NAVITIME: Supporting Pedestrian Navigation in the Real World

Almost 2 million Japanese citizens use NAVITIME, a mobile phone-based navigation service that incorporates various modes of transportation. User experiences reveal implications for designing urban-computing services.

Masatoshi Arikawa and Shin'ichi Konomi
University of Tokyo

Keisuke Ohnishi
NAVITIME Japan

Location-based services are a key pervasive computing application that could deeply influence urban spaces and their inhabitants. Recent advances in mobile phones, GPS, and wireless networking infrastructures are making it possible to implement and operate large-scale location-based services in the real world.

To understand the impact of context-aware navigation tools on urban pedestrians, we can learn from existing research that discusses how people learn and act in complex physical spaces, with or without tool support. People's images of environments[1] have deep implications for urban experiences. In particular, cognitive maps[2] and wayfinding[3] research inform the analysis and design of pedestrian navigation services. Moreover, earlier research acknowledges context as a critical factor in learning large-scale environments.[4]

Researchers have tested mobile pedestrian navigation systems in experimental environments.[5] But to our knowledge, no one has reported on the challenges and impact of context-aware computing[6] used by a large number of urban pedestrians. Systems that connect physical spaces and digital information[7] could require certain human skills to allocate attention resources and use various information correctly.

To help fill this research gap, we examined NAVITIME (www.navitime.co.jp), an increasingly popular mobile phone-based navigation service that primarily targets urban pedestrians. As of January 2007, 1.82 million people in Japan use the service,[8] and this number is expected to exceed 2 million soon. Our experiences with NAVITIME reveal implications for designing urban-computing services.

Context

The geographical and cultural context of our discussion is Tokyo and other Japanese cities. The greater Tokyo metropolitan area is the world's most populous, with an estimated population of more than 30 million. Tokyo's primary mode of transportation is rail. The city has a complex network of more than 600 train and subway stations (see figure 1).

About 97 million people in Japan use mobile phones, 28 million of whom also use GPS-enabled handsets.[9] Japan's E110 mandate, a counterpart of the US's E911 and Europe's E112, requires mobile phone companies to embed GPS receivers in all third-generation (3G) mobile phones debuting after March 2007. As 3G phones occupy 70 percent of Japan's market share, GPS-enabled phones are now increasing more rapidly than before.

Of NAVITIME users, 1.05 million use a GPS-based pedestrian navigation application (see figure 2) on the KDDI platform. Another 0.4 million use a cross-platform pedestrian navigation application with or without GPS, and 0.37 million use a GPS-based car navigation application on the KDDI platform.

An important factor influencing user experience is mobile phones' positioning accuracy. If no major obstacles impede GPS signals, mobile

Figure 1. Japan Railway's Akihabara station is used by 17,000 people daily. Tokyo has 16 other railway and subway networks, including Shinjuku, the busiest train station in the world, with 3.5 million passengers daily.

phones' GPS receivers can achieve an accuracy of less than 10 meters. We can achieve an accuracy of 3 meters by incorporating map-matching techniques. GPS positioning is less accurate in urban areas with tall buildings. When GPS signals aren't available in indoor spaces or urban canyons, we can often use cell-tower positioning. Although cell-tower positioning is generally much less accurate than GPS positioning, we can achieve an accuracy of less than a few hundred meters on the KDDI platform because KDDI has synchronized its cell tower clocks.

Recent advances in mobile phone technology critically improved Navitime's usability and usefulness. 3G network technologies reduce the latency in interactive server-based applications. Flat-rate services free users from the anxiety of receiving expensive cell phone bills. Also, many GPS-enabled mobile handsets can detect their location every few seconds using Mobile Station-based semiautonomous positioning methods. Unlike other mobile phone-based navigation services such as Mapquest Navigator, Google Mobile Maps, and smart2go, Navitime provides integrated support for various modes of transportation.

Total navigation support

Navitime guides users to their destinations via several types of transportation: walking, driving, and riding trains, buses, taxis, and airplanes. It computes the best overall itineraries from where a person is standing to his or her final destination. It interactively guides users with maps, itineraries, voice prompts, vibration alerts, progress bars, and so on. This closely approximates what we call *total navigation support*, which considers all modes of transportation and encompasses the entire traveling activity.

The following scenario shows how Navitime can address certain information needs that arise in everyday navigation tasks in Tokyo. The scenario is based on our user experiences, feedback from other users, and a preliminary user study.

Mari is a new employee at NeoTech, a Web design firm in Osaka. She has been attending an annual design expo in Tokyo. The expo just ended, and it's 1 p.m. Her return flight will leave Tokyo for Osaka at 5 p.m., so she decides to spend a little time in Akihabara, an area well-known for gadget shopping. She wants to visit Sakura Mall, a new shopping mall, but this is her first visit to Tokyo and she doesn't know the area well.

Mari walks out of the conference hall and launches a pedestrian navigation application on her mobile phone. The application prompts her to specify her destination. She inputs "akihabara sakura mall" and presses the search button. The search result shows the mall, so she clicks on it to show the interface that supports navigation and search related to Sakura Mall. When she selects "go there," her phone receives GPS signals and connects to a server that immediately recommends the four best routes to Sakura Mall. She quickly reviews the four routes and chooses the first one, which takes her to her destination in 34 minutes for the total travel expense of 260 Japanese yen. She selects the route and presses the "Start route guide" button. The phone then shows map-based walking directions to a nearby train station.

Mari's phone recognizes the direction she is walking and automatically rotates the map to align its orientation with the physical space around her. The phone continuously tracks her location and proactively notifies her with vibration and voice prompts when, for example, she needs to turn in a different direction (see figure 3a). She arrives at the train station safely without having to look at the phone the whole way.

At the train station's entrance, Mari closes the map interface to look at the train schedules. She finds that she can take the Hanzomon Line to Jimbou-Cho, where she must change trains. She uses the train station's information signs to get to the right platform. Checking her mobile phone again, Mari finds that the train is coming in a few minutes and that it will be easiest to change trains at Jimbou-Cho from the first, third, and seventh cars.

When the train arrives at Jimbou-Cho, Mari exits the train, walks to a platform, and enters a train that goes to Iwamoto-Cho. Mari didn't know Iwamoto-Cho was near Sakura Mall. Without the application, she would have traveled through Akihabara station, which is

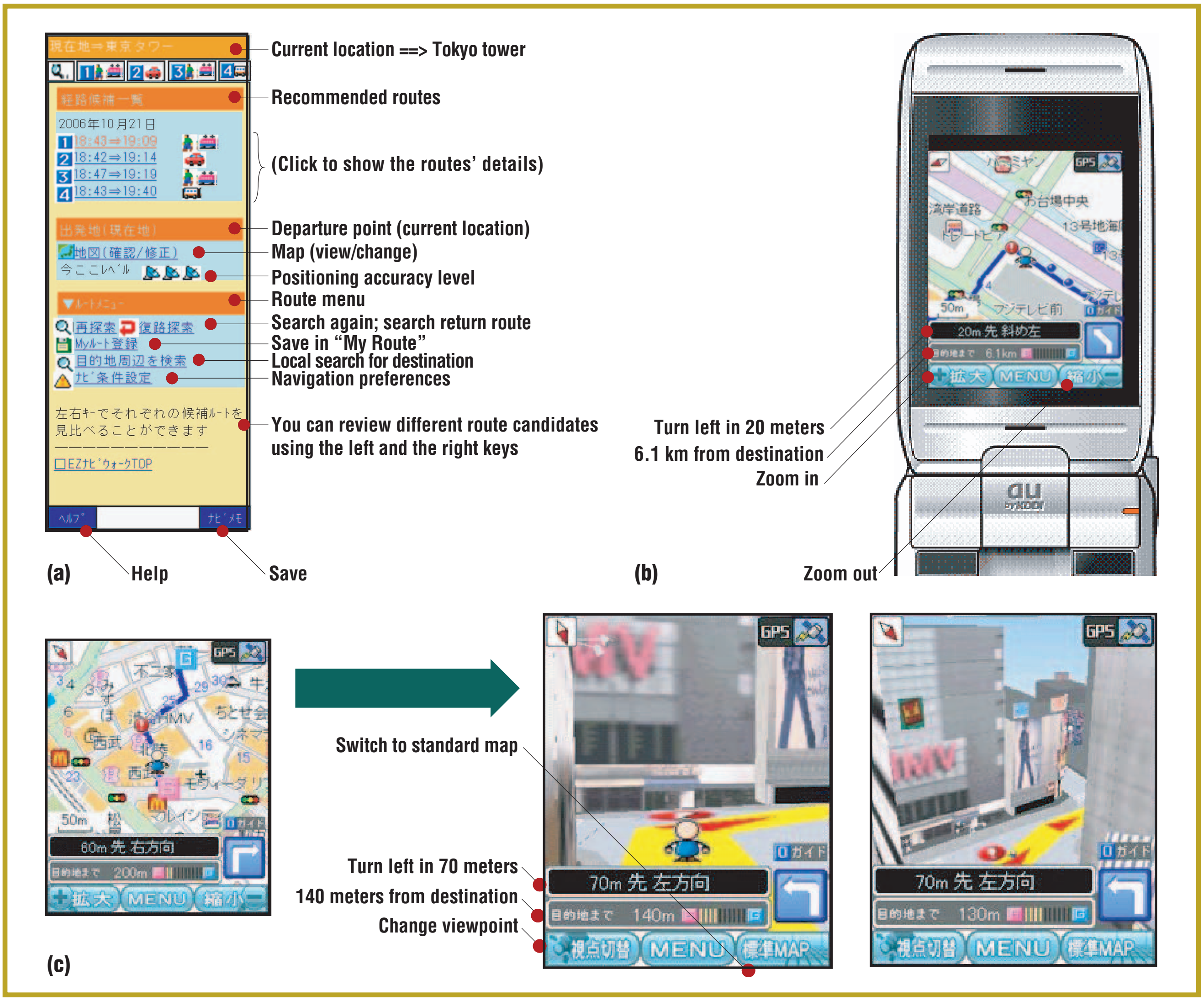


Figure 2. Using location-aware mobile phones: Navitime (a) lets users easily select a route and (b) shows a route-guidance interface that integrates dynamic maps, turn-by-turn instructions, progress bars, and so on. (c) A 3D user interface was recently introduced for some areas and will be more widely available in the future.

more prominent than Iwamoto-Cho but less convenient for her itinerary.

In the crowded train (figure 3b), she sees Kei, another expo attendee from Osaka. Kei is heading for Sakura Mall, so they decide to go together. Looking at her phone again, Mari says, "It's just a four-minute ride … and our exit is A3." They get off at Iwamoto-Cho and easily find a direction arrow for Exit A3.

Right after they exit, Kei selects "Start route guide" on her phone, which also uses Navitime. She shows Mari her phone, which says that they're close to their destination (figure 3c). Soon their phones start vibrating to confirm their arrival at Sakura Mall. At the mall's entrance, Mari quickly retrieves directions to the airport, specifying that she needs to be there at 4 p.m. Her phone recommends that she leave the mall at 3:10 p.m. So, Mari sets the alarm for 3:05 p.m. and has an hour to shop.

Space limitations prevent us from introducing other features in this scenario, such as searching locally for nearby ATMs, parking lots, coffee shops, convenience stores, and wallet-phone compatible stores (that is, stores that accept payment by RFID-chipped mobile handsets). Another available feature is bookmarking a place to revisit it or tell friends about it.

Service challenges

Several issues arose in the continuous effort to enhance and improve Navitime over the past 10 years. The system's designers use the service daily and enhance it primarily on the basis of their own use experiences as well as analysis of users' access records.

(a)

(b)

(c)

Figure 3. Mari uses the mobile phone-based navigation service (a) while walking down Harajuku Omotesnado Street. She accesses NAVITIME (b) on a crowded train and (c) on the street outside the train station. This is socially acceptable behavior because most people in Japan agree that you should avoid phone calls on public transportation, but thumb typing is okay.[10]

Computing

To provide useful information, NAVITIME often must process a substantial amount of data. At the same time, users expect real-time interactivity. It's challenging to develop efficient software components that can quickly search relevant routes from complex network data, especially when they're used on mobile devices with limited computing power, communication bandwidth, and memory capacity. Indeed, Japan alone has as many as 20 million roads, and the system must additionally process a large amount of timetable data.

NAVITIME distributes computing tasks on servers and mobile phone clients. Servers compute routes and generate maps in several seconds regardless of travel distance and geographic complexity. The system, for example, lessens the computation cost for long-distance routes by considering only major paths in intermediate segments. Clients can capture location information, handle user inputs, download data, visualize maps, generate voice prompts, and handle interrupts via incoming email messages and phone calls.

Route selection

In personal navigation services, best routes depend on the user's preferences and context. Even so, sometimes people just want to get from point A to B as quickly as possible. This provides one of the most important criteria in selecting best routes. NAVITIME considers other criteria for minimizing travel expense, transfers, or walking distance and displays the four best routes with additional information (such as the current weather at a destination or the amount of carbon dioxide you would emit for each route). Users can easily switch tabs to review different routes before choosing one (see figure 2a). Appropriately blending automatic processing and manual selection is a key design challenge, and the design space is fundamentally influenced by levels of computing and communication capabilities.

Interestingly, NAVITIME automatically adapts its user interface according to system capabilities and usage patterns. For example, the system slightly changes the user interface for local search to facilitate the use of different search categories at different times on the basis of collective usage patterns.

Location information

Location-aware mobile phones can automatically obtain their current locations. Still, users might have to manually specify indoor locations, past and future locations, and other locations of interest. NAVITIME therefore supports several interactive methods for specifying locations. Users can

- search locations using free-form keywords, phone numbers, and postal codes;
- reuse a location stored in a bookmark list or search history;
- select a location from hierarchically categorized lists;
- capture a location from a 2D barcode or numerical code; and
- use speech recognition to specify an address, phone number, landmark name, or keywords.

Users most frequently use free-form keywords because they let users search even when they don't remember exact addresses and names. The speech interface works on recent mobile handsets with dedicated voice-processing chips. 2D barcodes and numerical codes are printed on some commercial maps, business cards, and so on. NAVITIME provides these manual input methods to complement location-sensing technologies because the best method for capturing location information depends on users' capabilities and preferences, the usability of different location representations, and other contextual factors.

Moreover, users can prepare itineraries on PCs using Web accounts. The system stores the itineraries on a server, which users can access from their mobile phones. Similarly, users can access location names used on their mobile phones through their Web accounts. Such complementary uses of mobile phones and PCs should improve the overall user experiences before, during, and after travel.

Human-phone communication

Push is an attractive method for content delivery on mobile phones with a limited input modality. However, it's unlikely that NAVITIME will incorporate such push-based services (in particular, push-based ads). The system's designers believe that it's difficult to push information that interests users because mobile phones aren't fully aware of a user's context. Location is useful contextual information for supporting navigation; however, it might not be sufficient for considering users' broader activities and information needs. Instead, the designers are focusing on easy-to-use pull-based user interfaces.

The service presents information in various ways, not only to prevent and notify errors but also to increase users' confidence and trust,[11] using various media representations. For example, when you exit a train station and start a route guidance application, you might find it difficult to determine which direction to start walking in, even if your phone shows a route on a map. The designers realized this and recently introduced a 3D user interface (see figure 2c) to remedy the difficulty. However, we need faster mobile phone networks and more comprehensive 3D data to make the 3D interface more usable for massive everyday use.

Real-world data

Numerous data-supply companies collect and maintain various kinds of data, including sidewalk and road networks; small-scale, large-scale, and national maps; train schedules and connection information; real-time traffic and public transportation information; points of interest; addresses and telephone numbers; weather information; and so on. NAVITIME integrates these data by converting them into four common formats (see figure 4):

- *Dformat* integrates various timetable data for computing travel schedules.
- *Mformat* integrates various data that represent road and sidewalk networks as well as auxiliary data such as traffic regulation information, and allows for efficient computation of routes.

> The service presents information in various ways, not only to prevent and notify errors but also to increase users' confidence and trust.

- *Vformat* compresses 2D map data to about 10 percent of the corresponding map images using vector-based data that can be used to create display maps of various zoom levels.
- *V3Dformat* compresses 3D map data to about 2 percent of corresponding 3D map data used in car navigation systems. It does this by compressing texture data for small screen sizes and reusing similar textures.

Unlike research prototypes, real-world pedestrian navigation services must deal with imperfect and unstable data, which can easily cause problems in computing routes. We must update road network data periodically. After each update, a system that worked perfectly with the previous data set might slow down, show bad routes, or even fail to show any routes. Anecdotal evidence suggests that users may perceive NAVITIME as useless if it fails to show good routes a few times in a row. The designers solve this problem without locally modifying the data by either improving route search engines and converters or asking data suppliers to fix the problematic data.

Pedestrian experiences

To better understand NAVITIME's impact on pedestrians, we conducted a preliminary user study and examined the results considering demographic and usage statistics (see figure 5).

Procedure

The study involved two male graduate students, ages 25 and 26, who had never used NAVITIME. Subject A moved to Tokyo in fall 2006, and subject B has lived in the greater Tokyo area for many years. We asked them to travel independently using NAVITIME on a GPS-enabled mobile phone. The first set of trips took

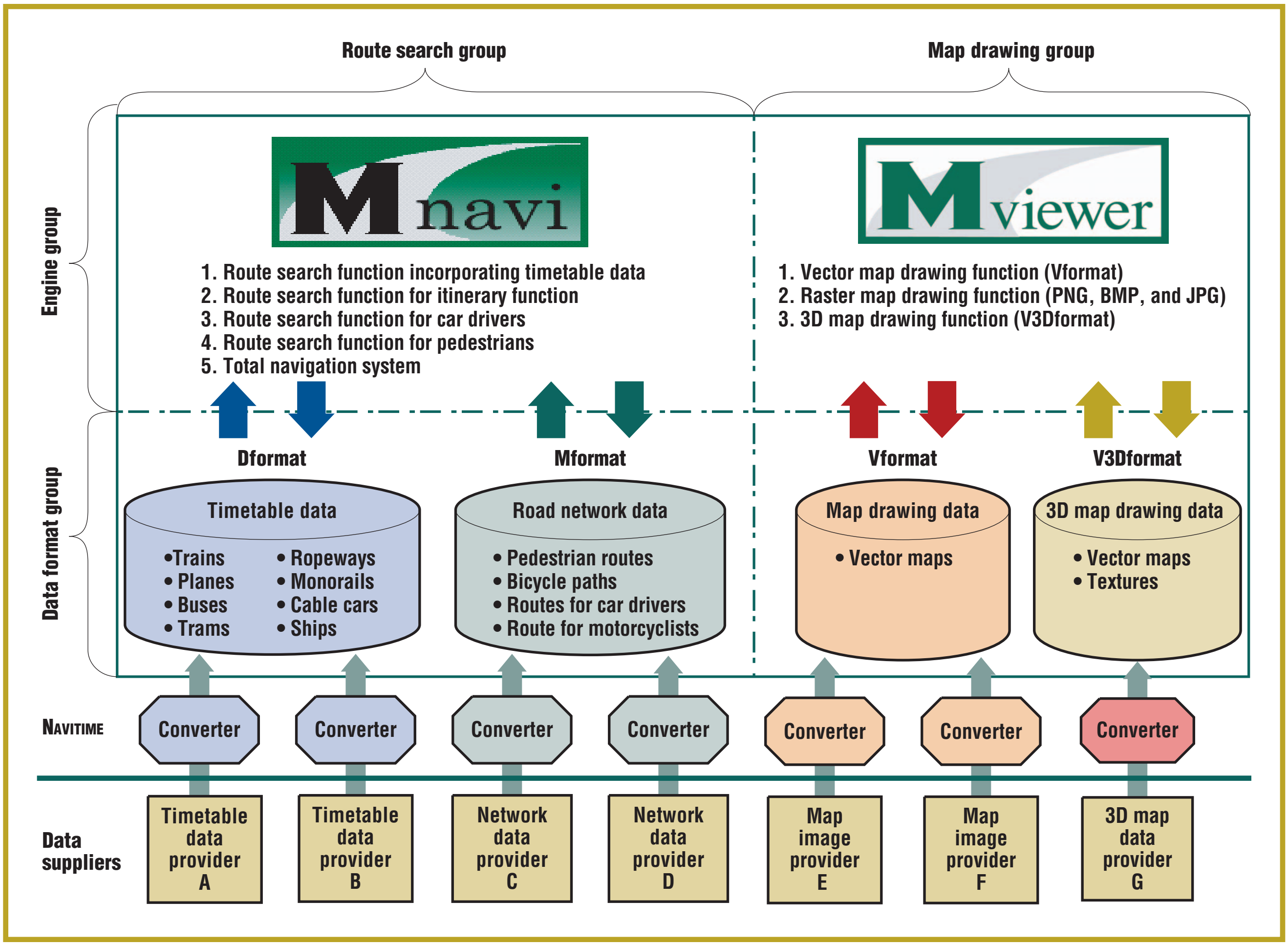


Figure 4. Navitime's data integration architecture merges heterogeneous data using common data formats that allow for efficient search and visualization.

place at 11 a.m. on a rainy Sunday. The subjects departed an intersection in Harajuku and headed for a restaurant near Akihabara. The second set of trips took place at 2 p.m., after the rain stopped, with the subjects departing the Akihabara restaurant for a restaurant in Ikebukuro (also in Tokyo). The subjects were unfamiliar with the areas near the restaurants. In all the trips, the subjects walked to a subway station, rode the subway, and then walked to a restaurant. Doing this took about 30 to 50 minutes.

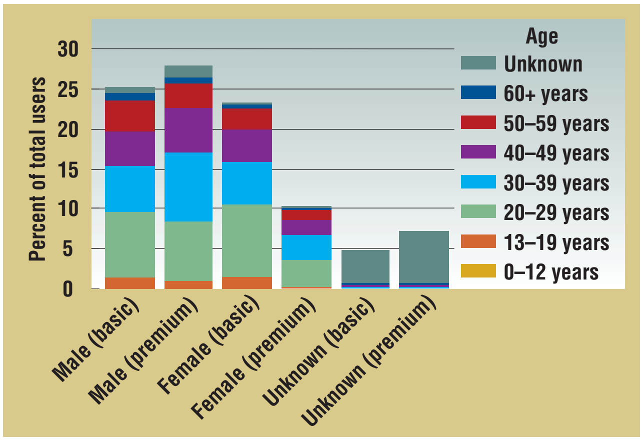
Two researchers followed and observed the subjects as they traveled. When they saw something interesting, they quickly asked the subjects short questions to capture their experiences with reference to specific real-world events. We also interviewed the subjects after each trip. We recorded the trips using portable digital audio recording devices and a think-aloud protocol (that is, a data-gathering method where subjects think aloud as they perform tasks, letting us capture some of what happens in their heads). We then coded the transcribed data from the audio recordings and the field notes.

Results

Because our study included only two subjects, we can't draw any conclusions from statistically analyzing the data. We present the results primarily as anecdotal evidence.

Both subjects completed the trips successfully; subject B needed less time to complete each trip than subject A. They both experienced some confusion near subway exits surrounded by tall buildings due to inaccurate GPS positioning. Subject A wandered for a long time before realizing that the instructions were incorrect. He then missed a subway train, but he managed to recalculate travel itineraries in an underground environment without a stable data connection. He also recalculated travel itineraries when he found himself diverging from the original route. This usually took about 70 seconds.

During subway rides, the subjects prepared themselves for their wayfinding tasks at destination stations. When subway trains are moving, there's no data connection or cell-tower positioning. The subjects used NAVITIME when the



(a)

Route selection criteria	Percent of users
Minimum travel time (default)	91.80
Minimum travel expenses	4.50
Minimum number of transfers	2.40
Minimum walking distance	1.30

(b)

Pedestrian navigation	Car navigation
Train or subway stations and airports	Expressway interchange
Universities and colleges	Ski and snowboard resorts
Hotels	Amusement and theme parks
Post offices	Local government offices
Manga café	Shopping malls and districts

(c)

Weekday (12 a.m.–5 a.m.)	Weekday (6 a.m.–11 a.m.)	Weekday (12 p.m.–5 p.m.)	Weekday (6 p.m.–11 p.m.)
Parking lots	Banks, credit unions, and ATMs	Banks, credit unions, and ATMs	Miscellaneous Japanese-style pubs
Banks, credit unions, and ATMs	Parking lots	Train or subway stations and airports	Banks, credit unions, and ATMs
Train or subway stations and airports	Train or subway stations and airports	Parking lots	Train or subway stations and airports
Bars, pubs, and nightclubs	Covenience stores	Covenience stores	Parking lots
Covenience stores	Hair, makeup, and beauty salons	Hair, makeup, and beauty salons	Ramen (noodle soup) restaurants

Weekend (12 a.m.–5 a.m.)	Weekend (6 a.m.–11 a.m.)	Weekend (12 p.m.–5 p.m.)	Weekend (6 p.m.–11 p.m.)
Parking lots	Banks, credit unions, and ATMs	Banks, credit unions, and ATMs	Miscellaneous Japanese-style pubs
Hotels	Parking lots	Parking lots	Parking lots
Bars, pubs, and nightclubs	Train or subway stations and airports	Train or subway stations and airports	Banks, credit unions, and ATMs
Train or subway stations and airports	Hair, makeup, and beauty salons	Ramen (noodle soup) restaurants	Train or subway stations and airports
Banks, credit unions, and ATMs	Ramen (noodle soup) restaurants	Miscellaneous electric appliance and PC shops	Ramen (noodle soup) restaurants

(d)

Figure 5. Demographic and usage statistics as of February 2007: (a) subscribers to basic and premium services on NTT DoCoMo's i-mode platform by gender and age (the slightly more expensive premium service gives users real-time information on traffic congestion and train delays), (b) the percentage of users who chose each route selection criterion (each user can select only one), (c) the most popular pedestrian navigation destinations compared to car navigation destinations, and (d) the most popular local search queries by time of day.

trains stopped briefly at intermediate stations. Using cell-tower positioning, the system generated relevant itineraries.

Our subjects looked at their mobile phones and physical surroundings alternately to match the digital map and the surrounding physical space. They did this right after exiting from a subway station, when they needed to determine the right direction to walk. Both subjects felt that they might have looked at their phones too much and possibly missed important information in the physical spaces.

Discussion

Is Navitime changing the way people move around, make sense of spaces, and manage social relations in urban environments? We discovered related issues from our preliminary user study, demographic and usage data (see figure 5), anecdotal evidence from our experiences, and informal conversations with other users, as well as existing theories.[1,3,12]

Navitime calls for highly interactive usage patterns. Results from our user study suggest that unexpected events happen that systems can't easily detect. Users might need to manually select different options or recalculate itineraries in response to such events. Our subjects desired systems that automatically recognized more varieties of context. However, we could also argue that over reliance on complex automated processing could negatively impact user experiences. Figure 5b shows that more than 90 percent of users chose the default route selection criterion in their preference settings. The route guidance interface (see figure 2a) allows for interactive route selection, complementing the automatic route recommendation based on user preferences.

Users gain more benefits from Navitime as they become more experienced with it. Because our subjects hadn't used Navitime before, they sometimes couldn't decide whether to trust the information. Learning about data connection availability and positioning accuracy levels in different urban spaces could help users interpret Navitime's information. Also, the skill to match the digital information on mobile phones with what users perceive in physical spaces is critical for users to orient themselves and have integrated experiences.

Pedestrians can travel to familiar as well as unfamiliar places using Navitime. Our conversations with some users and our own experiences suggest that people who use complex transportation networks would keep using Navitime for routine commuting. It might be beyond human capability to compute in real time the best routes when these change constantly depending on train, subway, and bus schedules and traffic congestion.

Figure 5c shows the most popular pedestrian navigation destinations compared to car navigation destinations. Popular destinations for car passengers include ski and snowboard resorts and amusement and theme parks, which we tend to associate with special, rather than mundane, life events. In contrast, pedestrians' popular destinations could be more likely associated with both special and mundane life events.

Using Navitime, pedestrians can engage in microplanning during travel. Figure 5d shows that people use local search, a feature that facilitates ad hoc itinerary modification and creation, to look for various places of interest. Also, both subjects in our user study modified their itineraries during trips.

Navitime can function as a tool for living or learning and enhancing navigation skills.[13] People can become dependent on a mobile wayfinding device,[14] and we must think about Navitime's broader implications beyond convenience. You might think that following instructions on a mobile phone will reduce your chances of serendipitous discoveries. On the other hand, it could also create the sense of never being lost, which might let you wander freely, thus increasing your chances of serendipitous discoveries.

Mobile phones and physical spaces have different affordances and can complement each other. Mobile phones allow for comprehensive local search, while physical spaces provide richer cues for exploration. Interestingly, we can use the service to watch GPS-triggered scrolling maps to gain better awareness about the areas we travel through.

Over reliance on complex automated processing could negatively impact user experiences.

Location privacy is critical. There's a simultaneous need to both protect location privacy and disclose location information to others socially. Moreover, people might want to store their location histories at an easily accessible place to facilitate reuse and recall. However, private information stored on a computer is rarely perfectly secure.[15]

Navitime's approach to managing privacy-sensitive information reflects the tension of these conflicting issues. For each user, the servers store the 20 most recent location-search queries, which aren't linked to personally identifiable information. Mobile carriers detach and encrypt personally identifiable information such as mobile phone numbers before forwarding service requests to Navitime. In addition, users can easily delete their historical data.

So far, this approach hasn't caused major concerns in Japan. Nevertheless, privacy is a complex issue that can come into play differently in other social and political climates, and research communities can greatly contribute to this area.

Men and women use mobile pedestrian navigation systems differently. Existing research[5] and our demographic data (see figure 5a) suggest gender differences in mobile pedestrian navigation systems' usage patterns. Unfortunately, we can't discuss detailed age and gender differences without a full-scale user study.

Finally, there could be some unexpected usage patterns that we aren't fully aware of. For example, figure 5d shows that parking lots are popular places for pedestrians' local search queries. We're investigating whether this means that people are using pedestrian navigation systems in their cars.

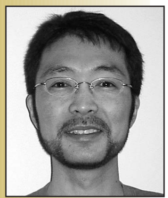
We believe that pedestrian navigation support will be a pervasive feature of urban-computing environments. As technologies evolve, we might soon be able to make the service work without data connection by using autonomous GPS positioning and mobile databases. Researchers and companies are exploring seamless, highly accurate positioning systems as well. Advances in mobile multimodal interaction technologies could enable new services for people with disabilities.

The company is extending NAVITIME to operate in multiple countries. Implementing a system that works in different cultures with different regulations (for example, traffic laws) is challenging. Data resources are often available only in a local language, and translating place names into other languages can be difficult. Translated place names on a map have limited use if they're not printed in the physical space (for example, using signposts, signboards, and so on). It's important to see the city as more than an accumulation of people, buildings, and services.[16] Indeed, there are numerous social, technological, and business challenges in simultaneously considering multiple cultural contexts within which systems must operate.

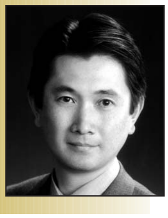
Future services for urban pedestrians would support various activities beyond just getting around efficiently. How can we exploit useful user-generated content without causing information overload? How can we integrate pedestrian navigation and other pervasive technologies such as RFID-enabled smart objects? How are such services changing people's practices? How can we protect users' privacy? Finally, we need to invent novel business models to fully explore the potential for supporting urban pedestrians. P

the AUTHORS

Masatoshi Arikawa is an associate professor at the Center for Spatial Information Science at the University of Tokyo. His research interests include cartography, spatial information technology, databases, virtual reality, user interfaces, and developing new spatial communication tools to enhance people's spatial ability. He received his PhD in computer science and communication engineering from Kyushu University. He's the chair of the Geographic Information Systems Association's special interest group on Spatial Information Technology. He's a member of the IEEE; ACM; Institute of Electronics, Information, and Communication Engineers; Information Processing Society of Japan; Japan Cartographers Association; and Architectural Institute of Japan. Contact him at the Center for Spatial Information Science, Univ. of Tokyo, 5-1-5, Kashiwa-no-ha, Kashiwa City, Chiba 277-8568, Japan; arikawa@csis.u-tokyo.ac.jp.



Shin'ichi Konomi is a research fellow at the Center for Spatial Information Science at the University of Tokyo. His research interests include interaction design and social implications of pervasive computing, HCI, context awareness, RFID systems, privacy-enhancing technologies, and urban computing. He received his PhD in computer science from Kyoto University. He's a member of the IEEE, ACM, Information Processing Society of Japan, and Database Society of Japan. Contact him at Ew-601, Inst. of Industrial Science, Univ. of Tokyo, 4-6-1, Komaba, Meguro-Ku, Tokyo 153-8505, Japan; konomi@csis.u-tokyo.ac.jp; www.iis.u-tokyo.ac.jp/~konomi.



Keisuke Ohnishi is a founder and CEO of NAVITIME Japan. He is also a visiting professor at the Center for Spatial Information Science at the University of Tokyo. His research interests include path finding technologies and navigation systems. He received his PhD in computer science from Sophia University. Contact him at Kandasuda-cho Place 5F, 1-9 Kandasuda-cho, Chiyoda-ku, Tokyo 101-0041, Japan; kohnishi@navitime.co.jp.

REFERENCES

1. K. Lynch, *The Image of the City*, MIT Press, 1960.
2. E.C. Tolman, "Cognitive Maps in Rats and Men," *Psychological Rev.*, vol. 55, no. 4, 1948, pp. 189–208.
3. R.G. Golledge, *Wayfinding Behavior: Cognitive Mapping and Other Spatial Processes,* Johns Hopkins Univ. Press, 1998.
4. A.W. Siegel and S.H. White, "The Development of Spatial Representations of Large-Scale Environments," *Advances in Child Development and Behavior, Vol. 10*, H.W. Reese, ed., Academic Press, 1975, pp. 9–55.
5. A. Krüger, I. Aslan, and H. Zimmer, "The Effects of Mobile Pedestrian Navigation Systems on the Concurrent Acquisition of Route and Survey Knowledge," *Proc. Mobile Human-Computer Interaction* (Mobile HCI 04), LNCS 3160, Springer, 2004, pp. 446–450.
6. T. Moran and P. Dourish, "Introduction to this Special Issue on Context-Aware Computing," *Human-Computer Interaction J.*, vol. 16, 2001; http://hci-journal.com/editorial/si-context-aware-intro.pdf.
7. T. Kindberg et al., "People, Places, Things: Web Presence for the Real World," *Proc. 3rd IEEE Workshop Mobile Computing Systems and Applications*, IEEE Press, 2000, pp. 19–28.
8. H. Kamio, "Current Status of a Continuously Evolving Service 'Ez Navi Walk,'" *ITmedia BizMobile*, 13 Feb. 2007; http://bizmakoto.jp/bizmobile/articles/0702/13/news055.html (in Japanese).
9. S. Goto, "SoftBank Mobile Subscribers Increased the Most—Number of May Subscribers," *ITmedia*, 7 June 2007; http://plusd.itmedia.co.jp/mobile/articles/0706/07/news078.html (in Japanese).
10. M. Ito, D. Okabe, and M. Matsuda, *Personal, Portable, Pedestrian: Mobile Phones in Japanese Life*, MIT Press, 2005.
11. A.J. May et al., "Pedestrian Navigation Aids: Information Requirements and Design Implications," *Personal Ubiquitous Computing*, vol. 7, no. 6, 2003, pp. 331–338.
12. L.A. Suchman, *Plans and Situated Actions: The Problem of Human-Machine Communication*, Cambridge Univ. Press, 1987.
13. S. Carmien and G. Fischer, "Tools for Living and Tools for Learning," *Proc. 11th Int'l Conf. Human-Computer Interaction* (HCII 05), Lawrence Erlbaum Associates, 2005; www.fit.fraunhofer.de/~carmien/papers/carmien_fischer_tools.pdf.
14. M.P. Peterson, "The Transition from Internet to Mobile Mapping," *Location Based Services and TeleCartography*, Springer, 2007, pp. 73–88.
15. "Big ID Theft in California," *Wired*, 16 Feb. 2005; www.wired.com/news/business/0,1367,66628,00.html.
16. A. Williams and P. Dourish, "Imagining the City: The Cultural Dimensions of Urban Computing," *Computer*, vol. 39, no. 9, 2006, pp. 38–43.