Design and Development of a User-Centered Mobile Application for Intermodal Public Transit in Bangkok: A Design Thinking Approach

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***Abstract*—With the constant increase in public transit coverage in Bangkok Metropolitan Area in Thailand, many people are still hesitant to switch from using private to public transit, with one potential cause being the unavailability and difficulty in accessing accurate and timely information about their itineraries, while they are commuting. To assess and tackle such issues, the researchers adopted the user-centric Design Thinking methodology to empathize with target users' pain points in this study. They proposed a solution in a user-centric manner by assessing the usability flaws of existing mobile navigation applications, such as Google Maps and ViaBus. By developing a holistic mobile application called '*Disgovery*' that covers all modes of public transit in the Bangkok Metropolitan Area and provides relevant information about their trips, the researchers aim to help commuters in Bangkok easily access it in a timely fashion. Through the user-friendly interface, commuters can eliminate the difficulty of finding routes and prices suitable to their needs. By making public transit more accessible with the help of ubiquitous mobile computing, commuters are also encouraged to switch from using private vehicles to public transit, which also can reduce accidents and carbon emissions. The findings from the usability testing in this study suggest that '*Disgovery*' is an effective and user-friendly application for daily commuters in Bangkok that can help them achieve their goals without difficulties. The findings also indicate the importance of user interface and user experience guidelines in designing such applications.**

***Index Terms*—Mobile Application for Public Transit, Bangkok Public Transit, Public Transit, Route Description, Route Instruction, Intermodal Public Transit Navigation, Navigation Application, Routing Algorithm for Public Transit, Design Thinking**

I. Introduction

Bangkok is known to have one of the worst traffic in the region. In modern-day Bangkok, as road traffic condition has been so deteriorating, the wide coverage and development of public transit in this metropolitan city should be prioritized [1]. To tackle this issue, there have been several public transit construction projects planned to be completed and spanning over 30 years [2]. The current public transit in Bangkok includes buses, MRT (Bangkok Metro), BTS Skytrains, and water taxi or boats. Over the past decades, the existing modes of public transport have been upgraded to be modern and convenient; however, many people in Bangkok are still driving their private cars instead of using public transit, leading to an ever-increasing number of car ownership and road accidents, which have become a significant concern for the authorities. One possibility is that there is a lack of reliable, accurate, and accessible sources of timely information for daily commuters to plan itineraries via public transit. Most of the existing tools people use are mobile applications, including Google Maps and ViaBus. Despite being widely used, these current mobile applications do not provide a holistic solution—i.e., complete, accurate, and timely relevant information—to the users, with some lacking pricing information and most being inaccurate (e.g., time) and insufficient (e.g., cost).

With the increased availability of mobile devices and countrywide access to high-speed Internet in Thailand, many people have become reliant on mobile-based applications to perform their daily tasks, including banking, education, and communication. Hence, a mobile-based solution has shown promise to address the needs of public commuters in Bangkok to access more reliable, accurate, and timely public transit information. Furthermore, although ubiquitous mobile computing for public transit has been in research for a few decades, the study is limited in user experience and usability of such applications. It can be noteworthy to research if a user-centric interface design and user-friendly experience would be a driving factor to an effective solution in user-centric system development. Hence, this study aimed to alleviate the difficulty in itinerary planning involving public transit in the Bangkok Metropolitan Area by providing personalized and accurate information on prices, timetables, transfers, and public transit modes in Bangkok Metropolitan Area as a mobile application. Furthermore, we are interested in understanding the role of usability and user experience in adopting such a mobile-based application.

In recent years, due to the advances in ubiquitous communication technologies, cognitive infocommunications (*CogInfoCom*) has become an important research area in which researchers have studies how users' cognitive processes can co-evolve with infocommunications devices such as mobile and tablets [22]. According to [23], *CogInfoCom*, which is a relatively young research area, has common interests with other disciplines including human-computer interaction, affective computing, ubiquitous computing, artificial intelligence, and so forth. Over the past decade, researchers have conducted studies related to this specific research area in *CogInfoCom*, for example, in [24], the researchers designed and developed a gamified system to

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improve the elderly people's mental wellness in terms of their cognitions (e.g., memories and learning). Also, in [25], the researchers studied how users engaged in immersive virtual reality spaces (VR), as well as their cognition in interacting with such VR systems. Similarly, in [26], the researchers reported the importance of user's cognition in using VR-based exercise systems for their physical health.

As the existing literature has clearly shown the importance of user's cognition in using communication systems, one of our study's objectives is to understand how the interface design of our system can affect users' cognition. Hence, to achieve our study objectives, the researchers in this study adopted the '*design thinking'* methodology to design and develop a user-centric mobile application that tackles the issues discussed earlier. During the process, the researchers would gain in-depth requirements and needs of the users through empathy-based user research, followed by designing and developing the application that conforms to the user experience and interfaces design principles. Eventually, the software would be tested and evaluated by conducting usability testing in a controlled setting. The findings from this study can be useful for designing and developing a mobile-based application for public transit in Bangkok and other cities worldwide. Being a design case-study using design thinking methodology, this study aims to contribute to the scientific community particularly in human-computer interaction and cognitive infocommunications research areas in terms design recommendations for future research.

II. Literature Review

According to the literature [3], the study estimated that the traffic demand from East Bangkok would far exceed the transportation supply. The researchers also indicated that extending the current public transit system could alleviate numerous issues caused by the excess demand in traffic in Bangkok. With the tendency of traffic demand in Bangkok to increase, there are also plans to accommodate the commuters. Namely, several mass transit systems on the rail will be under development and construction in 2022 [2]. The rapid expansion of mass transit systems means that commuters may have better and more convenient options for traveling; however, it is also a challenge for them to handle all the relevant information and familiarize themselves with the new transit lines and extensions that are opening more frequently than before [2]. The literature also highlights that when it comes to modern technologies for public transport systems, accessibility is one of the central clusters of issues persisting in all Bangkok public transit systems [4]. For simplicity, the problems can be subdivided into ones concerning intra-modal transit and others relating to inter-modal transit.

Regarding the intra-modal accessibility of Bangkok public transit, Noichan and Dewancker [4] 's analysis of BTS' Mo Chit Station, Victory Monument Station, and Saphan Taksin Station suggests that mass transit nodes in Bangkok still lack accessibility, especially on the inside of the station buildings. Accessibility gaps in wayfinding within a station building are one of the main issues for which this study aims to provide a solution. On the other hand, in terms of inter-modal accessibility, Amrapala and Choocharukul [5] mentioned the informal public transport service, "*Silor*" (literally "four-wheeler" in Thai), being the leading choice of mobility for connecting between larger public transit nodes. Apart from Silor, tuk-tuks and motorcycle taxis are popular for informal transit [6]. This suggests a higher flexibility and sophistication in intermodal transit in Bangkok since commuters may connect between transit modes by walking and informal public transport services.

Due to advances in ubiquitous computing, mobile devices have become integral to everyday life. Consequently, the mobile network plays a crucial role in connecting mobile devices to the internet, but limited literature exists exploring mobile network coverage in Bangkok. Regarding [7], although the network quality (measured in terms of download speed) is inferior compared to other countries (ranked as 77th out of 87 countries), Thailand has a mobile network signal that covers 95% of its area with acceptable speed (5.7 Mbps), which can provide access to virtual map at ease. Wi-Fi is an alternative way to access the internet used by 58.18% of Thai people, which is the majority compared to mobile, dial-up and hotspot [8]; thus, Wi-Fi availability in Bangkok has to be taken into consideration. As mentioned in [9], the Wi-Fi coverage area in Bangkok covers the entire city; however, the Wi-Fi used while transporting provides only a 55% successful transmission rate. Regarding mobile accessibility, 80% of people in Bangkok aged between 25 and 34 (the target group of this study) own at least one smartphone or mobile device [10]. All the repercussion above indicates that commuters in Bangkok have sufficient needs that support them to use virtual maps over paper maps.

The increased demand in traffic still cannot be fully resolved with the expansion of public transit lines since the experience of using public transit is limited to the poor design of the stations and the lack of data integration between operators. With the prominence in accessibility issues that seems to be expanding alongside the new transit line openings in Bangkok, there is still no research to integrate information accessibility among different public transit systems in Bangkok. Hence, in this study, we aimed to design and develop a user-centric system for intermodal public transit in Bangkok while considering the importance of usability and user experience in it.

III. Design Thinking

The Design Thinking approach is a user-centric way of designing and developing a solution, which consists of 5 main phases—empathize, define, ideate, prototype, and test [11]. Design thinking has been widely accepted by many designers and UX researchers worldwide, as it has been applied in many areas, including engineering, interaction design, business, and policy-making. To create an innovative solution for specific user groups with distinct needs, the Design Thinking approach allows us to genuinely empathize with the target users and develop a solution that effectively solves the users' problems and needs. Per this study, the researchers adopted the Design Thinking approach to gain insights into the problem space regarding public transit users in Bangkok to walk through the solution space appropriately.

A. Empathy (Understand and Observe)

In the *'Empathy'* phase, the problem statement was first formulated—commutes via public transit in Bangkok are inconvenient and burdensome—with target users of regular commuters whose commute regularly consisted of public transit. The researchers then gathered user requirements qualitatively by conducting interviews with a predefined set of questions and quantitatively using a questionnaire. The interview questions consisted of four parts: methods of transportation, itinerary planning processes, everyday issues of public transit, and applications and tools used to assist traveling via public transit. Each user interview session per participant took 40 minutes on average, and all participants were requested to confirm their consent to be recorded, strictly only for further usage in this project's scope.

As a result, the interview responses from 8 participants helped identify several issues with the public transit systems in Bangkok. The problems mainly included the frequent unpredictable delays on the transit systems, non-centralized information of routes, prices, and timetables, and poor user interface designs on existing public transit applications. In addition, the questionnaire results highlighted the issues concerning the public transit navigation systems, i.e., Google Maps, Apple Maps, ViaBus, and BKK Rail. The survey also let the participants pinpoint the severity of the problems in different aspects of each system using a 5-point Likert scale to score the techniques in each element, i.e., ease of use, time accuracy, route correctness, completeness of information, system performance, and bus location tracking accuracy (ViaBus only). From the questionnaire with a sample size of 47, it is found that most users are familiar with Google Maps (89.4%), followed by ViaBus (31.9%) and Apple Maps (29.8%), and lastly, BKK Rail (6.4%). Similarly, the average satisfaction score for Google Maps is highest at 3.91 out of 5 points, followed by ViaBus (3.60), Apple Maps (3.37), and BKK Rail (2.83). The user satisfaction scores of all existing systems were below 4 points, which is 80% of the total score. The findings from the initial user research confirmed that the current systems could not cater to the needs of public transport commuters in Bangkok in terms of adequacy, accessibility, and timeliness.

B. Define

After the user requirement gathering processes were completed, raw data from the user research was analyzed and transformed into graphical visualizations representing the satisfaction scores of each system. The interview results were convoluted into an empathy map, and a persona associated with the responses was created to represent the target users of the system. An empathy map is used in the '*Define*' phase to capture what users encounter daily, along with their pains and gains. Followed by the empathy map, a persona, a fictional character, was created to represent the target users of the system as a person with personal backgrounds, goals, needs, pain points, and personalities. For this study, a persona of an undergraduate student in an urban university who must regularly commute to the campus by public transit was created to represent the users who would benefit from this study. Following the persona, a user journey map—a tool that allows the authors to identify the user's thoughts, actions, and feelings across chronological phases while undergoing certain situations—was created to depict the as-is process of using public transit in Bangkok.

After the persona was created and the user journey map was illustrated, the researchers formulated the *How-Might-We (HMW)* questions in accordance with the persona's needs to narrow down the scope of the solution to be implemented in succeeding steps. The HMW question in this study was, '*How might we help daily commuters in Bangkok gain access to accurate, reliable, and timely information about their travel plans through a user-centric and user-friendly interface?*'. Furthermore, the specific user needs were brainstormed and generated from the empathy map, persona, and user journey map. The users' needs included accurate Time and price estimates, intuitive navigation, route comparison, and delay notification.

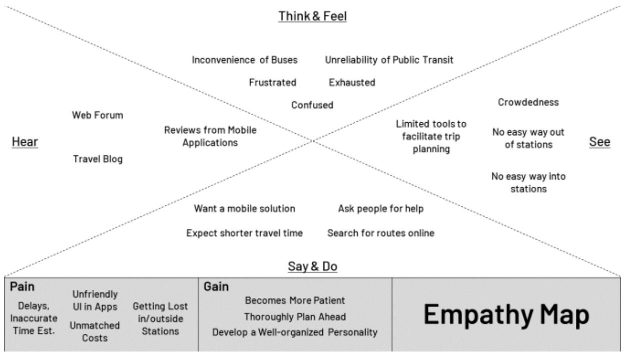

Fig. 1. Empathy Map

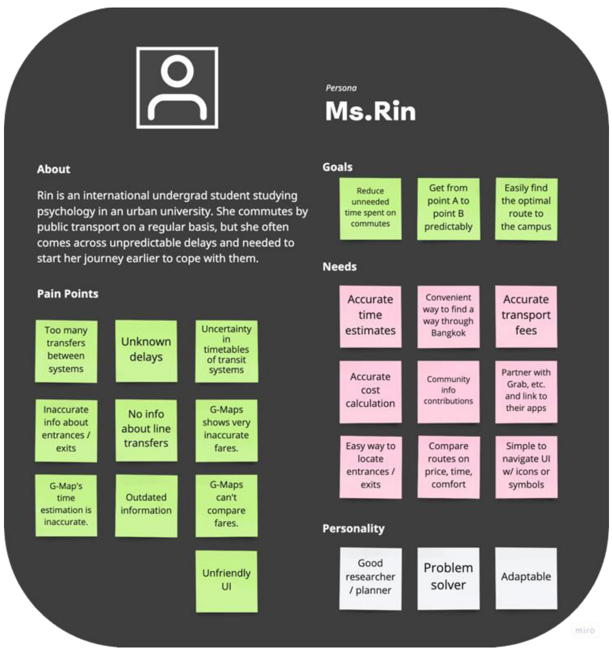

Fig. 2. Persona

STAGE	IDENTIFIES NEEDS	LOOKS FOR INFO / PLANNING	SITUATIONS / PROBLEMS ENCOUNTERED WHILE TRAVELLING	SEEKS HELP / SOLUTION
THOUGHTS (MENTAL)	Has no car On a budget Must be on time Has a morning class	Wants accurate info Are there delays? Is this info reliable? Which exit to choose?	Unreliable info sources Unknown delay Afraid of being late Worried about increased costs Ambiguous direction signs	Tries reading signs first Who to ask for help Might have to pay more Accepts being late
ACTIVITIES (PHYSICAL)	Uses public transit	Find a transit app Look up info on apps Calculate time & price Find stops & exits	Paid more than calculated Faced unexpected delays Gets lost Goes to class late	Asks officers for exits Looks around for signs Explains being late Finds other apps that prioritize arrival time
FEELINGS				
IMPROVEMENT		Improve time accuracy Improve price accuracy Provide suggested transit systems	Improve maps inside stations Add more maps around stations Delay notifications Revise exit signs	

Fig. 3. User Journey Map

Fig. 4. To-be system

C. Ideate

In the design thinking process, the *'Ideate'* phase is the process that consolidates ideas that contribute to the ultimate goal of creating a solution for each of the observed problems. Specifically, the method comprises the translation of solution ideas into functionalities or requirements of the system. This study discusses five user needs that take the form of solution ideas, which are translated into system requirements and functionalities. The most mentioned user's need was the accurate time information of the transits, and the solution idea for which is to frequently and regularly update timetables referring to the transit operators and research the "*Time*" required to transfer between each transit line. However, with the time and human resource limitations, the study only scopes the transfer research to transit stops with multiple transit lines, e.g., MRT *Tha Phra* and BTS *Siam*. The solution is translated into the system's functionality to display the expected time duration the user would spend on the trip shown.

The second proposed idea was regularly updating fare information for each transit line. Since public transit fares are occasionally discounted or waived with regard to national holidays [12], [13] and increased to match the rise in operational energy cost [14], a system requirement was formed such that the fare information should be regularly monitored and updated. The fare of each trip should also be accurately calculated and presented on the system accordingly. The third solution proposed was the turn-by-turn navigation system that would intuitively lead the users from their original locations to their destinations. Being prominent for almost 15 years, the turn-by-turn navigation system has proven itself through Time and has gone through much refinement until today [15]. A system requirement, design-wise that would accommodate such a solution idea would be to model from and improve upon an already existing turn-by-turn navigation system, e.g., Google Maps and Apple Maps, not only to provide familiarity in the user's journey but also customize the visual design to be more appropriate for usage in public transit. Due to their more straightforward nature and fewer details needing to be discussed, the other two solution ideas with their corresponding system functionalities and requirements are listed in Table I, alongside the solution mentioned above idea translations. With regards to the system functionalities and

TABLE I
FROM SOLUTION IDEAS TO SYSTEM'S FUNCTIONALITIES

Solution Idea	System Functionality / Requirement
Sufficient timetable updates	Display time obtained from transit operators; frequently and regularly check for timetable updates
Sufficient fare updates	Regularly monitor updates for fare rates, first entry costs and cross-operator integration adjustments, and promotional discounts of each transit operator; calculate fares by referring to existing rules and display on trips accordingly
Intuitive navigation system	Turn-by-turn navigation modeled after existing, widely used systems with minor adjustments and improvements to be more suitable for public-transit-based navigation
Trip personalization	Compute trips with priorities put on different preferable aspects of each user, e.g., Time, cost, fewer transfers, and allow users to choose from the list of offered trips to the same destination
Delay information updates	Provide real-time delay notification based on real delay data fetched from the transit operators—the information package includes the transit lines affected, transit stops or areas where the delay is caused, and expected delay time.

TABLE II
UX/UI PRINCIPLES APPLICATION

Principle	Application
Jakob's Law	According to the survey, design elements resemble those of Google Maps and Apple Maps, which is familiar to many people.
Fitt's Law	The most important actionable targets/buttons are prominent in size and placed vertically on the screen.
Hick's Law	Each page only contains a few actionable components/buttons, which are functionalities most likely to be used in the pages' context.
Aesthetic-Usability Effect	The color and shape aspects of the design were chosen to be more visually comfortable and aesthetically pleasing to be perceived as more usable.
Von Restroff Effect	The most vital actionable target, e.g., the "Go" button, which starts the navigation, for a page is shaped and colored drastically differently from the rest of the page's components for it to be distinguishable.
Doherty Threshold	To maximize productivity, the system reacts to the user's input within 400 ms.
Law of Common Region	A group of related information is packaged within a border, e.g., the price, duration, and arrival time of the same route are placed on the same border. In contrast, the same set of information of another route is placed on a different, separate border.
Law of Proximity	Related elements are placed near each other, e.g., a list of transit timetables for a transit stop consists of termini, and the frequency of each terminus is placed directly under the terminus name.
Law of Uniform Connectedness	The route directions in the route details page comprise different modalities, e.g., walking and departing on a subway, between which is a line that shows the connection between adjacent modalities.

system, e.g., Google Maps and Apple Maps, not only to provide familiarity in the user's journey but also customize the visual design to be more appropriate for usage in public transit. Due to their more straightforward nature and fewer details needing to be discussed, the other two solution ideas with their corresponding system functionalities and requirements are listed in Table I, alongside the solution mentioned above idea translations. With regards to the system functionalities and requirements translated from the generated solution ideas, a holistic view of the proposed system can be generally visualized in the to-be system diagram (see Fig. 1). The system would allow the users to search for details of transit stops or nearby locations as their origin and destination stops, view the suggested routes via different modalities, and see the detailed information of the selected route before starting the turn-by-turn navigation system.

D. Prototype

In the *'prototype'* phase of design thinking, the existing heuristic UX and UI guidelines and human-computer interaction (HCI) principles were applied so that we could design and implement a user-centric system for our target users [16]. First, we started with a low-fidelity user interface in which the selected UX/UI guidelines were applied. Based on the findings from the early evaluation of these low-fidelity prototypes and high-fidelity prototypes of the system, we improved the system's design, which led to the high-fidelity prototype, integrating with executable features and functionalities. Table II below expands on how each heuristic and principle was applied to the prototype design [16].

low-fidelity and high-fidelity prototypes in Figma. The high-fidelity prototype was created immediately with the mentioned constraints. The first page on the system's user interface is the home page (see Fig. 5-left), which includes a list of nearby transit lines, their termini, and the corresponding wait time for each line. The page also comprises a search bar that lets the users navigate to the search page, where they can search for transit stops and nearby locations. The main component of the home page is the map, which shows the user's place in the center of the screen; it can be rescaled and panned to different areas using common gestures on the smartphone, i.e., pinching and dragging.

The second page that will be used extensively by the users is the search page (see Fig. 5-right). The search page consists of a search bar that accepts transit stop names and location names input from the user. After the user starts typing the location name, the system automatically suggests transit stops and locations with the same starting letters, where users can select to view details. The page that follows the search functionality is the stop details page (see Fig. 6 - left), where the user can see relevant information about the transit stop, including the stop name and the distance from the user's current location. The information card also includes information about transit connectivity, consisting of transit lines through the stop, next departure, and timetables. Users can navigate directly from their current location to the transit stop by tapping on the "*Go*" button. The page also shows an enlarged map of the transit stop on the top half of the page, where users can see a detailed view of the stop.

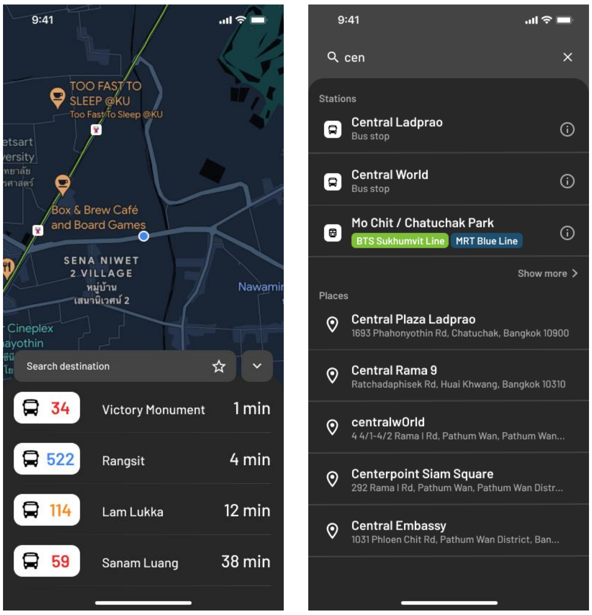

Fig. 5. Home Page (left) and Search Page (right)

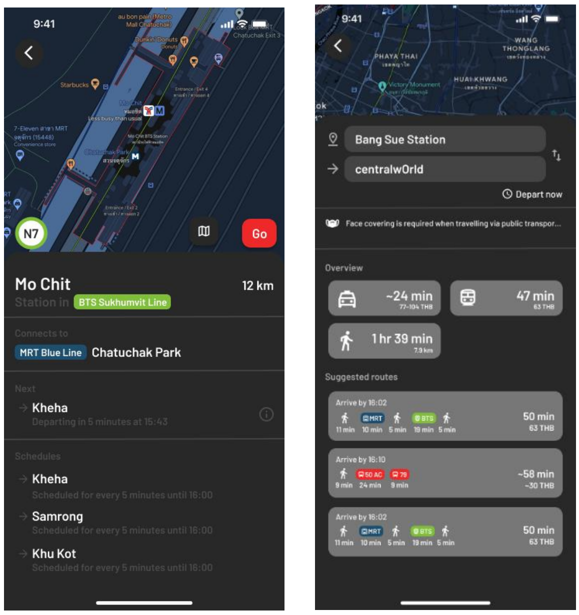

Fig. 6. Stop Details Page (left) and Route Selection Page (right)

Based on the system requirements and functionalities translated from solution ideas, a set of user interface prototypes was designed with regard to the UX/UI principles using Figma, including home, search, stop details, route selection, route details, and directions preview pages. However, the low-fidelity prototype was skipped due to the time limitation and the marginal effort gap between creating

Another essential page of the system where the large number of components could become challenging for the UI design is the route selection page. Users are shown the origin and destination on this page, with options to swap the choices and change the departure time. Users are prompted with a list of overviews of each route suggestion with the information for a time duration, arrival time, fare, and the order of transit modes from origin to destination. In addition, the system also shows a public health announcement to remind users when a face covering (e.g., surgical mask) is required (see Figure 6 – right). Lastly, the penultimate page of the system is the route Details page, which is followed by the actual navigation system. The route details page expands the information from the one shown on the route selection page (see Figure 7).

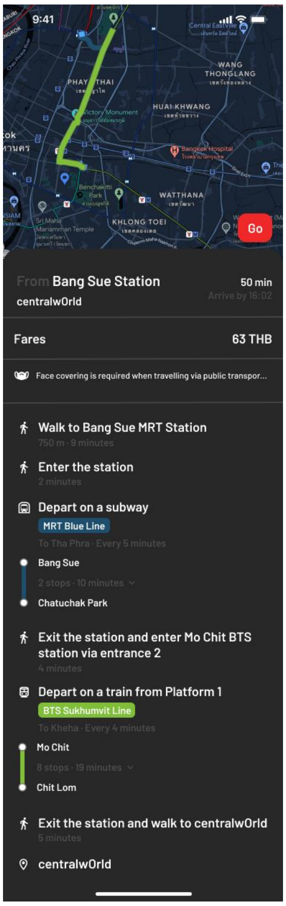

Fig. 7. Route Details Page

On top of the information already established, the page also shows, in detail, the step-by-step direction to accomplish the trip via the selected route, including but not limited to distance (walking only), time duration, transit frequency, and the transit line. The actual navigation page is not shown in this section as it had not been designed in of initial prototyping phase but was done after the early user evaluation. A functional prototype of the system was constructed on the tools and frameworks, including React Native (Expo) for the front-end, Node.js for the back end, Figma for prototyping, MySQL for database management, Git Version Control, GitHub for the remote repository, Amazon Web Service for Cloud server provider, and Google Maps API for navigation API respectively.

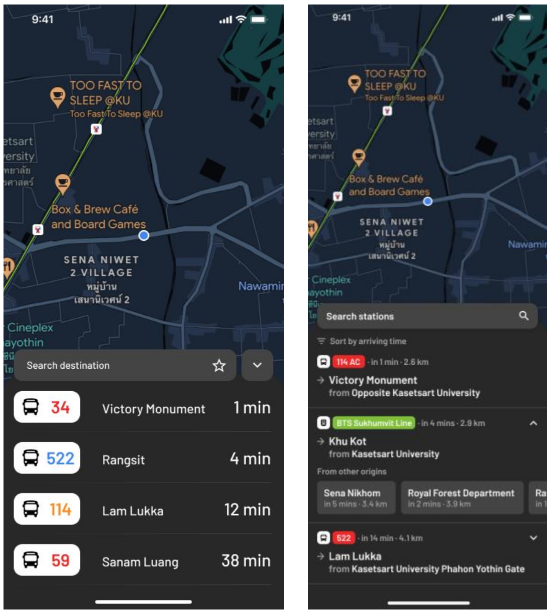

Fig. 8. Improvement of the home page UI prototype (from left to right)

TABLE III
Early User Evaluation Protocol

Item	Duration
Introduction, informed consent, briefing	1 minute
Inspection: Home	30 seconds
Interview: Home	3 minutes
Inspection: Route Details	30 seconds
Interview: Route Details	3 minutes
Inspection: Route Selection	30 seconds
Interview: Route Selection	3 minutes
Interview: Overall design	3 minutes
Debriefing	30 seconds

E. Test

The design of the prototype underwent an early user evaluation. To compensate for the time limitation, the evaluation process was brief and contained only essential steps that would be valuable to the continuation of design improvement. The process involved 3 participants who assessed the design of three pages of the system: home, route details, and route selection. The procedures of the early user evaluation (see Table III) were estimated to last 15 minutes per participant. The evaluation process began with a short introduction to the project, consent information, and a briefing for the upcoming tasks. The participants were then prompted with the home page, and 30 seconds were allowed to inspect the design, followed by a 3-minute interview about the participants' attitudes toward the design. The inspect-interview loop was repeated for the route details and route selection pages before a 3-minute summative interview took place, where the participants gave suggestions about the overall design patterns. Finally, the evaluation ended after a 30-second debriefing.

The results from the 3 participants were primarily consistent with each other, mainly suggesting a review in choice of color, text size, and order of text placement. Improvements aside, the participants had positive attitudes toward the shapes, font, and map placement. Feedback from the early user evaluation was then applied to the prototype of the three pages used, and the improvements were extrapolated to the other pages where applicable. The home page received suggestions from users in a few areas. Firstly, the placement of the terminus name of each transit line caused some ambiguity to the users as they struggled to realize the purpose of the displayed characters. Secondly, the card on the bottom half of the screen was said to be too loose in information density; there was too much free space around the texts and symbols where more useful information could have fitted. To resolve the design flaws mentioned, the bottom card was redesigned entirely (see Fig. 8) to include more helpful information for each transit line. The texts were labeled appropriately to minimize ambiguity. While the route selection page had better reception during the early user evaluation, some elements could be improved according to the feedback.

Firstly, the public health announcement text could be better had the reader been entirely displayed at once without the marquee effect. Secondly, the text sizes for the time duration and fare of each transit mode under the Overview tab were disproportionate to the importance of the information they represent. However, users would prioritize the time information over foods, and the importance of the fares to them would not be as diminished from the Time as represented by the minuscule text size. Thirdly, the contrast between the text and the background blocks was inadequate across the bottom card's Overview and Suggested routes sections. The design improvements (see Fig. 8) were to display the public health information text in 2 lines instead of using marquee effect on only a few overflowing letters, to adjust the text sizes under the Overview section by enlarging the Fares information and slightly lessening the size of the time duration text. Furthermore, the background color of the blocks was darkened to increase its contrast against the text on top, which improves readability for the users. The third page evaluated by the users is the route details page, where minor design flaws were discovered. Firstly, a participant suggested that the Go button above the bottom card have a color that resembles an exit button. Secondly, the text showing time duration was too small, considering it is one of the most desirable pieces of information in the section. Thirdly, the placements of the origin and destination names should be swapped since users tend to look for the destination over the origin and read top-to-bottom, where the design contradicts. Lastly, the secondary text color was too dim on the dark background, which reduced readability.

To improve the design, some minor design changes were made (see Fig. 9). The Go button was recolored to bright blue, which still follows the von Restroff effect but without the resemblance of an exit button. An upward arrow symbol was also added to emphasize the button. The order of placement for the origin and destination was switched, and an arrow was added pointing toward the goal to symbolize the trip heading to such a location. The text size for time duration was increased, and the secondary text color was brightened against the dark background. Finally, vertical ellipses were added to

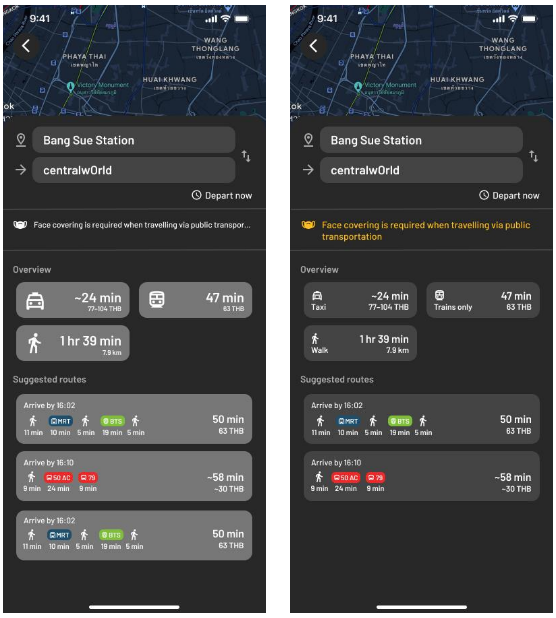

Fig. 9. Improvement of the route selection UI prototype (from left to right)

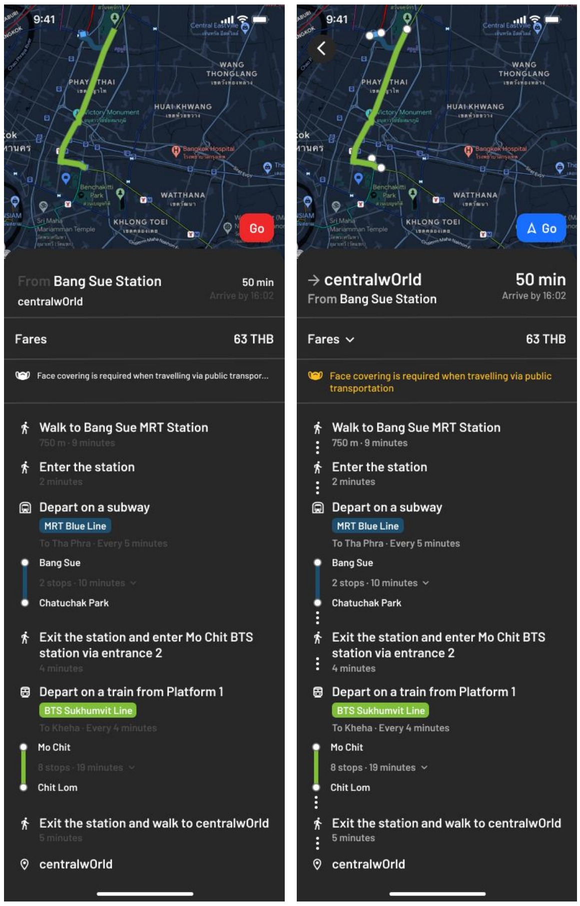

Fig. 10. Improvement of the route details page UI prototype (from left to right)

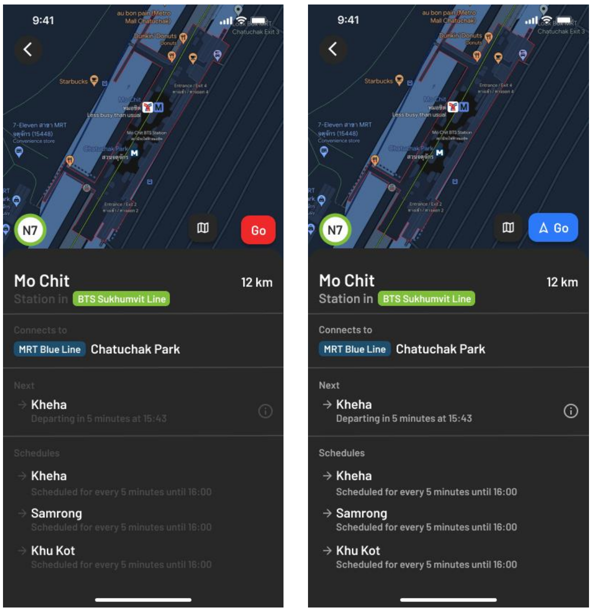

Fig. 11. Feedback extrapolation to the stop details page

the gaps between different transit modes to enhance usability following the Law of Uniform Connectedness. Marquee text was also removed from this page. In addition to improving the designs of the evaluated pages, some suggestions were considered for other prototype pages. For instance, the stop details page (see Fig. 11) had the same secondary text color and the same style of the Go button as the route details page (see Fig. 10)—with the feedback from the route details page, these two flaws were similarly fixed in the stop details page. Feedback extrapolation was applied across all functional prototype designs to maximize usability and reinforce similar designs across the system. Design prototypes, at this stage, were still subject to further improvements after usability testing. The procedural details and results will be discussed in IV, where users will evaluate the system's usability.

IV. Usability Testing

In a product development process, a usability evaluation is crucial in making the process and the product user-centric [17]. Alongside the design thinking principles, which is a user-centric development framework in itself, usability testing is one of the essential components of the study. The evaluation was carried out to assess the system's usability from the user's perspective, indicating how well the product could fulfill the users' needs [18]. This study conducted usability testing as each participant attempted to complete given tasks on the mobile application in a controlled setting. Participants were encouraged to think aloud during the process while being observed by a researcher, and a short interview was done after each task. A follow-up usability questionnaire then followed the studies. The table below (see Table IV) shows the usability testing protocol. The questionnaire used in the usability testing is the system usability scale (SUS), a nonproprietary measurement tool for the usability of a system that is considered simple, reliable, and versatile across different product categories [19]. The SUS is a 10-item questionnaire (see Table V) on a 5-point Likert scale on which the participants indicate their degrees of agreement or disagreement. The SUS can evaluate the system's overall usability from the user's perspective [20].

After each task completion, the participants were interviewed with two questions that let them point out particular features or components of the system that they had opinions about (see Table VI). The first interview question allowed the participants to indicate the features or details that they prefer and would appeal to them to use the system again in the future. This question aimed to identify the parts with the lowest priorities for fixing or redesigning, so the developers were informed not to make any drastic changes to these components yet. On the other hand, the second interview question asked the participants to indicate the features or details obstructing the flow of the system usage. This question aims to pinpoint the vital design issues of the system, which should be assigned the highest priorities for refinement or redesigning.

TABLE IV
Usability Testing Protocol

Item	Duration
Introduction, informed consent, briefing	1 minute
Task 1: Stop Details Usability	2 minutes
Task 1 Post-task Interview	1 minute
Task 2: Line Search Usability	2 minutes
Task 2 Post-task Interview	1 minute
Task 3: Navigation Usability	2 minutes
Task 3 Post-task Interview	1 minute
SUS and Debriefing	2 minutes

TABLE V
System Usability Scale Questions [20]

SUS1	I would like to use this system frequently.
SUS2	I found the system unnecessarily complex.
SUS3	I thought the system was easy to use.
SUS4	I think that I would need the support of a technical person to be able to use this system.
SUS5	I found the various functions in this system were well integrated.
SUS6	I thought there was too much inconsistency in this system.
SUS7	I imagine most people would learn to use this system very quickly.
SUS8	I found the system very cumbersome to use.
SUS9	I felt very confident using the system.
SUS10	I needed to learn many things before getting into this system.

TABLE VI
Post-task Usability Interview Questions

Interview Questions
Which parts of the system appeal to you to continue using it in the future?
Which parts of the system are stagnating the flow of usage to you?

In each task's procedure, the observing researcher took notes of the participants' thoughts and actions. The data of each participant's actions comprise the Time they spent on each task and the number of mistakes made along the way. A mistake is loosely defined as actions done by the participant that is unnecessary or would lead to other parts of the system that do not belong to the correct path toward the finishing line defined in Table VII.

TABLE VII
TASK DESCRIPTION

Task	Task Description	Finishing Line
1: Stop Details	Find the schedule frequency at N5 Ari	The user reaches the Schedules section under the stop details page of N5 Ari.
2: Line Search	Find the nearest Airport Rail Link station	The user reaches the stop details page of A8 Phaya Thai by searching under the Lines tab.
3: Navigation	Start navigation for a trip from Chamchuri 9 Building to RN08 Don Muang	The user reaches the turn-by-turn navigation page for a journey from the Current Location (Chamchuri 9 Building) to RN08 Don Muang

When starting a new task, the participant must always begin from the *Home* page. The process of navigating back to the *Home* page was not considered for the usability scoring, but suggestions for improvements were accepted (if any). The participants consisted of 10 people from the Chulalongkorn University Chorus Club since there are members of various participants were informed about the terms and conditions, and their consent was acquired before the testing. The personal information of each participant that could later identify the individuals is not recorded, and any other information is not kept for longer than specified in the terms to protect the privacy of all participants.

V. ANALYSIS AND RESULTS

Recruited participants were asked about their gender, level of education, age, and monthly income. The distribution of gender is 50% females to 50% males, and the period varies from 19 to 23 years old. The average monthly payment of the participants ranges from 0 to 50,000 baht. The results from the SUS were reported and translated into a meaningful score according to the procedures defined for the SUS [20]. For all ten questions in the questionnaire, the contribution score for each question ranges from 0 to 4, and there are different procedures for the event and the odd-numbered questions. Questions 1, 3, 5, 7, and 9 are scored by subtracting the user's response by 1, and questions 2, 4, 6, 8, and 10 are achieved by removing five from the user's response. Then, the sum of every question's contribution scores was multiplied by 2.5 to convert the score on a 0 – 40 scale to a score on a 0 – 100 scale. The entire procedure was repeated for every participant, and the average SUS score was calculated across all participants. After analyzing the responses from the SUS, the SUS score came out to be 77.5 out of 100 points. According to [21], a score of 77.5 lands on approximately the 82nd percentile on the SUS score distribution curve, where the average score is 68.

After each participant completes a task, the number of mistakes and the Time spent on the task were recorded. Those values were then converted into a usability score as a sum of contribution scores from both aspects. For the Time spent, the researcher had determined that each task given should ideally not take over 20 seconds; hence, a score of 5 was awarded for attempts that did not exceed 20 seconds. A deduction of 1 point from the time score was deducted for every 20 seconds spent over the first 20 seconds until the score reached 0. A 1-point penalty to the overall score was imposed if the attempt had taken 2 minutes or longer, where the attempt for the task is considered failed.

Meanwhile, the mistakes score has a maximum of 5 points, awarded to attempts with no mistakes made along the way. A 0.5-point penalty was imposed on the mistakes score for every error made. After three mistakes, the penalty increases to 1 point for every mistake made after the 3rd. From the observation of each participant's performance on completing the three tasks, it is consistent throughout all participants that the user interface was simple and intuitive to navigate through, partly because some participants were already familiar with the design of conventional mobile navigation applications such as Google Maps and Apple Maps.

However, the observer had noticed the system's flow was often obstructed by the need to double-tap on specific target components before correctly registering the gesture and the slightly small hitboxes for some buttons. Similarly, the post-task interview revealed that the participants were pleased with the overall placement of controls and components on the screen and the aesthetic aspects of the user interface design. The suggestions that the participants provided include increasing the sizes of some components' hitboxes, allowing the system to register gestures after only a single tap on the screen, and adding a brief introductory tour for the application's first start-up to showcase all unique features that might have been missed by new users. Lastly, the score for each task's completion, averaged across all participants, was translated from the observed Time spent and mistakes made. Using the scoring scheme defined in Tables IX and X, a total usability score of a task is the sum of scores from the two criteria, which combines to have a total score of 10. As a result, the total usability score of the three tasks averaged across all participants is 26.5 out of 30, which equals 88.3%. The averages of the recorded values and the converted scores are shown in Table XI.

TABLE VIII
SUS RESULTS

Item	Contribution Score (0–4)
SUS1	3.2
SUS2	3.1
SUS3	3.1
SUS4	3.0
SUS5	3.1
SUS6	3.2
SUS7	3.0
SUS8	3.1
SUS9	3.0
SUS10	3.1
Sum	**31.0**

TABLE IX
SCORING BY TIME CRITERION

Time Spent (minutes)	Score
2:00 or more, or task failure	-1
More than 1:40 but less than 2:00	0
More than 1:20 but less than 1:40	1
More than 1:00 but less than 1:20	2
More than 0:40 but less than 1:00	3
More than 0:20 but less than 0:40	4
0:20 or less	5
Full Score	**5**

TABLE X
SCORING BY MISTAKE CRITERION

Mistakes Made	Score
0	5.0
1	4.5
2	4.0
3	3.5
4	3.0
5	2.0
6	1.0
Seven or more	0.0
Full Score	**5.0**

TABLE XI
USABILITY TEST RESULTS AND SCORES

Task	Average Mistakes Count	Average Time Spent (seconds)	Average Usability Score
1: Stop Details	0.3	22.6	9.2
2: Line Search	0.9	33.6	8.5
3: Navigation	0.0	30.9	8.9
Total Usability Score			**26.5**

VI. DISCUSSION AND CONCLUSION

According to the results from the usability testing and users' feedback, the current system's design is excellently usable, partly due to thoroughly applying design principles and heuristics onto relevant components. Moreover, since the design of the mobile application had been evaluated once in the early user evaluation, most design flaws were eliminated from the early prototype. The SUS score at the 82nd percentile indicates that the system is well above average in terms of usability [21], and the usability score of 88.3% also agrees with the SUS score placement. From the usability score results in Table XI, the average Time spent on every task still exceeds the predetermined 20-second window. However, the Time spent for each use case will likely drastically reduce for non-first-time usage. In addition to fixing the double-tap issue, allowing users to personalize the application's layout could potentially drive the usability score higher [21].

Currently, the system can effectively solve the problems in the Bangkok public transit system by offering users information on the transit systems and real-time navigation across Bangkok via public transit. Having successfully designed and developed a functional system that solves the persisting issues of Bangkok public transit, the key takeaway from the study is the final design of the application pages themselves, which have been through multiple feedback loops via user evaluation sessions. Furthermore, the study also compiles the issues of Bangkok's public transit that are obstructive for public transit users. This study can only solve the problems that do not involve the government and official authorities. Some limitations to the system include the slight inaccuracy in the arrival and departure times, which is often caused by unexpected and unannounced delays from the transit operators. Nonetheless, the mobile application can outperform other existing systems, such as Google Maps, in terms of Time and price accuracy, which are the major concerns for users.

In conclusion, to design and develop a Bangkok public transit navigation system as a mobile application, the authors aimed to provide users with relevant and detailed information about traveling via various modes of public transit to reduce Time spent, redundancy, confusion, and burden. In contrast, the users plan for their itineraries. By applying the design thinking principles to the system's design and development processes, the authors have created a functional system with a design evaluated by users to be highly usable and visually appealing. In future studies, as the infrastructures of public transit in Bangkok improves and users' demand shifts, the system will require constant revision and refinement to stay up to date with the current issues faced by the public by iteratively traversing the feedback loops envisioned by the design thinking principles. The limitations of the study include the sample size of the usability testing and offline mode is currently unavailable. In this study, we sincerely thank Prof. Chotirat Ann Ratanamahatana (Faculty of Engineering, Chulalongkorn University) and International School of Engineering for funding this project. Also, we thank all participants for their generosity and support in this project.

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