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Digital Twin Concept for Multi-Modal Door-to-Door Travel Monitoring

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Abstract. To address the major issue of traveller frustration caused by delays or disruptions in their journey, this paper introduces a digital tool designed to assist travellers throughout their entire door-to-door travel experience. This tool monitors progress and warns travellers if a missed connection is anticipated so an alternative route can be chosen. Traveller satisfaction can be enhanced by tools that can provide personalized, up-to-date, and on-demand travel information. Consequently, there is a growing demand for an advanced digital travel model that can optimise travellers' travel according to their own preference and monitors progress along the way. In this study, a multi-modal, door-to-door travel companion is introduced that can be accessed through personal devices like smartphones or tablets. By providing delay warnings and alternative options in advance, the door-to-door travel companion helps travellers achieve seamless door-to-door travel. The functionality of the model was evaluated through real-world case studies conducted as part of this study.

Keywords. Digital twin, modelling, simulation, information technology, validation test, travel disruption, door-to-door travel

Introduction

The current travel process is fragmented with separate, usually unconnected, phases [1]. The different sectors face challenges in cooperating with each other due to the difficulty in exchanging information and data during travel, negatively impacting travel efficiency. To address this issue, the concept of a multi-modal door-to-door travel companion is proposed. The multi-modal door-to-door travel companion generates a travel itinerary based on traveller's preference and monitors travel progress. The companion gives a warning of a missed connection is anticipated, so the traveller can select an alternative route. The development of door-to-door travel is supported by digital technology, including personal devices, software development, information databases and internet connectivity [2]. The transdisciplinary project is focuses on human-centric design, by combining digital technologies, human behaviour and advanced modelling and simulation techniques to obtain a useful tool.

This paper introduces the development and testing of the multi-modal door-to-door travel companion. It begins by presenting a conceptual model for the door-to-door travel companion, followed by the introduction of the digital twin model and simulation. Finally, the multi-modal door-to-door travel companion was used in three real case studies conducted to evaluate the research outcome.

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1. Methodology

1.1. Conceptual Modelling

The model of the door-to-door travel companion covers the entire door-to-door travel process, and different segments are tightly connected, as shown in Figure 1.

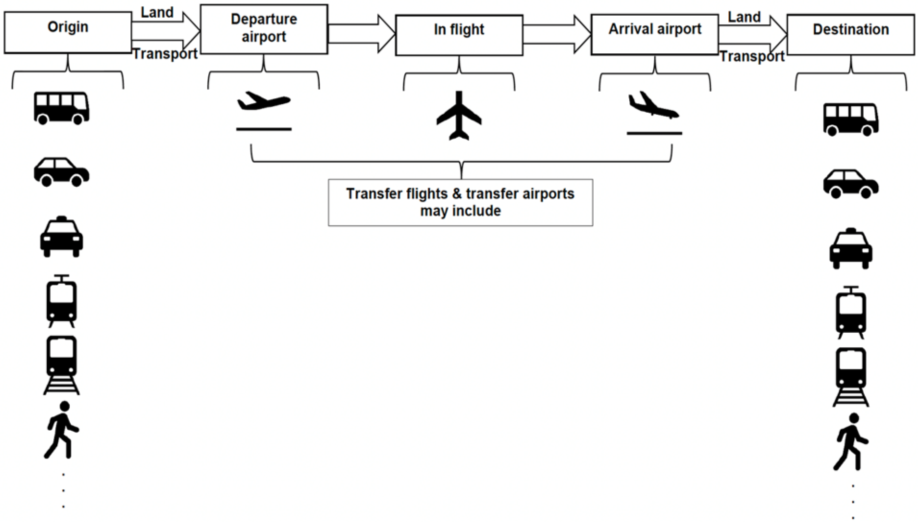


Figure 1. Travel stages of multi-modal door-to-door travel.

Conceptual modelling was used to support the development of the door-to-door travel companion, as it uses logic and modular representation the complete system [3]. The conceptual model developed for the door-to-door travel companion is shown in Figure 2. It represents the logic and flow of the door-to-door travel companion model while showing the processes and key elements of the travel chain.

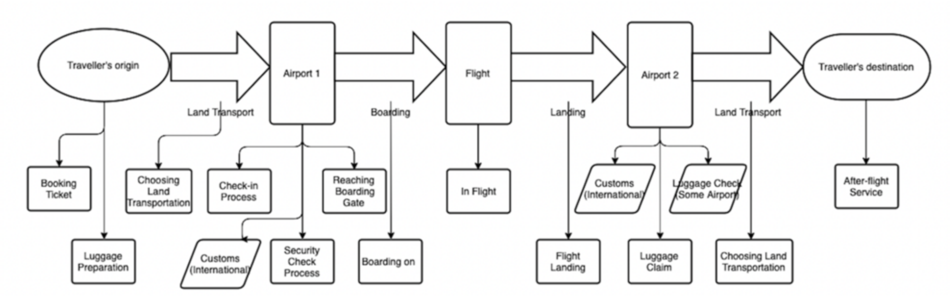


Figure 2. Conceptual model of the door-to-door travel companion.

During travel, it is common for a travel chain to involve multiple transfers and connections between different modes of transportation. To address this complexity, the door-to-door travel companion model allows flexibility of adding or removing transport modules as needed, ensuring that the model flow aligns with the real travel situation.

1.2. Digital twin

The digital twin concept was the main approach used to develop the door-to-door travel companion. Digital twin is to use virtual measures to improve the performance of physical entities [4]. Since the digital twin is a dynamic model, it can use real-time information to improve the twinning accuracy, and it can effectively manage complex production processes and develop digital twin-based smart products [5]. Based on the conceptual model, a digital twin model was developed in this study, presenting how the door-to-door travel companion operates during actual travel.

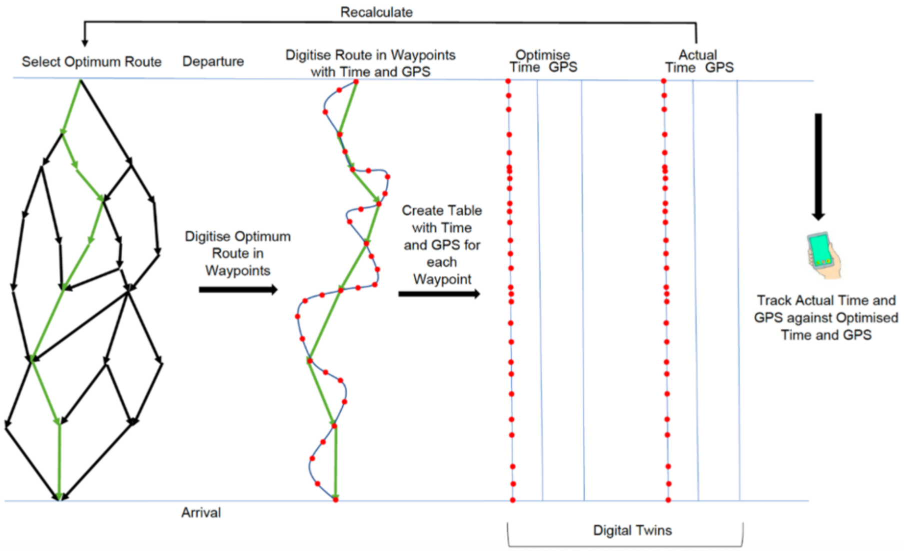


Figure 3. Digital twin model of the door-to-door travel companion.

Figure 3 depicts the workflow of the door-to-door travel companion, showing the digital twin concept. The process starts with determining the optimum route based on selected preferences, for example minimum travel time or minimum travel cost. The optimum route is subsequently discretised into waypoints, consisting of GPS coordinates and time stamp. This table of waypoints is transferred to the traveller's personal device. During the travel, the door-to-door travel companion compares location and time with the waypoint table. If a discrepancy occurs, the app sends a warning. If a missed connection is anticipated, the traveller can choose an alternative route and, hopefully, still make the connection.

1.3. Simulation

Digital twin is an extension of simulation, which can cover the whole product lifecycle [6]. In this study, the digital twin concept was used in conjunction with simulation to test, predict, pre-perform, examine, and optimise the technologies and processes in engineering, training, entertainment, or other areas [7]. The *Arena* simulation software was selected for route planning, which generates and digitises all alternative itineraries in the travel flow. The utilisation of *Arena*, which supports multiple transport modules, enabled the developed model to possess enhanced flexibility and better representation of the real-world environment [8]. As a case study, a journey from Melbourne to Hobart was chosen to illustrate how the door-to-door travel companion generates optimised options within the route planning simulation software during actual travel.

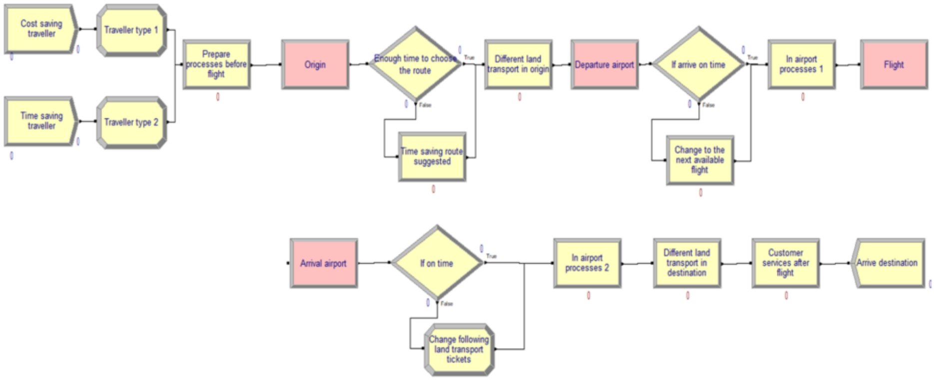


Figure 4. *Arena* frame and flow for the sample route.

Figure 4 shows the travel flow in *Arena* for a sample route, showing the ability to generate and digitise optimised travel routes for the entire journey. To ensure the accuracy and reliability of the simulation, data and information were collected from various sources, including the official websites of relevant airlines and airports, official websites of local land transport companies, navigation tools.

1.4. Information technology

The door-to-door travel companion monitors progress and assists travellers to avoid potential missed connections throughout their door-to-door travel. This unique feature distinguishes the door-to-door travel companion from other travel tools. During actual travel, travellers need to access the on-demand information provided by the door-to-door travel companion. Since the number of travellers prefer to use mobile devices Apps [9], an *iOS* App was developed as the front-end off the door-to-door travel companion, monitoring the entire travel process and enabling travellers to receive on-time route information.

The *iOS* App has the capability to monitor travel progress and access on-demand information through a personal device connected to the internet or mobile data network. By comparing a traveller's real-time travel status with the digitised route generated by the route planning simulation software, the door-to-door travel companion can predict potential missed connections and warn the traveller who can seek alternative options.

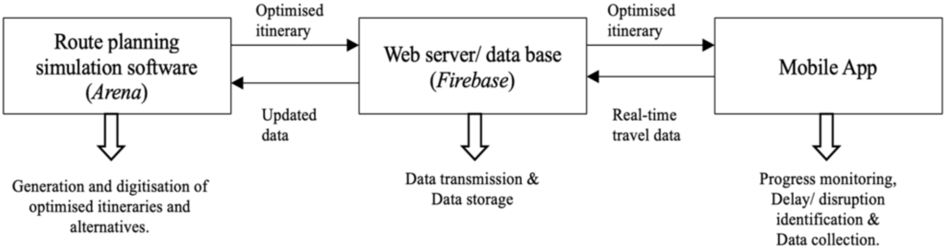


Figure 5. Door-to-door travel companion's workflow in actual travel.

To facilitate the smooth operation of the door-to-door travel companion, data connection between different sectors is crucial. For this purpose, *Firebase* was selected as the web server and online database to store traveller and travel-related information and transmit route data between the model processor and the end-users (Figure 5).

2. Findings

2.1. Case Study: Melbourne to Hobart

A sample route including both land and air transport was simulated in *Arena* to illustrate how the door-to-door travel companion generates and optimises travel options in the route planning simulation software. It also presents how the model uses real-time data to generate alternatives at any waypoints to assist travellers chose an alternative route to avoid a potential missed connection. Figure 6 presents all the options generated by *Arena* for both minimum-time and minimum-cost routes.

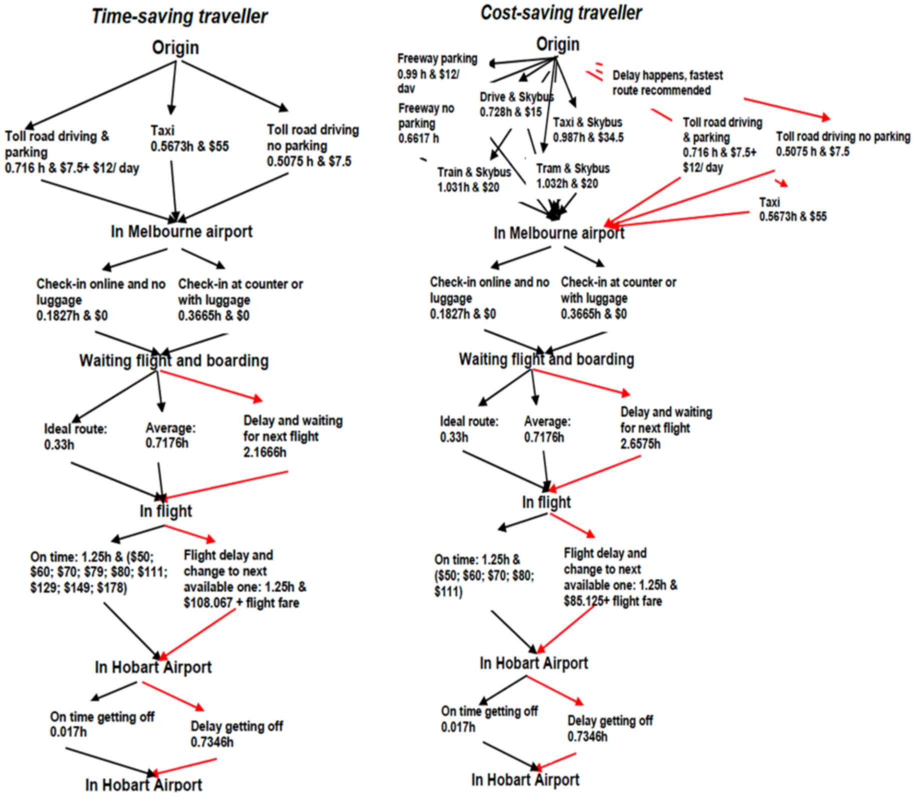


Figure 6. Optimal itineraries for Melbourne to Hobart route.

The door-to-door travel companion generates optimised itineraries based on user-specified criteria, providing personalised travel plans. In this study, minimum time and minimum cost were selected as examples of two frequently used criteria [10-15]. In the actual implementation of the model, more criteria can be incorporated by adding relevant decision-making modules to the model. By comparing and filtering the simulation results, *Arena* can determine the optimal itinerary based on the selected criteria.

As shown in Figure 6, the branches represent all possible routes for this journey, while the red branches indicate alternative routes in case of delay or disruption. In the simulation, personalised alternatives were provided by the model for different types of travellers, assisting them in avoiding potential disruptions. Since time-saving travellers were suggested to change their flights if a delay was identified at the first or second travel stage. The fastest option for time-saving travellers was to take a taxi or drive via the toll road to Melbourne airport, followed by the next available flight, and then choose driving or taxi options based on different situations. It took about 4.6 hours and cost about US$111 to US$197 depending on airfares.

For cost-saving travellers, once delays/ disruptions were identified at the first or second travel stage, they were suggested to take faster land transport mode or change their flights depending on the actual traffic conditions. If travellers were able to catch the flight by changing to faster land transport mode, the cheapest alternative option for cost-saving travellers in this scenario would cost about US$84 to US$125 depending on airfares and travel time was about 4 hours. However, in some situations, even if travellers opted to switch to faster land transport options, there was still a possibility of missing their scheduled flights at Melbourne Airport. As a result, they would need to take the next available low-cost flight to continue their journey. The cheapest option in this situation took about 5 hours and cost about US$96 to US$137 depending on airfares. Depending on alternative travel options, avoiding a missed connection is not always possible. However, these optimised alternatives will help travellers mitigate the negative impacts caused by the travel disruption.

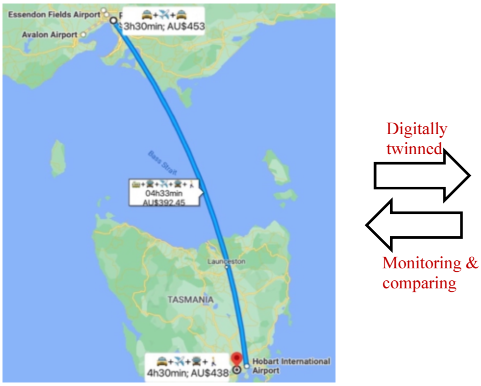
The simulation results demonstrate the capability of the door-to-door travel companion to provide a comprehensive range of itineraries for different types of travellers during their journey. Furthermore, the model generates optimised options and alternatives by considering various selection criteria, travellers' real-time data, and up-to-date travel information.

2.2. Model validation

To evaluate the functionality and capabilities of the door-to-door travel companion, multiple case studies were conducted, involving actual travel using the developed App in real-world scenarios, with three case studies presented in this paper. Case study 1 was the journey from Melbourne to Hobart presented in Figure 6. Case study 2 was conducted on a land transport travel route within Melbourne to assess whether the model can be applied to different travel chains with or without air transport. Case study 3 consisted of two flight travel routes: one long-haul flight from Melbourne to Singapore and one short flight from Rovaniemi to Helsinki. Data and information used in this section were collected from the sample routes.

2.2.1. Case study 1 – Melbourne to Hobart with flight transfer

To assess the capabilities of the door-to-door travel companion, an additional stage involving transfer flights was added and tested in case study 1. The results of case study 1 demonstrated that the door-to-door travel companion efficiently assists travellers to avoid disruptions in advance on both direct flight and transfer flight travel routes, ensuring seamless door-to-door travel experiences in various travel situations. The optimised itinerary, generated and digitised in *Arena*, is presented in Figure 7.



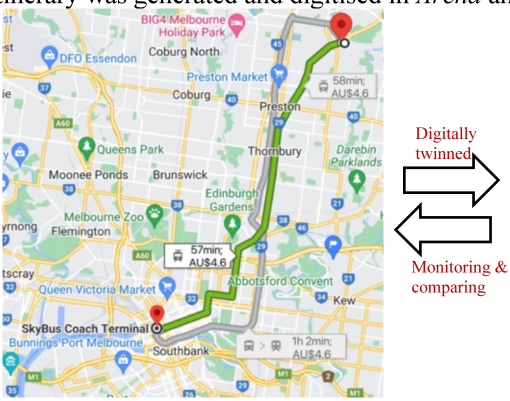
Digitised itinerary		
Waypoint	**GPS coordinates**	**Time**
1	-37.821; 145.026	10:37
. . .		
10	-37.674; 144.854	11:42
. . .		
30	-42.880; 147.332	15:09

Figure 7. Original optimised travel itinerary and its digital twin pairs – Case study 1.

After conducting the experiment, the traveller who participated in case study 1 confirmed that the functions of the door-to-door travel companion operated at every travel stage of the journey, which contributed to the successful model operation. Besides, the connectivity and seamless flow of the model of the door-to-door travel companion have been assessed. During the test, the door-to-door travel companion demonstrated its capability to provide information and alternative options about other transport modes/ means or travel stages. This is achieved through the generation of optimised itineraries that considered the overall journey and the holistic travel segments. As a result, travellers can flexibly make changes to their entire journey at any stage and independently manage their trips, which is one of the advantages of the door-to-door travel companion. By conducting case study 1, the main capabilities and key functions of the door-to-door travel companion have been assessed.

2.2.2. Case study 2 – Melbourne, Australia: with missed connection

Case study 2 was conducted to assess whether the door-to-door travel companion could assist travellers in catching the connected travel stages in the delay scenario. The results of the experiment prove the functionality of the door-to-door travel companion and demonstrate that it can be applied to other types of travel chains, thereby addressing the limitations of the project's application scope. During the case study, an optimised itinerary was generated and digitised in *Arena* and used in the experiment (Figure 8).



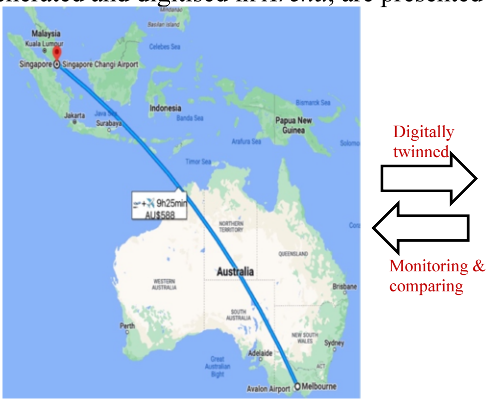
Digitised itinerary		
Waypoint	**GPS coordinates**	**Time**
1	-37.724; 145.027	19:10
. . .		
16	-37.793; 144.985	19:42
. . .		
23	-37.816; 144.952	20:07

Figure 8. Original optimised travel itinerary and its digital twin pairs – Case study 2.

During case study 2, travel delays occurred starting from Waypoint 2 and continued in the following waypoints. In this situation, the traveller's real-time data was collected through the App and used to generate alternatives. The alternative provided by the door-to-door travel companion was chosen at Waypoint 10 to avoid further disruptions. As a result, the traveller participated in case study 2 confirmed that the connected travel stage was reached on time in the delay/ disruption scenario by using the model. The successful results of case study 2 prove that the door-to-door travel companion is a unique digital travel model which enables travellers to avoid potential travel disruptions and achieve seamless door-to-door travel in the delay situation in different types of travel chains. Thus, this experiment further reinforces the results of simulations and case study 1.

2.2.3. Case study 3 - Melbourne to Singapore & Rovaniemi to Helsinki

In case study 3, the door-to-door travel companion's capability to assist travellers to seamlessly catch transfer flights and connected travel stages in the delay scenario was assessed. Connected flights were added to the end of both routes as the next travel stages, testing whether the door-to-door travel companion could provide the traveller with assistance regarding the arrival airports and connected flights while the traveller was in flights. In this case study, the experiments were conducted on the travel stages before taking the connected flights. The optimised itineraries for the two routes, which were generated and digitised in *Arena*, are presented in Figures 9 and 10.



Digitised itinerary		
Waypoint	**GPS coordinates**	**Time**
1	-37.670; 144.849	16:10
. . .		
13	-21.734; 126.833	19:20
. . .		
22	1.357; 103.907	22:35 (+3)

Figure 9. Original optimised travel itinerary and its digital twin pairs – Route 1 in Case study 3.

Digitised itinerary		
Waypoint	**GPS coordinates**	**Time**
1	66.563; 25.829	18:00
. . .		
8	63.358; 25.032	18:58
. . .		
13	60.318; 24.967	19:30

Figure 10. Original optimised travel itinerary and its digital twin pairs – Route 2 in Case study 3.

During the test, the traveller received various types of notifications and alternatives from the door-to-door travel companion, which included the information on both the current and connected travel stages. As a result, the traveller was able to catch the connected travel stages in both routes with the door-to-door travel companion's assistance. In addition, when the traveller changed to a new alternative, the relevant route information for both the current and connected travel stages was updated in the App, providing the traveller with timely and up-to-date support.

After conducting the experiment, the traveller in case study 7 found that the door-to-door travel companion was able to provide useful information during flights. The traveller somewhat agreed that the door-to-door travel companion performed as expected on flights because some functions required a Wi-Fi connection to process real-time information. If in-flight Wi-Fi is unavailable, travellers cannot use all functions of the door-to-door travel companion. However, other functions of the door-to-door travel companion, such as the disruption identification and delay warnings, are not affected by Wi-Fi connections and operate normally in all situations. The traveller also mentioned that the door-to-door travel companion was particularly useful at the in-airport stage of travel, which proves that the door-to-door travel companion provides useful functions and efficient itineraries at every travel stage during door-to-door travel. That is also a factor distinguishing the door-to-door travel companion from other travel models and digital travel tools.

The results of the case studies demonstrate that travellers can continue their journey without interruptions, even in the event of delays or disruptions, with the assistance of the door-to-door travel companion. During the test, timely warnings and alternatives were provided via the App for avoiding disruptions in advance, and these travel options were generated based on different conditions. Travellers' feedback on the door-to-door travel companion indicates positive evaluations of traveller satisfaction and user experience. Overall, the case studies evaluated the key capabilities and functionality of the door-to-door travel companion.

3. Discussion and conclusion

The door-to-door travel companion is an efficient digital travel model that addresses the needs of modern travellers and overcomes the limitations of the current travel models. By monitoring travel progress and predicting the overall process, the door-to-door travel companion offers personalised and optimised travel options to ensure a seamless travel experience. This advanced travel model fills the gap between travellers' expectations and existing digital travel applications, providing comprehensive support throughout the entire journey. It successfully resolves issues related to the fragmented travel experience and incomprehensive digital support in the current travel process, revolutionising the way travellers travel. The simulation conducted for the sample route assessed the logic and workflow of the door-to-door travel companion. In the simulation, all possible options and relevant route information were generated and digitised successfully, proving the model's capability to provide optimised itineraries and alternatives throughout the journey. After developing the mobile App, the entire workflow of the door-to-door travel companion has been completed, and its intended capabilities have been achieved. The results of the case studies assess the functionality and design of the door-to-door travel companion, further proving the simulation results. During the experiments, the door-to-door travel companion provided timely warnings and optimised alternatives at each travel segment, ensuring a seamless continuation of the journey.

In the next step, more tests can be conducted by independent travellers to further evaluate traveller experience with the door-to-door travel companion. Moreover, for future implementation, establishing collaborations with transport service providers can enable the door-to-door travel companion to access comprehensive real-time data during actual travel, enhancing its effectiveness.

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