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DOOR-TO-DOOR TRAVEL PLANNER FOR IMPROVED TRAVELER EXPERIENCE USING DIGITAL TWIN CONCEPT

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Abstract

This paper introduces a digital multi-modal door-to-door travel planner for improved traveler experience. Particularly long-distance travel with several change overs along the way, are susceptible to delays and missed connections resulting in a poor travel experience for the traveler. In case of travel disruption, the traveler needs access to reliable, independent, on-demand information which covers the entire journey so an alternative route can be selected. In this research, a digital multi-modal door-to-door travel planner has been developed that allows a traveler to generate multiple travel itineraries for a given departure and arrival point combination and the option to select an itinerary based on cost or travel time. A personal device-based application then tracker travel progress against the selected itinerary and give warning notifications if connections are going to be missed so alternative routes can be selected. The dual component system acts as digital twin where actual travel is tracked against an optimum process. The process is demonstrated using an example journey showing the effect of different travel choices.

Keywords: digital twin, door-to-door travel, multi-modal transport, traveler experience

1. Introduction

The aviation industry is one of the most essential and fundamental industries in society. The industry not only provides travelers with a highly effective travel method but also enables the transport industry to get a new opportunity to achieve improvement. Before the Covid pandemic, the development trend in this industry was positive and the market demand was growing rapidly. From 2017 to 2018, the revenue of global commercial airlines had occupied 3.2% of world economic growth, which reached the highest point in the recent five years [1]. However, the Covid pandemic negatively impacts the operation of the aviation industry. In 2019, the revenue of global commercial airlines had occupied 2.5% of world economic growth, and it only contributed to about 1% of global GDP [2]. In 2020, the aviation industry's performance has been influenced by Covid-19 to a greater extent. As IATA introduced in the Economic Performance of the Airline Industry Report in 2020, the revenue of the airline industry had occupied -4.2% of world economic growth. Although this negative trend started to be mildly improved in the following year, the global Revenue Passenger Kilometers (RPKs) in February 2022 was less than one-third of it in the same period in 2019 [3]. Therefore, the aviation industry is still under enormous pressure and facing big challenges. Since 2022, travel restrictions and flight bans in many regions have been released, and the transport market starts recovering gradually. In this situation, some measures should be applied to mitigate the operational difficulties of the aviation industry. Also, actions should be taken to attract more potential travelers and help the industry bounce back as before.

Door-to-door travel model is an effective model that can benefit both travelers and the transport industry. As Schmalz et al. introduced, door-to-door travel offers seamless and contactless travel process to travelers [4]. This travel model can improve transport efficiency and enhance travel safety. Besides, since industry 4.0 being proposed, various advanced technologies have emerged. Digital technologies, like digital twin and biometric identifications, start being employed by the aviation industry to improve the operational process and enhance industrial performance. These digital technologies enable the aviation industry to offer comfortable and reliable services to their customers, and travelers' satisfaction with transport can be enhanced accordingly [5]. Therefore, it is meaningful to investigate how door-to-door travel can be combined with digital technology to benefit travelers and the industry. This combination should consider not only what digital facilities and systems can be used in the travel process, but also how digital technology can be used to improve the entire door-to-door model. Besides, most of the current travel models have been designed and developed from the industry's perspective, and it is hard for travelers to manage and control the entire journey by using these models. Once delays or disruptions occur, travelers can only get the notifications from airlines/ airports, and they have to follow airlines/ airports' instructions to change their following trips. This causes low efficiency in travelers' trips, and travelers' satisfaction will be negatively impacted since they cannot manage their trips proactively. In this paper, an effective digital multi-modal door-to-door travel planner has been developed and digitally twined from a traveler's perspective, enabling travelers to flexibly manage the potential disruptions and delays during the travel. Then simulation was used to examine the usefulness and performance of the developed door-to-door model.

This paper has three sections. Firstly, the current digital impact on the aviation industry and travelers will be introduced, and the door-to-door concept will be reviewed. Then, the conceptual model and digital twin model of the digital multi-modal door-to-door travel planner will be presented and discussed in detail. At last, a sample travel route, which is a long-haul journey that covers multi-mode transport, will be simulated to assess the developed model.

2. Literature review

2.1 Digital transformation and the aviation industry

Digital transformation is a popular and inevitable trend in the aviation industry in recent decades [6]. The number of digital facilities and digital applications has increased year by year, and digital technologies impact the industry's development to a great extent. The industry and relevant researchers start focusing on digital transformation, and more digital services are expected to be delivered by aviation companies [6]. Indeed, digital transformation brings new opportunities to the aviation industry for its development. Processes and activities in the conventional travel model have been digitized and transformed by using digital technologies [7]. Moreover, management systems in the aviation industry have also been upgraded by involving digital transformation. In this situation, the mode of industrial operation and maintenance has been changed, and the aviation industry has the opportunity to achieve sustainable development [7]. According to Helmold, there are three important elements in the modern aviation industry: digital transformation, smart systems, and artificial intelligence [7]. Digital transformation and advanced technology are essential in the aviation industry's development.

Digital transformation and digital technologies provide opportunities for the aviation industry to interact with its customers. Social media affects the ways that aviation companies promote themselves and collect customer feedback [8]. Various advertisements and promotions have been posted on social media to attract existing and potential customers' attention. Besides, airlines and airports also use social media to collect travelers' information to analyze travelers' attitudes towards their companies [9]. By using different service parameters, aviation companies can obtain information from digital platforms to identify types of travelers. Then, after analyzing travelers' information, personalized services and products can be introduced to travelers to improve their travel experience and travel satisfaction [9]. Thus, digital technology makes the communication between the aviation industry and travelers become more effective.

From the reviewed literature, the current status of digital transformation in the aviation industry can be identified. Currently, there are already various digital technologies and digital facilities applied in different sectors of aviation. The use of digital technologies can improve aviation's performance and also can bring a better travel experience to travelers. Therefore, digital transformation has positive impacts on the development and improvement of the aviation industry.

2.2 Digital transformation and travelers

With advances in technology, the use of personal devices and connectivity is increasing. Since the market demand can be influenced by aviation companies, the industry should consider travelers' needs and wants from a digital perspective [10]. Although the number of travelers is rising, aviation companies can provide high-quality services and products for all customers by adopting advanced technologies. Besides, travelers' travel preferences and patterns can be well understood by involving digital products in the travel process [10]. In addition, travelers' travel experience can be improved by taking the simplified journey, and their satisfaction can be increased accordingly. Therefore, digital transformation in the aviation industry brings advantages to travelers.

Travelers are the customers of the transport process, and travelers' attitude will directly affect aviation's performance. In this situation, it is significant to analyze how traveler satisfaction can be influenced. Travelers prefer a travel process which is comfortable, convenient, fast, and reliable [11]. In the recent decade, various digital facilities and products have been applied by aviation companies to improve travelers' travel experience. However, whether these digital technologies really have impacts on travelers should be investigated. Chen et al. conducted a study and found that digital technologies and digital services have positive impacts on traveler value [11].

Mobile technology is developed rapidly in the recent decade, and the number of people who use mobile applications (mobile apps) to support their daily life is increasing. Aviation companies, especially airlines, have used mobile apps to attract more travelers and provide better services for their customers [12]. The use of mobile apps has a huge impact on the transport industry. Mobile apps become new tools to help travelers book their flight tickets, search for flight information, check luggage requirements, and do online check-in. In addition, travelers are willing to download and use travel-related apps to assist their trips [12]. Various user-friendly functions and services are provided via mobile apps, and travelers' travel experience can be enhanced by using this powerful technology. With the growing market demands, more aviation companies start paying attention to mobile technology. Liu and Law conducted a survey in 2013, which showed that more than half of international airlines adopted mobile apps in their businesses and these mobile apps have a significant impact on travelers. Travelers hope to use more mobile phones to manage and control their travel processes, and they are willing to directly interact with aviation companies via these apps. Besides, with the population growth and technological development, the potential market for travel-related apps is huge [12]. However, some issues cannot be overlooked in the development of transport apps. Completed functions and services are the key elements that travelers need in travel-related apps, but currently, functions and services in the existing apps are insufficient and incomprehensive [13]. In this situation, travelers fail to use current apps to support their entire journey. Therefore, more useful and effective travel-related apps need to be developed to provide travelers with an easier travel process, and more functions should be developed in these apps to improve traveler experience during the journey [13].

From the reviewed literature, how digital transformation impacts travelers can be identified. Indeed, digital transformation and digital technology have positive impacts on travelers from different aspects. By adopting digital technologies in the travel process, travelers' travel efficiency and experience can be improved. Within different digital technologies, mobile apps occupy a large place in the transport market. Mobile apps can bring more convenient and effective services and products to travelers with cost and time reduction. Besides, the willingness of travelers to use it is strong. However, the functions of current mobile apps are limited, and these apps are not useful enough to support travelers in the travel process. This will also be a gap between the current digital services and travelers' demands.

2.3 Door-to-door travel

Door-to-door travel is a newly proposed concept. According to Classen, door-to-door travel considers different transport modes and covers the entire journey [14]. It provides a stronger connection between each travel stage compared with conventional travel models. By understanding travelers' travel demands and needs, door-to-door travel can improve travelers' satisfaction and the competitiveness of the aviation industry can be increased accordingly [15]. Many organizations, including IATA, Lufthansa and many other international organisations, support that door-to-door travel can improve the current aviation industry's performance and bring new opportunities to help the transport industry get development [4]. Therefore, the research on door-to-door travel is significant as it can generate more reliable and effective travel models to benefit both the transport industry and travelers.

By adopting the door-to-door travel model, travelers can plan their whole journey and manage their travel process more flexibly. In this process, information sharing is a major challenge [15]. Different aviation companies involve in the door-to-door travel to support the travel process run smoothly. In order to achieve a seamless travel process, these aviation companies should collaborate with each other to gather useful data. Therefore, some digital technologies need to be employed to assist the travel process and provide reliable platforms for different aviation companies to communicate and cooperate [15]. In addition, involving digital technologies is essential in the integration of the transport process. Innovation products and services brought by digital transformation can reduce the pain point in the travel, and then the whole process will become smooth and highly connected [15]. Therefore, digital technology is essential for the aviation industry to maintain competitive and innovative.

Identifying the development trend of door-to-door travel is one of the key points that helps the aviation industry and transport market to develop a suitable strategy [4]. Door-to-door travel covers the entire travel process, including transport, transfer, and travel activities [4]. Thus, factors that affect the development trend of door-to-door travel may exist at any travel stage. As Schmalz et al. deemed in 2021, door-to-door travel has five stages: 1) door to kerb, 2) kerb to gate, 3) gate to gate, 4) gate to kerb, 5) and kerb to door. At these five stages, all travel activities have the possibility to be pain points that affects travelers' attitudes toward door-to-door travel [4]. Based on the main features and the key elements of the door-to-door travel model, Schmalz et al. proposed seven important factors in establishing the door-to-door model, and these factors impact the model development [4]. These seven factors are personalized, the use of traveler data, partnerships between different aviation companies, environmental-friendly air travel, airport feeder, disruption and delay management, and exogenous shocks that will affect the transport system [4]. These are the key fundamental factors that affect the door-to-door travel development and should be carefully considered while developing a door-to-door travel model. Therefore, the development of a door-to-door model needs to consider the holistic travel process and all possible activities.

Time and cost are the two main considerations for using the door-to-door model. Since travel time is one of the most important factors that affect travelers' satisfaction with the travel process, it is one of the key elements to evaluate the efficiency and usefulness of a door-to-door travel model [16]. According to Sun et al., a well-designed method for estimating the travel time in the door-to-door travel can help researchers and the industry understand the competitiveness of the door-to-door travel model, and it also can help the policymakers to identify the key points for improving the transport process [17]. However, although estimating travelers' travel time is important in the door-to-door model development, the process is complex [18]. When estimating the time of traveler's door-to-door travel, wait time, transfer time, and in-vehicle time should be considered [18]. Since it may be difficult for travelers to get real-time information and accurate prediction of the traffic situation, travelers may lose the opportunity to complete the optimized route provided by the door-to-door model [18]. Besides, misconnected processes and complex logic will also cause an increase in door-to-door travel time, which negatively impacts the model's performance [18]. Therefore, travel time can be used as an essential criterion to assess the usefulness and effectiveness of a developed door-to-door travel model.

From the above literature review, the key features of door-to-door travel model have been identified. Door-to-door travel is a holistic travel model which covers all the transport modes and the entire travel process. Besides, with technology development, digital transformation becomes an important trend in the development of door-to-door travel. However, the evaluation of the door-to-door travel model should be carefully considered. Since travel time is an important element in the transport process, it can be used to examine the performance of the door-to-door travel. In this situation, digital technology can be an effective method in building and assessing the door-to-door travel model, and this is also the motivation of this study.

2.4 Simulation and digital twin in the aviation research

Simulation has a long history in the aviation industry, playing a vital role in different aspects of the industry [19]. Digital twin and simulation are always used together to link the physical world and cyber world, and the digital twin model can effectively output the simulation results which consistently represent the physical results of the physical entity [20]. In aviation, digital twin and simulation have been applied in system development, system testing, education, training, and virtual simulation experiment [20]. These successful implementations are strong evidence that supports the digital twin and simulation methods can be applied to solve multiple problems in the aviation industry's development and help the industry achieve an effective improvement. As per Lo et al. (2021), digital twin and simulation can monitor the process and optimize the outcomes of the product design and development. From idea generation to product testing, digital twin and simulation can improve the process in the whole product lifecycle, with cost-saving and time-saving [21]. Moreover, the consistency of the twin model developed by using the digital twin and simulation with the physical model has been verified. Since the digital twin and simulation can accurately represent and simulate physical entities in the cyber world, the reasonability and usefulness of the physical models can be assessed and improved by applying these two methods [21]. Therefore, digital twin and simulation can be considered as effective methods to evaluate the performance and value of a new model or product.

In this study, a new door-to-door travel planner has been developed, and its efficiency and usefulness need to be assessed. According to the previous publications, digital twin and simulation have been verified as effective and accurate methods which can dominate the product design, product development, and product testing in the current digital era. Besides, to reduce the risk in the physical production process, digital twin and simulation are essential to be used to assess if the conceptual model or system can work as expected. Therefore, by taking the digital twin and simulation before the actual production, a time-effective and cost-effective testing process can be achieved to ensure the reliability of the developed model. Due to the time and page limitations, the digital twin and simulation have been taken to assess the developed door-to-door travel planner in the digital world in this paper. Then, based on the assessment results, a physical model, which will be built on personal devices, will be developed to allow actual users access to the door-to-door model in the next step. Therefore, it is meaningful to present and discuss the digital twin model and simulation results in this paper to illustrate the digital multi-modal door-to-door travel planner can perform well.

3. Methodology

3.1 Research aim

The development trend and the current impact of digital transformation and digital technology have been recognized by previous studies. Digital technology can be an effective and useful method to improve the aviation industry's efficiency and increase travelers' satisfaction. Travelers are willing to use digital products and services in their journey since digital technologies can improve the service quality in the travel process. Modern travelers prefer to have a seamless and contactless travel process, so-called door-to-door travel. In this situation, combining digital technology with door-to-door travel can effectively satisfy travelers' needs and demands. This paper aims to develop and digitally twin a digital multi-modal door-to-door travel planner which connects different travel stages and provides multi-mode transport options. Then, the objective is to assess and examine whether the developed digital multi-modal door-to-door travel planner works as expected. Besides, the primary research question is how the digital multi-modal door-to-door travel planner can improve the travel experience for different types of travelers. By completing this study, the gap between current digital services and travelers' needs can be filled, and the results can provide some guidelines for the industry on how to attract more travelers in the post-pandemic period. The results also contribute to the current knowledge body of digital transformation and door-to-door travel.

3.2 Conceptual modelling

Conceptual modelling is a method that uses the logic and content of a complex and sophisticated system to represent the frame and flow of the system [22]. It has three key elements. Firstly, the background of the system should be well understood. Then, problems that need to be solved should be clearly identified. Lastly, the identified problems should be well structured to a manageable scale [22]. Carefully considering these three elements before developing the conceptual model can provide a solid foundation for the modelling work.

In this study, a conceptual model has been built based on the door-to-door concept, and this model uses data and information from a sample route which is from Melbourne, Australia to Stockholm, Sweden. Figure.1 shows the conceptual model built in this study.

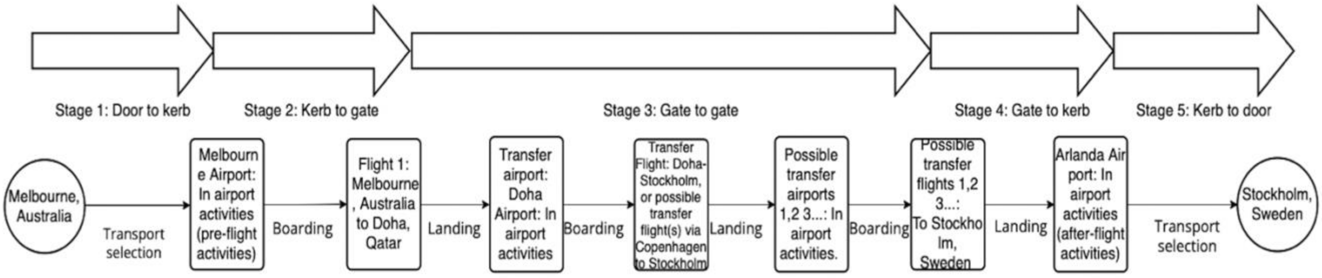

Figure 1 – Conceptual Model for the Digital Multi-Modal Door-to-Door Travel Planner (Using

Sample Route)

This conceptual model presents the process of the multi-modal door-to-door travel, and its frame and logic can be used to develop the digital twin model. It contains five stages and was built based on the steps proposed by Schmalz et al. [4]. At stage 3, the model can contain one or multiple transfer flights, which means the model can be changed and modified flexibly. The conceptual model includes all travel activities in the journey, and it also indicates the whole travel process from Melbourne to Stockholm. Besides, the model connects all the five travel stages and works as a holistic travel process, and travelers can use the model to control and manage their entire journey during the trip. Therefore, this conceptual model can be recognized as an effective multi-modal door-to-door travel planner, and it provides the foundation for the digital twin model and simulation work in this study.

3.3 Digital twin

Digital twin concept is the main method used in this study. In this method, an optimised model is determined in digital form which represents the whole lifecycle of the model [23]. The digital twin is often used in aerospace, aviation, and manufacturing to imitate a process or a system. By using a digital twin, the developed models and systems can be verified, validated, and optimized [23]. As Tao et al. proposed, digital twins provide a connection between the physical world and cyberspace [24]. It is a digital technology which uses data and information to predict a physical product. In the digital twin process, the model is the core [23]. The model should well present the physical object, and the components in the model should be designed and defined appropriately. Accurate data should be collected to support the model simulation [23]. Digital twin and simulation should not be considered separately, and they need to be used together to enable the digitized model to predict the physical object. The digital twin concept for door-to-door travel is shown in Fig. 2. The optimal route (simulation) is determined based on a given departure and destination point and selection criteria, for example minimum time or minimum cost. The selected route is then digitized into GPS coordinates and time pairs.

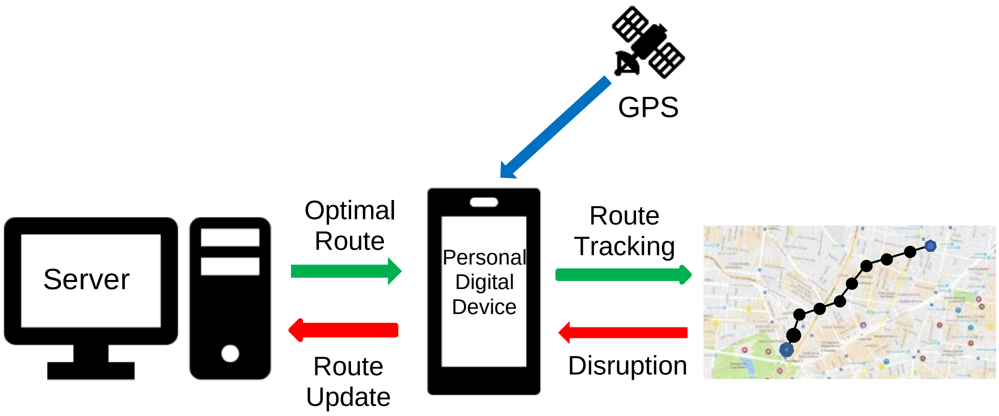

Figure 2 – Digital Twin Concept in Travel Itinerary Planning and Tracking.

The GPS-time table is then transmitted to a personal device where it can be displayed on a map. While traveling, the local GPS and time are compared to the selected itinerary and monitored for any deviation, hence the digital twin. If a deviation occurs due to delay, the traveler can select the itinerary to be updated so the journey can continue. Missed connections can be predicted at interchange points so the traveler can select and alternative route.

3.4 Simulation

3.4.1 Optimum Itinerary

After the digital twin model has been developed, data should be collected to simulate the travel process and assess the model performance. Simulation is considered to be a useful test method. It is a fundamental and experimental process, which can be used to study and understand physical models and processes [25]. In a discrete-event simulation process, like the transport process, a series of key elements should be considered, including inputs, outputs, state, entities, attributes, activities and events, resources, variables, calendar, etc. [25]. Therefore, an accurate simulation should be built by considering all these key elements.

In this study, simulation has been conducted based on the digital twin model. Since the transport process is a discrete-event process, Rockwell *Arena* simulation, which is a discrete-event simulation tool, has been used to simulate and assess the digital multi-modal door-to-door travel planner. A sample route, which is from Melbourne, Australia to Stockholm, Sweden via Doha, Qatar, has been used in the digital twin and simulation to determine the optimum door-to-door itinerary. In the simulation, all the data and information were collected from relevant organizations' websites, national websites, and airlines/ airports.

3.4.2 Assumptions

In order to make the simulation to be more realistic and improve the accuracy of the digital twin and simulation results, some assumptions have been used in the simulation process.

The simulation assumptions for the door-to-door model are:

- Different types of travelers have been classified into two categories: time-saving travelers and cost-saving travelers.
- Travelers are suggested to stop departing from the origins if the check-in courts at airports will be closed within 30 mins.
- Disruption and delay rates used in the simulation are calculated based on the recent historical data.
- Disruptions and delays may occur at any way point in the trip.
- In the simulation, cost-saving travelers will choose cost-saving options and time-saving travelers will choose time-saving options. However, other options may be suggested to travelers to maintain the smooth travel process.

4. Findings and discussions

Based on the conceptual model presented in the above section, the digital multi-modal door-to-door travel planner has been digitized and simulated. All the data and information used for digital twin and simulation have been collected from the sample route from Melbourne, Australia to Stockholm, Sweden via Doha, Qatar. The simulation results can support the usefulness and functionality of the developed model, and the results can also illustrate that the model can be managed flexibly and performs well on long-haul trips.

4.1 Optimum Itinerary using *Arena*

As Kluge et al. stated, door-to-door travel should be holistic, comprehensive and must include all travel stages and processes [15]. The conceptual model described in section 3.2 provides the frame and process of a holistic digital door-to-door travel model. Based on the conceptual model, a digitized multi-modal door-to-door travel planner has been built and digitally twinned. This digitized model includes all travel stages and activities, which can effectively reflect the physical travel process. The travel process and logic of the digital twin model have been presented in Fig. 3. The modules and activities in the model can be changed and modified to conform to the changing conditions of the real transportation process. For instance, at the land transport stage, different land transports are available in different regions. In this situation, land transport modules in the model can be changed and modified to conform to the region's real traffic conditions. Therefore, the digital twin model is realistic and reliable.

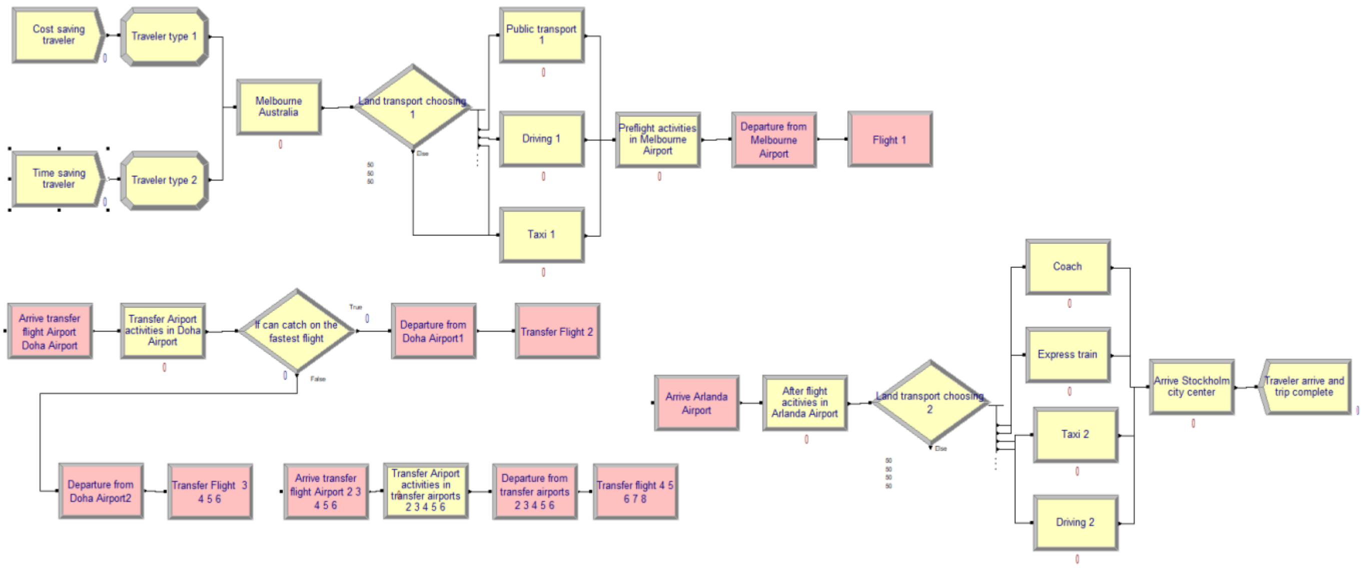

Figure 3 – *Arena* Frame and Flow for Digital Multi-Modal Door-to-Door Travel Planner.

Figure 3 shows the frame and flow of the digitized multi-modal door-to-door travel model. For clarity, specific actives and detailed procedures in the digital twin model cannot be introduced in the paper. However, Figure 3 completely represents the main features and the entire process of the digital multi-modal door-to-door travel planner, and it can present the holistic model and the working procedure of the model. Therefore, the analyses and discussions for Fig. 3 are consistent with the analyses and discussions for the full digital twin model.

Travel preference is the key factor to classify different types of travelers. Business travelers prefer an effective travel process and travel time is their primary concern, meanwhile, educational purposes travelers focus on travel cost more than travel time [26]. Besides, travel preferences have direct and continuous impacts on travelers' choices during the trip. Based on travelers' types and travel preferences, different travelers are identified and classified as time-saving purpose travelers and cost-saving purpose travelers in this research. Actually, travel time and travel cost are the two mostly mentioned factors in the travel process in recent decades [27-35]. Moreover, time and cost are also the key factors in the door-to-door travel process [16]. Thus, using these categories to classify travelers can effectively examine if the digital door-to-door model can provide useful travel options to satisfy different types of travelers.

The digital twin model contains all five travel stages, and these stages are strongly connected. The model can provide optimized travel routes to travelers by digitizing and simulating real-time traffic information and real transport data. After travelers confirming their routes and travel preferences, all possible routes and alternatives will be simulated in the digital twin model. Then, all simulation results will be compared by the model to identify the most suitable one for travelers, which is the optimized route. Once disruptions occur or potential delays are identified, real-time traffic data and travelers' new locations will be used in the model again to simulate all available alternatives. At last, travelers can smoothly transfer from the current travel route to another available route, which enables them to arrive the next travel stage on time. By accepting the recommendations provided by the digital twin model, travelers can change or modify their travel routes at any way point to avoid disruptions, and their actual travel routes can be optimized accordingly. Besides, since the model connects all the travel stages and transport modes, potential delays and disruptions in the whole route can be identified by comparing the current travel information with the digitized route information. With this function, travelers can receive the travel delay information from the model earlier than airlines/ airports' notifications, and they can take action in advance to maintain the seamless and smooth travel process. In this situation, travelers can achieve effective door-to-door travel.

At the first stage, travelers will take different land transports from their origins to the departure airports. Land transport at this stage includes public transport, taxi and private driving. Especially, the schedule and available resource number of public transport are sourced from the local transport departments and are set based on the real traffic conditions. In this research, the sample route used to examine the model is from Melbourne, Australia to Stockholm, Sweden via Doha, Qatar. Therefore, according to the real land transport conditions in Melbourne, available land transport at the first travel stage includes driving via the toll road, driving via the freeway, taxi, and express coaches called "Skybus". Travelers start their journey from a suburb in Melbourne, and they will be provided different land transport options based on their travel preferences. However, cost-saving purpose travelers may also choose options provided for time-saving travelers if the public transport is not available at their departure time. Besides, if disruptions or delays occur at any way point during this stage, travelers' current locations and real-time traffic information will be sent back to the model to simulate alternative routes, which can help travelers complete the current stage on time and transfer to the next stage smoothly. For instance, a cost-saving traveler has chosen the "Skybus" at the first stage, and the traveler's real-time location and time have been found later than the simulated travel location and time. At this time, the current traffic conditions will be used in the model to simulate all possible solutions, and new alternatives will be provided for this traveler as recommendations. At last, this traveler can take action and change the land transport immediately to avoid the disruption and delay.

The first travel stage is completed when travelers arrive at the departure airports, and then they will start the second travel stage which covers the process from kerb to gate. The processing time, queuing time, walking time, and available resource number of in-airport activities at this stage are set based on real-time information provided by airports/ airlines and relevant historical data. At this stage, travelers will be provided additional suggestions such as whether they have enough time to go to airport facilities. For instance, in the sample route, travelers will be suggested not go to shops or airport lounges if the flight taking off time is less than 65 mins. Therefore, the model keeps tracking travelers at each activity and simulating the optimized travel options, and travelers can make relevant decisions on their trip based on the optimized options.

The second travel stage is completed when travelers' departure flights take off. The third travel stage is the gate-to-gate stage, which may contain direct flights or transfer flights. This is the most important stage in the door-to-door travel, and this stage has the highest impact on the successful completion of the journey. During the in-flight time, travelers' GPS and time are still tracked by the model to identify if the flight will delay. After comparing the current flight's location with the simulated flight's location, travelers can receive the flight delay information from the model, which is even earlier than the airlines' notification. For direct flight routes, the model can analyze if the identified delays or disruptions will impact the processes at the following travel stages, and then alternative options for the following stages can be simulated and provided. For transfer flight routes, the processes and activities are complex. Similar to the direct flight routes, travelers' in-flight times can be tracked and compared to determine if disruptions and delays occur or will occur. If the identified disruptions or delays will influence the next transfer flights, the information of the transfer airports and real-time transport data can be sent to the model to conduct a new simulation. Then, available flights and other transport means can be provided to help travelers transfer to the next stage seamlessly. Besides, activities at transfer airports contribute to a large part of this travel stage. Similar to the second travel stage, relevant times and recourses of in-airport activities at this stage are also set based on the information provided by airports/ airlines and the historical data. During this stage, once the model identifies travelers cannot catch the connected flights, other suitable flights will be recommended to travelers to help them arrive at the next stage on time. In the sample route, travelers will take a transfer flight at Doha airport. However, disruptions and delays may occur. In this situation, based on travel preferences, travelers will be recommended to wait for the next available flight at Doha airport or to take another transfer flight from Doha, Qatar to Stockholm, Sweden via Copenhagen, Denmark. Therefore, activities and processes in the model can be flexibly modified and changed based on the actual transport conditions and real travel needs.

The third travel stage is completed when travelers arrive at the destination airport, and the fourth stage is tightly connected to the third one. The fourth travel stage is the door-to-kerb stage, covering the process from travelers getting off the flights to travelers arriving at the airport gates. Similar to the second stage, this stage connects air transport with land transport. In the sample route, the arrival airport is Arlanda airport in Stockholm, and the model can guide travelers to complete the in-airport activities at this airport. At this stage, the model tracks travelers to identify if the travelers can catch the selected land transport on time at the next stage. If disruptions and delays are identified by the model, travelers may be suggested to change the land transport means in advance at this stage.

The fourth travel stage is completed when travelers arrive at the airport gates, and then travelers will enter the last travel stage which is the land transport stage. At this stage, different land transport means, which includes both public transport and private transport, are available for travelers choosing. Besides, the schedules and available resource numbers of these transport means are set based on real traffic information. According to traffic conditions and transport information in Stockholm, land transport means at the last stage are private driving, taxi, express train, and coach. Since travelers' destination is the city center of Stockholm, all these four modes of land transport are available to travelers. Besides, if travelers arrive at the Arlanda airport before/ after the public transport available time, both cost-saving purpose travelers and time-saving purpose travelers will be suggested to take a taxi or drive to the destination. During this stage, travelers' actual locations and times are also tracked and compared with the simulation results. Same as the function at the first stage, travelers will be recommended new alternatives when disruptions and delays are identified by the model at this stage. Therefore, the multi-modal door-to-door model can provide travelers with real-time suggestions to complete this stage and then complete the whole journey.

As introduced above, the digital multi-modal door-to-door travel planner tightly connects all travel stages and covers all travel activities. The core of the model is to track and optimize travelers' entire travel process and enable travelers to manage the trips from their perspectives. The above analyses also prove that the digital door-to-door model is a multi-purpose travel model, and multi-mode transports are available in the model. The functions and modules in the model enable the model to generate optimized travel options using real-time information, realistic data and travelers' preferences. Therefore, the digital multi-modal door-to-door travel planner is considered as an effective travel model to help travelers achieve personalized and smoothly travel processes.

4.2 Simulation results

A sample route has been simulated in *Arena* to examine the functionality and usefulness of the model. The simulation results can be used as the digitized optimum routes which can support the journey between Melbourne and Stockholm. The traffic information and transport data used in this section are all set based on the actual transport conditions which are sourced from the local transport departments and relevant airlines/ airports. After simulation, the travel times and costs for all possible travel options can be presented for traveler choosing, and the optimized route can be identified. The simulation results of the sample route are presented based on traveler types in Fig. 4.

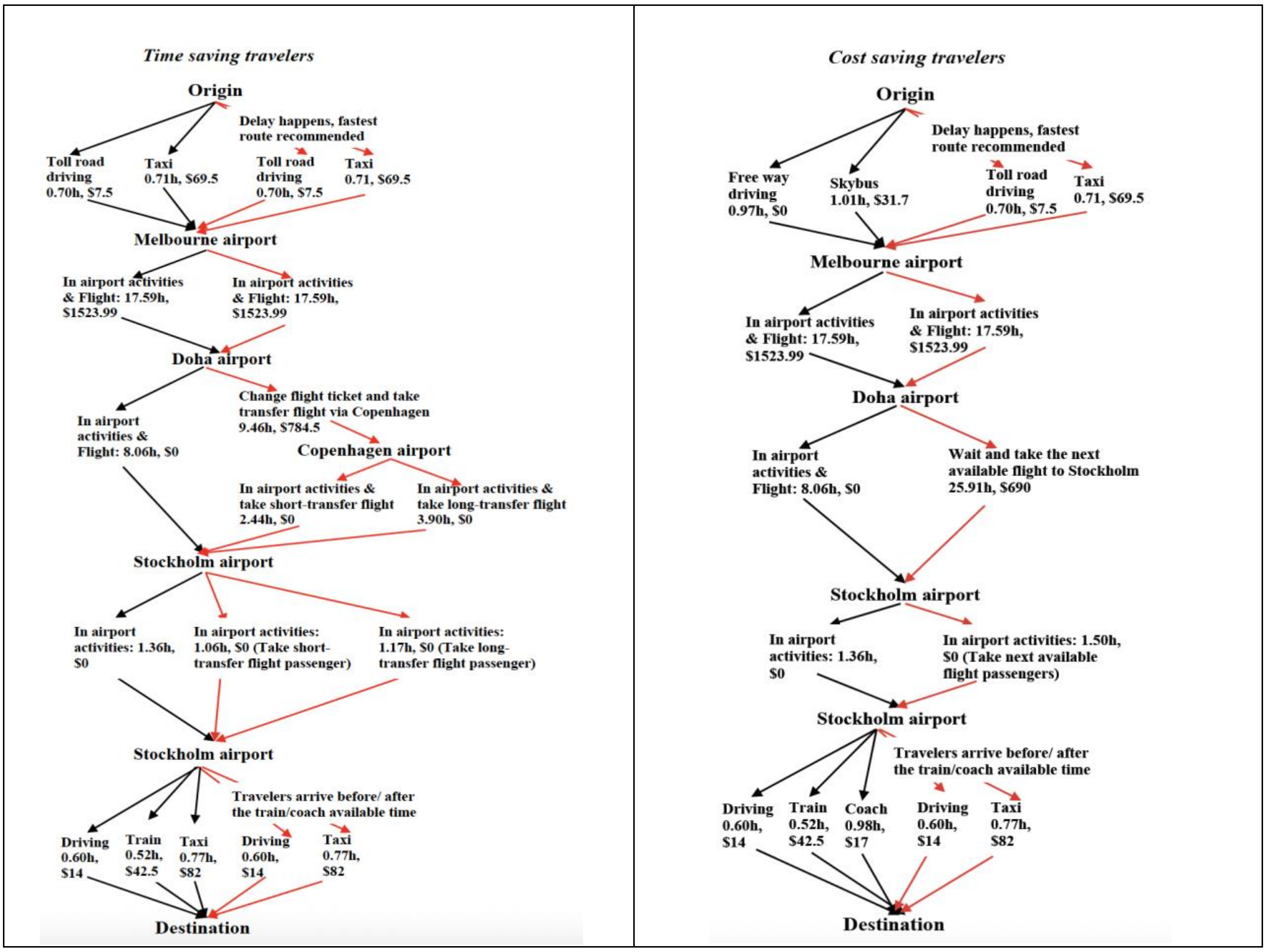

Figure 4 – Optimal Itinerary for Minimum Travel Time and Minimum Cost.

Figure 4 shows that travelers can be offered different options at each travel stage, and these options impact the following stages since the entire travel process is highly connected. For time-saving, there are 18 possible routes and totally 40 possible routes were simulated for cost-saving. In the travel process, disruptions and delays may occur and travelers need to change the remaining part of the journey, which is represented by the branches. In Fig. 4, black routes indicate the travel routes with no disruptions and delays, which are the optimized routes provided to the traveler. Within these routes, travelers can smoothly transfer between journey segments without disrupting the trip. The red routes indicate the routes with disruptions and delays, which require the traveler to make choices. Travelers are provided alternative routes based on real-time transport conditions to avoid potential disruptions and delays. In the simulation, time-saving travelers will consistently choose time control options and cost-saving travelers will prefer cost control options, however they can change their travel preferences and select other options during travel.

The ideal route for time-saving travelers is to take a taxi or drive via the toll road to Melbourne airport, followed by the departure flight in Melbourne and the transfer flight from Doha to Stockholm, and then choose driving or train options based on different situations. The ideal route for cost-saving travelers is to take Skybus or drive via the freeway to Melbourne airport, then catch the departure flight in Melbourne and the transfer flight from Doha to Stockholm, followed by driving, express trains or coaches based on different situations. No disruptions or delays occur in this route. The fastest journey for time-saving travelers in the ideal situation takes 28.23 hours. The travel cost is AU$1573.99, but the cost will increase by AU$62 if travelers choose to take a taxi at the first travel segment. The cheapest route for time-saving travelers takes 28.31 hours and costs AU$1545.49 from the origin to the destination. In this low-cost option, travelers must choose private driving at both the first and last travel stages, travel time and cost will change if travelers choose other land transport options at these stages. Furthermore, the longest route in the ideal situation will be suggested to travelers if travelers have to take a taxi. To complete this longest route, the total duration is 28.49 hours, and the total cost is AU$1675.49. However, for cost-saving travelers, the cheapest option in the ideal situation needs to take 28.58 hours and cost AU$ 1537.99. If travelers cannot choose the driving option at the two land transport stages, the travel cost will increase by AU$34.7 and the time will increase by 0.8 hours. The fastest route for cost-saving purpose travelers is to choose driving via the freeway or taking Skybus at the first travel segment and choose taking express trains at the last travel segment. In this route, the total duration is 28.5 hours, and the cost is AU$1566.49. The cost for this route will increase by AU$31.7 if travelers choose to take Skybus at the first travel segment. Besides, the longest route in the ideal situation is to take Skybus at the first travel segment and take coaches at the last travel segment. The total duration for this route is 29.38 hours, and the total cost is AU$1572.69.

In the actual travel process, disruptions and delays may occur, and travelers may fail to complete the travel in the ideal situation. Since time-saving purpose travelers have already chosen the time control transport options, they are recommended the fastest transport means at the land transport stages. Therefore, once disruption/delay occurs or is identified at the first stage and has impacts on the following stages, travelers will be recommended to change their flight tickets to take the next available flight the following day. Besides, the major delay that impacts the entire travel process will occur at the third travel segment. If travelers fail to catch the transfer flight in Doha, the model will recommend them to take another suitable transfer flight which is from Doha to Stockholm via Copenhagen. Therefore, the fastest routes for time-saving travelers in the disruption/ delay situation is to take a taxi or drive via the toll road to Melbourne airport, followed by the departure flight in Melbourne and transfer flights from Doha to Stockholm via Copenhagen, and then choose express trains at the last segment. Travelers who choose this fastest route take 31.77 hours to complete the journey, and the travel cost is AU$2358.49 if travelers choose to drive via the toll road at the first travel segment or AU$2420.49 if travelers choose to take a taxi at the first travel segment. In contrast, the longest route for time-saving purpose travelers in the disruption/delay situation will be suggested to travelers if they fail to catch the fastest transfer flight in Copenhagen. In this longest route, travelers take 33.42 hours and costs AU$2358.49 from the origin to the destination if travelers choose the driving option at the two land transport stages. Besides, the total duration will increase by 0.18 hours and the total cost will increase by AU$130 if travelers choose the taxi option at the land transport stages. The longest route indicates the situation that disruptions and delays occur at every way point. Moreover, the cheapest route in the disruption/ delay situation is the same as the longest route, the time for the cheapest route is also 33.42 hours and the cost for this route is AU$2358.49.

For cost-saving purpose travelers, at each travel stage, the model will provide digitized routes for travelers to help them transfer to the next stage smoothly, and these digitized routes contribute to travelers' optimum travel experience. At the first travel segment, travelers will be recommended to take faster routes in the disruption/delay situation, which aims to help travelers catch the departure flight in Melbourne on time. Besides, since the cost-saving purpose travelers pay more attention to travel cost than travel time, the model will suggest the travelers wait for the next available flight at Doha airport if disruptions or delays occur at the third travel segment. In the simulation, the cheapest route recommended for cost-saving purpose travelers in the disruption/ delay situation is to drive to Melbourne airport via the toll road and catch the departure flight in Melbourne, then wait for the next available flight in Doha, and choose the driving option at the last stage. Travelers who choose this cheapest route take 46.3 hours and cost AU$2235.49 to complete the journey. However, the travel cost will increase by AU$65 and the time will increase by 0.39 hours if travelers fail to choose the driving option at the land transport stages. The fastest route for cost-saving purpose travelers is to choose driving via the toll road at the first travel segment and choose express trains at the last travel segment. The total travel time for this route is 46.22 hours and the cost is AU$2263.99. If travelers have to choose a taxi at the first travel segment, the total duration will increase by 0.01 hours and the cost will increase by AU$62. Furthermore, if other land transport means are all unavailable and travelers have to choose the taxi option at the two land transport stages, the total duration will be 46.84 hours and the cost will be AU$2365.49. The longest route is the same as the cheapest route, the time for the longest route is also 46.3 hours and the travel cost is AU$2235.49 if travelers can choose the driving option at land transport stages.

Therefore, comparing the simulation results for the disruption/delay scenario, cost-saving travelers have to spend 14.45 hours more than time-saving purpose travelers to control the travel cost in the fastest route. Besides, time-saving purpose travelers have to spend AU$123 more than cost-saving purpose travelers to control the travel time in the cheapest route. Therefore, the results support the model can provide travelers with personalized travel options based on their travel preferences even if disruptions or delays occur. For different types of travelers, both the ideal situation and the disruption/delay situation have been considered and simulated. The above analyses also can illustrate that the digital multi-modal door-to-door travel planner can simulate travel processes by considering different traffic conditions and travel situations, and the model can provide travelers with optimized travel options based on travel time, cost, and route. The simulation results support that the model can effectively optimize travelers' door-to-door travel by tracking the real-time travel information and simulating all available options during the trip. Therefore, travelers can obtain useful recommendations from the model in any situation to ensure seamless and effective door-to-door travel.

5. Conclusion

Door-to-door travel provides travelers with new opportunities to experience a highly effective and highly connective travel process. In this research, a digital multi-modal door-to-door travel planner has been developed to support travelers to achieve smooth and flexible travel processes. The developed digital multi-modal door-to-door travel planner covers all travel stages and includes all travel activities. Besides, these travel stages and activities are highly connected, and they contribute to the whole logic of the model. Therefore, in the model, the optimized travel routes and real-time recommendations can be obtained by simulating the data and information of the entire travel process. In this situation, the simulation results for the entire route can be used in each travel stage, and the real-time information can be exchanged effectively within the model. These features ensure travelers can use the model to control and manage the whole travel process at any way point. Moreover, promptness and multi-options are the other two main features of the digital multi-modal door-to-door travel planner. In the model, travelers are tracked by GPS during the travel process, and their actual locations and travel times will be compared against the simulated locations and travel times provided in the optimized route. Once delays or disruptions are identified, real-time information will be sent back to the model, and new optimized routes will be simulated and provided for travelers to help them catch the next stage on time. Travelers' travel smoothness and efficiency can be improved since the model can provide optimized alternatives at each way point in advance.

Hence, the primary research question can be answered. The digital multi-modal door-to-door travel planner can offer personalized and seamless travel options to satisfy different types of travelers. For travelers with different travel preferences, the model can use real-time data and accurate transport information to simulate and optimize personalized routes for travelers. However, in the actual travel, disruptions and delays may occur, which may result in travelers being unable to travel as optimized routes. Therefore, travelers' travel status will be tracked and compared against the optimized routes by the model, and timely recommendations and new optimized travel options will be offered during the trip to help travelers avoid the travel disruptions in advance. By achieving optimization at each travel stage, the entire travel process can be optimized. As a result, the gap between the current digital services and travelers' demands can be filled by this digital multi-modal door-to-door travel planner.

Indeed, the digital multi-modal door-to-door travel planner can improve travelers' travel experience to a great extent. The model can also bring benefits to the aviation industry since the efficiency in the travel process can be improved and more potential travelers can be attracted. Therefore, this model is effective to enhance travelers' satisfaction and improve the industry's performance.

Future work will include development of the personal device app to receive optimum route information, typically GPS coordinates and time, and to track the journey by comparing actual time and location with the optimum route progression.

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7. Copyright Statement

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