Concept Design of Modular Transit and Efficiency Calculations based on Route Planning

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ABSTRACT

Classic transportation design is not suitable in this pandemic era. A new design that fits a new era is required, revolving around human-machine-environment relationships and ergonomics. This paper proposes a different way for modular transit to be used in the new environment. A calculation is made to provide analysis that modular vehicles have a significant traffic efficiency impact on the traditional transit system. In addition, the concept of modular transit used in the new environment is different from its usual function. The discussion shows that modular transit has higher passenger loading efficiency than classic transportation. Furthermore, the study simulates various scenarios of modular transit, showing its capability. The result verifies that modular transit will further improve new environment traffic efficiency.

CCS CONCEPTS

• **Applied computing** → Operations research; Transportation.

KEYWORDS

Modular transit, pandemic environment, public transportation, social distancing

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1 INTRODUCTION

Since 2020, the Covid outbreak has lasted for two years, greatly impacting travel for people worldwide. Numerous countries have implemented travel restrictions to decrease the rate of infection, resulting in significant losses for the transportation industry. In China, COVID-19 has hit public transport systems hard. During February's lockdown period, 27 Chinese provinces and 428 cities suspended transit entirely to combat the pandemic's spread [1]. This policy has proven to be effective, but maintaining the city economic growth has become a challenge due to the need to prevent citizens from becoming infected. Social distancing is an essential measure to prevent the virus from spreading, but most public transportation can't meet the distance requirements set by authorities [2]. Consequently, public transportation has suffered significant losses due to insufficient passenger capacity per trip, despite disinfectant measures being implemented.

According to several analysis reports, transit ridership dropped precipitately. In many European countries, transit lost more than 80% of its ridership in the initial phase of the pandemic [3]. Even in China, where the economy was fully opened after March 2020, transit ridership was still far below the pre-pandemic level [1]. Subway ridership from multiple cities in China shows that 85% of pre-COVID ridership levels have been restored six months after full reopening. Where a second wave occurred, only 65% of ridership was restored compared to pre-COVID levels [4].

In China, people use the subway more frequently to travel on weekdays. According to the statistics of 10 first- and second-tier cities by the Daily Economic News, in late May, the subway passenger intensity in these cities generally only recovered by 60% to 80% compared with December 2021. Taking May 28 as an example, Beijing recovered to 61.3%, Guangzhou was 66.9%, and Shanghai was relatively better, but only reached 77.6% [5].

The reasons that classic public transport does not fit for the pandemic era can be discussed in 3 different aspects. First, social distancing. When we talk about how to prevent infection in the crowd, social distancing seems to be the most common solution. However, this solution is unfriendly towards public transportation. This is mainly because public transport like buses and railways are designed to transport a specific number of passengers per trip. With the appliance of social distancing, buses, and railways having their passengers per trip lessened, the cost of public transport has risen significantly. In Malaysia, public transport and public area have reduced their seating by 50% by tagging seats as unavailable during the first wave of the pandemic.

Second, public transportation also faces challenges from hygiene issues. Awareness of personal hygiene became a popular topic during the pandemic. In short, the public demands higher hygiene levels for public transport. As the voice of demands rises, authorities must provide a better solution than just providing hand sanitizer in public transport [6].

Furthermore, more and more people prefer individual transportation to public transport during the pandemic. According to the statistics, Beijing's road congestion index was 123% in December 2021. The growth of Shanghai and Guangzhou's congestion index was lower than that of Beijing, but compared with last December, it also increased by 19.6% and 11.2% respectively [5], which means that the usage of individual vehicles has increased compared to last year before the outbreak. The reason lies in the fear of staying in crowded and compacted spaces. The people fear that in compacted spaces like buses or subways, the air circulation effectiveness is weaker. So, in order to avoid infection, more people prefer the safest solution for traveling, which is by private vehicle.

According to the United States Environmental Protection Agency (EPA), the spread of COVID-19 occurs via airborne particles and droplets. People who are infected with COVID can release particles and droplets of respiratory fluids that contain the SARS CoV-2 virus into the air when they exhale. These droplets carry the virus and transmit infection. Indoors, the very fine droplets and particles will continue to spread through the air in the room or space and can accumulate [7].

Since COVID-19 is transmitted through contact with respiratory fluids, a person can be exposed to an infected person coughing or speaking near them. They can also be exposed by inhaling particles that are spreading away from the infected person. Transmission of COVID-19 from inhalation of virus in the air can occur at distances greater than six feet. Particles from an infected person can move throughout an entire room or indoor space. The particles can also linger in the air after a person has left the room – they can remain airborne for hours in some cases [7].

2 FRAMEWORK OF MODULAR TRANSIT

2.1 Future Transportation Concept

Autonomous driving is now a technology trend most vehicle companies invest in. These vehicles are known as the Intelligent Connected Vehicle (ICV), an ICV is a vehicle equipped with advanced sensors, driven by artificial intelligence, precise control system to allow minimum error in calculation and cooperative driving with other intelligent vehicles. Thus, an ICV is designed to provide a safer traffic environment and relieve human drivers.

As the pandemic worsens each year, the society has already accepted the existence of Covid-19 and moved on to the next era. With the beginning of a new era, the future of transportation will shine in this new stage. Different concepts of transportation are ready to be tested in society. Considering the situation of pandemic and people's privacy, a small, lightweight, and eco-friendly transport will be more welcomed by society.

Modular Transit is a concept of future transportation, as shown in Figure 1. Imagine a small size vehicle that is fully autonomous, has great battery sustainability and is available for public use or private use. The concept of Modular Transit had been proposed by many scholars [8], and inspired by the system, a further use for modular transit in pandemic era seems achievable.

2.2 Modular Transit

A modular transit consists of modular vehicles connected. These electric cars are small in size and operate on a point-to-point system. Examples of point-to-point travel systems include buses and subways, which have fixed stations and require passengers to use other methods of transportation to reach their final destination from the station. However, modular transit is different from the traditional point-to-point transport system because it offers door-to-door services. The modular vehicle picks up its passengers and takes them to their destination following specific routes.

The modular transit system consists of three types of vehicles: private, public, and stationed. Private vehicles are owned by specific users who can choose not to join the modular chain with others but will still travel on the same route. These vehicles will be parked in designated spaces while waiting for their owners. Public vehicles are flexible and can be called upon to pick up passengers from door-to-door. However, they will return to the nearest station after dropping off their passengers. Stationed vehicles are owned by specific stations and will always return to their original station after each trip. They cannot be called upon and require users to access them at the station. For further details about the system, please refer to the section below [9].

2.3 Modular Vehicle

The modular system provides an alternative to traditional bus and subway transit systems. Like public transport, the modular transit system operates on a fixed route, with each modular designed to follow the same path. However, unlike public transportation, private modular transit does not have to stop at stations. Instead, it can drop passengers off at selected destinations like the entrance of a mall, specific streets, or the front gate of a restaurant [10].

Public modular transit offers a door-to-station service, which is different from private modular transit. It stops at the nearest station to the destination and passengers need to walk the rest of the way. Once it reaches the station, it will either park and recharge or continue roaming if the battery lasts.

The stationed modular transit system is designed to provide a fixed station-to-station service, focusing on maintaining the operational readiness and availability of the designated station. As part of its operational protocol, these vehicles revert to their assigned station following each trip, ensuring continuous service provision. In contrast to the public modular transit system, these

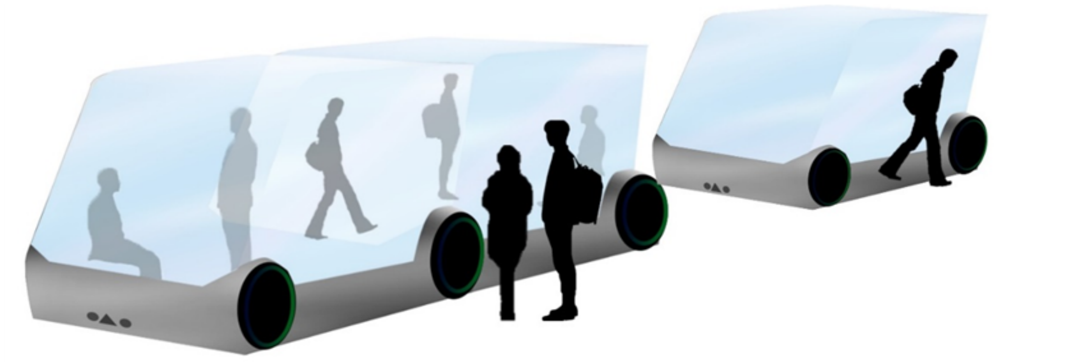

Figure 1: Modular Transit Concept

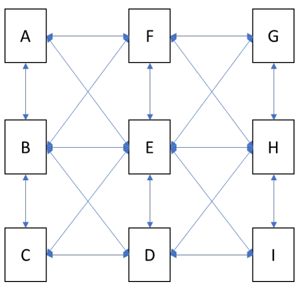

Figure 2: Reference for modular vehicle's route system

stationed vehicles operate within predefined routes and possess a predetermined capacity, signifying their capability to operate within a specific range. This configuration underscores the distinction between the two systems, as the stationary modular transit system prioritizes station maintenance and reliability, making it an essential consideration within the framework of transit infrastructure and operational management. Other than that, the stationed modular transit only can be accessed from its station. So, it can be seen as a replica of traditional public transport.

2.4 Route System

Figure 2 shows stations with different routes available. In a traditional public transport system, such as bus transit, the routes are predetermined and fixed, leading to a less flexible and personalized travel experience for users. For instance, if a passenger, like user X, wants to travel from station A to station H, they may have to wait for a bus at station E and then endure a potentially lengthy journey with stops at stations F and G before reaching their destination, station H. However, the concept of modular transit introduces a more dynamic and user-centric approach. In this system, modular vehicles are strategically positioned at various stations throughout the network. When user X needs to travel from station A to H, they can simply board the modular vehicle that is available at station A. The modular vehicle will then transport user X directly to their destination at station H, without making any unnecessary stops along the way. This on-demand, point-to-point service greatly reduces travel time, eliminates waiting periods, and enhances the overall efficiency and convenience of transit system [11].

According to the depiction in Figure 2, while modular transit systems offer the advantage of traveling directly from one station to another without making any intermediate stops, they still need to adhere to pre-designed routes that pass through specific stations. To maintain a smooth traffic flow, the modular transit system operates with two distinct lanes. The right lane is dedicated to modular vehicles that will be entering the next station for passenger transfer. As a modular vehicle approaches its target station, it seamlessly switches to the stopping lane without disrupting the traffic efficiency of the moving lane. Private modular vehicles, if present, have the option to drive on the moving lane, but they are not required to pair up with other vehicles or facilitate passenger transfers. However, the presence of private vehicles on the road can potentially lead to traffic issues, as it may hinder the pairing process between public modular vehicles, causing delays and inefficiencies in the overall transit system. Hence, careful consideration and management of private vehicles are crucial to ensure the optimal performance of the modular transit network.

In the proposed modular transit system, when a passenger selects their desired destination, a public modular vehicle located nearby will stop in front of the passenger to facilitate boarding. Once the passenger is on board, the modular vehicle will join the existing line of other vehicles and proceed toward the destination. Notably, only the first passenger to access the modular vehicle can select their destination. To illustrate this concept using Figure 2 as a reference, suppose a passenger requests a ride between station A and station B, with the intention of traveling to station H. In this scenario, the modular vehicle will follow the pre-designed route, passing through stations B and E before reaching the destination, station H. If another passenger is already on board and wishes to alight at station E, the vehicle will make a stop at designated station to allow for smooth disembarkation. Alternatively, the second passenger may opt to switch to a different modular vehicle that specifically makes a stop at station E. Furthermore, in cases where a passenger wishes to make an unscheduled stop during the journey, the modular vehicle will adjust its lane accordingly and come to a stop at the desired location. This system exhibits similarities to the functioning of an elevator, where a passenger on the ground floor wanting to go to the 5th floor may need to wait for another passenger who enters the elevator on the 2nd floor with the intention of traveling to the 4th floor [12].

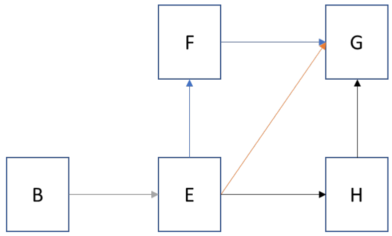

Figure 3: Three ways to travel from B to G

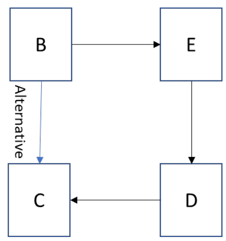

Figure 4: Alternative way to from B to C

In contrast, the stationed modular vehicle that stays in stations travels differently. Passengers can only board it from specific stations, and different stationed vehicles follow different routes. For instance, a stationed modular vehicle departing from B is directed to travel to D via E and then return to B through C.

Case1: As shown in Figure 3, when a passenger wants to reach G from B, he can travel to E and switch to another vehicle that travels to G on the road.

Case2: As shown in Figure 4, when a passenger wants to reach C from B, he can either travel to 2 stations including E, D; or travel in another route system from B directly to C.

2.5 Vehicle Design

The modular vehicle is designed to seat up to four people, with each seat positioned at a corner of the vehicle. Access to the vehicle is provided through four doors, with the side doors allowing passengers to embark and disembark while the front and rear doors are used for exchanging passengers while in transit. The vehicle is 2 meters in height and 1.8 meters in width, with a wheelbase of 2.8 meters. The seats are cushioned without backrests to maximize space efficiency, allowing a single modular unit to accommodate up to eight passengers. However, for private transport, backrests can be added to improve comfort, as shown in Figure 5, where a single modular unit seats a maximum of four people.

The unique feature of modular vehicles is that passengers can easily switch between vehicles while on the move. This is made possible by the exterior design and ”anchor” technology of the modular vehicle. Figures 6 and Figure 7 demonstrate how the ”anchor” technology works by enabling vehicles to connect to each other while in motion, allowing passengers to switch vehicles effortlessly while on the road. The ability to switch between vehicles is essential as passengers can ride any vehicle from a station or roadside in normal circumstances. However, during the pandemic, travel needs decreased significantly, which led to a reduction in the rate of exchange. To explain the ”anchor” in more detail, it is a lock that allows both vehicles to connect to each other, and when the ”anchor” is locked, passengers can switch vehicles with ease [13].

When a vehicle on a straight road decides to change lanes, it unlocks the ”anchor” preventing vehicles in front and behind from attaching to it. If there is enough space for a vehicle to fit between them, the rear vehicle will catch up to the front. The ”anchor” is also disabled when making a turn, preventing passengers from changing vehicles [14, [15]].

3 MATH MODEL OF THE EFFECT OF MODULAR TRANSIT

A mathematical model has been created to analyze the efficiency of modular transportation. The study examines the impact of various numbers of modular vehicles on traffic density and flow during different times, such as normal hours with few modular vehicles, half the total number of vehicles being modular, and all vehicles being modular.

Here are some measurements related to vehicles:
- A car’s length is 4.6 meters.
- A modular vehicle’s length is 2.8 meters.
- The traditional safety distance between vehicles is 23 meters.
- Normally, a 1-kilometer segment of road can accommodate a certain number of vehicles. This number can be calculated using the formula: (1000 + safety distance)/(safety distance + car length).Figure 8 The total number of vehicles on the 1km road segment.

Without traditional vehicles, the total number of modular vehicles filling in the 1km road segment is 357. In traditional cases, a 1km road segment can only hold an average of 37 cars in total. Assuming the average vehicle can have 4 passengers at once, complete modular vehicle traffic can take up to 1428 passengers in total. Not to mention that modular vehicles allow their passengers to move on board.

The traffic efficiency can be calculated based on the equation:

$$E = q * V * T \tag{1}$$

where:

- E= traffic efficiency (veh*km/h)
- q= volume (veh/h)
- v=travel velocity over an extended section of the freeway (km/h)
- T=duration of the time period for analysis of flow (h)

After analyzing Figure 9, we can infer that traffic efficiency also improves as the number of vehicles on the road increases. Consequently, adding more modular vehicles to the mix can further enhance traffic efficiency.

Several research studies have shown that focusing solely on serving the maximum number of ride requests may not always result in high-quality performance for the overall traffic system [8]. Zhang et al. (2020) found that adding more modular transits on roads with insufficient passengers leads to wasted energy. To enhance the efficiency of modular transit, a smarter modular transit system is needed for this purpose [16].

Efficient route planning is essential for improving traffic efficiency in modular transit. It helps ensure smooth and effective transportation by determining the most optimal paths for modular

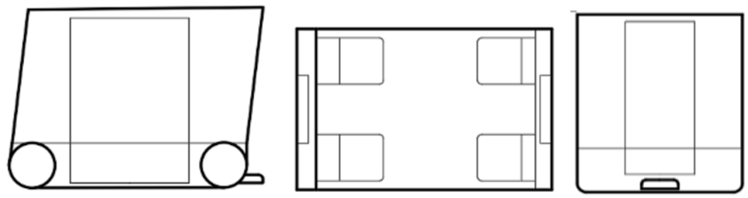

Figure 5: Modular Transit design side view, top view, and front view (from left to right)

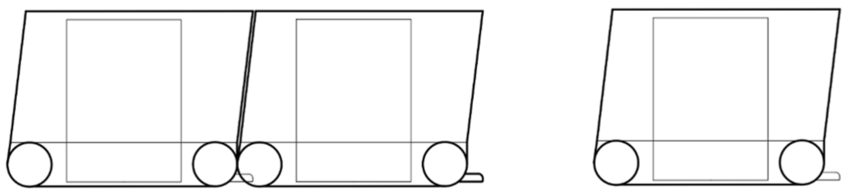

Figure 6: Reference for how 'anchor' works

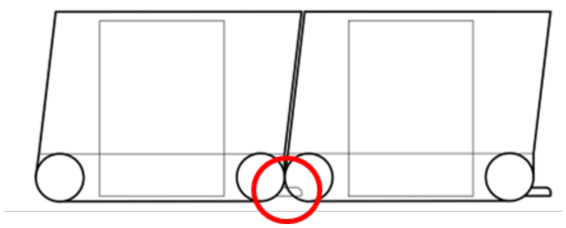

Figure 7: Anchor point of modular transit

Figure 8: shows the result of data calculations using Matlab software.

vehicles to take. Factors such as minimizing travel time, reducing congestion, and enhancing resource utilization are considered. Efficient route planning leads to quicker point-to-point connections, minimizing waiting times for passengers and vehicles. By avoiding unnecessary stops and congestion-prone routes, the system can maintain smooth traffic flow and adapt to real-time conditions. It also prioritizes user preferences, providing a personalized and efficient transit experience. Data-driven optimization utilizing advanced analytics and algorithms enhance the decision-making process, considering historical travel patterns, demand forecasts, and real-time data. In summary, route planning in modular transit ensures traffic efficiency, passenger satisfaction, and operational effectiveness, creating a user-centric and responsive transportation network for urban mobility needs.

As previously stated, modular transit provides door-to-door services, allowing for direct travel to the destination without making stops. Using Figure 10 as a reference, modular transit can travel directly from A to C only requiring 8 points while traditional transit must pass through stop B in order to reach C, resulting in more stops which require 10 points.

This study employs the A* algorithm to simulate route selection planning for modular transit systems, a pivotal aspect in the domain of urban transportation and mobility planning. By leveraging the A* algorithm, known for its efficiency in finding optimal paths in search spaces, the research aims to optimize the route choices of modular transit vehicles, considering factors like travel time, and resource utilization. The study's application of the A* algorithm to modular transit route planning holds promising implications for enhancing traffic efficiency and passenger experience, making it valuable to the field of transportation engineering and urban planning.

Different scenarios of modular transit in traffic systems are simulated using MATLAB, and the optimal route is determined using A* algorithm for every scenario. In this study, 4 sets of simulations that have the most representing value of modular transit are selected. The scenarios are designed as follows, modular transits when delivering different stations, modular transits when destinations are on the same path, modular transits pick up from different locations, and modular transit when breaking from the modular chain.

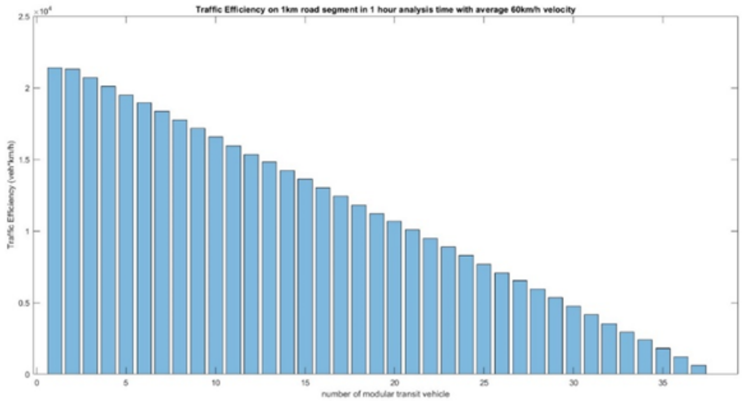

Figure 9: The correlation between the number of vehicles on the road and road efficiency.

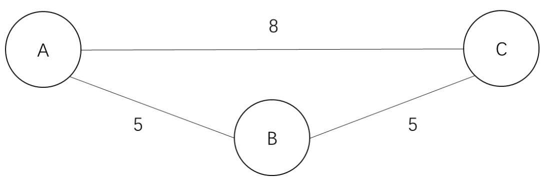

Figure 10: Modular transit path points reference

Each scenario's results are as shown in Figure 11, Figure 12, Figure 13, Figure 14:

This study only selects the classic problems of modular transit, and there are more factors that the study has not considered, such as urban traffic, real-time considerations, traffic laws, etc. In future work, the route planning of modular transit should consider real-time traffic data and each modular vehicle's power sustainability. Furthermore, modular transit's features like switching between cabs and connection between cabs to form modular chains are also a main challenge. In short, the study presents an idea for maneuvering modular transits and its design to support the idea.

4 CONCLUSION

In conclusion, the study introduces modular transit, a new way to travel. This innovative concept has been researched for years, with the idea of switching vehicles on the road first introduced in the 1980s and 1990s. Modular transit is particularly valuable during the pandemic, as it allows for social distancing and improved traffic flow. These lightweight vehicles have a maximum capacity of 4-6 passenger seats, creating a more comfortable and spacious environment than crowded buses or subways.

In order to continue the work on this paper, we will be conducting a simulation on the functioning of modular transit. Based on the research presented, it has been determined that modular transit is a more effective option for urban public transportation than buses. Moving forward, it is essential to consider various factors such as the working environment of modular vehicles, the structure of the vehicle, and its systems. This includes aspects such as the

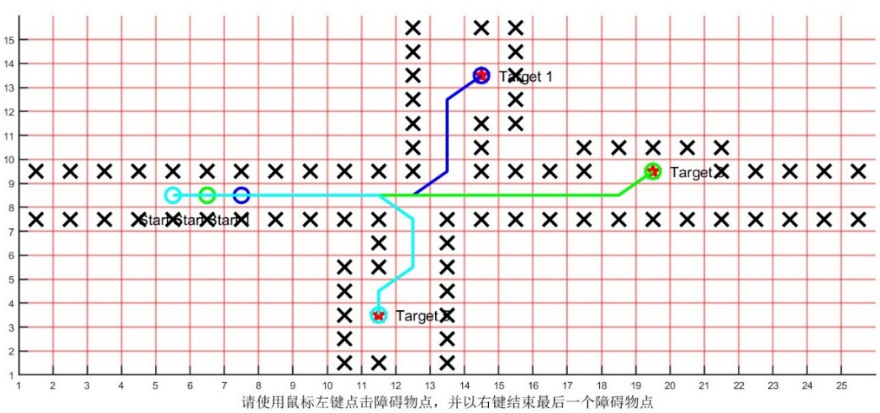

Figure 11: Scenario 1 (modular transit route planning in different destinations)

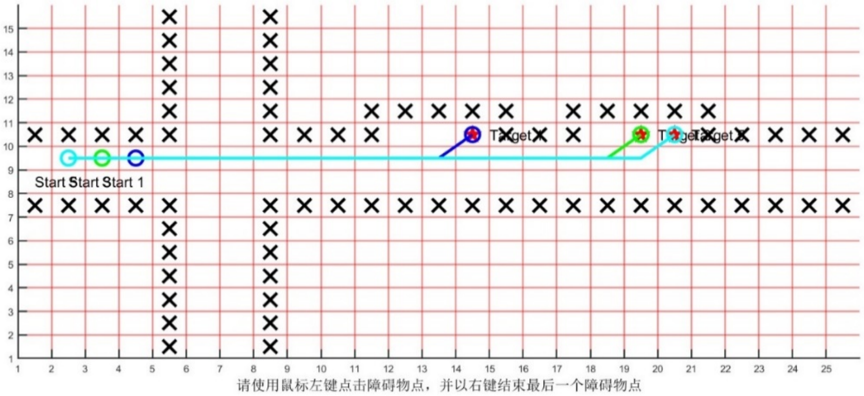

Figure 12: Scenario 2 (modular transit route planning with destination on the same path)

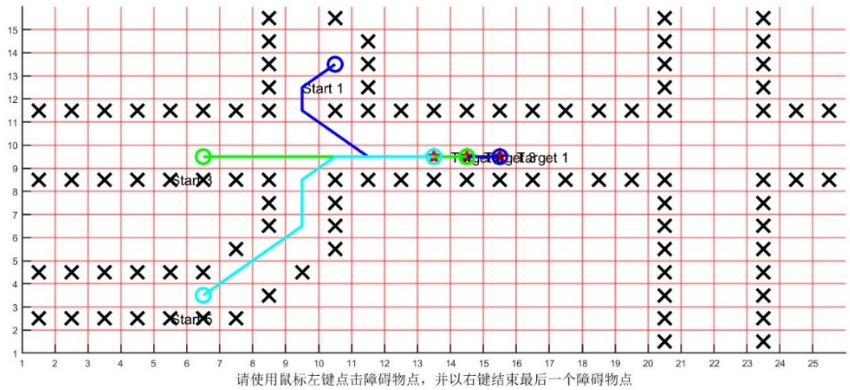

Figure 13: Scenario 3 (modular transit forming chain from different departure locations)

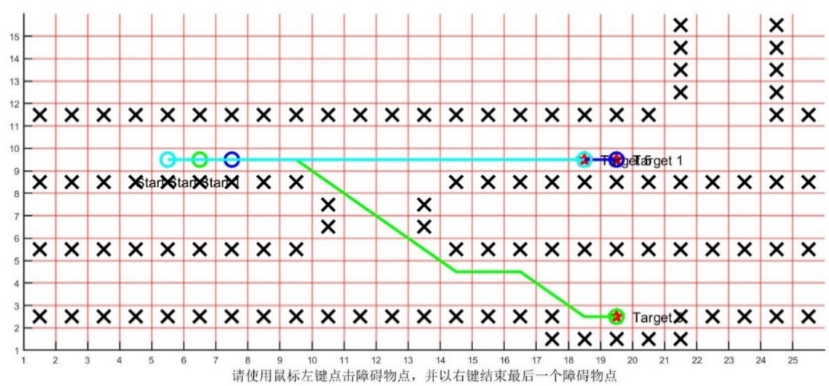

Figure 14: Scenario 4 (modular transit when breaking out from the modular chain)

battery life of the modular vehicle, the time it takes to exchange vehicles at a window, road complexity, weather challenges, and V2X autonomous driving, among others.

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