Different Destinations: Digital Twins Enabled Ambulance Path Planning

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1 Abstract

This paper proposes two aspects of care regarding ambulance routing to offer the best treatment to patients possible. We attach a great deal of importance to the time on the road and the treatment offered in different hospitals. With the help of the cloud and digital twins, we set out to determine the optimal hospital and the best route for its ambulance. As in the figure below, the cloud can gather the information to do route planning, and digital twins connected with reward mechanisms are able to mitigate congestion when an ambulance drives on the road. We believe that our project can save substantial amounts of the patient's time and cut down on errors that may be caused by people. We sincerely hope that every patient can benefit a lot from our project, which means that they are less likely to lose their life when falling ill.

Keywords:digital twins,ambulance route,route planning.

2 Project Background

According to data published by the UK National Health Service [1] on December 2, 2022, "the mean average response times for the most urgent category, C1, was 10 minutes 57 seconds, and the 90th centile was 19:25, both easily the longest since the category was introduced in 2017, and beyond the respective

7-and 15-minute standards" (Figure 1). The average C2 response time in England was 1:32:54 and the 90th centile was 3:41:48 in December 2022, each more than 50 percent longer than the previous longest value. C3 was 4:19:10 with a 90th centile of 11:05:56 in December 2022, both more than 50 percent longer than in November. C4 averaged 4:35:09 in December 2022 with a 90th centile of 11:39:08.

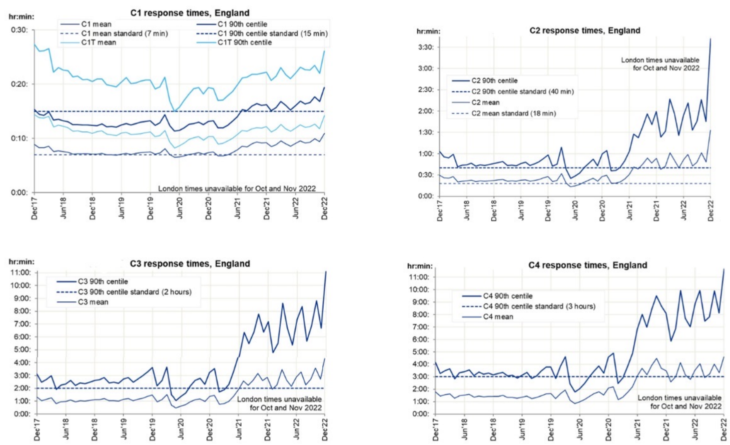

Figure 1: C1,C2,C3,C4 response times, England [1]

Our research process can be divided into three stages

The first stage concerns the shortest path. The shortest path optimization scheme is the most intuitive and easiest to implement. There are no other factors other than length. At this stage, there are also many schemes for the shortest path. For example, Zhao et.al. [2] propose an optimization plan to reduce transportation costs and CO2 emissions with the shortest path as the goal, and Rong et.al. [4] present a two-way interactive queuing concept based on buffer zone and shortest path analysis. Unlike these approaches, our project goal cannot be simply the shortest path, because the most important consideration in a rescue is time. Thus, we did not choose this direction.

The second stage concerns achieving effective rescue by optimizing the plan with the aim of achieving the shortest time. In this process, we looked up many specific models, such as that by Chen [9] who proposed an improved travel time estimation model based on the KSP algorithm. Additionally, Yao et.al [6] proposed an emergency vehicle route selection model for urban road networks using the TOPSIS algorithm. After studying the above models, we found that they did not play to the advantages of digital twins, but were more involved in building models, so we changed our thinking in the third stage.

In the third stage, we focused on the combination of digital twins and optimization path and found that the digital twins technology has been widely studied to support path planning. Marai et al. [7] investigate the use of digital twins to facilitate smart cities. The authors present a digital twins box to create a DT of the road. Using digital twinning, Martin et.al. [3] show that the path planning for autonomous robots and unmanned aerial vehicles is carried out considering the length and width of the path. Although path planning schemes have been widely studied, few have designed digital twins for ambulances. Therefore, we first designed the digital twins architecture to determine the path by controlling time and ensuring the treatment effect in the hospital. In the course of the research, we found that after determining the optimal path, that path may become unreliable due to congestion caused by other vehicles, so we applied the incentive mechanism proposed by Hui et.al. (2021) [5] to alleviate this situation.

3 Methodology

In Beijing China, When a person suddenly falls over, people will call 120 to connect with the Beijing 120 emergency center. At the same time, the cloud collects real-time information, such as the emergency department conditions and road conditions concerning various hospitals to determine which hospital is the most suitable for the patient, and decide the optimal driving route for the ambulance which is dispatched by the hospital.

After determining the optimal hospitals, the cloud collects real-time information about the hospitals' emergency room to determine the most suitable one (Ricci,2022) [5]. The cloud works as the figure shows below.

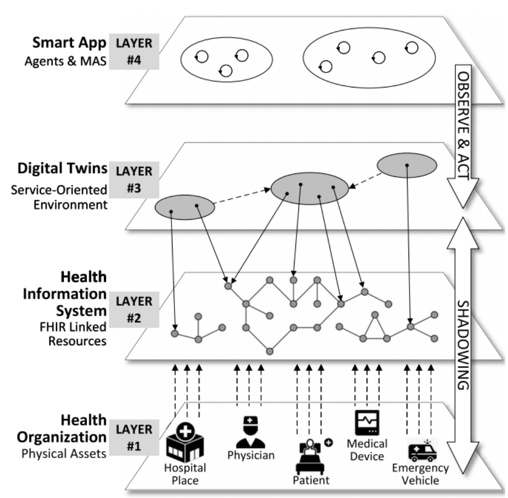

Figure 2: Use of digital twins in hospitals[8]

Every patient, doctor, and bed has its own digital twin, and their digital twins are attached to the cloud. Therefore, the cloud can know whether there are many patients in the Emergency Department in one hospital, what the technical competence of the doctor is, and whether there are free beds or not. After the cloud collects some information, it can consider these conditions in the choice of a hospital which is the most suitable for aiding the patient.

In reference to how cloud servers collect road condition data, we used cameras, base stations and other related equipment [8]. As shown in the figure below, the roadside camera senses and collects traffic data in real time, and further transmits the collected data to the cloud through base stations, so as to realize cloud storage information.

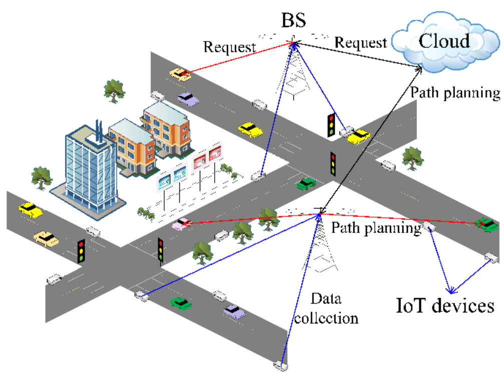

Figure 3: How the cloud collects information on the road [5]

About collecting the information about road conditions, we used certain mathematical models built by Chen [9]. The author considered five factors. As in the figure below, the five factors are the length of the road, the grade of the road, the traffic conditions, the section connectivity, and the intersection safety.

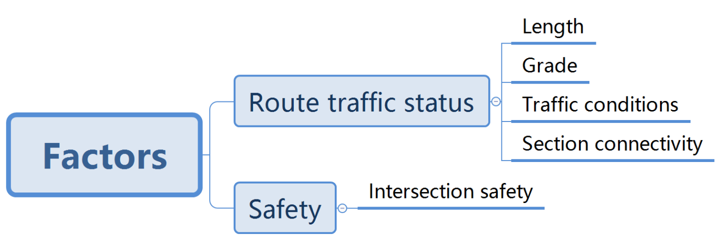

Figure 4: Five factors

When the cloud deals with the road condition data, the optimal route of the ambulance will be given.

As soon as the optimal choices of the hospital and the route are decided by the cloud, the ambulance will be ordered to save the patient. Because the ambulance can arrive at the scene by the fastest way, more opportunities to save the patient's life can be provided, for example.

However, nobody can predict that the ambulance will not be intercepted by other vehicles. Therefore, we introduce a reward mechanism [5] proposed by Hui (2021) to this system. In this way, our project is different from models in other papers. In our project, the cloud can set different kinds of rewards for different roads based on the vehicle density of all roads. For example, the cloud can set negative rewards on other roads to charge vehicle users. Instead, positive rewards can be set on the road so that the ambulance will not drive to attract more vehicle users that may occupy its roads. This may ease the congestion that ambulances may encounter.

However, a report by Hui (2021) found that people tend to show different preferences for cloud rewards. For example, some drivers may be so financially sensitive that they are willing to spend more time in exchange for rewards due to the fact that they are very concerned about money. But not every person thinks so. Other people might not care much about money; they pay more attention to their time. Therefore, such people are less likely to choose another way just for money. In addition, we can use parameters to measure the preferences of different people for driving time and driving rewards, so as to certify the effect of the reward mechanism. As we can see in the figure below, there are many digital twins of all vehicles on the cloud, where the digital twins of the vehicle are used to map the user's driving needs and preferences for driving time and rewards.

With the help of reward mechanisms and route planning, the time on the road can be quickly cut down to be as short as possible. Then, there will be pre-hospital treatment given on the spot by doctors. After that, the ambulance will go back to the hospital on the same route. The patient will be examined, and doctors will judge by the results whether he or she should be hospitalized for observation, hospitalized, or admitted to the Emergency Department. Naturally, if the patient is in a serious situation, they must be taken into the Emergency Department immediately.

4 Division of roles & responsibilities

Each team member participated in the whole process to conduct the discussion and put forward ideas. Besides this, We divided the research process into three stages, according to our abilities, namely: 1) reading relevant materials and determining the research direction 2) reading papers related to this direction and promoting the project, and 3) refining our ideas, completing a report, and making a presentation. We had a supervisor at each stage to ensure that the project was moving forward. Among our team members, ZHANG Yuyan was responsible for the first phase, FENG Shoyue was the person in charge of the second phase, and WANG Yiming was the person in charge of the third phase.

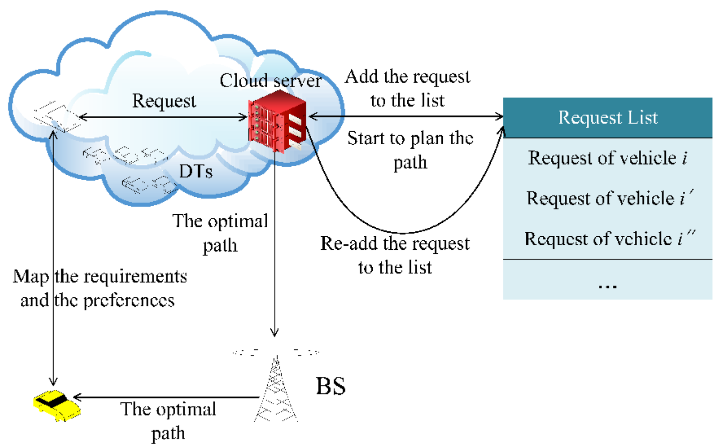

Figure 5: Reward mechanisms [5]

5 Challenges & Solutions

5.1 Challenges

In the early research, we encountered some challenges: 1) We did not fully understand the aims of the project and attached great importance to the perfection and comprehensiveness of the model, which resulted in fear of errors and difficulty. 2) We lacked a full understanding of digital twins and did not know how to apply them effectively. 3) We over-emphasized the details and wanted to study each factor thoroughly, which led to the fact that the project was very challenging. For example, we spent a lot of time on the question of whether alleys should be considered. 4) We were unable to apply the asset life cycle to the project, and thought that the overall planning of the project was difficult.

5.2 Solutions

After further research, we successfully solved each of the above challenges:
1) After some meetings and discussions, with the help of our professor and our teaching assistant, we finally understood the project requirements and focused on the innovative aspect of the project instead of the model.
2) We sought the help of the teaching assistant, repeatedly read papers recommended by the teaching assistant, conducted effective literature reading according to the method learned in the class to find a suitable paper for the project, and further learned about digital twins and their application scenarios.
3) We shifted our focus and did not dwell on the difficulties encountered in the process, and we conducted the project research with a positive and enjoyable attitude.
4) We asked questions and searched literature after class.

5) We recognized our feelings and ambitions. Drawing on our personal experience, starting from the reality of life, we aimed at solving and alleviating practical problems. After repeatedly considering the idea of the project, we finally formed a set of innovative systems, hoping that they could eventually be put into practice, reflecting not only the technical value of digital twins, but also their social value. We sincerely hope that patients will no longer be unable to receive timely treatment due to time, medical conditions and other issues, and we want to make medical treatment a fully human experience.

6 Contributions & Limitations

6.1 Contribution

Compared with the previous work, which only considered the shortest time, this study focused on two goals, namely time and destination, and organically linked path planning with the real-time state of the hospital. This was intended to reduce the risk of patients being hospitalized in the emergency room after being sent to the hospital in time. Simultaneously, there may be other vehicles occupying lanes on the way to the first aid road, so we adopted a reward mechanism. If a vehicle can avoid the route that the ambulance will drive, it will be rewarded, which will effectively provide a feasible road for the ambulance, make the ambulance safer on the way, and finally send the patient to the hospital in time.

In addition to the technical perspective, we believe that this research has certain value to society. More specifically, it makes a good contribution to public health. The allocation of resources through digital twins can help to coordinate the progress of hospital treatment, which will form a good cycle in the long run. From the perspective of human care, if the project is successfully implemented, more families can avoid the sadness of not being able to receive timely treatment or even a tragic death caused by the delayed treatment time. If it can be applied in a wider range in the future, the best driving path and the most suitable hospital can be quickly selected through digital twin technology, so that patients who call for help, especially critically ill patients, can get the most effective treatment immediately, and the survival rate and quality of life of patients can be improved.

It is worth noting that we do not constantly update the road data as in other research, Instead, we keep the planned path changeless. This is because if it is updated in real time, the optimal road may change frequently, which is a big test of the driver's reaction ability, and we cannot let the ambulance drivers take this risk. In fact, it is not very realistic, so we focused on protecting the planned path from being disturbed, and we placed our real-time focus on maintenance on this road, which is likely to be a good approach.

6.2 Limitation

However, there are still some limitations in this study. First there may be multiple patients calling for help at the same time, and there will be multiple starting points. In the process of planning the path and selecting the hospital, there will be serious delays due to too much data to be processed. Secondly, we still consider defects resulting from the interference of unreliable factors. At present, we only consider the interference that other vehicles may appear on the ambulance route. However, we have not come up with effective intervention methods for the sudden occurrence of traffic accidents on the road, because accidents are often not accurately predicted, and can only be roughly estimated by the accident rate and road conditions of a particular section in the past. In addition, at this stage, we only consider the doctor configuration of the hospital emergency room and the number of patients waiting. We do not consider the specific symptoms of more than 120 patients, for example, so we cannot provide them with the most suitable hospital for treatment. Thus, the treatment received by the patient may not be the most effective.

The goal is to eventually allow the ambulance to circumvent road difficulty, allowing patients to be transported to hospitals safely and promptly. Future developments in digital twin technology include simulating the driving conditions of vehicles on the road in the twin world, predicting traffic accidents in conjunction with road conditions, and more. If possible, we can also utilize digital twins to simulate the patient's state and modify the chosen location in accordance with their condition, allowing us to match the patient with the best hospital and reduce the risk of mortality.

7 Author Contributions

Conceptualization: Y.Z., S.F. and Y.W.;methodology, validation, analysis: Y.W., S.F. and Y.Z.;investigation, resources: Y.W., Y.Z. and S.F.;writing—original draft preparation, visualization: S.F., Y.Z. and Y.W.;writing—review and editing, visualization, supervision: Y.Z., S.F. and Y.W.;Project administration: Y.Z., S.F. and Y.W. All authors have read and agreed to the published version of the manuscript.

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