Hitonami (人波): 6G harmonious dynamic mobility management system in Japan

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Amidst impending demographic transitions, Japan's urban mobility faces challenges such as an aging population, amplified urban density, and a widening urban-rural divide. These dynamics intensify the reliance on its transportation infrastructure. In response to these challenges, the potential of 6G technology emerges as a pivotal tool, offering the capability to design systems that address both overarching urban planning objectives and the nuanced needs of individual users. This study explores the design potential of an inclusive navigational system, harnessing the capabilities of 6G technology, envisioned as an integrated service addition to Tokyo's train stations. Developed based on speculative and service design methodologies, this solution introduces a framework that promotes efficient transit in densely populated areas, capitalizing on this density by integrating swarm intelligence to temper sensory overload in bustling environments. Through this perspective, the research highlights the transformative role of inclusive design in charting the future trajectory of urban mobility.

Keywords: swarm intelligence; walkability; sensory overload; 6G

1 Introduction

Public transportation plays a pivotal role in Japan's socio-economy and social life. This sector is expected to confront the distinctive challenge of an aging population and growing density in central urban areas. Thus, there is a need for adaptive transportation systems that effectively support the collective needs of its diverse population of users (Baobeid et al., 2021; Somenahalli et al., 2013, Somenahalli et al., 2016). Current limiting factors, including granular location precision, computing speed, and rendering power for complex interfaces, hinder the development of comprehensive, seamless solutions. However, the emergence of 6G cellular technologies offers the potential to address these constraints.
Focusing on the user experience in public transportation and efficient mobility, this work provides insights into an efficient user-centric transportation system, employing service and speculative design methodologies to analyze current transportation challenges in Japan and propose solutions.

2 Theoretical background

2.1 Public transportation in Tokyo: challenges

With 36 million inhabitants, Tokyo offers an intriguing case study for addressing mobility challenges, with a unique urban planning characteristic and the central role of its train stations (Bagan & Yamagata, 2012; Kido, 2005; Zacharias et al., 2011). One of the major challenges is the city’s dense but aging population, approximately 40% of the inhabitants, representing a border trend of highly dense and centralized population hubs in contrast to diminishing rural peripheries population (Hosomi, 2015; Nishino, 2014; Statistics Bureau of Japan, 2021). Another challenge presented by Tokyo’s aging population is hikikomori – individuals who withdraw from society and live in isolation, highlighting the need to ensure public services are accessible to them and that they are not excluded from public arenas (Koyama et al., 2010; Teo et al., 2018).

Tokyo's transportation system currently services over 9 million passengers daily, making it one the world's most extensive, heavily used subways. Its stations are planned to serve multiple functions, both as transportation hubs and as vibrant commercial complexes that combine various services in a single, smaller space. These bustling spaces are filled with passengers and advertisements, which impacts vulnerable populations in particular (Somenahalli et al., 2016). Motivated to ensure its transportation systems are inclusive and support the needs of its aging population, Japan has continually invested in initiatives that leverage data to provide insights and develop services that support the well-being of elderly individuals (Doi, 1973; Liu et al., 2023; Yamagishi, 1988). Still, this population relies heavily on its already intricately-woven transportation system (Somenahalli et al., 2016).

2.2 Usability of public transportation: walkability

Walkability is an urban design paradigm that evaluates the usability of urban spaces based on factors such as accessibility, safety, and connectivity, all of which contribute to the overall quality of the pedestrian experience (Baobeid et al., 2021). At the individual level, walkability represents one’s ability to focus on relevant navigational data while filtering out distractions or noise (Kastner & Pinsk, 2004). In architecture, focal points and point visibility are essential for directing attention: a focal point serves as a visual center of interest in space, emphasizing the importance of a particular element, while point visibility establishes a visual connection between components in space, highlighting a specific signal from a given vantage point (Honma, 2019; Natapov et al., 2022; Simsarian et al., 1996). These design strategies manipulate one’s attention to enhance the coherence of built environments.

In densely populated areas, walkability can be assessed individually, as the quality of a path, and collectively, in terms of the efficiency of group movement (Jiang et al., 2021). Promoting walkability from both perspectives necessitates two distinct strategies: providing individual navigational cues and optimizing harmonious collective movement. Emphasizing both aspects is crucial for designing urban spaces that are inclusive and efficient, prioritizing pedestrian needs and experiences.
2.3 Effective information
Understanding the effect of crowded spaces, such as train stations, on passenger experience is crucial for designing pedestrian mobility arenas. One of the key factors contributing to the experience is the complexity and accessibility of the information presented to the user (Figure 3) (Kjellberg et al., 2019). Proxemics, studying human spatial behavior, can provide insights into how individuals navigate and interact within crowded spaces (Figure 2) (Greenberg et al., 2011; Zhang et al., 2022). When irrelevant information is abundant, individuals may experience confusion and stress, which could also affect the experience of others in that space. The adverse effects of non-selective presentation of information can be specifically significant among vulnerable populations such as older adults (Contoli et al., 2022; Elkmammash et al., 2023; Figueiredo et al., 2013; Manckoundia et al., 2020). By strategically limiting available information streams, we can direct individuals' attention to the most relevant environmental cues, reducing cognitive and sensory overload and improving their experience (Hu et al., 2019; Kjellberg et al., 2019).

2.4 Optimizing collective movement patterns
Identifying collective movement patterns in dense mobility arenas can help to improve the experience of the individuals using it (Adachi et al., 2011). Swarm behavior exemplifies how groups exhibit intelligence and offer solutions that surpass the capabilities of individual agents (Duarte et al., 2016). Swarm behavior can be used to solve problems in a way using the "wisdom-of-the-crowd", outperforming individual experts (Baltzersen, 2022). Swarm intelligence decision-making processes can be triggered by large gatherings, heterogeneous social interaction, and environmental sensing. Swarm behavior in mobility areas can provide a relevant platform to plan, design, and optimize population-level movement while supporting individuals in need.

2.5 6G
6th generation cellular technology is expected to support beam steering navigation, enhanced network performance, low latency, and precise positioning (Khaleel et al., 2022). In urban planning, 6G can potentially support real-time urban space mapping, optimizing traffic management (Khaleel et al., 2022). Integration of 6G in urban systems promotes participatory urban planning by allowing real-time civic engagement with location precision (Papangelis et al., 2022).

2.6 Service design approach
Service design approach uses demographic data, interviews, and observational insights to construct detailed profiles representing key user archetypes. Using design tools such as Empathy maps (an illustration of a user's attitudes and behaviors) informed a deeper look into the emotional and attitudinal journey and identified patterns (see Results). In turn, these prompted us to create journey mapping (visualization of the process that a person goes through to accomplish a certain goal). We visualized the user's touchpoints with the current transportation system and points of friction they experience as primary use cases.

2.7 Speculative design approach
Speculative design can be used to design future services. Popularized by Anthony Dunne and Fiona Raby, Speculative design is the practice of hypothesizing future products, systems, and services to conceptualize how they might affect future societies (Dunne & Raby, 2013). By using “worldbuilding” - the creation of imaginary worlds with coherent geographic, social, cultural, and other features (von Stackelberg & McDowell, 2015, p. 32), a technique commonly used in Science Fiction, Foresight and
Design, we were able to explore current trends of technological advancements, shifts in collective behavior, and evolving interplay with nature (Zaidi, L. 2019). This, in turn, enabled us to envision Tokyo in 2032, considering the potential impacts of ongoing natural crises, changes in societal norms, and sensory overload due to technological proliferation. For a deeper, user-centered analysis, we crafted future scenarios for each persona to understand their unique needs and pain points. The narrative structures illustrated possible futures and scenarios and guided the evaluation of prospective service concepts. We employed speculative artifacts and digital representations to bring these scenarios to life, further highlighting our concepts’ practical and emotional ramifications.

![Figure 1. Illustration of Data vs. Noise Signals as They Appear for Passengers Within a Train Station](image1)

![Figure 2. A Rendered Simulation of Contemporary Mobility Arenas Juxtaposed With the Integration of Emerging Technologies.](image2)

3 Methods

Our research design encompassed three cycles of discovery, analysis, hypothesis formulation, contextualization, and lo-fi prototyping, conducted from October 2022 to April 2023. The preliminary phase involved six interviews with experts in the Japanese context in urban planning, engineering, informatics, and civic activism. The insights gained from these interviews gave the team a foundation for understanding socio-technical dynamics influencing Japan’s transportation system. We also initiated a contextual inquiry by conducting three service design interviews with transportation system users in Tokyo. This process unveiled existing user experience friction points and potential service enhancement areas.
3.1 Observational studies

3.1.1 Cycle 1: preliminary observations and hypothesis generation
A team of three researchers conducted initial observations within Tokyo's mobility arenas to characterize the user's journey and identify obstacles and challenges. Supported by findings from ongoing contextual research, the observations highlighted pain points, such as behavior in dense environments. This led to the hypothesis that a significant pain point was the navigation within and around stations and between user interfaces with the transportation service (see Figure 4).

3.1.2 Cycle 2: global contextualization of challenges
Having generated a hypothesis, a team of four additional researchers examined the walkability experience in dense mobility arenas in a global context, conducting observational studies and five field interviews in New York, Tel Aviv, and Jerusalem, between Jan-Feb 2023. To explore multiple user perspectives, observations were made from four different vantage points: Bird's-eye view (movement and interactions), average eye level (direct line-of-sight and interactions), below-average eye level (potential barriers or elements from a vulnerable individual's viewpoint), and heel level (ground-level challenges and navigation insights). A comparative approach helped the team distinguish between cultural or region-specific issues and those universally applicable to dense urban environments (see Figure 5).

3.1.3 Cycle 3: solution-oriented observations in Tokyo
Follow-up observation within and around Tokyo's central mobility arenas – Shinjuku, Shibuya, Ikebukuro, and Kita-Senju stations – documenting the same vantage points as in Cycle 2 to contextualize previously identified challenges and uncover new ones.

3.2 Prototyping approach
As part of the speculative and service design process, prototyping played a key role in our study, as it allowed us to explore different elements within this system and their potential effectiveness. These were based on four planning principles:

1. Focal point and point visibility: Aiming to improve attentional manipulation by incorporating rhythmic focal points and open vantage points and reducing noise in densely crowded spaces.
2. Boundaries: Exploring the benefits of physical and visual boundaries by incorporating physical separations and defined spaces in our prototype designs.
3. Sensory deprivation: Integrating stimulus deprivation into a navigational context to improve individuals' ability to interpret and respond to relevant information.
4. Collective movement: Using crowd data and swarm intelligence to design efficient movement variations, reducing commute times and promoting practical travel.
Figure 3. Cycle 1 observations of Tokyo’s transportation revealed behavioral strategies users employed in navigating crowded and dense environments.

Figure 4. Perspective Analysis of Tokyo’s Train Stations: Bird’s-Eye, Average Height, Below-Average Height, and Heel Level
Figure 5. Prototyping - Rhythmic Focal Points and Vantage Enhancement

Figure 6. Prototyping - Boundary Exploration

Figure 7. Prototyping - Swarm-Informed Collective Movement

Figure 8. Prototyping - Navigational Sensory Deprivation
4 Results

4.1 Individual feedback loops
The user journey within Tokyo's public transportation system, especially during peak congestion periods, revealed a recurring decision-making process leading to an emotional feedback loop: uncertainty, stress, signal search, and control [Figure 10]. This loop presented a design opportunity, not only for optimizing movement but also for enhancing micro-experiences for a more balanced journey overall.

4.2 Collective movement patterns and swarm intelligence
Analysis of still and video documentation collected during three cycles of research highlighted that in dense environments, there are multiple barriers – clashes, overcrowding, and pathway challenges – disturbing harmonious movement flow [Figure 9]. Additionally, driven by swarm logic, movement patterns during rush hours and at movement junctions within stations were found to include (a) disorganized but goal-oriented movement, (b) self-organized movement, and (c) synchronized movement. By characterizing movement patterns, we can more easily define optimal goals for a given system – i.e., the shift from (a) disorganized but goal-oriented to (c) synchronized movement.

4.3 Navigational signals and sensory overload
Mapping visual and auditory signals in Tokyo's train stations showed that key navigational cues often conflicted with advertising and architectural features, leading to sensory overload—particularly in densely populated settings. This sensory overload arose from an imbalance between signals (relevant information) and noise (irrelevant information). For instance, while navigational signs are essential for train passengers, they can be distracting or irrelevant for those seeking other services, resulting in stress or disorientation. Our observations and interviews pinpointed rush hours as periods when high sensory overload was especially pronounced.

5 Solution
From our findings, we introduce the Dynamic Mobility Management System (DMMS) for Tokyo 2032: an integrated signaling system tailored for individual and collective navigation in mobility arenas with (1) a sensory-manipulating signal communication and navigation system [Figure 12]; and (2) a controllable light corridor to mitigate stimuli overload and group individuals by needs and movement patterns [Figure 11].

5.1 Light corridor
The DMMS features a central component: the controllable, interactive light corridor, which effectively groups users into new areas within a given space based on their similar destinations, needs, and movement patterns [Figure 12]. Utilizing point visibility, the light corridor guides people efficiently, reduces irrelevant noise (visual & vocal), and creates barriers within open spaces while supporting collective movement [Figure 13]. As station usage increases, we leverage the precise centimeter-level location and behavioral data enabled by 6G networks to analyze users' destinations and movement patterns [Figure 11]. Light paths emerging from the ground effectively manage passenger traffic, reducing stimulus overload.
5.2 Path optimization algorithm

We propose a preliminary machine learning algorithm with dual objectives: individually, it aims to reduce journey duration by incorporating destination and stress-level indicators; collectively, it streamlines station movement by managing active paths. For insights into the swarm behavior principles that inform this algorithm, see “Swarm Behavior” subsection above. This flexible algorithm allows customization, such as maintaining distance between passengers and selecting specific routes [Figure 12], presenting only accessible paths tailored to the user’s needs [Figure 13].
5.3 Directional Navigation

Another critical component of the DMMS is the individualized navigation system. It accompanies travelers in train stations and mobility arenas during peak hours and in high-density environments. As an intermediary between the station’s data about the journey and the user’s destination, this system significantly reduces the traveler’s uncertainty and stress by creating different focal points within the navigation journey, minimizing cognitive processing "noise" amidst potential stimulus overload.

With location precision enabled by 6G networks, we strategically position cues on the station floor and walls tailored to individual needs. The system incorporates four key signals: Acknowledgment, Following the lead [Figure 14] Navigation instructions and Turn Off [Figure 15] addressing the challenges of navigating crowded and complex environments [Figure 12]. By strategically guiding groups and individuals with similar destinations and paces, we enhance overall movement efficiency by using self-organized movement patterns based on decentralized autonomy.

*Figure 11. The Light Corridor - Barriers in Open Spaces. The Light Corridor Is Designed to Establish Barriers Within Expansive Areas, Facilitating and Guiding Collective Movement.*
Figure 12. Movement Patterns - Current vs. Proposed Design Movement Patterns Within Stations and Clusters of Individuals for Optimized Navigation.

Figure 13. Sensory Deprivation Through Light Path Design, Creates a Sensory Deprivation Environment and a Clear Focal Point for Users, Guiding Their Movement.

Figure 14. Navigation - Following the Lead. The Users Follow the System’s Provided Path and Guidance.

Figure 15. Navigation - Receiving Instructions. Detailed Instructions Ensure Users Remain on the Correct Path.
6 Discussion

Public transportation’s pivotal role in Japan’s socioeconomic landscape is obvious, and our findings further emphasize its importance. As emerging technologies such as AI and machine learning become increasingly integrated into daily life, prioritizing efficiency over inclusion can have negative environmental, social, and individual impacts. Thus, adopting a proactive approach is essential, emphasizing ethical, environmental, and user-centric considerations from the outset.

Our research identified an emotional feedback loop within Tokyo’s public transportation system, marked by uncertainty, stress, signal search, and control stages. This loop highlights challenges and suggests opportunities for design interventions to enhance user experiences. The movement patterns observed during peak hours reflect the broader challenges of urban density and the diversification of user needs. Driven by swarm logic, the barriers and movement patterns provide insights into potential solutions that can harmonize navigation, especially when combined with new technologies. The sensory overload in train stations, resulting from conflicting signals, underscores the challenges of urbanization and technological growth. This tension between signals and noise indicates the need for intuitive, user-centric transportation systems.

Our proposed Dynamic Mobility Management System (DMMS) addresses these challenges. By harnessing 6G capabilities, DMMS seeks to enhance movement and reduce sensory overload, catering to individual and collective needs. The system’s components, including the light corridor and individualized navigation, demonstrate the transformative potential of technology in public transportation. The speculative approach offers critical insights into the future of Japan’s urban mobility. The challenges of sensory overload and the promise of technologies such as 6G highlight the need for comprehensive urban design strategies. Both individual and collective experiences, along with broader societal implications, are crucial considerations.

In conclusion, this process suggests that a holistic approach to designing future services in the context of public transportation is becoming increasingly vital as Tokyo, like other megacities, grapples with demographic shifts, heightened growth, and technological progress. We hope to contribute to a harmonized and efficient urban mobility landscape with these insights and potential solutions.

Acknowledgment: limitations

This research was conducted by a team primarily composed of non-Japanese members. Thus, we cannot rule out the potential for cultural biases, despite our efforts to maintain cultural sensitivity based on a thorough understanding of Japanese societal norms. To mitigate potential biases and ensure the accuracy of our findings, we have relied extensively on peer-reviewed academic sources, local reports, and expert opinions. Furthermore, we have engaged in ongoing process reflexivity, critically examining our biases, theoretical predispositions, and roles in the research process. We encourage readers to consider the cultural context when reviewing our findings and conclusions. This research should be seen as a preliminary contribution to an ongoing dialogue rather than a definitive interpretation of the complex realities of urban planning, aging, and technology adoption in Japan.

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References


