

Article

Human-Centered Design of an Age-Friendly AR Navigation Product Service System for Older Adults: A QFD-PCN-Based Approach

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Abstract

Population ageing and the increasing digitalization of urban mobility have created new challenges for navigation services for older adults. Existing augmented reality (AR) navigation research has largely focused on interface interaction and wayfinding, with less attention focused on coordination across the wider travel service process. This study adopts a service design perspective to develop a conceptual age-friendly AR navigation product-service system. User research with 196 older adults in Nanjing, China, combined questionnaire findings with user portrait, journey, and stakeholder analyses. Eight requirement dimensions were prioritized using AHP and entropy weighting. QFD related 22 lower-level requirements to 15 functional elements, followed by PCN analysis of service activities across urban travel stages. Safety, operational ease of use, cognitive support, and sensory support emerged as the leading priorities, while traffic resource integration, AR road-condition display, and route indication ranked highest among the functional elements. The service analysis also identified opportunities to reorganize route planning, navigation assistance, transport coordination, and payment activities. The resulting conceptual system links wearable AR navigation, mobile functions, and backend service coordination, offering a structured approach to age-friendly navigation design.

Keywords: augmented reality; age-friendly design; navigation assistance; service design; process chain network

1. Introduction

China's rapidly aging population has expanded the "silver economy" [1] and increased demand for age-friendly products and services. Urban travel has become an increasingly important concern as cities continue to develop intelligent infrastructure and digital services. Many older adults maintain active social participation and have growing expectations for independent travel [2]. At the same time, age-related changes in mobility, perception, and cognition may increase the difficulty of interpreting complex travel information and using unfamiliar digital services. A gap remains between existing navigation services and the actual travel needs of older adults, making the design of age-appropriate travel navigation products increasingly important [3].

Growing policy support for age-friendly mobility, the increasing purchasing power of older consumers, and the still-limited adoption of intelligent products have created opportunities for developing new navigation services using emerging technologies [4].



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Augmented reality (AR) has received growing attention for its ability to present route and traffic information in relation to the surrounding environment. By overlaying route and traffic information onto real-world scenes, AR may help older adults perceive and interpret complex travel information more effectively [5–7]. Previous studies have begun to examine how older adults use AR in navigation and route planning. Handheld AR has been evaluated for public transport route planning, while NavMarkAR uses landmark guidance through smart glasses to support indoor wayfinding and spatial learning among older adults [8]. Research in this area also points to the importance of interface organization, information presentation, cognitive demand, and interaction design for age-friendly AR navigation.

Despite this progress, current AR navigation solutions still show limitations in age-friendly design [9]. Although the navigation products offer a “care mode” for the elderly, the age-friendly design of their functional architecture, interactive logic, visual design, humanistic care, etc., remains insufficient. Simultaneously, these products are weakly connected with other transportation resources, and the design of relevant supporting service systems is severely lacking [10]. The supply and demand of each unit’s operations are dispersed and fail to integrate into the system of the travel navigation chain [11]. Table 1 summarizes representative AR navigation products and related forms of navigation support.

Table 1. Analysis of the current state of AR navigation products.

Product	Core Navigation Functions	Interaction Mode	Age-Friendly Support	Limitations
Navigational APP	Route planning Positioning navigation AR technology assistance Help alarm	Touch screen trigger Voice trigger	Navigation planning possible AR technology intervention makes information easy for the elderly to receive	Planning route is not close to the needs of elderly users Dependent on mobile terminal Information receiving lag Poor picture quality Discomfort Limited usage scenarios

From the perspective of service design, navigation difficulties involve both interaction with the product and coordination across the surrounding service process. Service design is a comprehensive integration and innovative design activity based on user needs [12] and collaborative multifaceted stakeholders through personnel, products, information, and other elements to achieve system innovation of service process, service contact, service supply, and demand to enhance service quality [13]. Applied to navigation for older adults, this perspective allows interface requirements, mobility resources, and supporting services to be considered within the same travel process [14].

Accordingly, this study proposes a conceptual age-friendly AR navigation product-service system for older adults within a Mobility as a Service (MaaS)-oriented context [15,16]. The S-O-R framework is used as a conceptual structure for organizing navigation barriers identified through the user research. Quality function deployment (QFD) is then used to relate user requirements to functional priorities, and process chain network (PCN) analysis examines how relevant service activities are distributed among older adults, system functions, and supporting service actors. The resulting design organizes wearable AR guidance, mobile functions, and backend service coordination within the urban travel process. The study therefore extends the design focus from individual navigation functions to the connection between user requirements, functional organization, and service processes.

2. Materials and Methods

The methodological framework centers on the travel needs of older adults and links user research with requirement prioritization, functional analysis, and service process analysis. QFD and PCN connect identified navigation needs with functional priorities and the organization of service activities across the travel process.

2.1. Research Method

This study adopted a service design approach centered on the travel needs of older adults. The research connected user research and requirement identification with the prioritization of system functions and the analysis of related service processes. Quality function deployment (QFD) was first used to relate the identified user requirements to navigation functions and establish their relative design priorities [17,18]. Process chain network (PCN) analysis was then applied to examine how the prioritized functions were situated within route planning and navigation services, with particular attention to the distribution of activities among older adults, system functions, and supporting service actors. The sequential use of QFD and PCN connected requirement prioritization with the organization of service activities across the travel process. The user research and weighting procedures that informed the QFD analysis are described in the following sections. Figure 1 presents the overall analytical framework of the study.

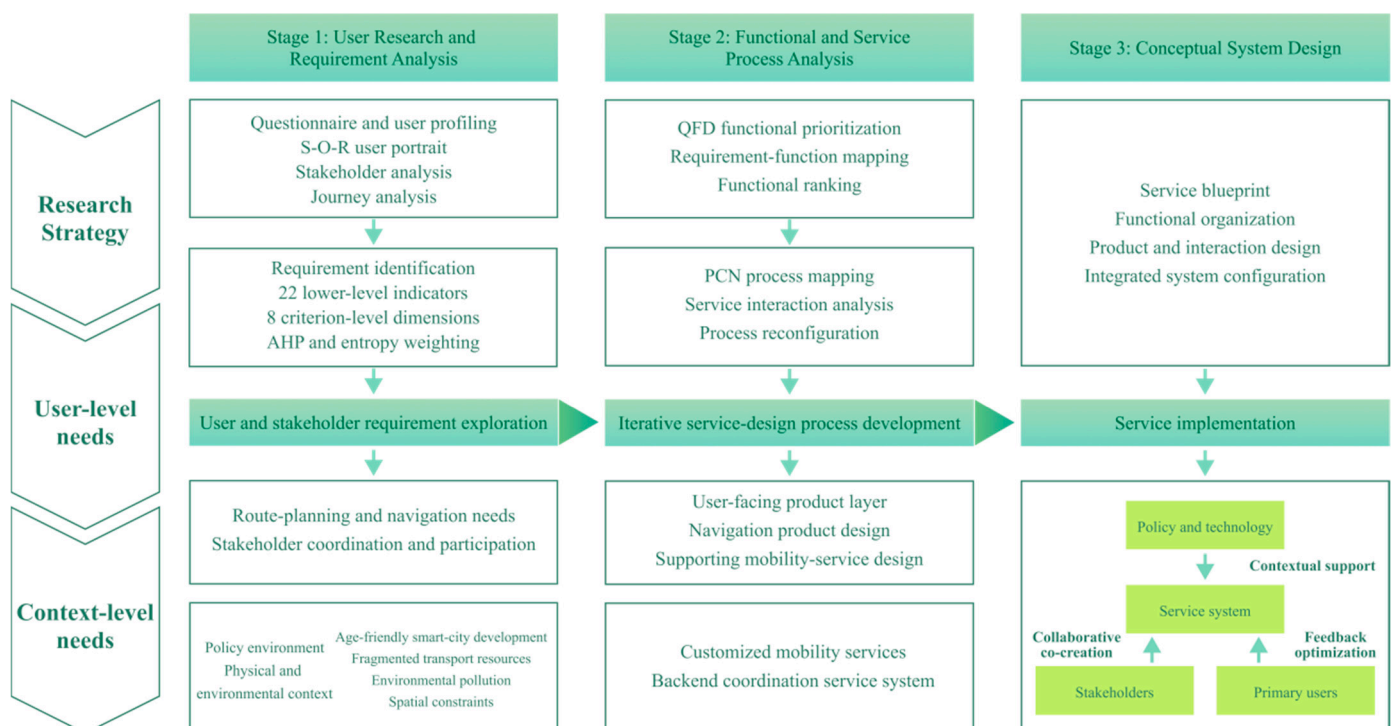


Figure 1. Design framework for an age-appropriate AR navigation product service system.

2.2. User Research and Demand Analysis

User research focused on the characteristics, navigation difficulties, and service context associated with older adults' urban travel. Questionnaire findings were combined with the user portrait structured using the S-O-R framework, and journey analysis to examine navigation barriers from user and service perspectives. Problems identified through the questionnaire, user portrait, stakeholder analysis, and journey analysis were consolidated into a structured set of requirements for subsequent functional and service analysis.

2.2.1. Questionnaire and User Portrait

The user research focused on urban older adults in Nanjing, China. Previous research has indicated that many older adults retain substantial mobility and continue to have active travel needs [19]. The questionnaire was designed for user profiling and requirement elicitation. The questionnaire collected demographic and capability-related information, including gender, age, living situation, visual condition, and smartphone proficiency, together with information concerning difficulties encountered in urban travel and navigation. The categorical variables reported in the study were summarized using frequencies and percentages. Participation was voluntary, and electronic informed consent was obtained before completion of the online questionnaire. A total of 215 questionnaires were distributed. After incomplete responses and responses showing evident patterned answering were excluded, 196 valid questionnaires were retained, corresponding to a valid response rate of 91.2%. The demographic and capability-related characteristics of the valid sample are summarized in Table 2.

Table 2. Characteristics of the valid questionnaire sample (N = 196).

Variable	Category	N	%
Gender	Male	91	46.4
	Female	105	53.6
Age	60–65 years	74	37.8
	66–70 years	80	40.8
	71 years or older	42	21.4
Living situation	Living alone	49	25.0
	Living with a spouse	97	49.5
	Living with children	50	25.5
Visual condition	Normal or corrected to normal	65	33.2
	Mild or moderate presbyopia or visual deterioration	131	66.8
Smartphone proficiency	Low: requires assistance	122	62.2
	Moderate: can use basic functions independently	55	28.1
	High: no apparent difficulty	19	9.7

A user portrait was subsequently constructed using the stimulus-organism-response (S-O-R) framework [20] as a conceptual structure for organizing barriers associated with older adults' use of AR navigation. The S-O-R framework was used to classify factors related to the external travel and system environment, perceptual and cognitive responses, and behavioral responses associated with navigation use. Environmental and system-related barriers were treated as stimulus factors (S), including problems associated with navigation services, information resources, interaction conditions, and the surrounding travel environment. Organism-level factors (O) were used to categorize perceptual, cognitive, and psychological responses associated with navigation barriers. Response factors (R) referred to behavioral difficulties or reluctance associated with the use of AR navigation products.

The resulting classification was examined from both service-system and user-capability perspectives. Service-system barriers concerned the navigation service environment [21], including backend technical support and service quality, coordination of information and stakeholder resources, perceived ease of use and usefulness, and the reduction in unnecessary interaction and perceived cost. At the user-capability level, particular attention

was given to perceptual, cognitive, psychological, and operational difficulties associated with ageing. The user portrait organized the identified navigation barriers in relation to usability, sensory and cognitive support, service coordination, and interaction burden. Figure 2 presents the S-O-R-based analytical framework.

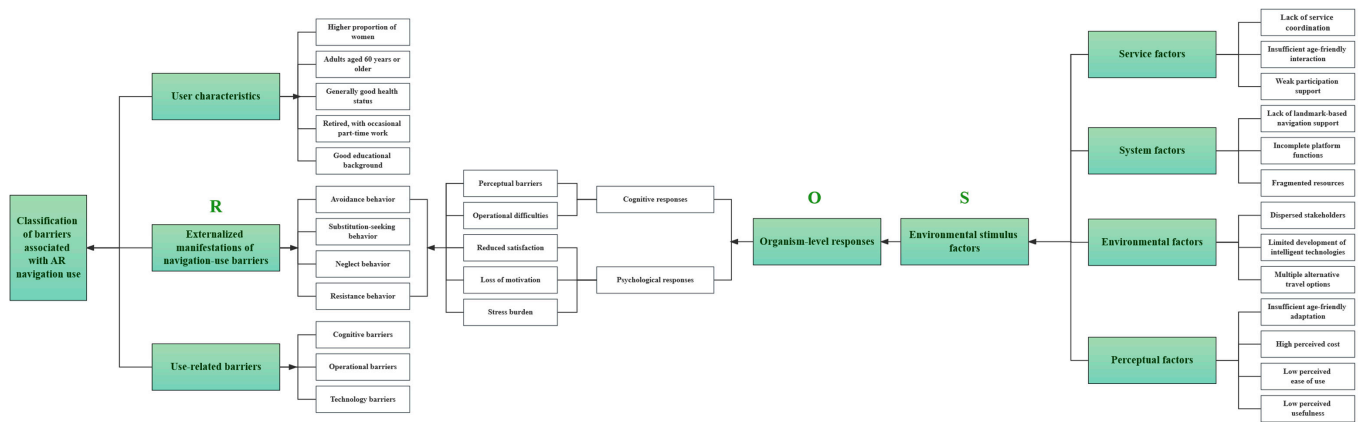


Figure 2. S-O-R-based conceptual framework for classifying barriers associated with older adults' use of AR navigation. S, stimulus; O, organism; R, response.

2.2.2. User Service Context and Stakeholder Analysis

To further investigate user needs, balance the supply and demand relationship of stakeholders [4], the service context of older adults' travel was examined by identifying the actors involved in navigation support and clarifying the potential contribution of each actor. The stakeholder groups included family members, transport operators, service personnel, product and system providers, and relevant public or commercial organizations. The stakeholder analysis considered the contribution of each group to route planning, navigation, payment, product maintenance, and service feedback. Table 3 summarizes the stakeholder groups and the corresponding functional contributions.

Table 3. Stakeholder roles and functional contributions in the proposed AR navigation product service system.

Benefits	Family members Shop stores	Macro Policy Department Product Decision Department	Material suppliers Production Collaborators Warehouse Logistics Assembly Manufacturers	Product Design Service System Design System Technicians	Market Sector Cooperative Brand Competitive Brands Media Legal	Product Service System Transport Operators	Installation Personnel Repair Personnel Customer Service Staff Managers
Service Function	User Monitoring Trip Assistance	Decision- making Level	Production Contractors	Design	Distribution	Operation	Management
Function Supply	Video Voice Phone Remote Control	Resource Co-ordination Supervision Policy Technical Support	Line Operation	Product Design APP Design AR Traffic Display Interface Design	Publicity and Marketing	Route Screening Route Customization Travel Process Planning Travel Cost Payment	Fault Repair Setting Management Customer Service Feedback Evaluation

The journey analysis further organized urban travel into key stages covering route selection, walking, transfer, payment, and arrival. Difficulties identified from the questionnaire and navigation barriers summarized in the user portrait were located within the corresponding stages of the journey. Common problems related to information acquisition,

repeated operation, transfer coordination, payment, and arrival confirmation were then consolidated as stage-specific pain points.

2.3. Requirement Hierarchy and Function Analysis Procedure

Building on the questionnaire findings, the user portrait structured using the S-O-R framework, the journey analysis, and the stakeholder analysis, the identified user concerns were consolidated into a hierarchical requirement structure. The questionnaire and user portrait characterized user capabilities and recurring barriers to AR navigation, the journey analysis identified interaction and service problems at different stages of urban travel, and the stakeholder analysis supplemented requirements related to assistance, information coordination, service support, and resource integration. Related concerns were synthesized according to their design relevance and functional implications, yielding 22 lower-level requirement indicators. The requirement indicators were organized into eight criterion-level dimensions: operational ease of use, perceived low cost, safety, sensory support, cognitive support, social needs, respect, and humanistic care [22]. Operational ease of use covered product operation, route planning, AR navigation accuracy, and travel-process simplicity. Safety addressed travel safety and health-related monitoring, while sensory and cognitive support concerned the presentation and comprehension of navigation information. Social needs, respect, and humanistic care covered requirements related to assistance, participation, privacy, feedback, and service experience. Table 4 presents the resulting hierarchy of eight criterion-level dimensions and 22 lower-level requirement indicators.

Table 4. Analytic hierarchy model of requirement.

Target Layer A	Service System Requirements and Function Evaluation A							
Demand Layer B	Operational ease of use requirements	Sensing low-cost requirements	Security requirements	Sensory system requirements	Cognitive system requirements	Social needs	Respect needs	Humanistic care needs
	B1	B2	B3	B4	B5	B6	B7	B8
Index Layer C	Products Easy to use	Transport Price Discount	Travel Safety	Excellent Sensory Experience	Operation Instructions Easy to Understand	Video Voice Call	Personalized Route Customization	Service Experience Careful
	C1	C5	C8	C10	C12	C15	C18	C21
	Route planning System Reasonable	Products Cost-Effective	Health and Safety Monitoring	Multisensory Information Tips Easy to Receive	Navigation Interface Instructions Easy to Understand	Itinerary Dynamic Sharing	Design Engagement Enhancement	Use Pressure to Reduce
	C2	C6	C9	C11	C13	C16	C19	C22
	AR Navigation Accurate	Travel Operation Efficient			Traffic Route Description Easy to Understand	Social circle footprint sharing	Feedback Communication Optimization Implementation	
	C3	C7			C14	C17	C20	
	Travel Process Simple							
	C4							

A panel of 15 experts with backgrounds in age-friendly design, human–computer interaction, and older-adult services evaluated the relative importance of the eight requirement dimensions. A separate AHP questionnaire was prepared for the expert evaluation. The expert questionnaire provided operational definitions of the eight requirement dimensions to establish a consistent basis for comparison, followed by 28 pairwise-comparison items covering all possible pairs of the eight dimensions. Saaty’s 1–9 scale was used to express

the relative importance of each pair, with intermediate values of 2, 4, 6, and 8 available for judgments falling between the principal scale points.

The expert evaluations were aggregated into an 8×8 group judgment matrix $A = (a_{ij})$. The judgment matrix was normalized by column as follows:

$$\bar{a}_{ij} = \frac{a_{ij}}{\sum_{k=1}^n a_{kj}} \quad (1)$$

where a_{ij} denotes the element in row i and column j of the judgment matrix, and n denotes the number of requirement dimensions. The AHP weight u_i for each requirement dimension was obtained from the mean of the corresponding normalized row:

$$u_i = \frac{1}{n} \sum_{j=1}^n \bar{a}_{ij} \quad (2)$$

The consistency of the group judgment matrix was evaluated using the consistency ratio, with values below 0.10 considered acceptable.

Entropy weighting was applied as a complementary procedure to account for variation in the expert evaluations [23]. For entropy weighting, the expert evaluations were organized into a matrix $H = (h_{ij})_{m \times n}$, with m experts and n requirement dimensions ($m = 15, n = 8$). The normalized evaluation proportion r_{ij} was calculated as follows:

$$r_{ij} = \frac{h_{ij}}{\sum_{i=1}^m h_{ij}} \quad (3)$$

where h_{ij} denotes the evaluation value assigned by expert i to requirement dimension j . The entropy value E_j for requirement dimension j was calculated as

$$E_j = -\frac{1}{\ln m} \sum_{i=1}^m r_{ij} \ln r_{ij} \quad (4)$$

The difference coefficient was defined as $D_j = 1 - E_j$. The corresponding entropy weight θ_j was obtained by normalizing the difference coefficients:

$$\theta_j = \frac{D_j}{\sum_{k=1}^n D_k} \quad (5)$$

The AHP weight u_j and entropy weight θ_j were combined using normalized multiplicative weighting:

$$W_j = \frac{u_j \theta_j}{\sum_{k=1}^n u_k \theta_k} \quad (6)$$

The comprehensive weights W_j represented the final relative priority of each criterion-level requirement dimension [24]. Detailed AHP, entropy, and consistency calculations are provided in Appendix A (Tables A1 and A2).

The 22 lower-level requirement indicators in Table 4 were used as customer-requirement entries and mapped to 15 functional elements in the House of Quality. The assessed relationships between user requirements and functional elements were used to calculate functional scores and rankings, while the roof of the House of Quality represented the assessed correlations among the functional elements [25]. The resulting functional ranking provided the basis for the detailed design analysis and the subsequent examination of service activities using PCN.

3. Results

The overall findings indicate that older adults' navigation difficulties extend across multiple stages of urban travel and involve both interaction with navigation tools and coordination between related services. The results also reveal clear differences in the relative priorities of user requirements and in the roles of navigation functions and service activities.

3.1. User Research Findings and Requirement Priorities

The user research identified navigation difficulties across different stages of urban travel, while the requirement analysis showed clear differences in the relative importance of the associated needs. The findings provide a clearer picture of the navigation problems experienced by older adults and the areas that require greater attention in subsequent design analysis.

3.1.1. Travel Scenarios and Navigation Challenges

Questionnaire responses and journey analysis identified navigation difficulties across route selection, walking, transfer, payment, and arrival. Older adults required clear route information together with continuous and comprehensible guidance from departure to arrival. Transitions between travel stages often involved additional interaction demands and interruptions in navigation information. The journey analysis examined opportunities to simplify key service contacts, maintain continuity of guidance, and reduce repeated manual input. Table 5 summarizes the main pain points and related design opportunities.

Table 5. Journey-based analysis of a typical older-adult travel scenario.

Travel Stage	Typical Task	Key Pain Point	Service Contact	Design Opportunity
Route planning	Search for and confirm a travel route	Navigation functions are difficult to understand; too many operational steps; too many route options	Route map display; AR navigation guidance	Simplify information interaction; optimize AR guidance; support personalized route planning
Walking to bus stop	Walk to the nearest stop	Unclear surrounding information; difficulty identifying the closest stop; inconvenient phone-based operation while walking	AR interface guidance; stop information board; landmark cues	Improve stop identification; provide clearer AR directional cues; reduce operational burden while walking
Bus travel	Ride the bus to the transfer point	Unclear arrival reminders; uncertainty about seat availability; lengthy payment process	Bus information display; automated payment; stop reminder	Improve stop reminder functions; integrate automated payment; support more accessible in-transit information
Transfer to metro/transit node	Move from bus stop to metro station	Complex route information; unclear indoor navigation; cumbersome payment and access process	Interface-based route guidance; icon/sign guidance; payment integration	Improve interface and icon design; strengthen indoor navigation cues; simplify transfer and payment procedures
Indoor walking/mall entry	Enter a mall and continue short-distance walking	Unclear entrance/exit information; confusing indoor navigation; users can easily lose orientation	Indoor navigation interface; sign guidance; remote assistance from stakeholders if needed	Improve indoor wayfinding; enhance sign recognition; provide contextual support in complex indoor environments
Arrival and trip completion	Reach the destination and end navigation	Unclear confirmation of arrival; unclear exit from navigation mode	Arrival prompt; automatic location confirmation; one-click trip completion	Provide explicit arrival feedback; simplify trip termination; reduce unnecessary final interaction

3.1.2. Requirement Priorities and Functional Ranking

The relative priorities of the eight criterion-level requirement dimensions are summarized in Table 6. Safety received the highest comprehensive weight (0.3872), followed by

operational ease of use (0.2191), cognitive support (0.1680), and sensory support (0.1197). Perceived low cost ranked fifth with a weight of 0.0443, followed by humanistic care (0.0392). Social needs (0.0129) and respect (0.0096) received comparatively lower weights.

Table 6. AHP and comprehensive weights of the user requirement dimensions.

User Requirement Dimension	AHP Weight u_j	Entropy Weight θ_j	Comprehensive Weight W_j	Rank
Operational ease of use	0.2002	0.1775	0.2191	2
Perceived low cost	0.0801	0.0897	0.0443	5
Safety	0.2807	0.2238	0.3872	1
Sensory support	0.1409	0.1379	0.1197	4
Cognitive support	0.1612	0.1690	0.1680	3
Social needs	0.0383	0.0548	0.0129	7
Respect	0.0395	0.0397	0.0096	8
Humanistic care	0.0591	0.1076	0.0392	6

The four highest-ranked dimensions accounted for 89.4% of the total comprehensive weight. Both the AHP and entropy weighting results assigned the four leading positions to safety, operational ease of use, cognitive support, and sensory support. The combined weighting placed particular emphasis on travel safety, ease of operation, manageable information processing, and sensory accessibility. Perceived low cost and humanistic care remained secondary considerations, while social needs and respect received lower relative priorities within the eight-dimensional requirement structure.

The 22 lower-level requirement indicators presented in Table 4 were entered into the QFD matrix and mapped to 15 functional elements. The QFD matrix linked individual functions to multiple user requirements and yielded the functional ranking. Traffic resource integration received the highest functional score, followed by AR road-condition display, route indication, remote navigation assistance, and route planning. Safety requirements were reflected in functions related to traffic information, road conditions, route guidance, route screening, and warning and correction. Figure 3 presents the relationships between the lower-level requirement indicators and the functional elements, together with the resulting functional ranking.

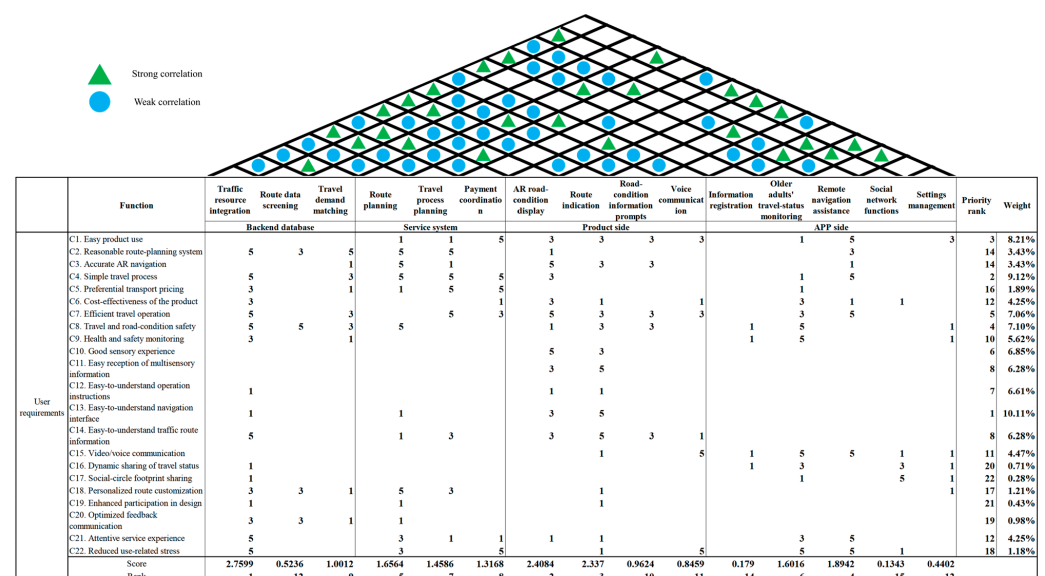


Figure 3. Requirement evaluation and functional prioritization matrix for the age-friendly AR navigation service system. QFD matrix showing the relationships between the 22 lower-level requirement indicators and 15 functional elements, together with the resulting functional ranking.

3.2. Design Analysis of Selected Navigation Functions

To further specify the design elements associated with the requirement priorities and system functions identified in the preceding analysis, route screening, AR traffic display, and route indication were considered in greater detail. Route screening covered the criteria used to compare travel options. AR traffic display addressed the presentation of navigation information and the available interaction modes, while route indication focused on directional guidance during travel. Table 7 summarizes the corresponding design elements.

Table 7. Preference analysis of design elements for prioritized user requirements.

Selected Function	Relevant Design Elements	User-Oriented Design Considerations	Visual Summary
Route screening	Route Line Rule Route Safety Shortest route distance Routes take the least time	Road condition safety More linear distribution Fewer transfers	
	transport choice behavior	Bus + Walking/Short Riding	
AR traffic display	Display portable easy to watch	Wearable AR glasses products	
	Interactive instructions easy to trigger	Traditional button-assisted voice interaction and somatosensory interaction	
	Visual information easy to understand	High acceptance of image information Green favorite high/red yellow stimulus sensitive	
	Speech interaction easy to understand	Love bright lively slower child voice speech	
	Sensory stimulation receives fast	Prompt response in long vibration form	
Route indication function	Signpost direction identification Easy to recognize	“East West South North” scale Arrow identification Voice assistance	

3.3. Service Process Chain Analysis and Optimization Based on PCN

To examine how service activities were organized throughout the travel process, the existing service process was first mapped using PCN. The distribution of activities across different interaction regions was then examined to identify points where the service process could be simplified or reorganized.

3.3.1. Establishment of the Service Process Chain

The PCN diagram was developed to map service activities related to transportation resource integration and scheduling, trip planning, navigation, and travel payment [26]. In PCN analysis, a process entity refers to any actor involved in carrying out service activities, and the actions of each actor are mapped within a corresponding process domain [26]. The PCN framework comprises three domains: direct interaction, surrogate interaction, and independent processing [27]. In this study, the PCN analysis was developed around the travel process of older adults using AR navigation products in urban settings. Based on the

main functional requirements identified in the preceding QFD analysis, the overall service process was divided into two parts: route planning and AR navigation (Figure 4).

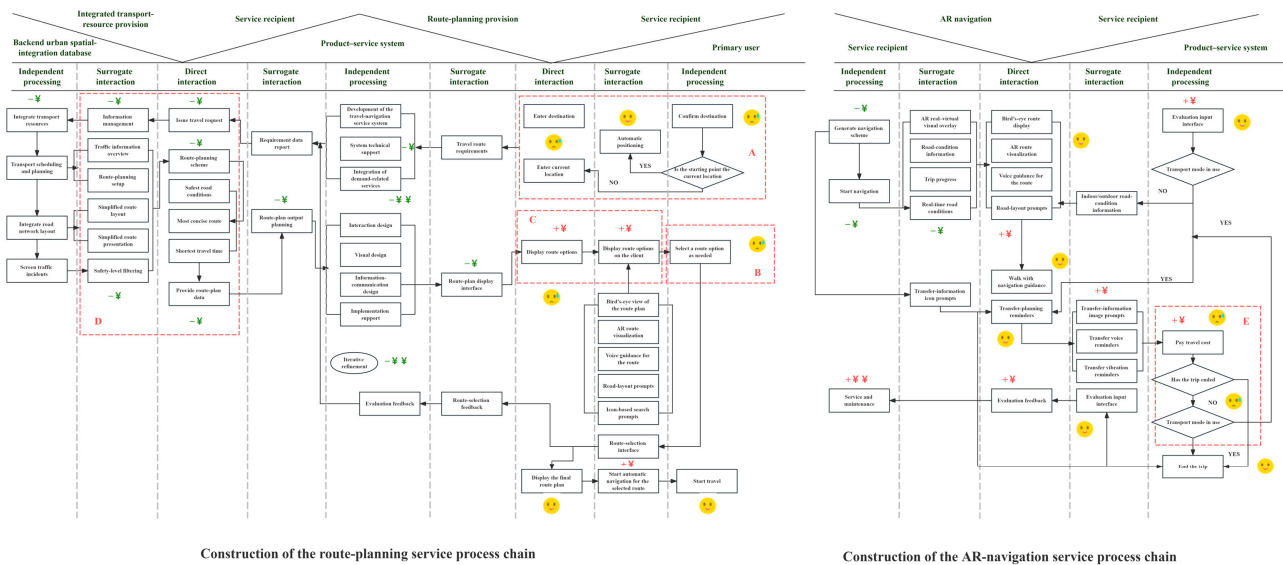


Figure 4. Service process chain construction. The diagram organizes route-planning and AR-navigation activities across the direct interaction, surrogate interaction, and independent processing domains and shows the involvement of users, the product-service system, and supporting service actors. The + and − signs indicate resource gain and expenditure, the number of ¥ symbols qualitatively indicates their relative magnitude.

Within this process chain, the AR navigation product service system was defined as the core service entity. The main process entities involved in the service process included the AR navigation service provider, family members, friends, retail stores, public transport operators, online ride-hailing platforms, and shared bicycle or electric vehicle services. In the PCN diagram, a smiley face symbol “😊” was used to indicate interaction steps associated with a positive service experience, whereas a sad face symbol “😞” indicated steps associated with a negative service experience. The symbol “+¥” was used to mark steps that generated economic or other circulating resource gains for the service provider, while “−¥” indicated steps associated with resource expenditure or loss [28]. The number of “¥” symbols qualitatively indicates the relative magnitude of the corresponding gain or expenditure; more symbols represent a greater magnitude. Temporal relationships between interaction steps were represented by lines and arrows.

3.3.2. Service Process Chain Deconstruction Optimization

First, the value proposition and service quality of each process stage (service contact) were examined. The PCN analysis identified several process problems, including repeated manual operations, discontinuities between service stages, and activities requiring coordination among multiple service actors. Process adjustments focused on activities that could be simplified, reassigned, or supported by the system to reduce repeated user operations and improve continuity across the travel process. The optimization strategy followed three principles: customization, reduced user effort in direct interaction, and more efficient surrogate interaction [29]. In practical terms, process efficiency was improved mainly by reducing independent processing or by relocating process steps from direct interaction to surrogate interaction. For example, in regions A and B, users were originally required to enter their locations and destinations manually and then select routes from multiple suggested options. The steps increased manual input and created opportunities for input

error. In the optimized process, these independently processed steps were shifted to the surrogate-interaction domain of the product-service system. Automatic positioning and voice input were introduced, and both semi-automatic and automatic selection options were provided. To support remote assistance, selected route-planning tasks that had previously been completed by the user could also be shared with other service actors, such as family members, stores, and online ride-hailing drivers. In region C, AR presentation was introduced for traffic information and route planning, allowing relevant information to be accessed with fewer repeated direct interactions. In region D, user requirements were transmitted directly to the backend information system, and route screening was transferred to the backend database for integrated urban spatial processing. Routes were screened according to user requirements and returned through backend processing, reducing the number of route-selection steps requiring direct user input. The optimized stages are indicated by the dotted green boxes in Figure 5.

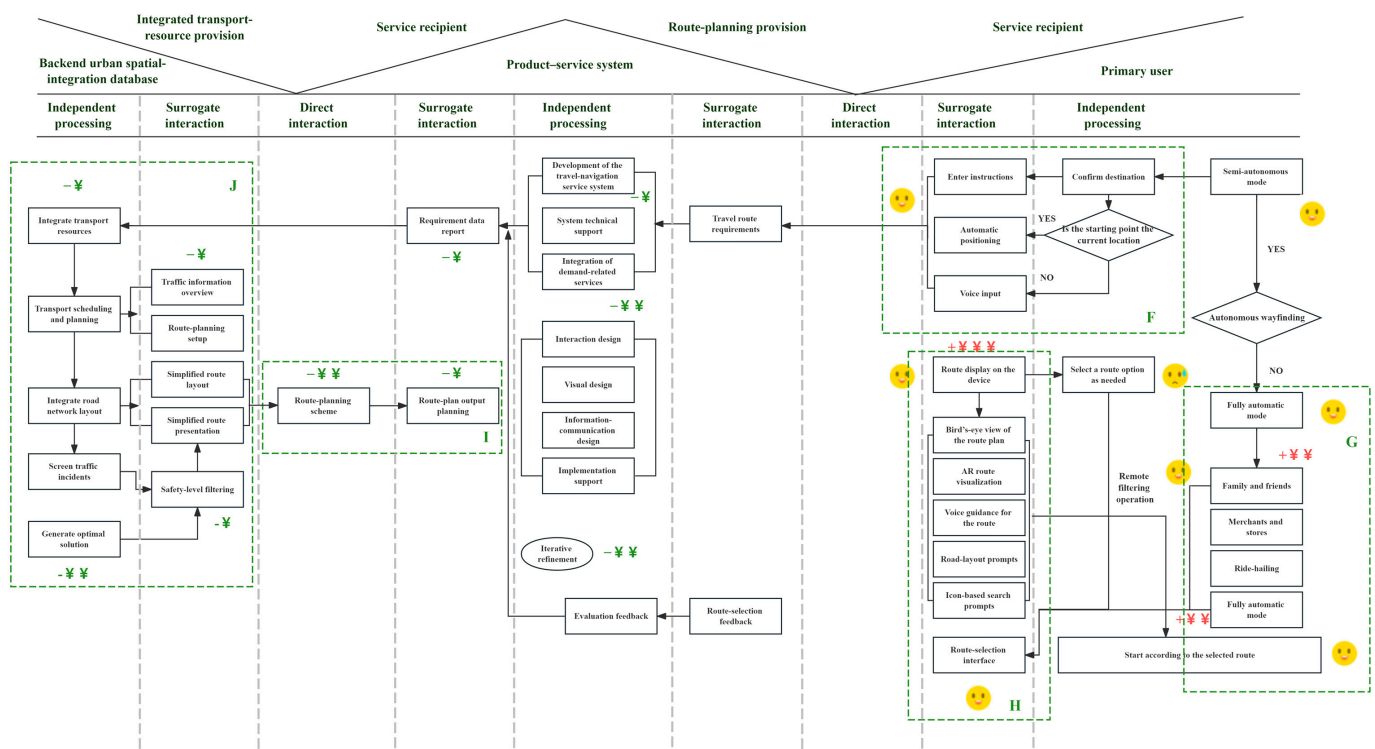


Figure 5. Efficient PCN optimisation based on agent interaction. The diagram shows the redistribution of selected service activities across the independent processing, direct interaction, and surrogate interaction domains. Dotted green boxes indicate the reconfigured stages.

The process innovations in this stage were classified into two types: enabling innovation and disengagement innovation. Enabling innovation means that, with guidance from the service provider, the user becomes able to carry out process steps that were previously completed by the provider [30]. Disengagement innovation means that the service provider takes over process steps that were previously completed by the user. In the AR navigation service PCN diagram, region E contained several user-side payment steps involving independent processing and coordination with service providers. To address the fragmented payment process, the relevant process steps were moved from the process domain of the service recipient to process domain K of the service provider. This optimization simplified the payment process and introduced automatic payment and bundled ticket packages into the product-service system, thereby improving service efficiency and increasing revenue.

resources. As shown in Figure 6, monthly passes and other preferential packages were also included as possible service options.

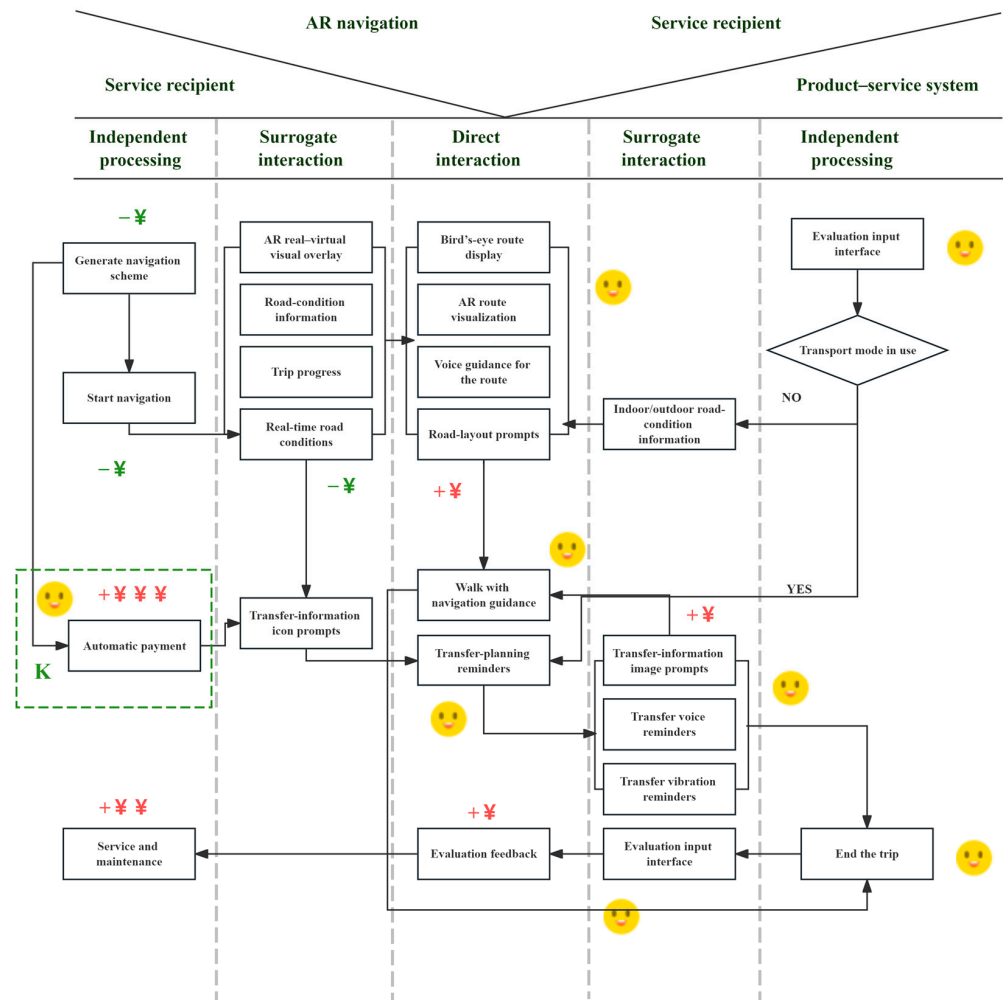


Figure 6. PCN optimisation based on disengagement innovation.

4. Discussion

Our study approaches age-friendly AR navigation from a service design perspective and focuses on the relationship among older adults' travel needs, functional organization, and service coordination. By considering navigation support across different stages of urban travel, the study extends the design focus beyond individual interface functions to the broader travel service process. The conceptual system organizes wearable navigation, mobile functions, and backend services within a coordinated structure spanning different stages of the travel process.

4.1. Service Execution Blueprint

Older adults' travel needs often extend across multiple stages, including route selection, walking, transfer, payment, and arrival confirmation. Within the service blueprint, users are able to adjust the level of system assistance according to their own needs, select routes that better match their cognitive abilities and travel preferences, and complete transfers with the support of the AR navigation device. The service system integrates ticket payment, bicycle return, and seat coordination across the travel process so that fewer operations need to be completed separately at each stage. With user authorization, route-selection and navigation data can also be retained to support personalized route recommendations

in later journeys. The service blueprint does not simply describe a sequence of service steps; it demonstrates how product functions, travel resources, and background service coordination can be combined to support smoother and more comprehensible mobility for older adults.

4.2. Functional Organization of the System

As shown in Figure 7, the user-facing functional framework is organized around two main components, the wearable hardware and the mobile application, both of which are supported by backend service functions. Functions are distributed according to different stages and contexts of use. The wearable component supports high-frequency functions required during travel, including access to common information, one-click route finding, one-click sharing, and automatic acquisition of the departure location. The mobile application mainly supports information setup and background coordination. Dedicated interfaces for family members or guardians provide access to user characteristics and current travel conditions, while also enabling functions related to product maintenance, safety monitoring, and situation awareness, such as road conditions, obstacles, falls, and physiological status. Access to travel and physiological information should require user authorization and be limited to what is necessary for the relevant assistance function, particularly when family members or other remote users are involved.

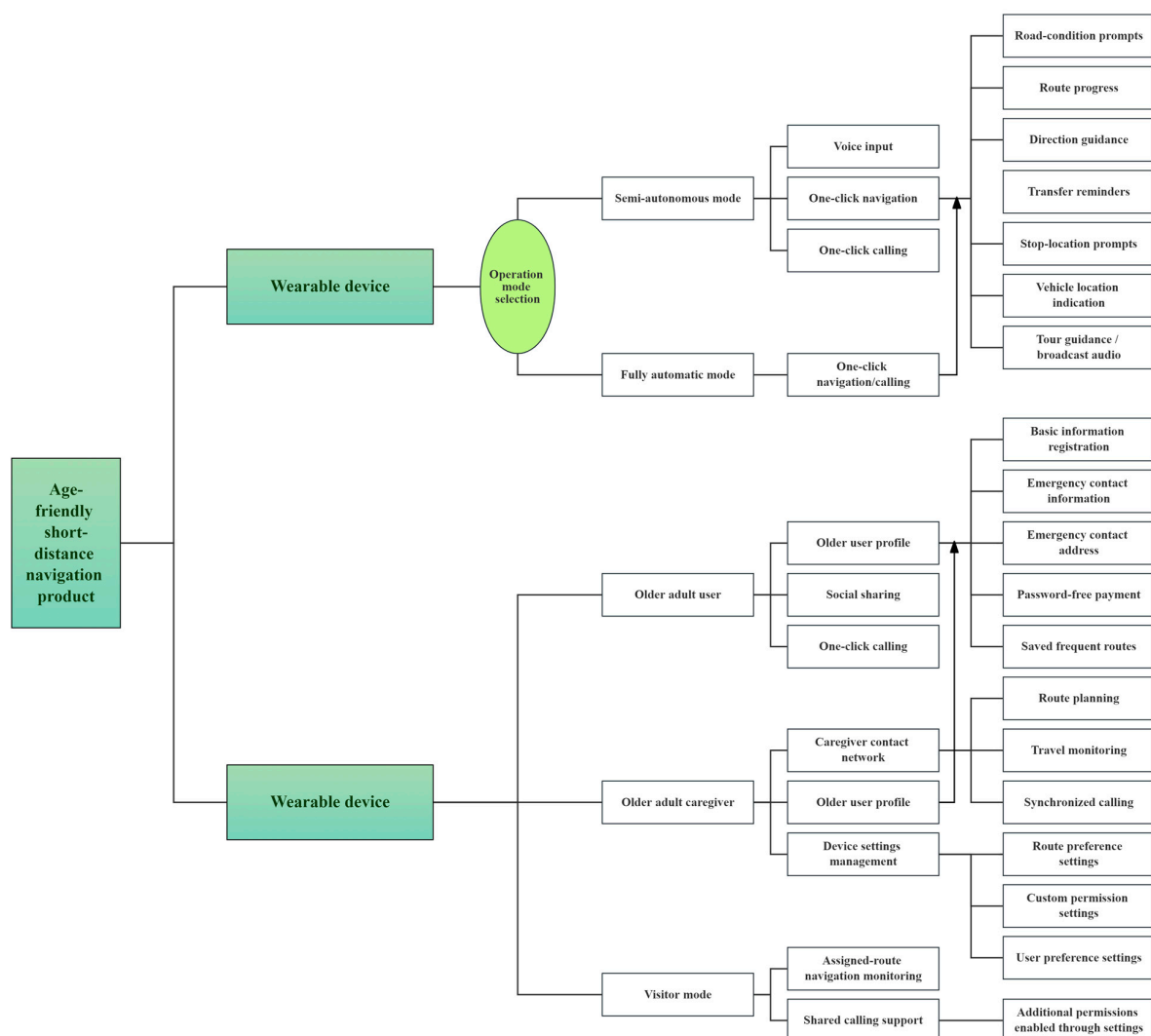


Figure 7. Layered functional framework of the wearable navigation system.

In addition, the hierarchical operating framework divides system use into two modes, namely full automation and semi-autonomy, so that different levels of support can be matched to different user abilities and preferences. Users should retain the ability to select or change the level of assistance rather than having navigation decisions transferred entirely to the system. Within this framework, the intelligent voice assistant serves as a key interaction channel, providing older adults with accessible and supportive guidance during travel.

4.3. Integrated AR Navigation Product-Service System

The system is composed of three interconnected parts: the wearable product, the mobile application, and the backend service platform. The three components work together to support route selection, navigation assistance, information management, and service coordination throughout the travel process. Based on the extraction of functional requirements and supporting facilities, a product-level component model was developed to align system functions with user requirements and interaction tasks. The three-layer organization clarifies how functions are distributed across the wearable, mobile, and backend components. The configuration integrates device functions, mobile services, background data, and supporting service actors within a coordinated navigation service process. Figure 8 presents a conceptual visualization of the wearable device and several representative navigation scenarios.

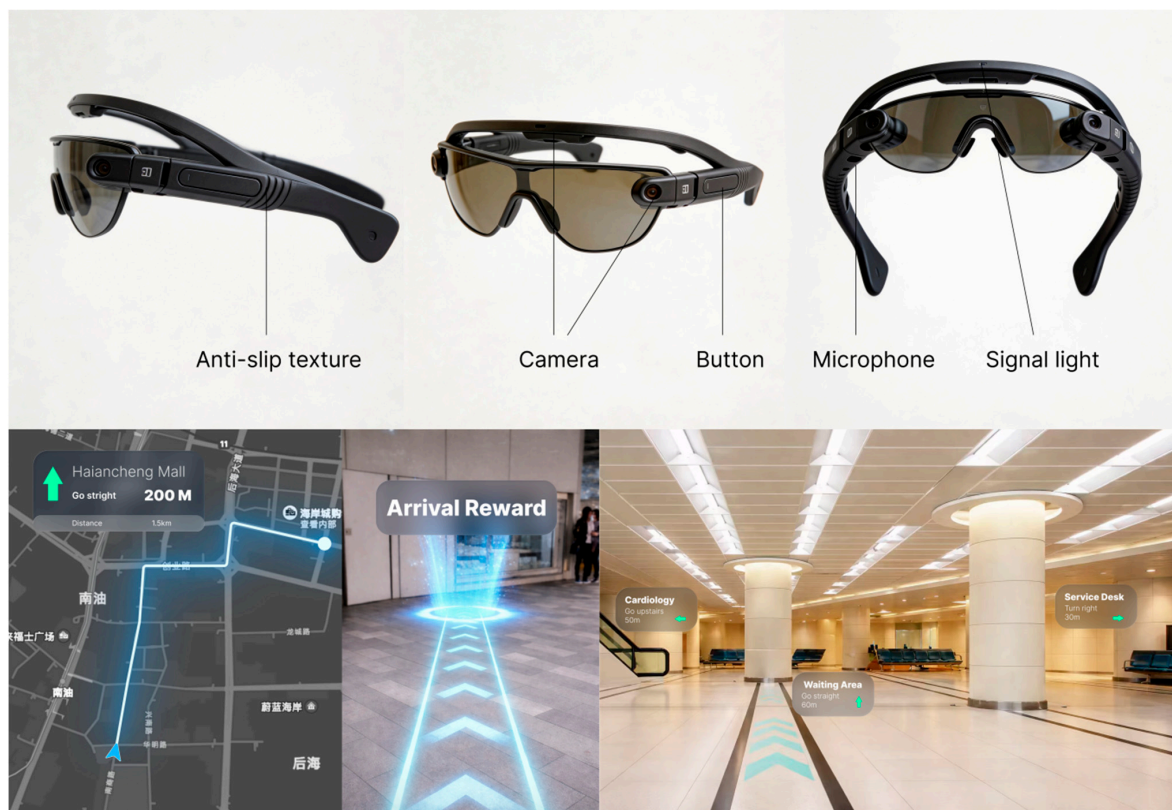


Figure 8. Conceptual visualization of the AR navigation product and representative navigation scenarios. The upper panel presents the wearable device from different viewing angles and identifies the main hardware components, including the camera, control button, microphone, signal light, and anti-slip texture. The lower panel illustrates route guidance, destination-arrival guidance, and indoor AR navigation as representative application scenarios. The wearable device was modeled and rendered by the authors using Blender (4.1), and the conceptual navigation scenarios were created using Figma. No external visual materials were used.

4.4. Limitations and Future Implementation

Several limitations should be considered when interpreting the findings of the present study. The user research was conducted with older adults in Nanjing, and the resulting requirement priorities may partly reflect the characteristics of the local urban travel environment, available digital services, and participant group. The priority structure identified in the present study requires further examination in other older populations and urban contexts. Future research could extend the analysis to cities with different transport infrastructures and to older adults with more diverse levels of mobility, sensory and cognitive ability, and digital experience, allowing the consistency of the identified requirements across different contexts to be further assessed.

The study focused on requirement structuring, functional prioritization, and service configuration and did not include prototype testing in everyday travel settings. Subsequent system development should address technical reliability, usability under real-world conditions, and integration with existing transport and service systems. Prototype development and field evaluation are also needed to assess the service process across different stages of urban travel.

The use of location, travel, and potentially physiological information also raises questions of privacy and user control. A key implementation issue concerns how different types of information are collected, stored, accessed, and used within the navigation service. The level of system assistance should remain adjustable so that older adults can choose an appropriate level of support for different travel situations while retaining control over navigation decisions. Field studies in realistic travel settings can assess usability, navigation performance, perceived safety, workload, and user acceptance.

5. Conclusions

This study applied a service design perspective to the development of an age-friendly AR navigation product service system for older adults. By combining multiple user-research methods with QFD and PCN analysis, the study identified travel characteristics, service requirements, and interaction problems across the urban travel process. Safety, operational ease of use, cognitive support, and sensory support emerged as the leading requirement priorities. QFD translated these priorities into a functional hierarchy, while the PCN analysis extended the design logic to the organization of service activities across the travel process. The final system configuration brings together wearable navigation, mobile functions, and backend services within a coordinated service structure. The study contributes a structured design process that connects user requirements with functional organization and service configuration in the context of age-friendly AR navigation. The findings also provide practical considerations for designers and mobility service providers when addressing interaction complexity, navigation support, and service continuity for older adults. As the system remains at the conceptual design stage, future work should develop and evaluate functional prototypes in realistic travel settings, with particular attention to usability, navigation performance, perceived safety, and longer-term user acceptance.

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Institutional Review Board Statement: Ethical review and approval were waived for this study by the Science and Technology Ethics Committee of Southeast University because the research involved only a non-interventional, minimal-risk electronic questionnaire and design-evaluation activities with adult participants. No clinical intervention or biological sample collection was conducted, and no directly identifying personal information was collected.

Informed Consent Statement: Electronic informed consent for participation was obtained from all participants before data collection. A participant information and consent page was presented at the beginning of the questionnaire, explaining the study purpose, procedures, voluntary nature of participation, confidentiality arrangements, intended use of the data, and the right to withdraw. Only participants who selected the option indicating their agreement to participate were permitted to proceed with the questionnaire.

Data Availability Statement: The data presented in this study are available on request from the corresponding author due to privacy and ethical restrictions intended to protect participant confidentiality. The data are not publicly available.

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Abbreviations

The following abbreviations are used in this manuscript:

AR	Augmented Reality
AHP	Analytic Hierarchy Process
MaaS	Mobility as a Service
PCN	Process Chain Network
QFD	Quality Function Deployment
S-O-R	Stimulus-Organism-Response

Appendix A

Table A1. Group pairwise comparison matrix and consistency test for the eight requirement dimensions.

Requirement Dimension	1	2	3	4	5	6	7	8	AHP Weight (u_i)
Operational ease of use	1	3	1/2	2	1	5	5	4	0.2002
Perceived low cost	1/3	1	1/4	1/2	1/3	3	2	2	0.0801
Safety	2	4	1	2	2	6	6	4	0.2807
Sensory support	1/2	2	1/2	1	1	4	3	3	0.1409
Cognitive support	1	3	1/2	1	1	3	4	3	0.1612
Social needs	1/5	1/3	1/6	1/4	1/3	1	1	1/2	0.0383
Respect	1/5	1/2	1/6	1/3	1/4	1	1	1/2	0.0395
Humanistic care	1/4	1/2	1/4	1/3	1/3	2	2	1	0.0591

Note: Columns 1 to 8 correspond respectively to operational ease of use, perceived low cost, safety, sensory support, cognitive support, social needs, respect, and humanistic care. The consistency statistics were $\lambda_{\max} = 8.1676$, $CI = 0.0239$, $RI = 1.41$, and $CR = 0.0170$. The group judgment matrix met the stated consistency criterion because $CR < 0.10$.

Table A2. Entropy weights and comprehensive weights of the eight requirement dimensions.

Requirement Dimension	Entropy Value (E_j)	Difference Coefficient ($D_j=1-E_j$)	Entropy Weight (θ_j)	AHP Weight (u_j)	$u_j \times \theta_j$	Comprehensive Weight (W_j)
Operational ease of use	0.812	0.188	0.1775	0.2002	0.0355	0.2191
Perceived low cost	0.905	0.095	0.0897	0.0801	0.0072	0.0443
Safety	0.763	0.237	0.2238	0.2807	0.0628	0.3872
Sensory support	0.854	0.146	0.1379	0.1409	0.0194	0.1197
Cognitive support	0.821	0.179	0.1690	0.1612	0.0273	0.1680
Social needs	0.942	0.058	0.0548	0.0383	0.0021	0.0129
Respect	0.958	0.042	0.0397	0.0395	0.0016	0.0096
Humanistic care	0.886	0.114	0.1076	0.0591	0.0064	0.0392
Total	6.941	1.059	1.0000	1.0000	0.1623	1.0000

Note: E_j denotes the entropy value, D_j denotes the difference coefficient, θ_j denotes the entropy weight, u_j denotes the AHP weight, and W_j denotes the comprehensive weight.

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