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A STUDY ON USER-ADAPTIVE NAVIGATION INCORPORATING PREFERENCE OF ELDERLY PEDESTRIANS USING THEIR ROUTE EVALUATION AND WALKING HISTORY

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ABSTRACT

Our study aims to devise a new method for route planning that caters to the distinct needs of elderly pedestrians. We established a quantitative model to capture the relationship between the characteristics of elderly users and their route preferences. Additionally, we evaluated a user adaptation methodology that incorporates user preference assessment and walking history data. “Acceptable detour time” was used as a measure of user preferences. As the primary plan, we suggested a method based on post-walking evaluations of route factors by the user, which was validated through an empirical walking experiment, highlighting the feasibility of our approach. However, this approach relies on user input for each route factor, raising concerns over user convenience. To address this issue, we extended our objective to devise a methodology that incorporates walking history, eliminating the need for user input. Drawing insights from an additional walking experiment, we formulated an alternative strategy for adjusting the acceptable detour time in our secondary plan. This strategy estimates the user's evaluation of each route factor by comparing the shortest route with the actual route walked. Application of this method to our experimental data demonstrated its utility and viability, but it also revealed an exacerbation of estimation error with updates in some situations, requiring further research to enhance the efficiency of our proposed methodology.

KEYWORDS

Pedestrian Navigation, Elderly, User Adaptive Model, Preference Estimation, Intelligent Transport Systems

1. INTRODUCTION

Pedestrian navigation services have become a standard feature in mobile devices equipped with GPS functionality. Research has also been undertaken into path-finding methodologies that incorporate requirements beyond simply the shortest distance. Concurrently, several studies have identified a multitude of factors that impede the outdoor activities of the elderly population (Muronaga and Morozumi, 2003; Yoshikawa, 2011; Mizuno, 2011). To enhance the quality of life (QOL) for seniors, supportive measures to facilitate outdoor activities have come under scrutiny. However, traditional pedestrian navigation systems that merely offer the shortest routes are insufficient to aid the elderly in their outdoor pursuits.

Our research focuses on developing a route-finding methodology employing a model that quantitatively addresses physical difficulty, psychological vulnerability, sense of security, and preferences regarding environmental factors along the route - an environmental factor cost model - to devise an effective route guidance mechanism to enhance the QOL for seniors. Specifically, we have endeavored to discern factors that take into account the physical and mental states of elderly users and build a quantitative cost function predicated on these factors. We have noted significant variance in individual subjective evaluations, thus revealing the inadequacy of relying solely on an average value model for achieving high user satisfaction (Furukawa, 2015).

To address this, we have proposed personalized navigation, taking into account subjective evaluations of walkability, safety, and pleasantness (Furukawa and Wang, 2020). Despite the global pursuit of research into personalized adaptation methodologies, these can potentially diverge from users' actual conditions due to restrictions in model-building techniques and adaptability deficiencies (Novack, 2018; Torres, 2018). Our focus in the practical application of this methodology is on "automatic responsiveness to individual user differences." This objective is especially significant in enhancing the QOL for seniors and in making critical decisions during disaster evacuations.

The following conditions have been set for the practical application of the proposed methodology: 1) To negate the effects of individual differences, we will construct a set of environmental factor cost models specific to each user, 2) To maintain the usability of the navigation system, we will not conduct in-depth interviews about user preferences, 3) similarly, solicitation of user feedback on environmental factors during use will be kept to a minimum.

Under these conditions, the research question becomes, "Could a model that estimates environmental factor costs and automatically adapts to each user's attributes be useful in identifying a route that meets each elderly individual's specific needs?" If this proves feasible, the cost model would be semi-automatically adjusted at the time of use, with the user receiving personalized route guidance services with only minimal input to the evaluation mechanism.

2. RELATED WORKS

Global research endeavors have been conducted in the field of personalized navigation, with a particular focus on enhancing pedestrian navigation services. What follows is an overview of seminal studies in this domain, juxtaposed with how they differentiate from our study.

2.1 Adaptable Methods for the Personalization

Nair et al. (2022) put forth a novel system coined ASSIST, conceived explicitly to facilitate indoor navigation for individuals with visual impairments and blindness. The distinguishing characteristic of this system resides in its tailored user interfaces that incorporate individual users' distinctive indoor wayfinding experiences and provide varied degrees of multimodal feedback. Users are required to choose the feedback modality and level, turning the selection process into one that is predominately driven by trial and error. This paradigm, however, may fall short in offering options that are optimally attuned to the specific needs of each user. To bolster adaptability for individual users, the current research implemented an adaptive strategy reliant on quantitative feedback garnered from users.

2.2 Adaptive Methods for the Personalization

2.2.1 Collecting Preference Information from the User

Zhu et al. (2022) advanced a personalized landmark adaptive visualization methodology applicable to pedestrian navigation maps. This methodology takes into account the user's familiarity with the surrounding environment, adjusting the representation of landmarks on the map accordingly. However, the range of user characteristics categories is limited, and the model does not adapt to the diverse preferences of users in an agile manner.

Ertz et al. (2021) put forth a procedure for generating comfortable pedestrian routes that incorporate green spaces, social zones, and quiet streets. This procedure relies on environmental factors and processes, which are derived from questionnaire surveys. The necessity and sufficiency of route factors and the validity of the cost quantification remain unverified. Through a series of evaluation experiments, we have already amassed considerable and reliable knowledge (Furukawa, 2015, 2020), which gives us a notable advantage.

Inada et al. (2014) offered a method that integrates both physical and psychological burdens in route selection to determine the level of difficulty. This difficulty level merges the psychological burden experienced by wheelchair users, computed via the Analytic Hierarchy Process using user-input data, with the physical burden, based on the data collected for the study, to emulate user route selection within the system. Darko et al. (2022) suggested a route search methodology adapted to each user's psychological and physiological states, specifically tailored for individuals with disabilities. The problem is modeled by considering personalized preferences, which change over time, sidewalk segment traversability, and the interaction between sidewalk factors and weather conditions that contribute to path selection. These methods predominantly focus on physical accessibility and may not sufficiently consider other impactful factors on users' experiences, such as individual preferences and perceived risks associated with different route factors.

The distinguishing feature of our approach is that it minimizes the amount of information needed to be procured in advance and adaptively tailors route factor cost models based on the user's subjective evaluations reported at the time of use.

2.2.2 Acquisition of User Preference Information via Social Network

Karimi et al. (2014) introduced an "experience-centric" concept for pedestrian wayfinding and navigation, wherein individuals disseminate their navigation experiences to others (members) via SoNavNet (Karimi, 2009), a Social Navigation Network. The integration of "compute-centric" approaches predicated on models, algorithms, and map databases and "experience-centric" approaches built upon the collective empirical knowledge of all users has the capacity to furnish the necessary information for the development of services attuned to user needs and predilections. However, for a route assessment predicated on individual characteristics, particularly preferences, it becomes imperative to devise a methodology for extracting user-specific preference information and implementing an information processing method tailored to this data. The focal point of our research lies in these methodologies. Also, the study doesn't provide a comprehensive treatment of potential privacy issues and data security concerns pertinent to this approach. Our technique employs individual reports or walking history to assess each route factor, thus circumventing privacy-related concerns.

2.2.3 Preference Information Extraction from Users' Walking History

Jonietz (2016) conducted research primarily concentrating on the physical capacities and preferences of users, extracting environmental attribute data (such as aesthetic structure, stair count, road conditions, green spaces, and so forth) from the user's walking history. From this data, a route recommendation methodology was proposed. However, Jonietz did not incorporate subjective user evaluations, a factor we have considered in our study. The approach also equates highly-rated visits to user interest, potentially diverging from the user's actual situation. Moreover, the costs used in their model prove challenging to modify by the users themselves.

Subsequently, de Oliveira e Silva et al. (2022) proposed a personalized route recommendation methodology by analyzing the historical travel behaviors of individuals. Their approach amalgamates trajectory clustering, Markov chain modeling, and a personalized route recommendation algorithm to anticipate and suggest routes, tailor-made to individual preferences and historical travel patterns. Nonetheless, the effectiveness of the personalized route recommendation might be constrained when applied to users with limited or sparse travel history, since the system's recommendations are heavily dependent on past user behavior. In contrast, our study seeks to establish a methodology that allows swift adaptability by successively updating the preference model for each route factor as data becomes available.

3. A METHOD FOR QUANTIFYING PREFERENCES

Given the diverse nature of users, quantifying preferences such as walkability, safety, and pleasantness in a manner that can inform route guidance presents a formidable challenge. In our current study, we operationalize the concept of Acceptable Detour Time (ADT) as initially proposed by Matsuda et al. in 2004.

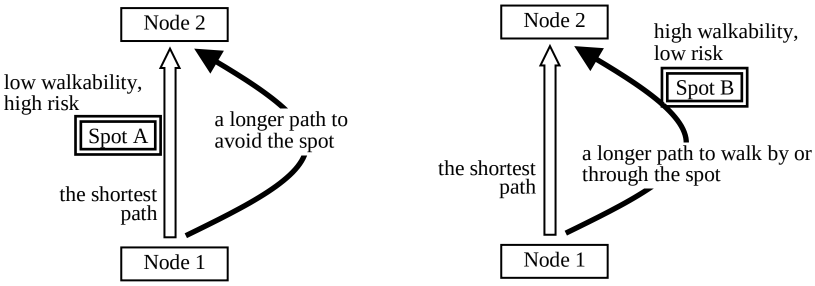
Matsuda (2004) presupposes two conditions concerning ADT. Figure 1(a) depicts the scenario where detour time signifies the additional duration a user is willing to accommodate to circumvent areas characterized by high physical demand, for instance, steep inclines, or elevated risk, such as roads devoid of sidewalks. Conversely, as demonstrated in Figure 1(b), the detour time denotes the extra time that a user is amenable to in order to select a path featuring a preferred spot, which could be easier to traverse, pose less risk (for example, an intersection equipped with traffic signals), or offer enhanced pleasure (for instance, a park).

Leveraging the principle of ADT, we define the cost that incorporates the user's preference via Equations (1) and (2).

$$C_R = \alpha_U C_D, \quad (1)$$
$$\alpha_U = T_S / (T_S + T_A), \quad (2)$$

where C_R is the revised cost of the detour path, C_D is the cost based on the physical distance of the detour path, T_S is the travel time for the shortest path, T_A is the ADT, and α_U is the cost update parameter.

As the value attributed to a detour route by a user escalates, implying an increased ADT, there is a corresponding decrease in the revised cost. This revised cost, characterized by the conditions laid out in Table 1, is substituted for the original cost when the path encompasses one of the specified spots. The deployment of this cost function enables the incorporation of pedestrian preferences into the process of route planning.



(a) a longer path to avoid a spot (b) a longer path to walk by or through a spot

Figure 1. The situations assumed for the definition of the ADT

4. PREFERENCE ESTIMATION MODEL USING ADT

4.1 Preference Estimation Model Based on User Attributes

In an effort to devise personalized routes that cater to the specific needs of the elderly, we present a method to estimate preferences for route factors derived from user attributes. This model focuses on calculating ADT for each route factor, guided by individual user characteristics such as age and physical capability.

Incorporating attributes such as age and gender is straightforward, but quantifying physical fitness presents challenges due to its multifaceted nature and the difficulty in standardizing a single measurement. Given the system’s need for accessibility, it is impractical to require pre-use physical strength assessments or to burden the user with excessive inquiries. It’s questionable whether a system can truly offer supportive assistance if it demands substantial preparation time prior to utilization. In light of these considerations, we strive to develop a preference estimation model that utilizes four predefined attributes: age, gender, frequency of daily activities (including work, shopping, and recreation), and desired intervals for rest.

4.2 Building a Model Based on Reported Data on ADT

4.2.1 Paper Survey on Acceptable Detour Time

To elucidate the relationships between user characteristics and their preferences toward various route attributes, we implemented a paper-based survey targeted at our experiment participants. This survey was specifically designed to gather data on the ADT associated with each route factor. We incorporated factors whose practicality had been validated in previous research (Furukawa and Wang, 2020) into this study. Further inquiry sessions were carried out, leading to the inclusion of additional factors, such as routes featuring convenience stores, into our pool of potential candidates. We worked with a total of 14 factors, all of which are enumerated in Table 1. Each of these factors has some correlation to either walkability, safety, or pleasantness. A paper-based survey was conducted to determine the ADT for each factor. The study saw the participation of fifty individuals aged 60 and above, who were compensated with an honorarium for their involvement.

4.2.2 Construction of Estimation Models using Acquired Data

Multiple regression analysis was performed for each of the 14 route factors, incorporating user attributes (age, frequency of outings, desired break intervals, etc.), weather, and temperature as independent variables, and ADT as the dependent variable. Separate models were developed for females and males. By utilizing pre-collected data, we assessed the feasibility of estimating users' route preferences. Table 1 presents the adjusted R^2 values obtained from the multiple regression analysis. The results suggest that female and male route selection is influenced by different factors, necessitating the use of separate models for each gender in route finding.

Table 1. Adjusted R2 values of the regression analysis models for the 14 route factors

Factors	adjusted R^2		Factors	adjusted R^2	
	male	female		male	female
1) Road with steep slopes or stairs	0.261	-0.09	8) Road around school	0.223	0.186
2) Road with many pedestrians	0.236	0.197	9) Road around a park	0.230	0.331
3) Road with a sidewalk	0.243	0.208	10) Road near the water edge	0.199	0.345
4) Road with traffic lights at an intersection	0.277	0.158	11) Road with a police box	0.266	0.327
5) Road with guardrails	0.179	0.257	12) Narrow road with poor visibility	0.230	0.408
6) Road with a pedestrian overpass	0.258	0.178	13) Road with a convenience store	0.231	0.323
7) A bright road	0.207	0.244	14) Road with a guide map	0.224	0.341

The adjusted R^2 value for the multiple regression analysis is relatively low, indicating a lack of high reliability in the model. The multiple regression model, employing the factors investigated in this study, lacks sufficient accuracy to provide comfortable routes for users. To address this issue, two potential approaches are identified. One approach involves incorporating additional factors as independent variables into the model, which may have an impact on its performance. The other approach entails adaptively enhancing the model for individual users by leveraging information gathered after each walk. Given the substantial variations in preferences among individuals, the constructed model serves as a fundamental framework, while exploring a sequential model improvement method based on individual users' route evaluations and walking data.

5. AN ADAPTIVE METHOD FOR ENHANCING ESTIMATION MODELS

To present routes that align with user preferences and offer ease of walking, it would be effective to update the cost model by incorporating information gathered during walking as well as post-walking evaluations of the routes. However, considering the convenience of navigation, it is not appropriate to burden the user with time-consuming and attention-demanding questions. Instead, it would be desirable to utilize simple questions that do not impose a heavy burden on the user or leverage data that can be obtained passively. Therefore, in this method, we adopt a technique that utilizes the user's actual walking speed and their evaluation results of route factors as a means to adapt the model to individual users. The former corresponds to data that can be acquired passively, while the latter pertains to the user's evaluation of the routes. In this research, we assess the fundamental effectiveness and feasibility of this idea through the utilization of a straightforward method.

5.1 Model Improvement through Adjustment of Walking Speed

Given that the ADT serves as a preference metric, it is essential to incorporate the user's walking speed in the calculation of route cost. Accurately estimating walking speed in advance poses a challenge due to its potential variation influenced by attributes such as age, gender, exercise habits, and personality traits. To address this issue, the present study proposes a system that measures the user's walking speed and utilizes this information to generate the subsequent route.

5.2 Model Improvement Based on Preference Evaluation Results

To enhance the cost estimation model and tailor it to individual users, incorporating subjective evaluation data regarding preferred and rejected route factors is necessary. When users are prompted to provide their ADT for each factor while utilizing a navigation service, they are required to make a generalized evaluation of each route factor independent of their specific travel situation. This implementation is anticipated to demand a certain amount of time and attention from the user, potentially compromising convenience. In this approach, instead of utilizing the ADT, the evaluation value of the user's preference for the route factors encountered during their journey is employed. The evaluation value is obtained using a 5-point scale (5: strongly prefer to go through - 1: strongly prefer not to go through). By utilizing these results to adjust the ADT, the cost model can be improved.

Specifically, the user's preference estimation model is updated using the following update equations (3) and (4). Distinct methods are employed for positive factors and negative factors. The correction factor is determined as 1.5 times the current ADT when the preference evaluation value reaches its maximum value, which is 5. Conversely, it is 0.5 times the current ADT when the preference evaluation value is at its minimum, namely 1.

For favorable factors: $T_1' = (1/4 * E + 1/4)\ T_0$ (3)
For factors to be avoided: $T_1' = (-1/4 * E + 7/4)\ T_0$ (4)

where T_1' is the updated ADT, T_0 is the current ADT, and E is the user's evaluation value of the route factor.

6. A VALIDATION EXPERIMENT ON THE MODEL IMPROVEMENT METHOD

The aim of this experiment is to validate the efficacy of the proposed cost-improvement method in enhancing user walkability and comfort along the intended route. During this experiment, participants were requested to physically traverse the routes planned by the model, both before and after the implementation of improvements. Subsequently, a composite evaluation of each route was conducted, and the results were compared. Furthermore, participant interviews were conducted to identify the level of fatigue experienced after walking and to ascertain any factors that caused discomfort during the walk, thereby pinpointing areas for improvement.

6.1 Experiment Procedure

(1) Employing the estimation model constructed in Section 4, which is based on ADT, we devised route plans tailored to each participant.
(2) With the assistance of the navigation system, participants were directed to traverse toward three distinct destinations.
(3) After each route, we solicited participants to render a composite appraisal, on a scale from 0 to 100, evaluating walkability, safety, and pleasantness.
(4) Participants were requested to express their preference, on a five-level scale, for each of the identified factors within the given route.
(5) By harnessing the model improvement method specified as Equations (3) and (4), utilizing the participant's preference values for the route factors, we updated the set of ADTs for each individual.
(6) Utilizing the updated ADT and the collected walking speed data for each participant, we executed a fresh round of route planning tailored to each individual.
(7) Once again, aided by the navigation system, participants were guided to revisit the initial three destinations.
(8) After each route, we prompted participants to provide a composite evaluation, again on a scale from 0 to 100, of walkability, safety, and pleasantness.

6.2 Experimental Setup

Our experimental participants consisted of nine senior citizens, comprising three females in their 60s, two females in their 70s, three males in their 70s, and one male in his 80s. Participants were specifically selected based on their unfamiliarity with the experimental regions, premising the scenario where the user visits the area for the first time. Before the experiment, an explicit explanation of the study's significance, objectives, procedures, potential risks, and respective countermeasures was provided to the participants. Only those who expressed consent proceeded to partake in the experiment, for which they received remuneration. The research design was subjected to an ethical review, and was subsequently approved by the Ethics Review Committee of the Institute of Systems and Information Engineering, University of Tsukuba (Approval number: 2019R349).

Our proposed route planning methodology, which utilizes ADT, necessitates precise speed measurements due to the significant impact of inter-node travel time on cost computation. In this experiment, participants were required to wear a specific GPS device, the i-gotU GT-600. The participants were guided to their destinations using a navigation application installed on a smartphone, while being asked to walk. The smartphone model employed in this study was the "SONY Xperia XZ3 SO-01L." The navigation application was custom-built for this experiment using the map development kit "GeoTechnologies MapFan SDK."

6.3 Locations of Experimental Execution

The experiment was carried out in the area surrounding Nagareyama Otakanomori Station, located in Nagareyama City, Chiba Prefecture, Japan (refer to Figure 2 for the corresponding area map). The region is characterized by a multitude of potential route determinants, which include school buildings, waterfront zones, and a complex network of narrow, winding roads.

Figure 2. Area covered by the walking experiment

Below are succinct descriptions of the three areas traversed by the participants.

Area 1: Broad, Well-Maintained Thoroughfares

The first area covers the region around the path leading from the initial location (Point 1) to the subsequent destination (Point 2). This vicinity boasts a plethora of properly maintained roads. Its close proximity to a train station attracts a considerable number of pedestrians and, correspondingly, the sidewalks are generously wide. Residential zones showcase slightly narrower roads, yet these are devoid of significant variations in elevation, making them easy to traverse. The landscape's contributing factors are diverse, including river-adjacent roads and a considerable abundance of parks.

Area 2: Constricted, Busy Roads Accompanied by Sidewalks

The second area encapsulates the region surrounding the trajectory from the starting point (Point 2) toward the subsequent destination (Point 3). In contrast to Area 1, the majority of roads here lack appropriate maintenance. Several instances of narrow sidewalks and areas entirely devoid of them are observed. Furthermore, some of these constricted roads are accompanied by sloping terrains.

Area 3: Busy Roads Devoid of Sidewalks

The third area represents the vicinity enveloping the route starting from point 3 and culminating at destination 4. A significant proportion of the roads here lack sidewalks. Its closeness to the hospital results in an influx of pedestrians. Away from the main roads, there exist rather narrow streets located alongside the railway tracks.

6.4 Analysis of Experimental Data and Results

Figure 3 presents a box-and-whisker plot illustrating the distribution of the composite evaluation scores (ranging from 0 to 100) for each region. The t-test revealed no significant difference between the means of the composite evaluation scores for the initial and improved models, at a significance level of 5%. In Area 1, the data from each participant exhibited either marginal or no change between the two evaluations, or even a decrease in value. Conversely, for Area 3, the assessment scores of 8 out of 9 participants exhibited an increase, suggesting successful improvements in the cost model. Given that the original routes were characterized by a high level of risk, amendments to the model, driven by participant preference scores, likely contributed significantly to enhancing route safety and subsequently boosting their scores.

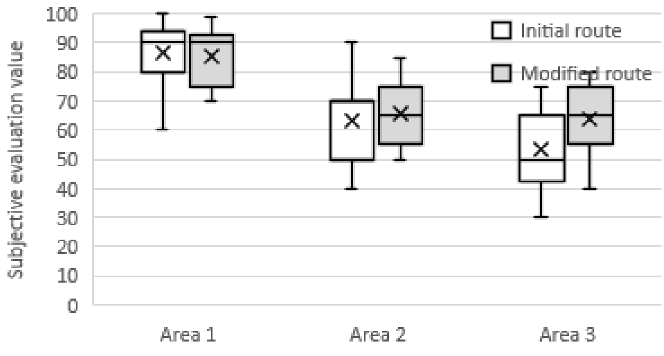


Figure 3. A box-and-whisker diagram of the composite evaluation for each area

Subsequently, the data underwent statistical analysis wherein the attributes of the participants were classified as conditions. Independent t-tests were performed for both male and female groups separately, revealing no significant discrepancies in the mean scores of the composite evaluations of the initial and enhanced models for both genders (at a 5% significance level). Figures 4 and 5 display box-and-whisker plots of the composite ratings for each demographic area for males and females, respectively. For the male group, the evaluation shows little evidence of improvement. Conversely, a progressive trend towards improved evaluations is observed amongst the female group. The women's composite evaluations of the initial routes tend to be lower, suggesting a greater emphasis on route "safety." When the analysis was conducted categorizing by other attributes, such as age and frequency of outings, no significant impact was discerned on the composite evaluations.

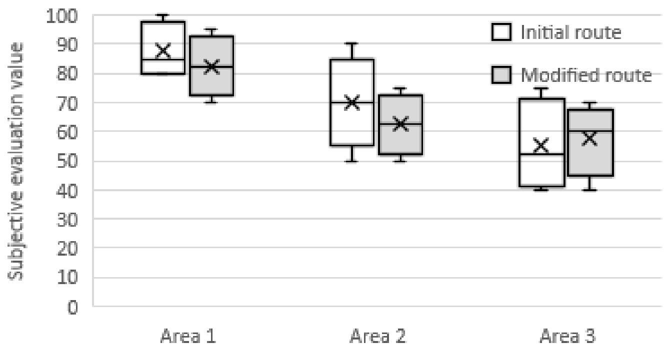


Figure 4. A box-and-whisker diagram of the composite evaluation of males

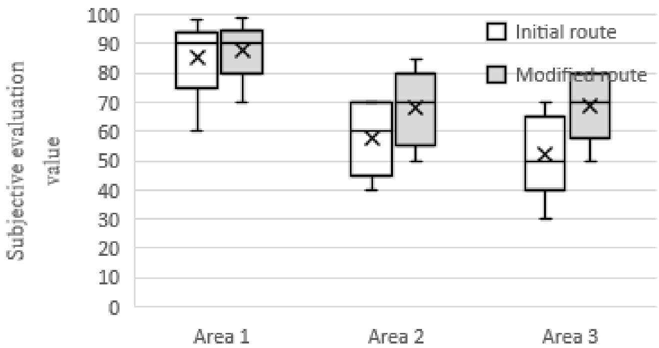


Figure 5. A box-and-whisker diagram of the composite evaluation of females

6.5 Discussion

6.5.1 Efficacy of the Cost Improvement Methodology

Despite no discernable statistical disparity in route assessments, evidence of enhanced evaluation was observable under certain circumstances. High-risk roads or those heavily congested with vehicular traffic were common features of initial routing in Areas 2 and 3. However, these were circumvented in the revised routing, which likely bolstered the evaluation from a safety perspective. This pattern is particularly evident in results derived from female participants.

In contrast, Area 1 displayed a different trend where numerous users bestowed high ratings on the original routing, while the revised route garnered a diminished appraisal. There is a potentiality that the model's precision may have been compromised due to an over-adjustment of model parameters predicated on the participants' evaluation metrics. As our study was oriented towards validating the "enhancement of route evaluation via the proposed route modification methodology," we configured the update parameter to accommodate substantial values. For bolstering the model's adaptability, the scope of variation for update parameters should be constricted, and the modification methodology should leverage a vast dataset of evaluation metrics for transit locations.

Given the utilization of a composite assessment encompassing walkability, safety, and pleasantness as a basis for participant evaluation of routes in this study, it might lead to ambiguous results and complicate discussions regarding the impacts.

6.5.2 Suitability of the preference evaluation method for route factors

The present study utilized a 5-point scale to garner ratings for the route factors, as referenced in Section 5.2. Given the considerations for the user's load, the time required, and the enhancement in model precision, this method can be regarded as fitting. To further alleviate the user's load, a proposal is also under consideration to categorize route factors and decrease the count of evaluation items.

7. A PROPOSAL FOR THE DEVELOPMENT OF A NOVEL ADAPTIVE IMPROVEMENT METHOD

7.1 A New Strategy towards the Development of an Adaptive Method to Update ADTs

In Section 5, we introduced an individualized adaptation approach for cost estimation models utilizing post-ambulation evaluations of route factors. Through our walking experiments, notable enhancements in participants' appraisals of their routes were identified, demonstrating the practicality of the user adaptation technique predicated on the user's preferential evaluations for route factors.

The current approach, however, necessitates the user to scrutinize every route factor encountered, which can be perceived as an excessive burden when applying this method. As a response, rather than insisting users evaluate every individual factor, we propose to devise a method to revise the model based on the user's ambulation history. The fundamental concept is to contrast the route suggested by the navigation system with the route the user actually traversed. ADTs for each route factor can then be adjusted by taking into account whether a specific route factor was either avoided or traversed, which in turn reflects the user's assessment of each respective factor.

7.2 An Ambulatory Experiment on Aging Populations for the Development of Improvement Techniques

In pursuit of establishing an updating protocol grounded in the fundamental principles, we implemented an experiment to gather the walking patterns of the elderly population. We defined an origin and a destination such that the most direct route would approximate 1 kilometer in length. Subsequently, we invited our elderly participants to traverse routes that appealed to their comfort and inclination toward the destined location. Moreover, we solicited information on ADTs pertaining to each route factor, both before and following the walking activity.

7.2.1 Experimental Setup

The participants for this study comprised ten senior individuals (five females and five males, with an age range of 65 to 78, a mean age of 72.5, and a standard deviation of 3.23). We purposefully selected participants unfamiliar with the designated experimental areas, operating under the assumption that the user represents a first-time visitor to these locations. Before conducting the experiment, all participants were provided with a comprehensive explanation of the study's objectives, methodology, potential risks, and procedures. Only those who gave their informed consent were included in the experiment and received a compensatory reward. The study protocol received ethical approval from the Ethics Review Committee at the Institute of Systems and Information Engineering, University of Tsukuba (Approval Number 2022R689).

Our proposed route planning methodology, which is based on ADT, requires precise speed measurements due to the significant impact of node-to-node travel time on cost calculations. For this experiment, participants were equipped with a dedicated GPS device (Fitbit Charge 4). They were instructed to navigate towards their destinations using a custom-built smartphone navigation application on the SONY Xperia XZ3 SO-01L. This navigation application was specially designed for this study, developed utilizing the "ArcGIS Pro" and "ArcGIS Field Maps" map development kits.

Figure 6 presents a sample of the pedestrian navigation interface utilized in this study. The following features are displayed on the map: the starting point (in blue), the endpoint (in red), the user's current location (in black), the shortest route (highlighted by a pink line), roads containing stairs (denoted by a grey line), and roads on an incline. Inclined roads are marked with a color gradient ranging from clear to yellow, red, and brown, representing increasing incline levels. The gradient was computed using the Numerical Elevation Model, a fundamental component of the map data provided by the Geospatial Information Authority of Japan (GSI).

The experiment was undertaken near two locations in Japan: Nagareyama-centralpark Station situated in Nagareyama City and Minami-Nagareyama Station located in Matsudo City. Each participant was instructed to traverse three distinct paths daily over the course of two consecutive days. Consequently, we secured walking histories for a total of six different routes per individual.

Drawing from the outcomes of our preliminary experiment, we prompted the participants to indicate their ADTs concerning the route factors presented in Table 2. In this context, factors 1, 2, and 8 potentially represent factors the users would prefer to circumvent, while the remaining factors could be perceived as factors the users may opt to traverse.

Table 2. Route factors targeted in the second experiment

Factors	Factors
1) Road with steep slopes or stairs	7) Road near the water edge
2) Road with many pedestrians	8) Narrow road with poor visibility
3) Road with a sidewalk	9) Road with a convenience store
4) Road with traffic lights at an intersection	10) Road around school
5) Road with guardrail	11) Road around a shrine or a temple
6) Road around a park	

Figure 6. Example of the pedestrian navigation screen used in the second experiment

7.2.2 Experiment Procedure

(1) Initially, participants in the experiment are requested to indicate an ADT, considering each route factor. They have the flexibility to select within a range of one-minute increments, between 0 and 10 minutes, as their ADTs. If the time exceeds 10 minutes, they are provided with an alternative to select the option "greater than or equal to 10 minutes."

(2) The following steps are undertaken across six different routes:

(2-1) Participants are shown a digital map of the experimental area on their smartphones. This map explicitly presents the points of origin and destination, alongside the shortest possible route. Utilizing this map, participants are encouraged to establish their walking route by opting for the roads they find comfortable and prefer to traverse.

(2-2) Participants are then instructed to follow the chosen route, keeping an eye on the map displayed on their smartphones.

(2-3) Upon reaching the destination, participants are once again requested to report the ADTs of the route factors on both the shortest path and the walked route. Moreover, they are prompted to provide an open-ended response concerning any potential issues or points of interest encountered during the walk.

7.3 Analysis of the Relationship Between Chosen Route and ADT

The analysis delineated three instances in which participants evaded the route factors of "Roads with steep slopes or stairs" on the most direct path. These instances provided an opportunity to compare changes in the ADT before and following the walking exercise, as well as the actual time necessitated by the detour (refer to Table 3).

Preceding and succeeding Participant F's third walk, labeled F3, a discernible shift was noted in the ADT, which expanded from 0 minutes to 2 minutes. Likewise, in the case of Participant H's third walk, termed H3, the ADT demonstrated a decreasing trend, shrinking from 4 minutes to 1 minute. In both instances, it can be verified that the ADT, post-walk, underwent a change that brought it closer to the actual time taken by the detour. Contrarily, in the case of Participant E's initial walk, E1, the ADT remained unchanged.

Table 3. ADTs reported by the participants and the actual detour times (route factor: Roads with steep slopes or stairs)

	The first trial of Participant E (E1)	The third trial of Participant F (F3)	The third trial of Participant H (H3)
ADT reported before the actual walking (min.)	3	0	4
ADT reported after the actual walking (min.)	3	2	1
The actual detour time (min.)	0.92	0.65	0.65

8. A NEW ADAPTIVE ENHANCEMENT TECHNIQUE AND ITS VALIDATION

8.1 Adaptive Update Mechanism for Inference Models Leveraging User's Walking History

The outcomes presented in Table 3 suggest that the ADT, considering potential route alterations users might opt for, tends to either approximate the actual detour time or remain stable. The application of the previously examined update technique revealed that updates could potentially diminish estimation precision, as it operates within a relatively large update range from 0.5 to 1.5 times. Consequently, we introduce a method intended to gradually converge toward an optimal ADT by implementing repeated updates with reduced increments.

The ensuing discussion presents the method for updating the ADT, devised in light of the aforementioned observations.

$$T_1' = ((\alpha-1)T_0 + l/w) / \alpha, \quad (5)$$

where T_0 is the ADT before the walking, l is the distance detoured to avoid the route factor, w is the user's walking speed, T_1' is the updated ADT, and α is an update parameter.

In this revised equation, the detour duration, represented by l/w, is incorporated to adjust the initial ADT before walking, T_0, for estimating the revised ADT post-walking, T_1'. It's worth noting that as the parameter α approaches 1, the impact of the detour time becomes more significant. On the contrary, increasing α diminishes its influence, reducing the extent of the adjustment from the initial ADT before walking.

8.2 Association of Update Parameter with Estimation Error

This section quantitatively validates the relationship between the parameter α and estimation error with a view to determining the optimal parameter value. The experimental participants' routes included three instances where they deviated via "Roads with steep slopes or stairs" and five instances via "Narrow roads with poor visibility." The proposed method was applied to each instance to investigate the effect of parameter variations on the estimation error. The average walking speed was derived from the experimental data for each participant and was utilized as the walking speed w.

Figures 7 and 8 illustrate the disparity between the estimated ADT, calculated when applying the update method with varying α values, and the actual time reported post-walk. The horizontal axis represents the value of the parameter α, whereas the vertical axis signifies the absolute difference between the estimated and the actual reported values.

In the instance of E1, as illustrated in Figure 7, the ADTs both before and after traversing roads characterized by steep slopes or stairs remain constant. Consequently, an increase in the value α corresponds to a diminishing disparity. Conversely, for the instances of F3 and H3, it was observed that as the value α grows, so does the difference.

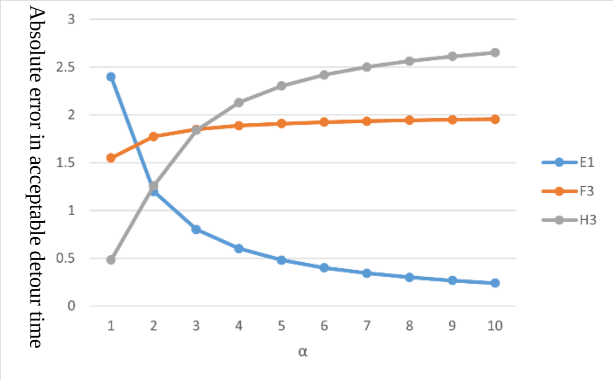


Figure 7. Change in absolute error in ADT with the update parameter α as an independent variable (route factor: Roads with steep slopes or stairs)

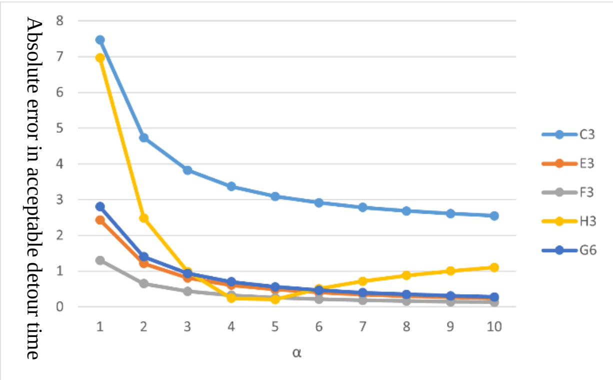


Figure 8. Change in absolute error in ADT with the update parameter α as an independent variable (route factor: Narrow roads with poor visibility)

When operating under the condition of navigating narrow roads with compromised visibility (Figure 8), we discerned that case H3 exhibited the minimal difference when α equals to 5. For the instances of C3, E3, F3, and G6, we confirmed that an increment in the parameter α is associated with a decreasing difference.

In this study, the participants opted to bypass the route factors in merely three instances for roads with steep slopes or stairs and in five instances for narrow roads with poor visibility. Given the opportunity to observe more cases, it might be feasible to ascertain the optimal α for each route factor, which can be grounded on the relationships between the deviation of estimated and actual values and the parameter α. Notably, a subset of participants did not register any variation in the ADT. Hence, it may be necessary to establish the optimal value α on an individual basis.

8.3 Outcomes of Implementing the Proposed Method for Updating ADT

This section delves into the outcomes derived from the implementation of the proposed method for updating the ADT following the walking trials, by employing the results of the study on parameters presented in Section 8.2.

8.3.1 Roads with Steep Slopes or Stairs

Table 4 displays the outcomes of implementing the updating technique on three specific cases which necessitated taking detours around "routes with significant inclines or stairways." In these instances, we selected a value of $\alpha = 2$, representing the smallest sum of differences between the estimated and actual values for the three cases illustrated in Figure 7. The table provides the ADT as reported by participants before the walking trials, T_0, the ADT reported post-walking, T_1, the ADT updated through the proposed method, T_1', along with the absolute error in the ADT before and after the update, denoted by $|T_0-T_1|$ and $|T_1'-T_1|$ respectively.

In Instance F3, an increased value is reported as the ADT post-walking, as compared to its pre-walking counterpart, while the update utilizing the proposed method also elevated the value compared to its pre-walking version. In the H3 instance, the ADT reported post-walking is smaller than the one reported pre-walking, and it is further reduced by the update using the proposed method. In contrast, Instance E1 demonstrates that the ADTs reported both before and after walking are identical, leading to an increase in error after the update.

Table 4. The absolute errors of the ADT before and after revision by the proposed method (route factor: Roads with steep slopes or stairs)

	E1	F3	H3
ADT reported before the actual walking: T_0 (min.)	3	0	4
ADT reported after the actual walking: T_1 (min.)	3	2	1
The revised ADT by the proposed method: T_1' (min.)	1.80	0.23	2.26
The absolute error of the ADT before the revision (min.)	0	2	3
The absolute error of the ADT after the revision (min.)	1.20	1.77	1.26

8.3.2 Narrow Roads with Poor Visibility

Table 5 illustrates the outcome of implementing the update method on five instances that circumvented the "Narrow roads with poor visibility" factor. For all scenarios except H3, the divergence between the estimated and the measured value diminished as the parameter escalated. For Instance H3, the difference reached its minimum at $\alpha = 5$. Thus $\alpha = 5$ was adopted for the application.

For Instance H3, the reported ADT post-walk is lesser than its pre-walk counterpart. Interestingly, the adjustment by the suggested approach also reduced the value below its pre-walk level. Conversely, in Instance C3, the ADT post-walk is greater than its pre-walk counterpart. However, the adjusted value is lower than the pre-walk reported value. This discrepancy implies that the suggested approach fails to implement an appropriate update under these circumstances.

In Instances E3, F3, and G6, the ADT before and after the walk was identical, and the absolute error escalated post-update.

Table 5. The absolute errors of the ADT before and after revision by the proposed method (route factor: Narrow road with poor visibility)

	C3	E3	F3	H3	G6
ADT reported before the actual walking: T_0 (min.)	6	3	0	10	0
ADT reported after the actual walking: T_1 (min.)	8	3	0	8	0
The revised ADT by the proposed method: T_1' (min.)	4.91	2.51	0.26	8.21	0.56
The absolute error of the ADT before the revision (min.)	2	0	0	2	0
The absolute error of the ADT after the revision (min.)	3.09	0.49	0.26	0.21	0.56

8.4 Discussion

8.4.1 Efficacy of the Cost Improvement Approach

As discussed in Section 8.3, the implementation of the proposed revision methodology to the ADT, corresponding to route factors potentially opting for avoidance, led to the enhancement of the estimation error in three out of eight scenarios. In these instances, the ADTs, as articulated by the participants, were modified, approaching more closely the detour times experienced during walking. This underscores the soundness of the fundamental principle underlying our proposed approach.

In one of the eight instances, the ADT, as stated post-walk, escalated from its pre-walk value, yet its orientation towards time reduction was noted following the update through the proposed methodology. In this particular instance, the original route incorporated two factors of the same category, making it plausible that the ADT was augmented when the participant engaged in route planning with the aim of avoiding both factors. As for the remaining four instances among the eight, no variation in the ADTs pre and post-walk was observed, leading to their degradation induced by the proposed approach.

Drawing from these outcomes, to consolidate the approach, it becomes imperative to elucidate the circumstances under which our method proves advantageous, those in which it turns out to be unsuitable, and the rationale behind its unsuitability. Given the restricted number of scenarios in this investigation, it was not feasible to accomplish these tasks.

8.4.2 Analysis of Optimal Parameter

As previously delineated in Section 8.2, the experimental results witnessed a limited number of instances where participants successfully avoided avoidable route factors. Such a limited dataset presents a significant challenge in scrutinizing the optimal value of parameter α. Consequently, it is imperative to amass additional data and conduct an exhaustive analysis of the appropriateness of the update magnitude under diverse conditions. This will further our understanding of the calibration of the parameter α.

8.4.3 Diversity in Attributes of Participants

In the conducted experiment, a majority of the participants were observed to be healthy, exhibiting a daily walking routine and no difficulty in navigating routes encompassing slopes and stairs. Participants for the experiment were procured through the Tsukuba City Senior Citizens' Human Resources Center. It is postulated that most of the registered elderly individuals at this center were seeking employment, indicating a general state of good health. Considering that the participant group is comprised primarily of healthy elderly individuals, it is indispensable to incorporate a more varied demographic of elderly individuals for an accurate evaluation of the generalizability of the proposed method.

9. CONCLUSION

9.1 Summary

In this project, our objective is to devise a route planning technique that tailors to individual users, specifically considering the unique preferences of elderly users, including walkability, safety, and overall pleasantness of the route. To fulfill this objective, we constructed a quantitative model that delineates the relationship between the characteristics of elderly users and their route selection preferences. We then scrutinized the feasibility of two types of user adaptation methods: one that relies on the user's evaluation of route factors and another based on the user's walking history.

The concept of "acceptable detour time" was employed to quantify user preferences in this research. Our survey findings revealed that user characteristics, such as "age" and "desired break intervals," significantly influenced route selection, and the influence of these attributes was found to vary by gender. These findings suggest that focusing on specific user characteristics can effectively estimate the preferences of elderly users for different routes. Consequently, it becomes essential to construct separate models for males and females when developing user-friendly walking routes.

For the first plan, we proposed an individual model adaptation method, using post-walk evaluations of route factors, and validated its efficacy through walking trials. We were able to discern improvements in the route evaluations of the participants in certain scenarios, which indicates the feasibility of the user adaptation method that relies on the user's evaluation of route factors.

In the first method, the user is required to provide an evaluation of each route factor post-walking, which compromises convenience. Hence, we sought to develop a technique that allows for individual model adaptation based on the user's walking history, eliminating the need for user-input data. We investigated a method to estimate the user's evaluation of each route factor by contrasting the shortest route and the actual walked route, and analyzing the disparities.

We first conducted a walking experiment involving elderly participants. Having shown them the shortest route, we collected data on the actual walking by choosing either a comfortable road or a road the participant preferred to walk. Through analysis, it was confirmed that, when certain route factors were avoided, there were instances where the reported ADT approximated the actual detour time required, while in other cases, the ADT remained consistent pre- and post-walking.

Relying on these analytical results, we conceived a novel method for updating ADT as the second plan. Applying this method to data acquired from the previous experiment, we validated that, in several instances, the method was successful in making updates consistent with the changes in ADT measured before and after walking. Hence, under certain circumstances, the proposed method demonstrates utility and viability. However, it has been observed that the estimation error escalates due to updates, necessitating further research to elucidate the cause and enhance the method.

9.2 Future Works

The first objective is to conduct a novel validation experiment involving an adequate number of participants to ascertain definite conclusions through statistical analysis. Additionally, to elucidate the outcomes, it is imperative to employ dedicated evaluation indicators for assessing walkability, safety, and pleasantness when evaluating planned routes. Secondly, it is necessary to acquire supplementary route factors. To address route factors not encompassed in this study, a comprehensive survey investigating the factors influencing route selection is required. The third aspect pertains to enhancing the model adaptation method. By utilizing data from additional experiments, it is crucial to clarify the conditions under which the proposed method is suitable, unsuitable, or inappropriate, as well as understand the underlying reasons for its inadequacy. Subsequently, an individually adaptable routing method that can cater to the diverse attributes of users and various situations should be developed.

The fundamental concept of the proposed method can be applied to the planning of evacuation routes in the event of a disaster. The authors are currently developing a pedestrian navigation method that incorporates a model to quantitatively evaluate the fear experienced by individuals during evacuation actions based on the conditions of the roads, with the aim of providing evacuees with fear-free routes (Furukawa and Koshimizu, 2022). While the results demonstrate that the mean level of fear is lower for the revised method compared to the shortest path, addressing the significant individual differences in fear estimation is necessary to enhance the accuracy of estimation. We posit that employing an individual adaptation approach to the model, utilizing post-walking evaluations of route factors, has the potential to mitigate this issue.

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