 (9), 1127–1147. doi:10.1177/0013916515596364.

Folco, P., *et al.*, 2023. Data-driven micromobility network planning for demand and safety. *Environment and planning B: Urban analytics and city science*, 50 (8), 2087–2102. doi:10.1177/23998083221135611.

Frank, L.D., *et al.*, 2005. Linking objectively measured physical activity with objectively measured urban form: findings from SMARTRAQ. *American journal of preventive medicine*, 28 (2 SUPPL. 2), 117–125. doi:10.1016/j.amepre.2004.11.001.

Gao, L.N., *et al.*, 2022. A short-distance healthy route planning approach. *Journal of transport and health*, 24 (April 2021), 101314. doi:10.1016/j.jth.2021.101314.

Gladwell, V.F., *et al.*, 2013. The great outdoors: How a green exercise environment can benefit all. *Extreme physiology and medicine*, 2 (1), 1. doi:10.1186/2046-7648-2-3.

Hochmair, H.H., Bardin, E., and Ahmouda, A., 2019. Estimating bicycle trip volume for Miami-Dade county from strava tracking data. *Journal of transport geography*, 75, 58–69. doi:10.1016/j.jtrangeo.2019.01.013.

Huang, D., Jiang, B., and Yuan, L., 2022. Analyzing the effects of nature exposure on perceived satisfaction with running routes: an activity path-based measure approach. *Urban forestry and urban greening*, 68, 127480. doi:10.1016/j.ufug.2022.127480.

Huang, D., Tian, M., and Yuan, L., 2023. Sustainable design of running friendly streets: environmental exposures predict runnability by Volunteered Geographic Information and multilevel model approaches. *Sustainable cities and society*, 89, 104336. doi:10.1016/j.scs.2022.104336.

Jacobs, J., 1961. *The death and life of big cities in the United States*. New York: Random House.

Latham, A., 2015. The history of a habit: jogging as a palliative to sedentariness in 1960s America. *Cultural geographies*, 22 (1), 103–126. doi:10.1177/1474474013491927.

Lee, D. and Ahn, J., 2019. Vehicle routing problem with vector profits with max-min criterion. *Engineering optimization*, 51 (2), 352–367. doi:10.1080/0305215X.2018.1458845.

Lee, E.H. and Jeong, J., 2024. Accessible taxi routing strategy based on travel behavior of people with disabilities incorporating vehicle routing problem and Gaussian mixture model. *Travel behaviour and society*, 34, 100687. doi:10.1016/j.tbs.2023.100687.

Liu, Y., *et al.*, 2023. Quantifying human mobility resilience to the COVID-19 pandemic: a case study of Beijing, China. *Sustainable cities and society*, 89, 104314. doi:10.1016/j.scs.2022.104314.

Meschke, J., 14 January 2019. Michigan City's heated sidewalks make it a running winter wonderland. *Runners' World*. Available from: https://www.runnersworld.com/races-places/a25349263/holland-michigan-snowmelt-system-runners/.

The Ministry of Health, Labour and Welfare of Japan, 2000. *Report on the national health promotion sport in the 21st century*. Available from: https://www.mhlw.go.jp/www1/topics/kenko21_11/pdff.html.

Morelle, K., *et al.*, 2019. Nearby outdoor recreation modelling: an agent-based approach. *Urban forestry and urban greening*, 40, 286–298. doi:10.1016/j.ufug.2018.07.007.

Norman, P. and Pickering, C.M., 2019. Factors influencing park popularity for mountain bikers, walkers and runners as indicated by social media route data. *Journal of environmental management*, 249, 109413. doi:10.1016/j.jenvman.2019.109413.

Normark, D., 2023. Recreational mobility on a busy street: visual studies of alterity by doing jogging and doing dog-walking. *Mobilities*, 18 (5), 756–772. doi:10.1080/17450101.2023.2220943.

Novack, T., Wang, Z., and Zipf, A., 2018. A system for generating customized pleasant pedestrian routes based on OpenStreetMap data. *Sensors*, 18 (11), 3794. doi:10.3390/s18113794.

Ospina, J.P., *et al.*, 2022. The maximal covering bicycle network design problem. *Transportation research part A: Policy and practice*, 159, 222–236. doi:10.1016/j.tra.2022.02.004.

Paulsen, M. and Rich, J., 2023. Societally optimal expansion of bicycle networks. *Transportation research part B: Methodological*, 174, 102778. doi:10.1016/j.trb.2023.06.002.

Ribeiro, P.J.G., Dias, G.J.C., and Mendes, J.F.G., 2022. Health-oriented routes for active mobility. *Journal of transport and health*, 26, 1–17. doi:10.1016/j.jth.2022.101410.

Santos, T., Nogueira Mendes, R., and Vasco, A., 2016. Recreational activities in urban parks: spatial interactions among users. *Journal of outdoor recreation and tourism*, 15, 1–9. doi:10.1016/j.jort.2016.06.001.

Sasakawa Sports Foundation, 2019. *The 2018 SSF National Sports-Life Survey*. Available from: https://www.ssf.or.jp/thinktank/sports_life/datalist/2018/.

Schuurman, N., Rosenkrantz, L., and Lear, S.A., 2021. Environmental preferences and concerns of recreational road runners. *International journal of environmental research and public health*, 18 (12), 6268. doi:10.3390/ijerph18126268.

Selala, M.K. and Musakwa, W., 2016. The potential of strava data to contribute in non-motorised transport (NMT) planning in johannesburg. *International archives of the photogrammetry, remote sensing and spatial information sciences - ISPRS archives*, 41, 587–594. doi:10.5194/isprsarchives-XLI-B2-587-2016.

Shuvo, F.K., Feng, X., and Astell-Burt, T., 2021. Urban green space quality and older adult recreation: an international comparison. *Cities & health*, 5 (3), 329–349. doi:10.1080/23748834.2020.1766781.

Statistics Bureau of Japan, 2017. *Survey on time use and leisure activities*. Available from: https://www.stat.go.jp/data/shakai/2016/pdf/gaiyou2.pdf.

Stavropoulou, F., Repoussis, P.P., and Tarantilis, C.D., 2019. The vehicle routing problem with profits and consistency constraints. *European journal of operational research*, 274 (1), 340–356. doi:10.1016/j.ejor.2018.09.046.

STRAVA, 2018. *Year in sport 2018*. Available from: https://blog.strava.com/ja/press/2018-year-in-sport/.

Streets Division of Transportation Services Department of Holland Village Michigan City, 2016. *Snowmelt system*. Holland: MI - City of Holland. Available from: https://www.cityofholland.com/879/Snowmelt-System.

Sun, Y., *et al.*, 2017. Examining associations of environmental characteristics with recreational cycling behaviour by street-level strava data. *International Journal of Environmental Research and Public Health*, *14* (6), 644. doi:10.3390/ijerph14060644.

Tso, G.K.F. and Yau, K.K.W., 2007. Predicting electricity energy consumption: a comparison of regression analysis, decision tree and neural networks. *Energy*, 32 (9), 1761–1768. doi:10.1016/j.energy.2006.11.010.

U.S. Department of Health and Human Services, 2018. *Physical activity guidelines for Americans*. 2nd ed. Available from: https://health.gov/sites/default/files/2019-09/Physical_Activity_Guidelines_2nd_edition.pdf.

Wang, H., Chen, H., and Cai, M., 2018. Evaluation of an urban traffic Noise-Exposed population based on points of interest and noise maps: the case of Guangzhou. *Environmental pollution*, 239, 741–750. doi:10.1016/j.envpol.2017.11.036.

Willamowski, J., *et al.*, 2019. Running tour generation for unknown environments. *In*: C. Stephanidis, ed. *HCI international 2019—posters*. Springer Cham, 528–535. doi:10.1007/978-3-030-23528-4_72.

World Health Organization, 2020. *WHO guidelines on physical activity and sedentary behaviour*. Available from: https://www.who.int/publications/i/item/9789240015128.

Xue, K., *et al.*, 2022. Research on health promotion strategies of public recreation space in the coastal area of Qingdao City Center, China. *Sustainable energy technologies and assessments*, 52 (PB), 102144. doi:10.1016/j.seta.2022.102144.

Yang, W., *et al.*, 2023. Examining the influence of neighborhood and street-level built environment on fitness jogging in Chengdu, China: a massive GPS trajectory data analysis. *Journal of transport geography*, 108 (March), 103575. doi:10.1016/j.jtrangeo.2023.103575.

Yang, W., *et al.*, 2024. Environmental factors for outdoor jogging in Beijing: insights from using explainable spatial machine learning and massive trajectory data. *Landscape and urban planning*, 243 (November 2023), 104969. doi:10.1016/j.landurbplan.2023.104969.

Zhang, S., *et al.*, 2023. The effects of street environment features on road running: an analysis using crowdsourced fitness tracker data and machine learning. *Environment and planning B: Urban analytics and city science*, 1–17. doi:10.1177/23998083231185589.