Research on the Delivery Plan in Suzhou in Jiangsu Province in China

Case: Suzhou Xuantong Precision Tools Co., Ltd.

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Abstract

For enterprises, sudden social changes are an opportunity to seize, but failure to seize will become a challenge for the future. Suzhou Xuantong Precision Tools Co., Ltd. saw this opportunity and wanted to seize, so the delivery plan was proposed as a research project.

The research method is case and quantitative research, and the task is to improve the delivery plan of the case company and obtain the optimal delivery routes based on time cost. What was done was to define the type of problem in order to choose the processing tools, compare the availability of each tool to determine the final used one, which is ArcGIS Network Analyst, and then collect the required data and apply it to the tool after processing to obtain the optimal delivery routes. More importantly, actual trial operation was conducted to verify its rationality. The final result is a delivery plan, including delivery time, delivery personnel, and delivery vehicles.

The research found that the optimization calculated by ArcGIS Network Analyst not only optimized the delivery routes and reduced the delivery costs, but also provided a structure for delivery personnel management, and even benefited the improvement of the urban environment. Of course, considering the cohesion of the company, the method of reducing the personnel needs to be taken as a nonnegligible point when implementing the plan. The research described the entire research process of the generation of an efficient delivery plan, helped improve the efficiency and competitiveness of the case company, and even will bring more business opportunities and benefits to the case company. The research also provided a feasible optimization method of delivery plan for other logistics companies in Suzhou.

Keywords/tags (subjects)

ArcGIS; Vehicle Routing Problem; VRP solver; Delivery Plan; Delivery personnel; Delivery vehicle

Miscellaneous (Confidential information)

None

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1 Introduction

1.1 Current situation in Jiangsu Province in China

On January 8, 2023, the National Health Commission of China officially announced that the "COVID-19 infection" would be changed from a "Category A" disease to a "Category B" disease, meaning that people no longer need to be checked for the "Health code" and "Itinerary code" when entering and leaving public places. China, which has been under control for three years, has been fully open since then. In other words, we are "free". The crowd on the streets is gradually increasing and almost everyone is saying that "the familiar feeling has finally come back" (J. Bai et al., 2023). From the perspective of enterprises, this is also a good opportunity to lean internal management, maintain old customers and find new customers.

As a matter of fact, before the official laws and regulations were promulgated, together with Shenzhen, Hangzhou and other big cities, some cities in southern Jiangsu were first opened up as pilot cities, and almost all enterprises in these cities were eager to find opportunities. A news that a chartered plane from Suzhou to Japan got more than 1 billion new orders and 1.86 billion dollars of intended investment directly topped the hot news search list and ignited the entrepreneurial spirit across China. Therefore, Guangdong Province, Anhui Province and Zhejiang Province were unwilling to lag behind and went to "grab orders" all around the world (J. Bai et al., 2023). It can be seen that even an ordinary company in China cannot "lie flat" because customers need to be found and maintained. Moreover, three years of silence has led to the closure of a large number of enterprises due to their inability to operate, let alone an enterprise located in such a competitive city as Suzhou. At present, opportunities are in front of us. How to make good use of them is the interesting problem for every enterprise.

1.2 Introduction of Suzhou Xuantong Precision Tools Co., Ltd.

Case company is called Suzhou Xuantong Precision Tools Co., Ltd., which is located in Hengjing Street, Wuzhong District, Suzhou.

The company is a small to medium-sized enterprise, which has been in operation for 11 years. Its main business is to sell, produce and process CNC tools. CNC ("Computerized Numerical Control") machine tool is a kind of machine equipped with “computer digital control” system for the production of parts or other machines, and CNC tools are the tools that these CNC machine tools need to use when producing, such as various types of drill bits, milling cutters, etc. The dimensions, accuracy and materials of these tools will have a great impact on the efficiency and results of machine production, so these small tools are of great value (Rattat & Cloot, 2017, Chapter 3).

Figure 1. Examples of the products of the company

In the past 11 years, the company has developed from a small store to a scale that can be partly produced by itself and has assumed the role of distribution, which also has undergone various decisions. It was founded in February 2012 and mainly run as a retail store in the first three years. At that time, the sales model was only that customers bought in the store. Sometimes, when the customer’s factory needed tools but did not have time to pick them up from the store, they would call the company’s salesperson and the company would ask their staff to deliver them. This is the original delivery model that had not formed yet. In this mode, the company did not even have a delivery person, because there were not so many orders and tools needed to be delivered, and also due to the uniqueness of CNC tools, people preferred to go to the store to purchase in person.

After the fourth year of operation, the company accumulated a certain amount of capital, expanded the product scale, and deepened the understanding of the products gradually. So it rented a factory of 500 square meters and hired more than twenty employees, which were mainly responsible for production and processing business. In addition, in order to keep up with the trend of the times, the company also created an online store on the electronic platform and added itself a dealer role to operate, which formed a sales model that combined both online and offline channels. If the order was beyond the scope of Suzhou, it would be delivered by sending a package, while the order which was in the city of Suzhou would be delivered to the customer's door by the employed delivery personnel. By the way, the "scope of Suzhou" here does not include the four county-level cities under the jurisdiction of Suzhou, but only all districts. The specific scope is explained in detail in the data collection section. Returning to this topic, this model let the company gradually accumulate some fixed customers and orders, so a distribution department was also emerged in 2017. In this department, there are now ten employees as the delivery personnel, three new energy vehicles, three oil-fueled automotive and four electrical bicycles. Basically, each delivery personnel is assigned one vehicle and is responsible for the corresponding distribution area.

At the beginning of 2023, China announced the comprehensive opening up, which was the official opening up since its lockdown. This is a rebirth for any Chinese enterprise, and it is also an opportunity for the delivery department of the case company to formulate delivery plan. It is time to consider adopting a new delivery plan. In this plan, there will be a more efficient route, which means less deliver personnel and lower costs.

Electrical bicycle | Oil-fueled automotive | New energy vehicle

Figure 2. Examples of three types of distribution vehicles in the company

1.3 Target of the thesis

The main target of this thesis is to solve the problems existing in the company's delivery plan in order to improve the delivery results and increase customer satisfaction so that the company can seize the opportunity of this era to develop its own delivery situation and attract more customers. On the other hand, from my point of view, through the analysis of the information related to the case company as well as the study and application of a series of knowledge involved in the process of finding solutions, including software learning and application, the ability of information acquisition, analysis, and application can be strengthened, the understanding of logistics professional knowledge can be deepened, and also some new things in the aspect of logistics will be brought into my mind. At the same time, it can also practice my ability to think and solve problems, which is a crucial ability for me in the working life in the future.

In this case, the most challenging problem is the poor delivery efficiency and cost-effectiveness caused by the chaos of logistics routes and uneven arrangement of delivery personnel. Actually, this problem has existed in the case company for a long time. In the first place, the company leaders did not consider too much about the delivery route, and directly divided the whole city into five regions, each of which was in the charge of two delivery personnel. What's more, through my communication with the delivery personnel and my two-month internship experience in the case company, the delivery stage was characterized by unreasonable allocation of deliver personnel. For example, delivery points in some regions were relatively centralized, and some were scattered. For centralized delivery points regions, the delivery tasks of two delivery personnel were not saturated, so there was slack work. On the contrary, regions with the relatively scattered delivery points would make it almost difficult for only two delivery personnel to complete the delivery tasks in one day.

Either of the above situations will lead to the reduction of customer satisfaction and increase the risk of customer churn. Therefore, a delivery plan with efficient delivery routes and appropriate number of delivery personnel will play an important role in solving the delivery effect problems of the case company. Of course, the case company do not completely lack its own expectations for this plan. In summary, the following two points are included: 1. The delivery should be divided into two batches, with the first batch starting from 8:00 am and being delivered by electric bicycles, and the second batch starting from 9:00 am and being delivered by automobiles. 2. The delivery time should be minimized as much as possible.

Hence, in order to achieve this goal, I started by researching the methods or tools that can be used to solve such a series of problems. In this process, I compared the process of using various methods or tools to solve problems, the data required, accessibility, and convenience through reading and learning. After determining the tool, I collected the required data, processed these data according to the software requirements. In this process, I tried my best to make it consistent with the actual situation, and finally put it into the software for actual simulation delivery experiments to determine the optimal delivery routes and obtain the required delivery vehicles and personnel.

1.4 Research questions

The whole research followed the research questions as follows:

- What data is needed from the case company?
- How to optimize the routes to make delivery more efficient?
- What are the advantages and disadvantages of the optimization?

1.5 Research methods

The research method is case and quantitative research. I took an actual company as this case, analyzed the company's environment, and simulated the actual situation using ArcGIS software to find out a possible solution of the company's problems. In this process, I used some simple quantitative methods to calculate and solve problems as well. Finally, I collected feedback from the employees and customers through the actual trial operation of the plan in the delivery department in order to reflect on the optimization, then made a conclusion and completed the whole thesis.

The first chapter is to describe the current situation in Jiangsu Province, company background, the opportunities and challenges the company facing, research methods and put forward the research questions: 1. What data is needed from the case company? 2. How to optimize the routes to make delivery more efficient? 3. What are the advantages and disadvantages of the optimization?

The second chapter is literature review. In this chapter, I talk about some literature reading and knowledge storage related to my topic that I did before the actual implementation, mainly about two contents: last-mile delivery method in the city, vehicle routing problem in general.

The third chapter talks about several Geographic Information System tools for solving the Vehicle Routing Problem, which includes “ArcGIS Network Analyst”, “QGIS Network Analysis” and “pgRouting”. There is a comparison among these tools and the decision of the final selection is made after that.

Chapter 4 is the process description of data collection. After the summary and learning, it is clear that the data required for using this software to handle the problems of the case company can also be listed. The data are mainly collected from the boss and employees of the company, as well as some experience when I worked in the company and the data from government public platforms.

Chapter 5 describes the process of running using the ArcGIS Network Analyst function. Given the obtained data, how to apply it to create a simulation environment in ArcGIS for solving the problem of the case company is the purpose of collecting data. So, it mainly includes three parts: Network Dataset Creation, Attributes Setting, Running.

Chapter 6 is result and analysis. Through the description of the process, a result can be obtained, so first this chapter describes the specific delivery plan calculated by ArcGIS, including what delivery tools were used, how many people, and so on. To test the feasibility, I put the optimization into practice, which was to let the delivery personnel in the case company try the optimization. After that, I got some feedback from them, so this chapter also describes the analysis from the feedback.

Chapter 7 is the “Answers” chapter, which answers the three research questions posed in the first chapter.

Chapter 8 is a conclusion of the whole processes, including the improvement of the shortcomings of the plan and its significance for the real society and future.

2 Logistics in a city

2.1 Last-mile delivery method in the city

The delivery scope of the company is mainly in Chinese metropole Suzhou with nearly 13 million people, which is equivalent to the Last-mile delivery. Therefore, the definition of the last mile will be explained first, and then the research on the delivery method of the last mile will also be discussed.

The definition of the last mile delivery introduced by Motavallian (2019) is “The last transportation of a consignment in a supply chain from the last dispatch point to the delivery point where the consignee receives the consignment.” (p. 106).

From the perspective of development history, Cherry (2003) found that the word “last mile” was originally used in the telecommunications industry to describe the difficulty of connecting end users’ homes and businesses to the main telecommunication network. Since the last “mile” cable or wire had no means of sharing, the installation and maintenance costs of this infrastructure were very high compared to many customers in the trunk line. Later, with the continuous development of the logistics industry, this word was also used in supply chain management. Similar to the telecommunications industry, “The Last Mile” demonstrates the problem of people and goods transportation. For example, goods can be quickly transported by ship, train, or plane to the central hub, however, such conveyance cannot be used to deliver goods to the customer’s door directly. In this situation, some small vehicles must be used as transportation tools to deliver goods to every customer via the city delivery by delivery personnel. This is the last mile.

At present, there has been an increasing amount of literature on the last mile of delivery mode, and at the same time, more and more new technologies and ideas have been propounded. For instance, Nils et al. (2021) realized that the delivery of the last mile brought some troubles to global cities, so more and more new ideas about the delivery method were generated, which also meant that the last mile delivery would be given new concepts. They investigated both existing and innovative methods and paid special attention to the decision-making problems that need to be solved before establishing and operating each method from the perspective of operational research. Finally, they found that most of the alternative delivery methods still require an abundance of additional research and development work, which also indicated the development potential of the delivery method in the last mile in the future.

From the economic point of view, to determine the effects of delivery method, Seghezzi et al. (2022) created a comparison between two last-mile delivery options - parcel lockers and traditional home delivery under the two different implementation environments - urban and rural areas, and then came to a conclusion that that the delivery cost of parcel lockers was lower than traditional home delivery and had nothing to do with the conditions.

From the perspective of green logistics, Boysen et al. (2022) studied the problem of cargo tunnels. They found that using the two-echelon delivery method based on cargo tunnels would be helpful but faced some troubles at the same time. The case in point is when it comes to customers far away from the micro hubs, they should have to use vehicles to complete the delivery task. In addition, it would require excessive use of environmentally friendly vehicles to achieve the expected carbon dioxide emissions. So just like the point Nils et al. (2021) hold, we always need a lot of research and decision-making as the basis before we operate a new delivery mode.

The case company is a small to medium-sized company, so the choice of delivery method is two directions for it. In addition to employing delivery personnel, that is to choose outsourcing delivery. Therefore, the feasibility of using the outsourcing delivery method in the case company triggered my thinking.

In recent years, outsourcing has received widespread attention at home and abroad, resulting related discussions and studies more and more proposed. Moreover, it is currently in the stage of continuous development, from the initial product parts outsourcing to suppliers outsourcing, to the current service outsourcing, and then to further outsourcing in the future. Everything is possible. Take the actual situation as an example, with the swift development of ecommerce, Dolan (2023) pointed out that an increasing number of people were gradually accustomed to using local services provided by some digital platforms. For example, there are “Ele.me” and “Meituan” in China and “Uber”, “Wolt”, “Airbnb” in Europe. These location-based outsourcing digital platforms provided consumers with services such as taking a taxi, ordering food to home or office, and even hiring someone to help clean their house or take care of their baby, which are only unexpected to people, not impossible to them. As the old Chinese saying goes, it is easy when one's living condition ascends from economical to luxurious; conversely, that becomes hard (Sima, 1936). Once people are used to enjoying these conveniences, it is difficult for them to return to the former way. Even the CNC tool industry where the case company is located is not able to avoid this trend. However, compared with other products or services, the CNC tools in the same unit is a higher price product, which seem that the quantity is only a little but actually it is worth a lot of money, meaning there will be greater risks (Maes, 2021). The benefits brought by outsourcing are indeed attractive to every enterprise, but once the risks brought by some high-value enterprises using outsourcing are considered, these benefits may become not so important. As the conclusion drawn from the research (Huq et al., 2020), HVM companies preferred the insourcing strategy, because the risks caused the benefits brought by low costs to became unnecessary.

Outsourcing may be a huge challenge for the case company, so in this case, the method of employing delivery personnel was still chosen for the last-mile delivery of the case company instead of outsourcing.

2.2 Vehicle Routing Problem in general

In the case, the company has a team of delivery personnel who need to deliver the order to each customer and the task of mine is to ensure that the total time is as short as possible. This problem of route optimization can also be called **Vehicle Routing Problem (VRP)**.

VRP is a well-known combinatorial optimization and integer programming problem which asks "What is the optimal plan of routes for a fleet of vehicles to traverse in order to deliver to a given group of customers?" and it is the promotion of the **Travelling Salesman Problem (TSP)** (Labadie et al., 2016). The goal is to find the optimal plan so that all customers can be satisfied while the total distance or total time traveled by the vehicle is the shortest (Braekers et al., 2016).

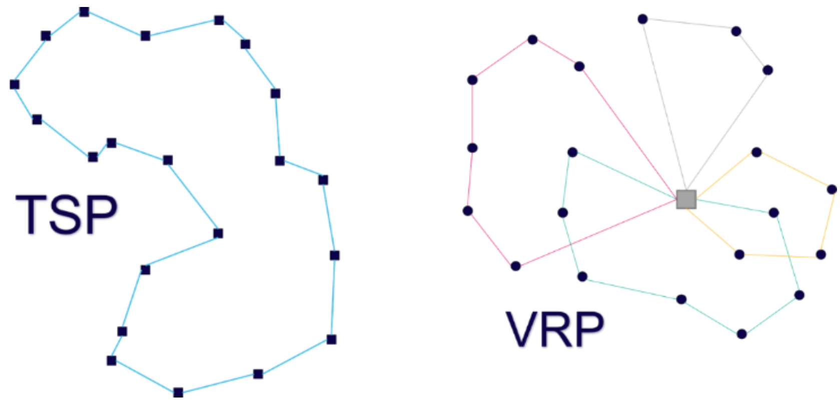


Figure 3. Outline of TSP and VRP

From a historical perspective, it first appeared in a paper by American scientists Dantzig & Ramser (1959), in which the first algorithmic approach was written and was applied to petrol deliveries. This is the early VRP problem. This problem can be described as finding "a way to assign stations to trucks in such a manner that station demands are satisfied and total mileage covered by the fleet is a minimum" (p. 80). Compared with the current concept, there is basically no significant difference.

Subsequently, the VRP has been widely studied and applied (Konstantakopoulos et al., 2022). In addition to the most basic vehicle routing problem (VRP), there are many variation problems (Labadie et al., 2016), such as Capacitated Vehicle Routing Problem (CVRP), Vehicle Routing Problem With Time Windows (VRPTW), Multiple Depot Vehicle Routing Problem (MDVRP), Vehicle Routing Problem With Backhauls (VRPB), and so on. Of course, variation problems for different research objects may also vary, such as the Electric Vehicle Routing Problem With Time Windows (EVRPTW) studied by Lin et al. (2022), and the Dynamic Vehicle Routing Problem with Time Windows (DVRPTW) studied by Yang et al. (2017). The case has not only capacity constraints but also a time window, so it is a relatively complex VRP.

As problems were proposed and studied, the methods for solving the problems were naturally explored. What we all know is that "almost all vehicle routing and scheduling problems are NP-hard and hence unlikely to be solvable in polynomial time." (Lenstra & Rinnooy Kan, 1981, p. 3), and VRP is no exception, the larger its scale, the greater its difficulty. Therefore, many scholars are committed to finding efficient algorithms to solve this problem. Among them, such methods described by Wolsey & Nemhauser (2014) like Accurate Algorithms, mainly including Branch and Bound Approach, Cutting Planes Approach, Network Flow Approach, and Dynamic Programming Approach, can be used to obtain the optimal solution of small-scale VRPs.

However, as Braekers et al. (2016) expounded, when faced with a large-scale problem, these methods will not be sufficient to support, which requires the application of metaheuristics and heuristic algorithms. Of course, among the metaheuristics and heuristic algorithms, there are also some commonly used algorithms, such as linear programming, genetic algorithm, simulated annealing algorithm, particle swarm optimization algorithm, ant colony optimization algorithm, and other algorithms. These algorithms iteratively improve the solution by making small modifications to the route until a satisfactory solution is found.

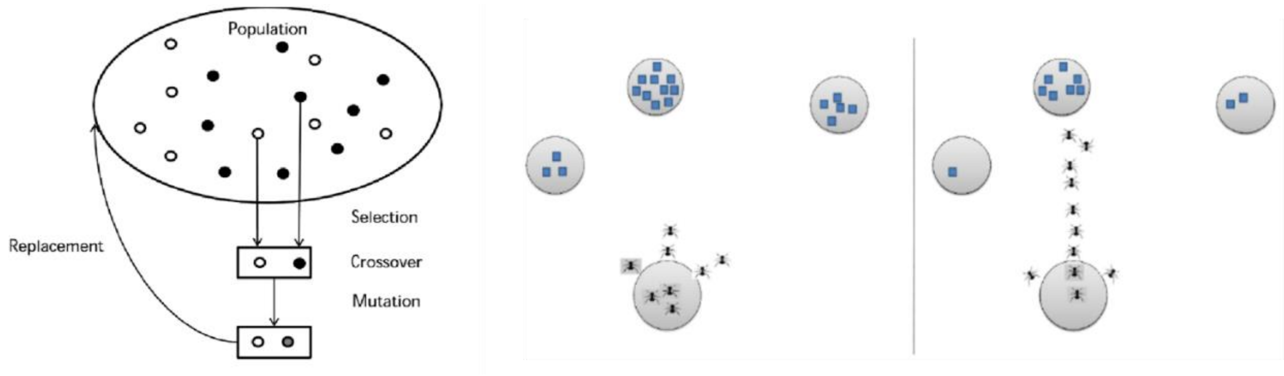


Figure 4. Examples of principle illustration – GA (left) and ACO (right) (Labadie et al., 2016)

In recent years, with the rapid development of computer technology, people are increasingly concerned about using machine learning to solve VRP (R. Bai et al., 2021). For instance, in order to transport blood samples from clinics to centrifugation centres, Elalouf et al. (2021) presented a novel simulation-based approach to the VRP, which was designed and implemented in MATLAB, a commonly used mathematical calculation software. They wrote MATLAB code through the optimization toolbox to solve the model, and finally acquired an optimal blood sample collection and distribution plan through comparison of different strategies and plans.

What attracted me more was that Joel (2019) pointed out that the routing problems can also be solved through network analysis using GIS tools combined Python or other languages. For example, Omobepade et al. (2021) used the ArcGIS network analyst tool to model and analyse the transportation network, mainly assessing the transportation logistics for prospective consumers and marketers of white shrimp (Nematopalaemon hastatus) within a 500 km buffer to processing and marketing areas in Ondo State, Nigeria. Finally, while solving the routing problem of distribution, they optimized the transportation network, reduced the logistics costs, improved the market competitiveness of white shrimp prospective shrimp marketers, and even provided a guide to consumers within the 500km buffer who are interested in accessing this highly nutritional species and other aquatic products from the processing and marketing areas for effective trade and marketing.

As a consequence, GIS tools with VRP solver were selected as candidate tools for solving the case problem.

3 Geographic Information System (GIS) tools

There are lots of GIS tools available for solving the routing problem like this, I took the following three common tools as candidates for handling the case problem: “ArcGIS Network Analyst”, “QGIS Network Analysis” and “pgRouting”. Therefore, I studied and compared various aspects of these three tools, and finally found out the tool used to solve the case problem.

3.1 ArcGIS Network Analyst

“ArcGIS Network Analyst” is an extension of Esri’s products which is a commercial software that requires a license fee. As the name implies, it provides network-based spatial analysis tools for solving complex routing problems. What’s more, it uses a configurable transportation network data model, allowing organizations to accurately represent their unique network requirements, such as route optimization, location allocation, and resource allocation.

As Allen (2013) described, users can create and manage network datasets, automatically generating corresponding layers through this function. And then several operations can be done in this layer, for example, paths and locations analysis, network accessibility and capacity evaluation, resource allocation and planning optimization, and so on. When solving a problem, multiple path analysis algorithms can be taken into consideration, such as the shortest path, the fastest path, or the most cost-effective path, all of which depend on the needs and thoughts of users.

In addition to the basic functions mentioned above, it also provides many advanced functions. (Gorr & Kurland, 2021). One example is network obstacle analysis. While creating the corresponding customers (Orders), we can also create obstacles (Breaks). In reality, the possible scenario is a sudden road repair, which means that the road is temporarily blocked. In this way, the final route we obtain after running will avoid the obstacles and also be the optimal route. What's more, the priority of roads can also be arranged, for example, users can set a priority to take higher-level roads so that when facing two equally accessible roads during operation, the higher-level road will be preferred. Of course, corresponding service areas can be constructed and analyzed. All of these can be achieved through ArcGIS Network Analyst.

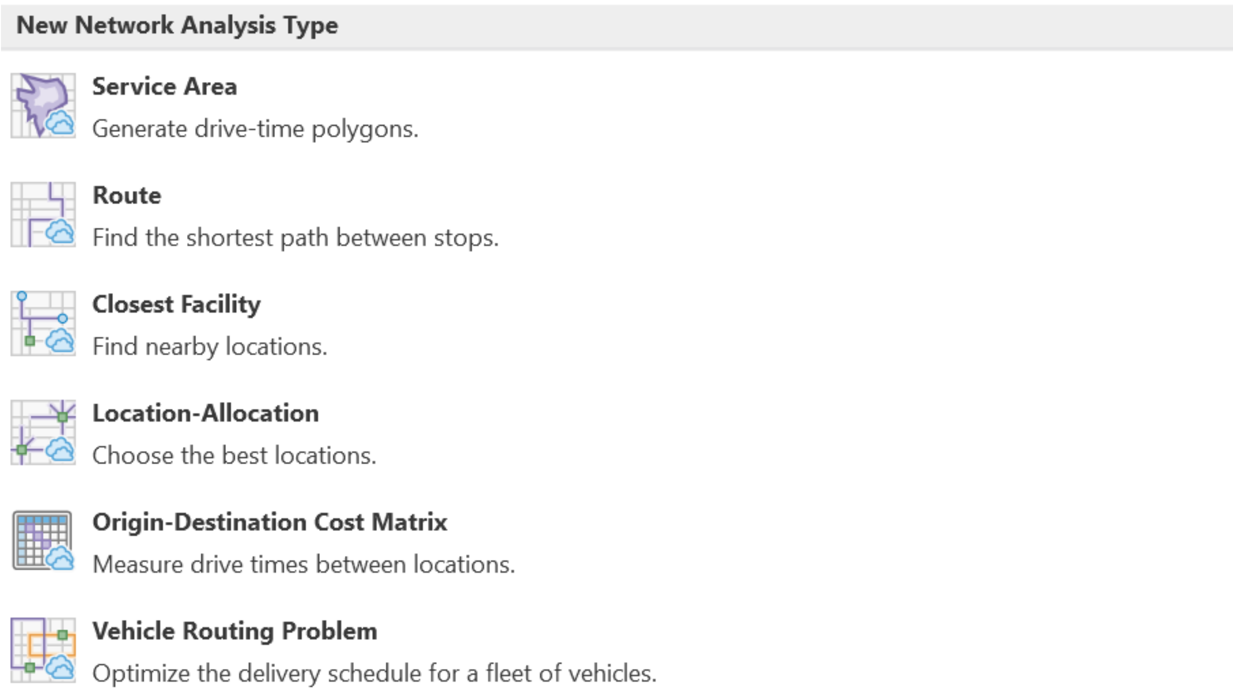


Figure 5. Network Analysis types in ArcGIS pro

As shown in Figure 5, VRP is one of the problem-solving types in ArcGIS Network Analyst that can be used for delivery route analysis. In this layer, attributes such as traffic conditions, turning restrictions, and vehicle restrictions can be prepared in the network dataset, and then the VRP solver can be used to directly figure out the optimal goods transportation route.

3.2 QGIS Network Analysis

As stated in the official document published by QGIS (Thiede et al., 2019), QGIS Road Graph Plugin was originally a plugin for QGIS, which is a free and open-source cross-platform desktop GIS application that supports viewing, editing, printing, and analysis of geospatial data. In the latest version (Thiede et al., 2023), it has been integrated into the Processing tool part, so it is no longer necessary to install the plugin separately. It has route calculation and network analysis functions and is an open-source tool that anyone can use and modify for free. However, before running the function, Open Street Map (OSM) or other network data needed to be input, so that the road network can be generated, and the shortest path, shortest distance, or shortest time from one location to another can also be calculated.

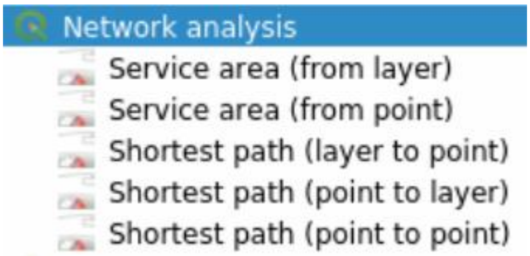


Figure 6. Network Analysis types in QGIS

Joel (2019) pointed out that QGIS plugins written in Python or C++ can geocode using the Google Geocoding API, perform geoprocessing functions like those of the standard tools found in ArcGIS, and interface with other databases. Besides, its interface design is very intuitive, making it easy for users to get started and operate. At the same time, QGIS Network Analysis also has a lot of functions that can be implemented, such as driving route planning, public transportation route optimization, traffic evaluation, and so on.

3.3 pgRouting

As introduced by Obe & Hsu (2017), pgRouting is an open source routing algorithm library based on PostgreSQL or PostGIS, which extended the PostGIS or PostgreSQL geospatial database to provide geospatial routing functionality and provided an efficient way to perform spatial analysis and route lookup. Originally, “PgRouting” was called “pgDijkstra” because it only used the Dijkstra algorithm to search the shortest path. Later, due to other functions added, “pgDijkstra” was renamed as “pgRouting”. At present, in addition to Dijkstra algorithm, pgRouting also includes A* algorithm, Yen’s Algorithm, etc. It can be used to calculate the shortest or fastest path between two points, and meanwhile, different route types can also be taken into consideration such as vehicles, public transportation, or just walking. What is more commendable is that pgRouting is able to add various conditional restrictions, such as vehicle steering restrictions, driving speed, congestion, and so on, bringing about a more real-life simulation.(Obe & Hsu, 2017).

When it comes to solve the VRP problem (Corti et al., 2014), pgRouting simulates the delivery problem by adding entities such as vehicles and delivery points to the road network, and then continues to set restrictions on the vehicle’s carrying capacity or on the arrival time of the delivery point so that the maximum capacity of the vehicle will not be exceeded while meeting the delivery requirements, and the delivery point can be similar to the running time in real life. After that, the optimal delivery route will be directly figured out though running under the set restrictions.

From this point of view, pgRouting is very similar to ArcGIS Network Analys, so they may treat each other as their own competitor (Joel, 2019). The most obvious difference between them is that pgRouting requires users to input code by themselves to run the tool, which results in users must have some basic knowledge or relevant experience in computer programming, while ArcGIS is relatively less required.

3.4 Comparison summary

By using GIS tools such as these, delivery routes can be optimized to improve delivery efficiency and reduce transportation costs.

When it comes to their respective advantages and shortcomings, the commercial tools, such as “ArcGIS Network Analyst”, typically have richer features and a more friendly user experience than open-source solvers. And they also offer customer support and training, which can be beneficial for projects with a tight timeline or limited expertise in the software. However, commercial software is more expensive, and the cost may not be feasible for smaller projects or organizations with limited budgets. At the same time, open-source VRP solvers like “pgrouting” and “QGIS Road Graph Plugin” are free to use, and they can provide a cost-effective solution for small to medium-sized projects. They are also highly customizable and can be modified to fit specific project requirements. However, open-source solvers require more technical expertise to use effectively, and they may not have as many features as commercial software.

Fortunately, JAMK has the license for “ArcGIS Network Analyst”, so I can use this commercial tool as a JAMK student in this case for free, regardless of cost and technical proficiency.

4 Data needed for analysis in ArcGIS and trial operation

4.1 Data Processing and Analysis steps in ArcGIS in general

According to the guide book written by Gorr & Kurland (2020), ArcGIS provides a variety of tools for processing data. Before VRP analysis, the collected data needs to be processed accordingly so that an efficient network dataset can be built successfully. This network dataset is a dataset containing information such as routes, directions, and traffic restrictions.

Therefore, in the data collection phase, the data should include road information, traffic restrictions, vehicle speeds, etc. One alternative channel for obtaining these data can be to extract directly from existing GIS data or open data sources, and the other can be collected through surveys in this field (Corbin, 2018).

Corbin (2018) also pointed out that commonly the relevant data obtained through the above channels requires to be processed correspondingly, such as cleaning, transformation, or integration, which belongs to the scope of data editing, means that it is necessary to open the editor during operation. By the way, in order to check the feasibility of the edited network, topology can be created to verify by setting certain rules. After that, a network dataset for it can be created by users. All of these operations can be completed in ArcMap or ArcGIS pro. What is the most significant thing here is that the selection of geographic coordinate system should be paid more attention by users, as different geographic coordinate system uses different units for measurement and counting. What’s even worse, if the data and dataset are located in different geographic coordinates, they cannot be displayed on the same layer, which directly affects subsequent analysis. At the same time, network attributes should be defined, including speed, direction, traffic restrictions, travel mode and so on. (Corbin, 2018). In this way, a dedicated network dataset is successfully constructed.

As instructed by Gorr & Kurland (2021), the operations after constructing the network dataset will be relatively uncomplicated. Due to the support of ArcGIS's Network Analyst function, a VRP analysis layer will be automatically created by selecting the type of VRP. In this layer, users can complete the steps of creation and attribute setting of orders and departure points based on the obtained customer data and terminal data, then route attributes setting step based on real vehicle conditions, and finally travel mode selection step from the previously set modes or creating a new one. Meanwhile, in order to avoid unnecessary errors and ensure that the results after running are more convenient for comparison, the units of time and distance cannot be repeatedly confirmed too much. After all of the above steps are set up, through "Run" button clicked and a period of time given by the user, ArcGIS will figure out the optimal delivery routes based on the conditions set previously.

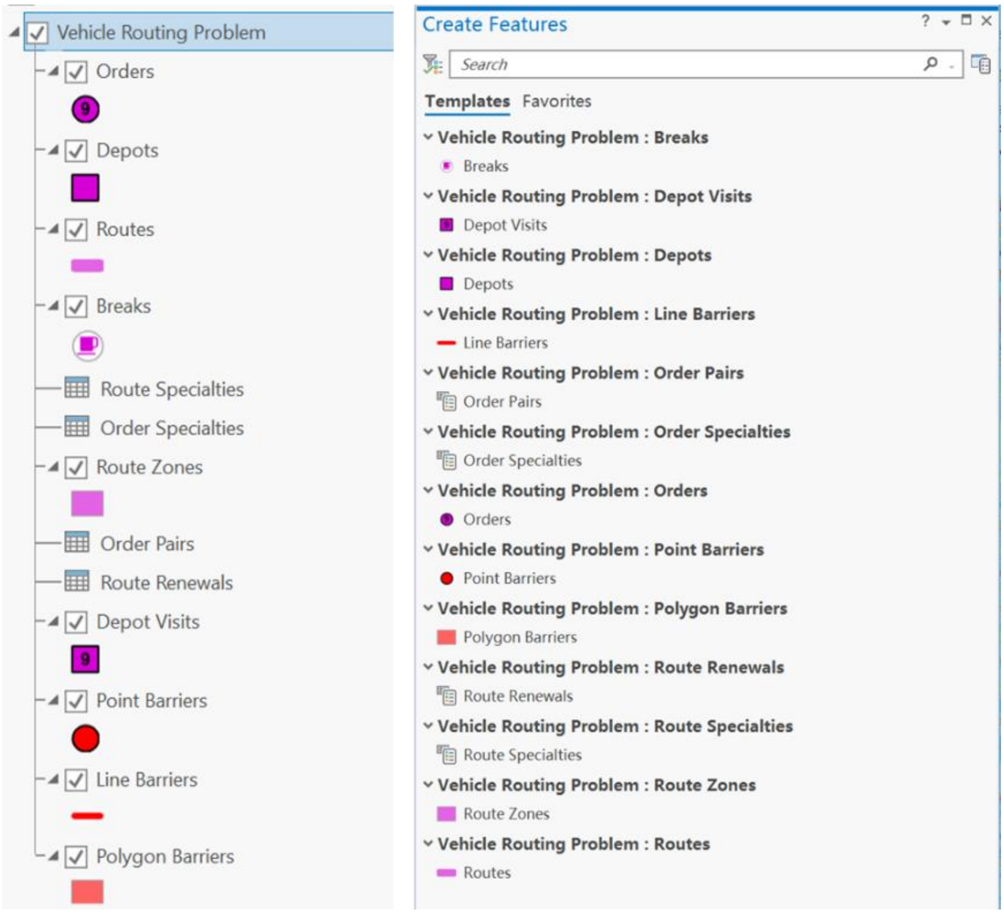


Figure 7. Features in VRP analysis layer

4.2 Data Collection and Preparation

After studying and summarizing the theory and software above, I have decided to use the VRP function in ArcGIS Network Analyst to solve the problem of the case company. This section mainly describes the collection of data, and all the data I need can be divided into two categories: basic data and feedback data after implementation.

4.2.1 Basic data

Basic data mainly refers to the data that needed to be used in network analysis, which was roughly divided into the following four types in the case: 1. Suzhou Road Data; 2. Order Information; 3. Delivery personnel information; 4. Vehicle conditions.

Suzhou Road Data:

Road data within the Suzhou area were obtained from official website of the open-source map, OpenStreetMap (OSM). Since the whole city of Suzhou also includes four county-level cities within its jurisdiction: Changshu City, Kunshan City, Zhangjiagang City and Taicang City, and the case research area only included the district area, I tried to narrow the extraction range, and used the export channel “Overpass API” provided by the OSM to obtain the data of the research area in the “osm” format.

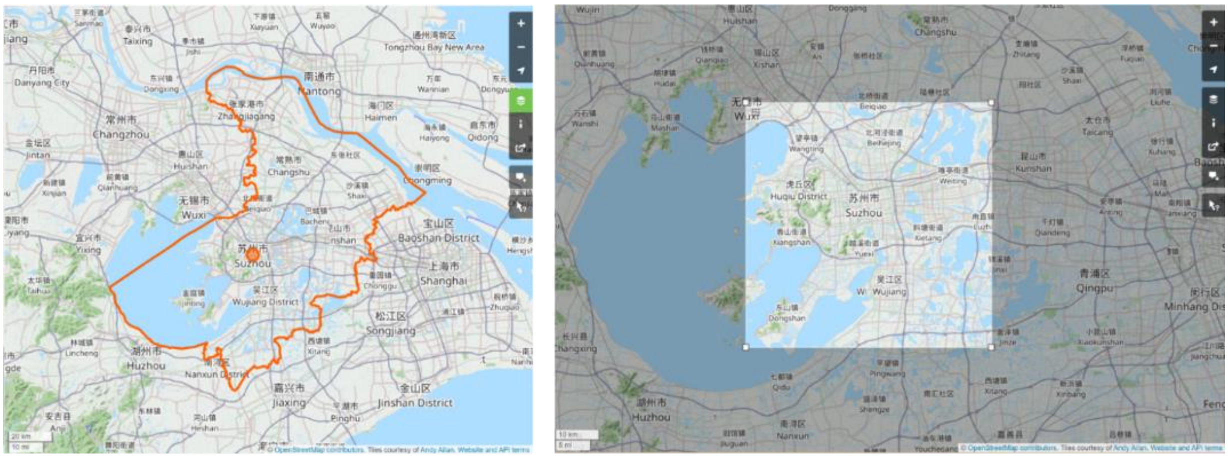


Figure 8. Suzhou City (left) and Extraction Scope (right) from OSM

It should be noted that the data in ArcGIS is in the “shp” format, and the “osm” format cannot be directly used, which leads to the need for format conversion. However, do not worry too much about this issue because ArcGIS has taken this issue into account for users. What I only need to do is to use the “load osm file” tool in ArcGIS’s OSM plugin tool to directly convert the obtained “osm” format data into a “shp” format that can be used for subsequent network analysis. The following figure shows the converted elements.

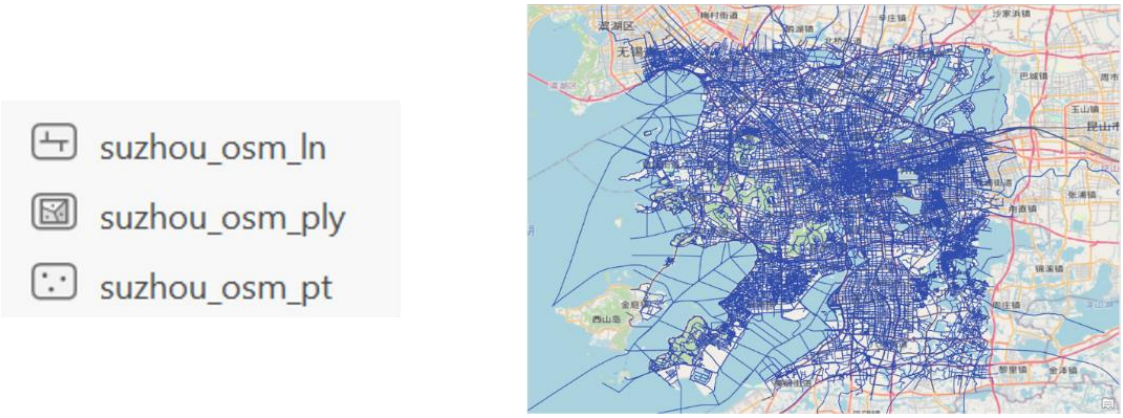


Figure 9. Available data after conversion (left) and overview of data in line (right)

From the left side of Figure 9, the converted data consisted of points, lines, and surfaces. Specifically, they included roads, railways, waterways, natural areas, buildings, boundaries, land uses, and other detailed elements. The useful data for me was only a part of the highway, so the first step in processing was to selection. And selection step was done twice, the first-time selection was to select line data from points, lines, and surfaces, which removed point and surface data such as building and facility points. And the second time selection was to select the required road based on the level of highway from the line data. According to the company’s requirements, two network data sets were needed, including bicycle roads and vehicle roads. Therefore, the roads I selected are shown in the following figure. The classification of roads will be mentioned in the following processing steps. In this way, the road data acquisition from OpenStreetMap was completed after the selection step. Of course, I also combined it with AMAP in the processing steps to make it more realistic.

Highway Level	Link
motorway	motorway_link
trunk	trunk_link
primary	primary_link
secondary	secondary_link
tertiary	tertiary_link
residential	
cycleway	

Table 1. Highway type after selection

Order Information:

Order information was the information of those fixed order of the case company, which referred to the orders that need to be delivered every day. There were two channels for obtaining this information, one was the case company and the other was the delivery personnel.

The information provided by the company included customer address, the delivery time range allowed by the customer, order quantity, and weight. Among them, what I would like to explain is the range of delivery times allowed by the customer, which is called "TimeWindow" in the attribute table of "Orders" in ArcGIS, following the "ServiceTime" and referred to the specific time when the service starts or ends.

The information provided by the delivery personnel was about the usage time, which is called "ServiceTime" in the attribute table of "Orders" in ArcGIS. This time referred to the time from when the delivery personnel arrived at the designated location and got off the vehicle, until they returned to the vehicle and departed to deliver the next order. Simply understood, it could be the customer's inspection time.

Delivery personnel information:

The delivery personnel information could also be referred as the company delivery related information, which was mainly collected in order to set the attribute table of "Depots" in ArcGIS.

Luckily, the attribute table of "Depots" is relatively simple, and this information mainly included the location of the company and the working hours of the delivery personnel, which were provided by the company.

Vehicle conditions:

The collection of vehicle condition data was aimed at setting the attributes of "Routes" in ArcGIS. One route in the attribute table referred to one vehicle, so the information included the loading limitations of the quantity and weight of the vehicles, loading time, unloading time, earliest and latest departure time, fixed cost of the vehicle, unit time cost, and unit distance cost. These data were provided by the case company.

The above is a description of the collection of the basic data used to calculate the optimal delivery path in the VRP solver in ArcGIS in this case.

4.2.2 After the implementation

Situation	Grade (max 5)
1. Punctuality	
2. Order task completeness	
3. Reasonableness of order task allocation	
4. Suggestions and ideas	

Table 2. Feedback form

Although the results of software are generally much more accurate than manual calculations, this does not mean that the results are perfect. Therefore, after the final calculation, I set up a feedback stage to ensure that this delivery plan can pass the test of actual situations. This way, the risks faced when officially launched in the future can be reduced.

The specific feedback stage was as follows: after figuring out the optimal distribution route through ArcGIS software, I provided the plan to the case company so that the plan could be entered into the trial operation stage and then a feedback form provided to the delivery personnel demonstrated the points where the route needed to be improved. After that, I tried to make corresponding modifications to the data based on feedback before running it, checked the extent to which the plan had been affected, and then considered whether or how to modify it.

In addition, due to time constraints, the feedback phase was set to last for one week. Due to distance issues, the collection method was mainly online. I will mention the issues and explanations in the feedback form together in the final analysis of the feedback.

5 Making the analysis in ArcGIS

With the above data, the problem could be started to be solved. Due to the company's requirements, the first batch of deliveries starting from 8:00 am should be delivered by electric bicycles. After completion of the first batch of tasks, these electric bicycles would be used to manage some sudden orders. The second batch should be delivered by fuel automotives or new energy vehicles starting from 9:00 am. Therefore, two layers were initially built and analysed in sequence. The first layer included cycling roads to figure out the first batch of delivery orders and corresponding routes. The second layer was the car roads in order to find the delivery route of the remaining orders. According to the table 3, it could be divided into three steps when using the ArcGIS Network Analyst solver: 1. Network Dataset Creation; 2. Attributes Setting; 3. running. This chapter is a detailed description of how these three steps were conducted.

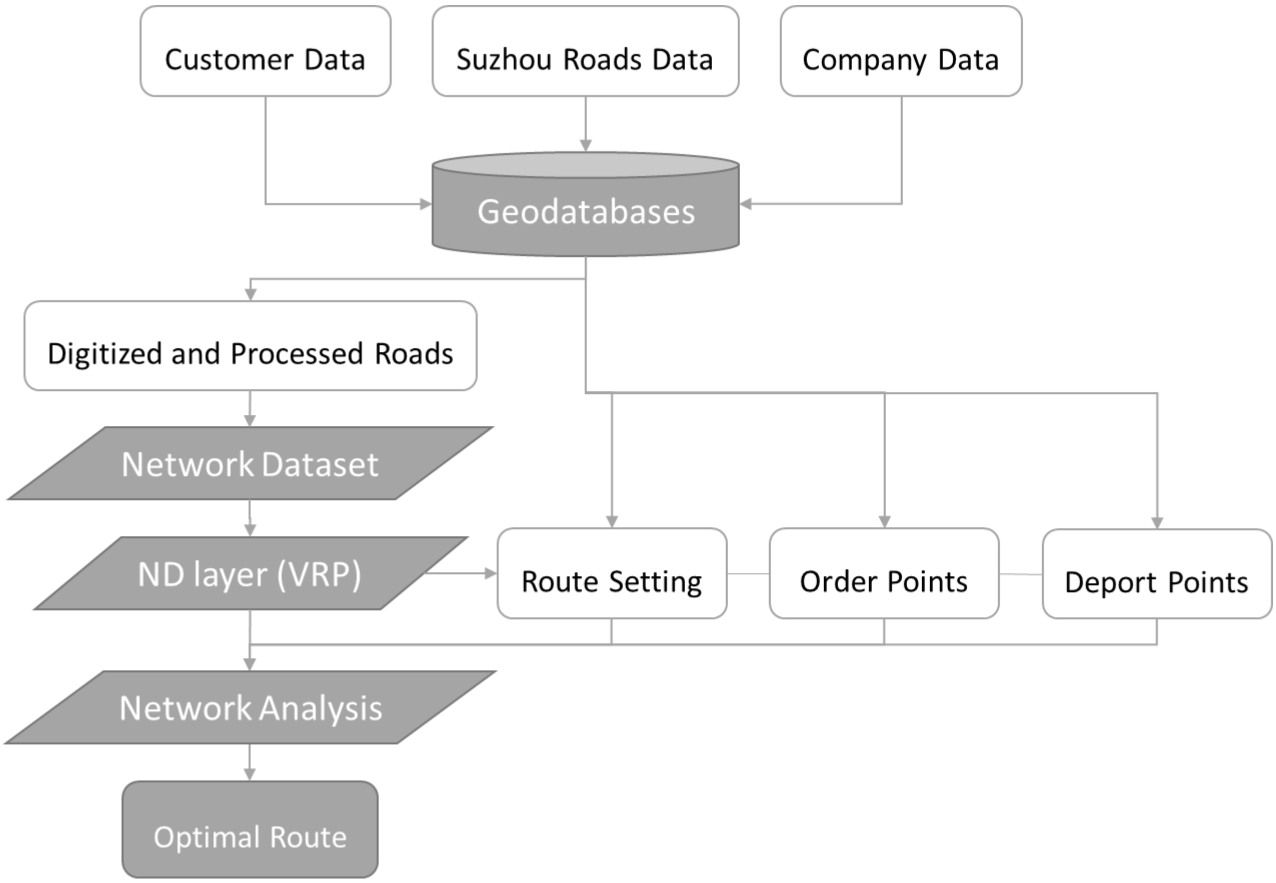


Table 3. Overview of solving process

5.1 Network Dataset Creation

The most important element in the construction of a network dataset for solving the case problems was road network. Although the road data had been filtered in the steps of data collection and preparation, this network could not be directly created as a network dataset because the various roads in this network had not only not been checked for connectivity, but also had not been set for the speed of the roads, making it impossible for such a network dataset to be used for vehicle routing analysis. As a consequence, the first step in creating a network dataset was to process the roads.

First of all, project the geographic coordinate system. The default coordinate system in ArcGIS was the geographic coordinate system "WGS 1984", which used the ellipsoidal surface as the reference plane, the normal as the basis, and the longitude and latitude to represent the position of the ground point on the ellipsoidal surface. However, what we analyzed should be a plane, so it should be projected into the projection coordinate system. It was important to note the selection of the region here. According to the announcement of the Suzhou Municipal People's Government (Su Fu Gong, 2020), the central longitude of Suzhou is "120° 47' 00" east longitude", and the projection coordinate is "WGS 1984 UTM Zone 51N". Hence, it was projected into this coordinate system.

The second step was to break the intersecting lines. Due to the fact that each road was separated in the network, even the roads that were on the ground and able to pass in reality were in an impassable state, so it was necessary to process the roads by breaking the intersection lines. This can also be also divided into two types. One type is the roads on the ground, which were all passable, and the roads in the electric bicycle layer was of this type. For this, there were two main operating steps: select all roads except for "motorway" and "trunk", and then select "Planarize" in the edit area. This way, the intersection lines of the selected features were broken, resulting in a road network that extended in all directions. Another type includes highways and elevated roads in addition to some roads in the first type, such as "motorway" and "trunk", which also include some tunnels, and the vehicle layer in this case was of this type. This type is only interrupted where it is able to pass. The operation was similar to the first type, but more patience and careful screening were required during the process. In special circumstances, such as elevated connections and elevated roads, elevated connections and ordinary roads, the intersection lines of them need to be broken so that the network can be run smoothly. Last but not least, check the roads. If it was an impassable intersection or a T-junction, what I did was just merging. Of course, it can also be checked by creating a topology. These two feature datasets can be separated by exporting data after all roads have been processed, or they can be separated first and processed separately before processing. I chose the former and named them "bicycle_roads" and "vehicle_roads". For the sake of clarity, the level of highway in "bicycle_roads" layer included "primary", "secondary", "tertiary", "residential", "cycleway" and their links. The level of highway in "vehicle_roads" layer of included "motorway", "trunk", "primary", "secondary", "tertiary", "residential" and their links.

Step 3, set the traffic speed and travel time. According to the second requirement of the case company, the main cost should be the time. But the problem I faced was that it was not possible to directly obtain the travel time on the road. Looking back at the data I owned - the length of the road, in this way all I need to know was the speed so that the travel time could be indirectly calculated through the mathematical formula of "time equals distance divided by speed". According to the statement made by the Municipal Public Security Bureau (2016) and in combination with the constantly updated road information from the Suzhou Municipal People's Government, the vehicle travel time settings for each level of highway in “vehicle_roads” are shown in the table below. Besides, it should be noted that the units in this coordinate system were meters and minutes, while the units of the obtained speed were “km/h”, which should be converted. For “bicycle_roads”, the safe speed for electric bicycles is “15km/h”, so all roads were set to “250”.

Highway Level	motorway	trunk	primary	secondary	teriary	teriary_link	residential	Other link
Speed (km/h)	100	80	55	50	40	30	30	40
Speed (m/min)	1666.666	1333.333	916.666	833.333	666.666	500	500	666.666

Table 4. Speed setting in “vehicle_roads”

Finally, create the network datasets separately. What I did for both was to input the network into the feature dataset of a new geodataset file. After that, the network datasets were created by the “Create Network Dataset” tool and the networks were built by the “Built network” tool.

5.2 Attributes Setting

After the network dataset was created, the most basic first step was completed. Next, the second step towards success is to set attributes and parameters.

In order from the outside to the inside, the first set was the attributes of the network dataset created in the previous step. The most important thing here is the setting of travel modes. Through the “properties” sheet, it will be found that the default cost is distance. Therefore, I first created a “time” in the cost area and then added it to the newly created travel mode. This way, the travel mode had both time and distance costs. For “bicycle_roads”, “U-Turn” was set to “all”, and “type” was selected “walking”. For “vehicle_roads”, “U-Turn” was set to “Dead-End and Intersections” and “type” was selected “driving”.

After opening the analysis layer, it is the turn to set the attributes of the orders, deports, and route. The first was the “bicycle_roads” layer. Based on the obtained data, the position of the deport point (case company) and order points (customer) were placed. Afterwards, in the attribute table, the corresponding attributes were filled in by referring to the obtained data. There are some explanations I want to add in this section. For the order section, there were a total of 45 customers, so I numbered them by “C1, C2... C45” in order of their geographical location, from north to south and from west to east. By the way, “DeliveryQuantity_1” here referred to the specific number of pieces, and “DeliveryQuantity_2” referred to the weight in kg. For the deport section, the main attribute is the “TimeWindow”, which was set to two periods based on the working time of the case company, namely 8:00 to 11:30 and 13:00 to 17:30. For the route part, it can also be described as the vehicle situation. As mentioned above, the company has four electric bicycles, so here were four routes named as “B1, B2, B3, B4”. An electric bicycle can carry up to 300 pieces or 10kg of products, so “Capacity_1” and “Capacity_2” were set to “300” and “10” respectively. In addition, the “MaxTotalDistance” and the “MaxTotalTime” were also set to ensure that they do not exceed the allowed range.

When it comes to the “vehicle_roads” layer, the operation was the same as what I did in the “bicycle_roads” layer, but there were some differences in parameter settings. It was also set based on the obtained data, but the difference was that the orders did not include the orders in the first batch of delivered. And the deport point was changed to start from 9:00 and the capacity were expanded to “1000” and “100”.

5.3 Running

After all parameters and attributes were set, the optimal delivery route based on the cost of time and distance was generated. The following was mainly an explanation of the results solved by ArcGIS and my attempts according to the result.

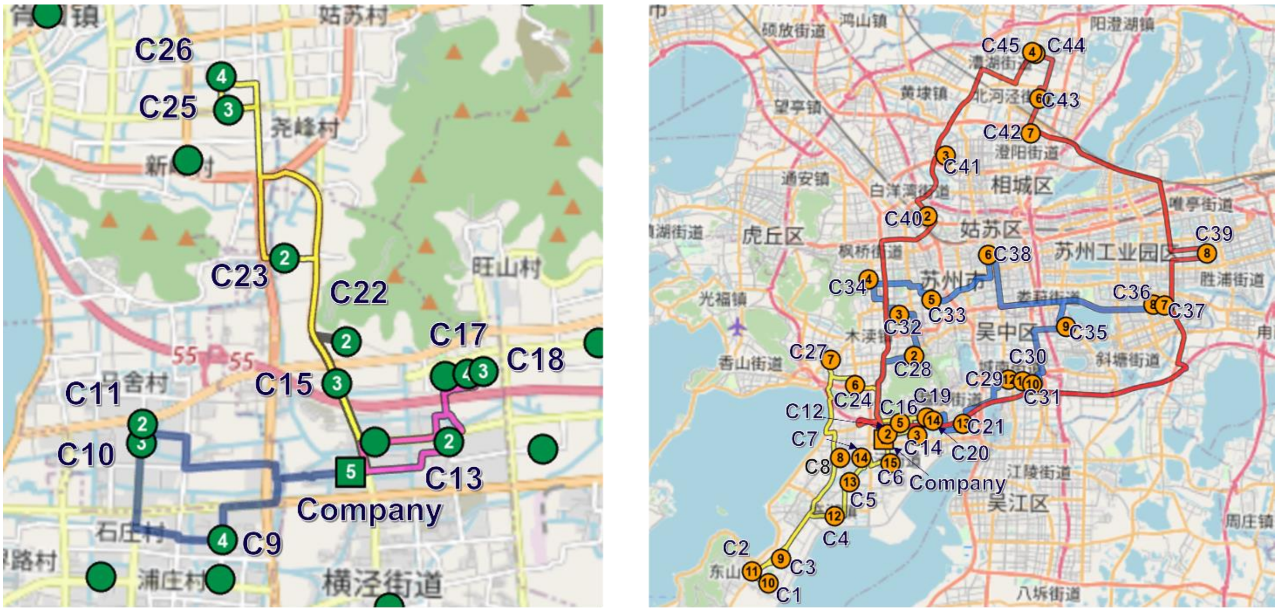


Figure 10. Illustration of the first (left) and second (right) batch distribution plans

The delivery plan of first batch, which was delivered by electric bicycle, was shown on the left-hand side of the figure 10. Specifically speaking, taking the route of electric bicycle “B1” as an example, which was shown in blue in the figure on the left-hand side, with a total of three orders delivered, namely “C9”, “C10”, and “C11”. Starting from the company, go straight along Shangxin Road, turn right on Dongshan Boulevard, then turn left into Changan Road, and turn right at the intersection with Pujin Road and enter Pujin Road. After a straight journey, turn left into Huian Road, continue along Huian Road until reach the intersection with Puzhuang Boulevard and then turn right to enter Puzhuang Boulevard. “C11” is located on the left side of the road. After delivering “C11”, drive south along Puzhuang Boulevard for 72 m, and “C10” is located on the right side of the road. Afterwards, continue south for 1.3km and enter Shizhuang Road. After 600m, enter Shajing Road and drive 600m to reach “C9”. After delivering all orders in this route, continue straight along Pusha Road for 400m and then turn to Dongtaihu Road. Continue straight until the junction with Dongshan Boulevard and enter Dongshan Boulevard to drive north. After turning to Shanxin Road, head west to return to the company. The delivery task was delivered like this.

The other routes will not be listed one by one like “B1”. Simply put, the electric bicycle “B2” appeared black in the figure and was partially blocked by the yellow “B3”. A total of two orders were delivered, which were “C15” and “C22”, and the route was: Company/ Mudong Hwy/ Yanan Rd/ “C22”/ Yanan Rd/ Mudong Hwy/ “C15”/ Mudong Hwy/ Company.

“B3” was shown in yellow. A total of three orders delivered, which were “C23”, ”C25” and “C26”. The route was: Company/ Mudong Hwy/ “C23”/ Dongshan Blvd/ Gaofeng Rd/ Zoumatang Rd/ Shijin Rd/ “C25”/ Shijin Rd/ Xiecun Rd/ “C26”/ Shijin Rd/ Zoumatang Rd/ Gaofeng Rd/ Dongshan Blvd/ Mudong Hwy/ Company.

“B4” was shown in rose red. A total of three orders delivered, which were “C13”, “C18” and “C17”. The route was: Company/ Shangxin E Rd/ Xingdong Rd/ “C13”/ Xingdong Rd/ Tianedang Rd/ Lianjiexian Ave Rd/ Tiankai Rd/ Mingxuan Rd/ S Guandu Rd/ “C18”/ S Guandu Rd/ “C17”/ S Guandu Rd/ Lianjiexian Ave Rd/ Tianedang Rd/ Mudong Hwy/ Company.

In the same way, the delivery plan of second batch, which was delivered by oil car or new energy vehicles, was shown on the right-hand side of the figure 10. From the figure, it can be seen that there are three delivery routes, namely “Vehicle 1”, “Vehicle 2”, and “Vehicle 3”.

The route here included a large number of roads relatively. Take the “Vehicle 1”as an example, which was in blue. A total of 13 orders delivered, which were “C20”, “C21” and “C28” to “C38”. The route was: Company/ Mudong Hwy/ Jinfeng S Rd/ Baodai W Rd/ “C28”/ Baodai W Rd/ Kaisheng St/ Fengrui Rd/ Xiangyang Rd/ “C32”/ Xiangyang Rd/ Zhujiang S Rd/ Zhuyuan Rd/ Jinfeng Rd/ Yushan Rd/ Jinshan S Rd/ Jinshan E Rd/ “C34”/ Jinshan Rd/ Changjiang Rd/ Shishan Rd/ Tayuan Rd/ Yushan Rd/ Huangpu St/ Zhuyuan Rd/ Laodong Rd/ Sanxiang Rd/ Daoqian St/ Yangyu Ln/ Zhongjie Rd/ “C38”/ Dongzhongshi/ Renmin Rd/ S Ring E Rd/ Dushuhu Blvd/ Jingyuan Rd/ “C37”/ “C38”/ Jingyuan Rd/ Dushuhu Blvd/ Xinggang St/ Shupu Rd/ Dongfang Blvd/ “C35”/ Dongfang Blvd/ Wudong Expy/ Nanhu Rd/ Shuangqi Rd/ Xinwu Rd/ “C31”/ Xinwu Rd/ Yingchun S Rd/ “C30”/ Xinnan Rd/ “C29”/ Tianshangjiang Rd/ Xing’ang Rd/ Shao’ang Rd/ Wenxi Rd/ Xidong Rd/ Xihong Rd/ “C21”/ Xihong Rd/ Tianedang Rd/ Longxiang Rd/ S Guandu Rd/ “C19”/ S Guandu Rd/ Wangshan Rd/ N Guandu Rd/ Suwang Rd/ Tianedang Rd/ Mudong Hwy/ Company.

Therefore, the explanation of the other two routes would only indicate the sequence of the delivered orders instead of mentioning the specific road names they have passed through. “Vehicle 2” was in yellow, with a total of 14 orders delivered, and the sequence of the orders was “C12”, “C14”, “C19”, “C16”, “C24”, “C27”, “C8”, “C3”, “C1”, “C2”, “C4”, “C5”, “C7”, “C6”. Then “Vehicle 3” was in red, with a total of 7 orders delivered, and the sequence of the orders was “C40”, “C41”, “C45”, “C44”, “C43”, “C42”, “C39”.

Based on the above results, it was found that only three new energy vehicles were used as the delivery of the second batch of orders, and no oil-fueled automotive were used. Therefore, I came up with the idea that if all orders were delivered using new energy vehicles, it would cost less time. For this reason, I added the order delivered by electric bicycles into the “vehicle_roads” layer, set parameters for it, and then run it again. Of course, the settings in the original layer have also been slightly modified accordingly, for example, the delivery time no longer starting from 9 o'clock, but at 8 o'clock. After running, comparing the new statistical data with the previous one, it was found that the total time has indeed decreased by about 10% of the previous one, while the total cost has increased by 50%, which was far beyond my imagination. Although I expected the cost to increase, I did not expect it to increase so much. As a result, for my idea, if it was only from a time perspective, it did have a positive effect. However, if cost was taken into consideration, more aspects needed to be comparison before making a decision of not using electric bicycles. However, it is certain that with the emergence of new energy vehicles, the advantage of oil-fueled automotive gradually disappeared. The previous distribution plan of the case company designed by region did also need to be updated.

6 Results and Analysis

6.1 Delivery plan

After the running, explanation, and a small attempt in the previous chapter, a result was obtained. The delivery plan was as follows:

The first batch started at 8 am, with four delivery personnel each selecting their respective goods and loading them onto electric bicycles before departure. One person was responsible for two orders (“C22”, “C15”), and the other three people were responsible for three orders respectively (“C11”, “C10”, “C9”) (“C23”, “C25”, “C26”) (“C13”, “C18”, “C17”). The sequence here represents the sequence of delivery. And at the latest at 10:30 am, all delivery tasks would be completed and returned to the company. There were even three people who can return to the company before

9:45 am, and if necessary, they could even be directly responsible for the delivery task of seven orders in the second batch.

Similarly, the second batch of deliveries would be completed by three delivery personnel each driving one new energy vehicle. One person was responsible for 13 orders (“C28”, “C32”, “C34”, “C38”, “C37”, “C38”, “C35”, “C31”, “C30”, “C29”, “C21”, “C19”). One person was responsible for 14 orders (“C12”, “C14”, “C19”, “C16”, “C24”, “C27”, “C8”, “C3”, “C1”, “C2”, “C4”, “C5”, “C7”, “C6”). They started loading and shipping from 9 o'clock. The other person was responsible for 7 orders (“C40”, “C41”, “C45”, “C44”, “C43”, “C42”, “C39”), starting from about 9:45 am for loading and delivery. At the latest at about 5 pm, all delivery tasks would be completed and returned to the company.

	Start time	End time	Order quantity	Tool
First batch	8:00	9:41	3	Electrical bike
	8:00	9:11	2	
	8:00	10:30	3	
	8:00	9:26	3	
Second batch	9:00	16:16	13	New energy vehicle
	9:00	17:03	14	
	9:45	14:45	7	

Table 5. Delivery time, tool and order quantity

6.2 Analysis after trial operation

The analysis mainly involves analyzing the feedback forms after trial operation. In the feedback form shown earlier, there were a total of four questions. They were punctuality, order task completeness, reasonableness of order task allocation, and suggestions. In this section, the feedback I collected are described and the issues of the plan reflected from the feedback are discussed. The participants in this feedback were the delivery personnel who also participated in the trial operation stage.

To begin with, punctuality, which referred to two “whether”, namely “whether orders can be delivered within the time allowed by the customer” and “whether delivery personnel can return to the company before the completion time”. For the first “whether”, all responses were 5 points, which was within my expectations, as all customers’ working hours were slightly longer than those of the case company. For the second “whether”, only one person gave a score of 4, citing a delay of 20 minutes from the expected time, specifically due to experiencing traffic congestion on the old city section.

The second was order task completeness, which referred to whether all assigned tasks could be completed within the corresponding time period. This question corresponded to the first “whether”. Although the second “whether” in the previous question experienced traffic congestion, which was 20 minutes later than expected, the completion rate was all 5 points.

Thirdly, reasonableness of order task allocation, which referred to whether each person agrees with the quantity of assigned delivery tasks. The answer to this question exceeded my expectations, with everyone giving a score of 5, indicating that everyone agrees with the quantity allocated in the plan. Their reason was that they had fixed working hours, and the task allocation of fixed orders was only a part of them. For example, the first batch of delivery personnel would be responsible for delivering temporary orders after finishing the task of delivering the fixed order assigned to them, and the rest of the time would be responsible for warehouse organization, sending and receiving express orders. In the case of 7 people, each had their own work, no one was slacking off, and what was the most important factor was that all tasks were able to be completed successfully.

Last but not least, suggestions and ideas. They all expressed their love for the new distribution plan, believing that the past delivery plan was too unreasonable. As I pointed out in my introduction sector, some people only had one delivery task and due to having 10 delivery personnel, most of them were idle in the warehouse. Now this plan saturated the work of the delivery personnel. In addition, they provided some suggestions for traffic congestion issues, such as parking outside the congested road section and replacing public bicycles for delivery, which inspired me deeply.

After analyzing and receiving all the feedback from the delivery staff, the traffic congestion problem they mentioned was put on the agenda for solving. The traffic jam was located in the old city area, where traffic jams often occurred due to narrow roads, and there were only two ways to solve this problem. One of them was a detour, but the old city area designed to a circular shape, with almost every road being congested, so the detour plan was not feasible. Then, as suggested by them, another was to replace the means of transportation. So, the “bicycle_roads” layer and the “route” method in ArcGIS was used to set the parking area of the vehicle as one “stop” and the company as another “stop”, so that the shortest path between the two stations was found. Unluckily, the results showed that the shortest path took approximately the same amount of time as the car congestion, meaning that the results generated by these two methods were the same. Therefore, I did not make any changes, but added a note to the plan here. The specific decision depends on the delivery personnel's choice on the day of delivery.

7 Answers to the research questions

Looking back at the research questions raised in the first Chapter, which is as follows:

- What data is needed from the case company?
- How to optimize the routes to make delivery more efficient?
- What are the advantages and disadvantages of the optimization?

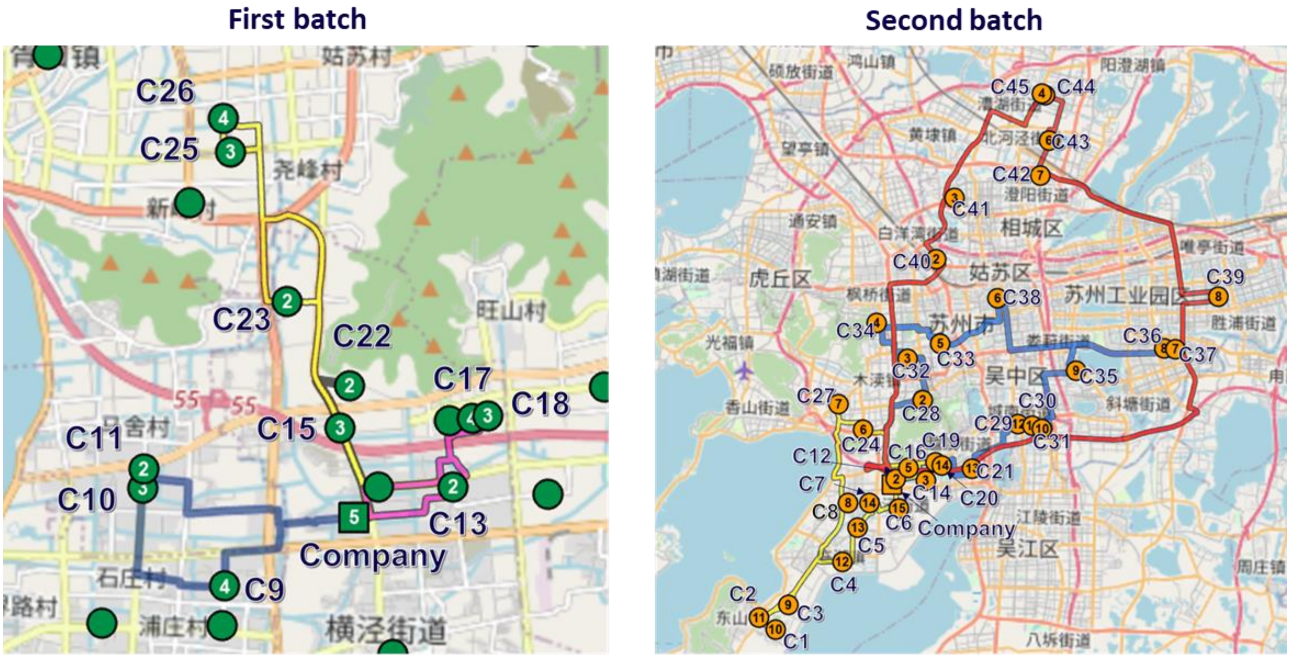
During the above research process, these questions have been resolved already, so their answers will be clarified one by one in this section.

What data is needed from the case company?

The tool used in this research is the VRP Solver in ArcGIS, so the required data is also determined based on it. From the final running point of view, the logistics data obtained from the company mainly includes customer addresses and order information, which are Appendix 1 and Appendix 2, respectively. Of course, the data obtained from the company also includes the condition of the vehicles, which included the loading limitations of the quantity and weight of the vehicles, loading time, unloading time, earliest and latest departure time, fixed cost of the vehicle, unit time cost, and unit distance cost.

How to optimize the routes to make delivery more efficient?

The method is to put the data into the software and the software made the calculation for the route. Therefore, research of several different tools was made in order to find out the right one for this case, which is “ArcGIS Network Analyst”. Finally, the optimization is as follows.



	Start time	End time	Order quantity	Route color above	Tool
First batch	8:00	9:41	3	Blue	Electrical bike
	8:00	9:11	2	Black	
	8:00	10:30	3	Yellow	
	8:00	9:26	3	Rose red	
Second batch	9:00	16:16	13	Blue	New energy vehicle
	9:00	17:23	14	Yellow	
	9:45	14:45	7	Red	

Figure 11. The optimization

The first batch start at 8 am, with four delivery personnel each selecting their respective goods and loading them onto electric bicycles before departure. One person is responsible for two orders

(“C22”, “C15”), and the other three people are responsible for three orders respectively (“C11”, “C10”, “C9”) (“C23”, “C25”, “C26”) (“C13”, “C18”, “C17”). The sequence here represents the sequence of delivery. And at the latest at 10:30 am, all delivery tasks will be completed and returned to the company. There are even three people who can return to the company before 9:45 am, and if necessary, they can be directly responsible for the delivery task of seven orders in the second batch.

The second batch of deliveries is completed by three delivery personnel each driving one new energy vehicle. One person is responsible for 13 orders (“C28”, “C32”, “C34”, “C38”, “C37”, “C38”, “C35”, “C31”, “C30”, “C29”, “C21”, “C19”). One person is responsible for 14 orders (“C12”, “C14”, “C19”, “C16”, “C24”, “C27”, “C8”, “C3”, “C1”, “C2”, “C4”, “C5”, “C7”, “C6”). They start loading and shipping from 9 o'clock. The other person is responsible for 7 orders (“C40”, “C41”, “C45”, “C44”, “C43”, “C42”, “C39”), starting from about 9:45 am for loading and delivery. At the latest at about 5:30 pm, all delivery tasks can be completed and returned to the company.

What are the advantages and disadvantages of the optimization?

For the advantages, the optimization has great significance and can be divided into two perspectives. The first one is from the perspective of the company. The case company is not only improved the delivery plan through this research, but also provided some assistance for the management of personnel in the delivery department by the optimization. For example, according to the original delivery plan, where there were two delivery personnel in one area, and there were inevitably five delivery areas, then ten delivery personnel would be needed. However, with the implementation of the optimization, the number of the demand for delivery personnel has become seven, or even six, which can be said to directly optimize the personnel structure of delivery department. Secondly, from a social and environmental perspective, the delivery vehicles used in the optimization are electric bicycles and new energy vehicles, combined with a public bicycle. These are all low-carbon transportation vehicles that benefit the low-carbon development goals of the city. Moreover, the noise generated by these transportation vehicles is much smaller than others, which is very beneficial for improving the noise pollution situation in the city.

For the disadvantages, still regarding personnel. Compared to the previous delivery plan, the optimization has reduced the number of delivery personnel from 10 to 7 or even 6, which means that 3 to 4 people will be laid off, and these employees can be called as old employees. Coupled with three years of social and economic pressure, negative emotions will inevitably arise, which will also have an impact on other employees, disrupt their morale, and even affect the cohesion of the company. However, this drawback is not unsolvable, and the method of reducing personnel is another very important consideration point.

8 Conclusion

On the positive side, sudden social changes are an opportunity for most company, and whether or not to seize this opportunity to improve itself has a crucial impact on the company's market competitiveness. The case company saw this opportunity and wanted to seize so this research was generated.

This research aims to improve the delivery plan of the case company and obtain the optimal delivery route based on the cost of time. What I did was to define the type of problem in order to define the processing tools, compare the availability of each tool to make the decision of the final software used, then collect the required data and apply it to the software after processing, and finally come up with a delivery plan. What’s more importantly, verify its rationality through actual trial operation. Throughout the entire process, I was constantly learning and experimenting, and got the final optimization, which can not only optimize the delivery personnel department and reduce the delivery cost, but also benefit the improvement of the urban environment.

Of course, there is no perfect thing in this world, and this plan is no exception. From the perspective of the tools used, considering accessibility factors, ArcGIS Network Analyst was used in this case, but as mentioned above, there are many software that can handle this kind of problems, and they may be even better if the programming basics are met . At the same time, every region's data is constantly updated, so it also needs to be constantly updated to adapt to this constantly changing social environment. In addition, the management of personnel by the company, as well as the selection of personnel for layoffs and retention, are all points worth considering.

From a future perspective, with the development of e-commerce and the further improvement of the global logistics system, logistics costs and efficiency have become important factors in the competitiveness of enterprises, leading to an efficient delivery plan playing a crucial role. The research, as a useful case, described the entire research process of the generation of an efficient delivery plan, including the application of the efficient tools and the reasonable decision of personnel and vehicles, helped improve the efficiency and competitiveness of the case company, and even will bring more business opportunities and benefits to the case company. What’s more, a feasible optimization method of delivery plan for other logistics companies in Suzhou is also provided by the research.

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Appendices

Appendix 1. Example of customer address

送货上门名册

序号	电话	公司名及收货人	地址
1		威联科（张哲师傅/刘师傅）	横泾天鹅荡路小骆驼里往左走到底
2	18098795087	图瑞尔（任师傅/韦经理）	东山大道10722号大门直走往里到底
3		恒凯（周芬/周盼盼）	子胥路199号大门直走到底左手边（东门）
4		百盛（刘小姐）	货：谢村路1号对准大门第一幢，从两幢房中间路走过左手转弯西门送小办公室
5	货平安路1168号吴老师13285190065	百盛（姜	发票：平安路1168号苏州格瑞美医用材料有限公司内3号楼
6		1.博仕铭/陈总，2.亿可利/王总，3.博瑞钠/王总，4.鹏天科技/	时进路151号大门往里直走到底
7		诺力亚（李总/张	天鹅荡路2900号富民置业工业园公司
8		弘谷（老板/老板娘/	尧南路35号
9		星光	尧南路12号
10		恩尔希	尧南路9号
11		朱先生	尧南路5号
12		锐来（刘师傅）	兴巷路11号
13		琪亚	兴巷路10-1
14		威凯实（翁/王师傅）	兴巷路10-2
15	15150468106	和元（孙总）	木林路
16	18662493819	骏乐（王师傅）	吴中区北官渡路28号苏州路霸汽车有限公司里边
17	15252331489	珍博起龙（贾国平）	城南街道兴南路27号（名扬纺织内）
18		诺真（孔师傅/姚师傅/张师傅）	胥口镇浦庄大道3999号苏州森昌实业内2幢
19		阿尔比恩	胥口镇浦庄大道3939号2幢
20		迪普（崔丹）	浦沙路355号大门进去直走右手边卷帘门进去
21		吾来盛（黄海磊）	吴中区临湖镇和安路950大门走到底右手边
22	13771835580	恒国（陆女士/韩师傅）	木东公路6338号湖桥工业二区46幢恒国精密
23	181 1567 9011刘金星	锐竹	吴中区浦庄和安路1019号 界路村和安工业园
24	17712172141	顺合鑫（张师傅）	横泾西桥下右转到底左手边
25	13901542180	派恩（姚总	吴中区凤凰山路四巷苏州派恩精密五金有限公司
26	15050106802	诺达佳（邱萍）	吴中区临湖镇银藏路480苏州诺达佳自动化技术有限公司
27	15800814646	派顿液压（黄师傅）	吴中区南官渡路苏州派顿液压科技有限公司
28	19962839528	迈尔特	苏州市工业园区东富路33号A栋104单元（苏州迈尔特模具有限公司）
29	13616275551	诺特（修钻头）	苏州相城区黄桥镇旺盛路18号（诺特）
30	13405070705	纳福特	苏州相城渭塘镇澄阳路3338号（纳福特）
31	18912797561	米奇尔	苏州相城旺庄路意可机对面
32	66153673	科泰科技	苏州相城区如元路633号（苏州科泰科技）

Appendix 2. Examples of order quantity and time

订单				
公司	时间	验货时间	订单数量	订单重量
C1	8：00-18：00	30	115	21
C2	8：30-18：30	10	20	3
C3	8：00-18：00	10	30	5
C4	8：30-18：30	15	25	4
C5	8：00-17：30	10	40	4
C6	8：00-17：00	30	30	4
C7	8：00-17：30	20	20	5
C8	8：00-18：00	15	22	3
C9	8：30-18：30	15	25	4
C10	8：00-18：00	15	25	3
C11	8：00-18：00	10	20	3
C12	8：00-18：00	30	20	5
C13	8：00-17：00	10	16	3
C14	8：30-18：30	10	20	4
C15	8：00-17：00	15	18	4
C16	8：00-17：00	30	25	5
C17	8：00-18：00	10	30	3
C18	8：00-17：00	15	28	4
C19	8：00-18：00	15	21	5
C20	8：00-17：00	20	21	5
C21	8：00-18：00	10	11	5
C22	8：30-18：30	10	23	5
C23	8：00-17：00	10	12	3
C24	8：00-18：00	10	40	5
C25	8：00-18：00	10	30	3
C26	8：00-18：00	30	30	4
C27	8：30-18：30	30	98	24
C28	8：00-18：00	10	13	3