Green Transportation System Project

Design of Public Transport System in Changzhi City

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June 20, 2023

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1 INTRODUCTION

Given the OD matrix of some divided zones and a .dwg file containing information about these zones, we are asked to design a public transportation system for Changzhi City. Using python and AutoCAD, we extracted vital information from these files, mainly consists of the location of the zones and traffic demand. Besides, we put efforts in visualization of these numbers, in order to get inspirations of network designing from data. Firstly, we merged small zones into 'large zones', according to first two numbers of their identifiers. Figure 1 shows large zones and corresponding small zones. Figure 2 shows visualization of OD-matrix of large zones.

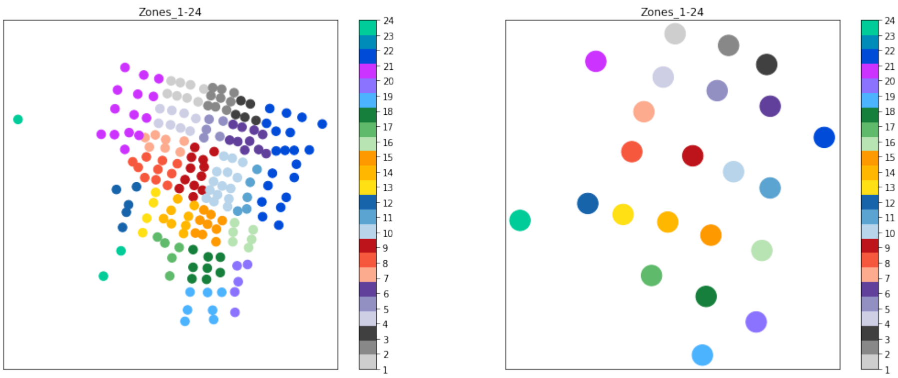
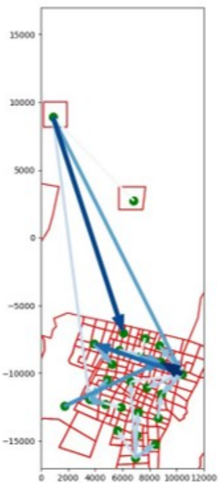
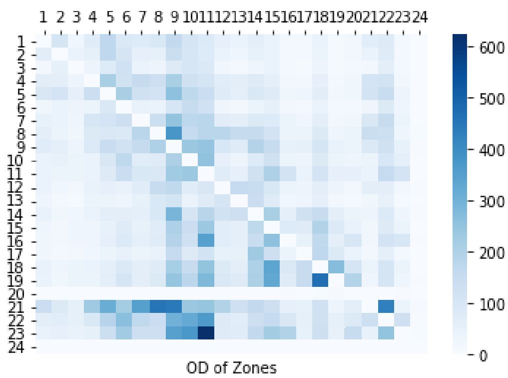


Figure 1: Large Zones(1-24) And Small Zones



(a) Top Traffic Demands Among Large Zones



(b) OD Matrix of Large Zones(1-24)

Figure 2: Analysis Based On Large Zones

Also, we did analysis and visualization based on small zones. For Figure 3, the unified sum of traffic demand of each zone when it served as origins or destinations are presented. For Figure 4a, we simply visualized the OD-matrix. For Figure 4b, we draw a rectangle for each OD pair, with OD points served as diagonal vertices, and simply overlay these rectangles on the road network.

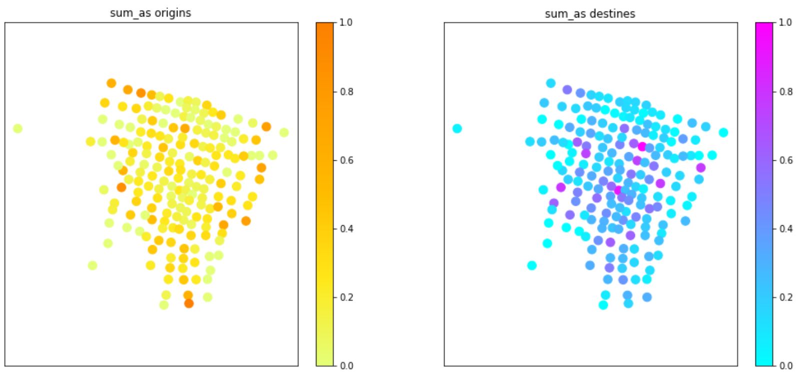
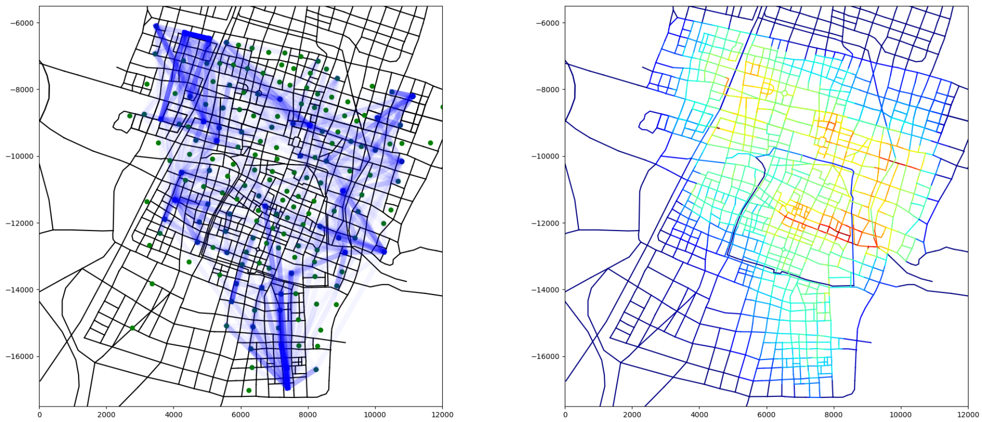


Figure 3: Unified Traffic Demands as Origin and Destination



(a) Top Traffic Demands Among Small Zones

(b) Roughly Estimated Traffic flow

Figure 4: Analysis Based On Small Zones

From these figures, we can locate some vital zones that have large demand, which is a guide for the Application section when we look into the real map. Also, we developed a further understanding of the zone and the OD information. For example, the data is probably collected during morning peak hours when most demands originated from outer circle and head for center areas. Northwestern area and southeastern area are more important than northeastern and southwestern areas.

2

Region Characteristics

2.1 Regional Data

Changzhi City's main urban area is located in Luzhou District, covering an area of 356 square kilometers. The built-up area in the Luzhou District, which has a highly dense road network, occupies approximately 50 square kilometers. The region possesses a relatively narrow and elongated shape, with a length of approximately 10 kilometers along the north-south axis and a width of roughly 7 kilometers along the east-west axis, exhibiting an unsymmetrical form with a long axis running in a northwest-southeast direction. The road network is arranged in a grid-like pattern, containing 15 east-west main roads with an average spacing of about 0.7 kilometers and 9 north-south main roads with an average spacing of roughly 0.9 kilometers.

Based on available data, the common speed limit for public transportation is 40 kilometers per hour. Assuming uninterrupted driving in the urban area, not stopping at intersections and bus stops, the average speed can reach 30 kilometers per hour. Considering the influence of intersection parking on cruising speed, but not bus stop parking, the study focuses on Yingxiong Road, the primary north-south main road spanning 10.8 kilometers with 18 signal-controlled intersections, having an average spacing of 640 meters. For simplification, the research assumes a 50% probability of stopping at each intersection with an average delay of 30 seconds per stop, leading to a cruising speed of approximately 25 kilometers per hour. Lastly, the research examines the bus stop spacing on Yingxiong Road, finding an average distance of approximately 0.5 kilometers between bus stops in the surveyed 10.8-kilometer section.

Regarding cost, the value of time can be calculated using the following formula:

$$C_0 = \frac{Regional\ Annual\ GDP}{Regional\ Resident\ Population \times Annual\ Working\ Days \times Daily\ Work\ Duration}$$

According to the data, the seventh population census of Luzhou district reports a total of 895,280 individuals. Given the relative stability of population growth, this data can be directly utilized. Additionally, the GDP of Luzhou district in 2022 was 60.24698 billion yuan. Assuming a standard daily work duration of 8 hours and a total of 250 working days in a year, the value of time can be calculated as 0.384 yuan/(person × minute).

As for the operational costs, in December 2019, Changzhi City released a survey report about the operating costs of routes 3, 10, and 101 of the Changzhi Public Transport Corporation. Select Routes 3 and 10 as reference routes to determine various costs. For the reason that these two routes are both suburban-urban lines, there exists some deviation from the costs of urban buses. The survey report contains basic data on the bus routes, including the length of the route, the number of stops, the number of vehicles, and the number of trips per day, and categorizes the operating costs. Through analysis, calculation, and estimation, the following results were obtained:

The average fixed cost per vehicle per day is **119.3 yuan**.

The average cost of operating one kilometer per vehicle is **4.7 yuan**. (assuming the staff wages are only related to operating distance)

The average daily infrastructure cost is **119 yuan/km**.

Other data can also be obtained from the report, the number of vehicles per bus line is **32**, the length of the route is about **30 km**. Based on the previously calculated average speed, the minimum time interval between buses is estimated to be **9 minutes**.

2.2 Bus System

The urban bus lines under the jurisdiction of Changzhi Public Transportation Co., Ltd. operate on an unmanned ticketing system, with a flat rate of 1 yuan per trip. However, the Mining & Suburban lines implement a ticketing system with fares ranging from 1 to 4 yuan. The county-level subsidiaries of Changzhi Public Transportation Co., Ltd. provide free bus services within their respective county seats, while ticketed services with fares ranging from 1 to 3 yuan are offered on routes connecting distant suburbs and villages.

The bus lines operated by Changzhi First Automobile Transport Co., Ltd. are all subject to fare-based ticketing. Given the lower level of government subsidies received, the ticket prices for these lines are relatively higher, ranging from 1 to 8 yuan. Passengers using the unmanned ticketing lines within the city limits governed by Changzhi Public Transportation Co., Ltd. can enjoy a 20% discount by using the Changzhi City Transport Card.

2.3 Further Characteristics

The present study reports on the demographic characteristics of the city's resident population, as determined by the latest census. The results indicate that the city's resident population has decreased from 3,334,564 in 2010 to 3,180,884 in the most recent census, a decline of 4.61% over a decade, with an average annual growth rate of -0.47%. In contrast, the permanent resident population in the main urban area of the city has increased by 17.05% over the same period, with an average annual growth rate of 1.59%.

The age structure of the permanent population reveals a declining proportion of the population aged 0-14, a decreasing proportion of the population aged 15-59, and an increasing proportion of the population aged 60 and above, with a significant increase in the population aged 65 and above. Specifically, the proportion of the population aged 0-14 has decreased by 1.05%, the proportion of the population aged 15-59 has decreased by

routes	winter operating time	summer operating time	route type	remark
1	5:55-19:40	5:55-20:30	Urban	
2	5:55-19:30	5:55-20:27	Urban	
3	5:40-18:40	5:40-19:00	Mining&Suburban	
5	5:50-18:25	5:50-18:40	Mining&Suburban	
6	6:00-19:10	6:00-20:05	Urban	
8	6:10 7:00 7:40 8:20 9:00 14:20 15:00 15:40 16:20 17:00	6:10 7:00 7:40 8:20 9:00 14:20 15:00 15:40 16:20 17:00	Mining&Suburban	
9	6:00-19:30	6:00-19:50	Urban	
10	5:40-18:40	5:40-19:00	Mining&Suburban	
11	6:30 7:00 7:30 14:30 15:30 17:00	6:30 7:00 7:30 14:30 15:30 17.00	Mining&Suburban	
12	6.06 6.50	6.03 6.59	Mining&Suburban	
13	5:50-18:25	5:50-18:40	Mining&Suburban	
14	5:35-17:30	5:35-17:30	Mining&Suburban	40-minute frequency
15	6:40-18:20	6:30-18:45	Urban	
16	6:40 17:15	6:40 17:15	Mining&Suburban	
17	5:50-19:00	5:50-19:20	Urban	
18	5:50-19:06	5:50-19:20	Urban	
19	6:00-19:00	6:00-19:00	Urban	
20	6:00-18:50	6:00-19:15	Urban	
21	6:00-19:00	6:00-19:15	Urban	
22	10:00 17:00	10:00 17:00	Urban	
23	6:30-18:30	6:30-18:45	Urban	
24	7:00-18:45	7:00-18:45	Urban	
25	6:15-18:50	6:15-19:10	Urban	
26	6:40-18:20	6:40-19:00	Urban	
27	6:20-18:20	6:00-19:00	Urban	
28	6:40-18:20	6:20-18:50	Urban	
29	6:40-18:20	6:20-18:40	Urban	
32	6:30-18:30	6:30-18:30	Urban	
33	5:55-19:30	5:55-19:50	Urban	
34	7:00-11:20 14:00-17:20	7:00-11:20 14:20-17:40	Mining&Suburban	40-minute frequency
35	6:15-18:50	6:15-18:50	Urban	
36	6:30-18:30	6:30-18:30	Urban	
38	6:45-18:30	6:45-18:30	Urban	
41	6:00-18:00	6:00-18:30	Mining&Suburban	40-minute frequency
42	7:20 7:40 8:30 9:50 13:40 15:30 16:30 17:30	7:20 7:40 8:30 9:50 13:40 15:30 16:30 18:00	Mining&Suburban	
48	6:30-19:30	6:30-19:30	Urban	
49	6:30-19:30	6:30-19:30	Urban	

Table 1: Bus Routes and operating times

routes	winter operating time	summer operating time	route type	remark
50	6:30-19:20	6:30-19:20	Urban	
101	6:15-18:30	6:15-18:30	Mining&Suburban	
7	6:00-18:30	5:20-18:30	Mining&Suburban	
309	6:10 9:30 13:00 16:30	6:10 9:30 13:00 16:30	Mining&Suburban	
313	6:00-18:40	6:15-18:45	Mining&Suburban	
601	6:30-18:30	6:30-18:30	County&District	free
602	6:30-18:30	6:30-18:30	County&District	free
605	7:05-18:50	7:05-18:50	County&District	
606	8:00-18:00	8:00-18:00	County&District	
607	9:15-18:50	9:15-18:50	County&District	
608	5:50-17:50	5:50-17:50	County&District	
610	10:15-16:15	10:15-16:15	County&District	
611	7:00 10:00 14:00 17:00	7:00 10:00 14:00 17:00	County&District	
612	6:10-17:30	6:10-17:30	County&District	
613	7:00 10:00 14:00 16:30	7:00 10:00 14:00 16:30	County&District	
615	10:15 16:15	10:15 16:15	County&District	
616	9:15 13:45 16:45	9:15 13:45 16:45	County&District	
617	6:30 16:30	6:30 16:30	County&District	
618	7:00 10:00 14:00 17:00	7:00 10:00 14:00 17:00	County&District	
619	6:30 16:00	6:30 16:00	County&District	
620	6:50 16:20	6:50 16:20	County&District	
621	8:30 10:30 14:20 16:30	8:30 10:30 14:20 16:30	County&District	
622	7:00 10:00 14:00 17:00	7:00 10:00 14:00 17:00	County&District	
623	7:30 10:30 13:30 16:00	7:30 10:30 13:30 16:00	County&District	
625	6:50-14:50	6:50-14:50	County&District	
626	Mon.Wed.Fri. 7:30 16:00	Mon.Wed.Fri. 7:30 16:00	County&District	
627	6:00-8:00	6:00-8:00	County&District	
628	Tue.Thu.Sat. 7:00 16:30	Tue.Thu.Sat. 7:00 16:30	County&District	
629	8:40 14:00	8:40 14:00	County&District	
630	6:30 16:20	6:30 16:20	County&District	
631	7:00 10:00 14:00 16:30	7:00 10:00 14:00 16:30	Mining&Suburban	
632	7:00-17:00	7:00-17:00	Mining&Suburban	
639	7:10-16:10	7:10-16:10	Mining&Suburban	
642	7:10 10:15 14:10 16:45	7:10 10:15 14:10 16:45	County&District	
802	8:00-18:30	8:00-18:30	Mining&Suburban	
902	6:00-18:30	6:00-18:45	Mining&Suburban	

Table 2: Bus Routes and operating times

6.8%, and the proportion of the population aged 60 and above has increased by 7.85%, with the proportion of the population aged 65 and above increasing by 6.09%.

Moreover, the permanent population is distributed unequally between urban and suburban areas, with 56.47% living in urban areas and 43.53% living in suburban areas. The urban population has increased by 401,109, while the rural population has decreased by 554,789 since 2010, resulting in a significant increase in the proportion of the urban population by 14.63%.

The total number of registered residents in the city is 960,767, among which the number of registered residents living separately from their families is 960,767. Among them, the number of registered residents living separately from their families within the urban area is 341,811, and the number of migrant population is 618,956. Of the migrant population, 495,067 are from within the province, among which 88,629 are from other cities, and 123,889 are from outside the province.

3 MODEL

The hybrid networks combine a grid structure in the city center with a hub-and-spoke pattern in the periphery. The hub-and-spoke pattern includes branching lines in order to provide uniform spatial coverage far away from the CBD.

Figure 5 depicts the idealized system studied in this section. The service region is a rectangle of sides D_x and D_y (km). Without loss of generality, the rectangle is assumed to be aligned with the (x, y) axes in a "landscape" orientation; i.e., so that $D_x \geq D_y$, as shown in the figure.

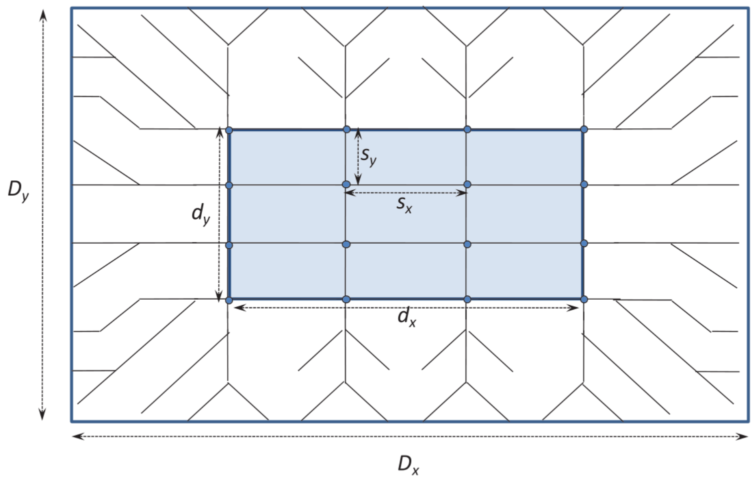


Figure 5: The hybrid concept for an urban HPB network in a rectangular zone.

The structure of the system and the decision variables that define it are now described. The system's core is a bidirectional grid of transit lines with spacing s_x and s_y (km), which cover a rectangle concentric with the service area; see gray rectangle defined by $d_x \times d_y$ in Figure 1. This line spacing is assumed to be an integer multiple of the stop spacing s (km); i.e., $s_x = p_x s$ and $s_y = p_y s$, where p_x and p_y are integers. If $p_x = p_y = 1$, every stop in the central grid is a transfer point served by two orthogonal lines. Otherwise, for each direction, $a = x, y$, only 1 in p_a stops is a transfer point. The dimensions of the central rectangle are denoted $d_x \leq D_x$ and $d_y \leq D_y$, as shown in Figure 5. They will be expressed in terms of the dimensionless ratios: $\alpha_x = d_x/D_x$ and $\alpha_y = d_y/D_y$. The transit lines in this central grid continue to the periphery, where they branch (more than once if necessary) to cover all parts of the periphery as uniformly as possibly with similar spacing as in the center. All the lines operate in the central area with a common headway H (h); but this headway increases in the periphery at those points where the lines branch. This information is enough to configure the idealized system and devise an operating plan; i.e., only five decision variables need to be chosen: H, s, s_x, s_y , α_x and α_y.

3.1 Model Formulation

The objective function and constraints of the design problem form a mathematical program that is described below.

$$\begin{array}{ll} \min & Z = [\pi_V V + \pi_M M + \pi_L L] + [A + W + T + (\sigma/v_w)e_T] \\ \text{s.t.} & s_x = p_x s,\ s_y = p_y s, \\ & p_x, p_y \in \mathbb{Z},\ s > 0, \\ & s_x/D_x \leq \alpha_x,\ s_y/D_y \leq \alpha_y, \\ & H \geq H_{min}, \\ & O_x, O_y \leq C, \\ & \alpha_x D_x/s_x + \alpha_y D_y/s_y \leq N \end{array}$$

Here are a brief explanation of the variables. In the objective function, total cost can be described in two parts, which are agency cost and cost with passenger component. In agency cost, v stands for operation-related cost, M stands for vehicle-related cost and L stands for infrastructure cost. Each of them is multiplied by a coefficient. In cost with passenger component, it consists of accessing(A), waiting)(W), in-vehicle travelling(T) and transfering. Due to our setting of parameters, the transfering part is ignored.

In the constrains, $O_x$and O_y stands for maximums of vehicle occupancy during rush hour in both directions. α_x and α_y is the limitation of $\frac{s}{D}$in both directions. Because the area we choose to apply this model is a square instead of a rectangle, and the OD is assumed to be uniformly distributed, so we assume $\alpha_x = \alpha_y = \alpha$. H is the lower bound of headway we can accept. N is the upper bound of the total amount of BRT lines in both directions, which is usually given by government due to macro planning and economics.

For this public transportation system, we designed it with the needs of seniors in mind. The elderly see waiting time more important than travelling time, so we added a coefficient of 0.9 to the travel time.

$$\begin{aligned} \min \quad & Z = [\pi_V V + \pi_M M + \pi_L L] + [A + W + 0.9T + (\sigma/v_w)e_T] \\ \text{s.t.} \quad & s_x = p_x s,\ s_y = p_y s, \\ & p_x, p_y \in \mathbb{Z},\ s > 0, \\ & s_x/D_x \le \alpha_x,\ s_y/D_y \le \alpha_y, \\ & H \ge H_{min}, \\ & O_x, O_y \le C, \\ & \alpha_x D_x/s_x + \alpha_y D_y/s_y \le N \end{aligned}$$

3.2 Input Data and Analysis Simplifications

A summary of our input data is presented in Table 3. Values of these parameters are determined through investigation of official government documents online, published papers, reliable websites and given O-D data.

Concept	Symbol	Value	Unit
Rectangular dimensions	D_x, D_y	7,7	km
Average hourly demand	λ	10000	pax/h
Peak hourly demand	Λ	18000	pax/h
Vehicle capacity	C	100	pax
Cruising speed	v	30	km/h
Time lost per stop	τ	30	s
Boarding and alighting time per passenger	τ'	1.5	s/pax
Minimum time headway	H	8	min
Walking speed	v_W	1.5	km/h
Maximum number of corridors	N	20	1
Unit infrastructure cost	$\$_L$	4.9583	yuan/(km-h)
Unit distance cost	$\$_V$	4.7	yuan/(km-veh)
Unit vehicle cost	$\$_M$	4.9708	veh/h
Value of time	μ	23.04	RMB/pax-h

Table 3: Input data of Changzhi city

From the perspective of this problem, it can be seen that the constraints are all linear, but the objective function to be optimized is very complex. Therefore, we adopted a search algorithm to search the entire feasible space of the problem, and finally found the global optimal solution to the problem.

3.3 Model Selection and Output Results

There are usually four choices of (p_x, p_y):(1,1),(1,2),(2,1) and (2,2). By changing (p_x, p_y), we can get 4 models and their value of objective function, as presented in Table 4. To minimize the total cost, we choose the model in which $(p_x, p_y) = (1, 1)$.

p_x, p_y	Value of objective function
(1,1)	0.5782
(1,2)	0.5850
(2,1)	0.5850
(2,2)	0.5829

Table 4: Model Selection

We also made slight ajustments on H and N, in order to make the final result more reasonable due to our comprehensive knowledge of Changzhi. The final results of the best model is presented in Table 5.

Decision Variable	Value
p_x, p_y	1,1
α	0.87
H	8
s	0.62
Other results	Value
Infrastructure length,L	138.36 km
the maximum number of vehicles operating simultaneously,M	117.66 veh
the average total vehicular distance travelled per hour of operation,V	2202 veh*km
(Ox, Oy)	94
n the probabilities of requiring zero, one or two transfers, (P0,P1,P2)	(0.1450.820, 0.03)

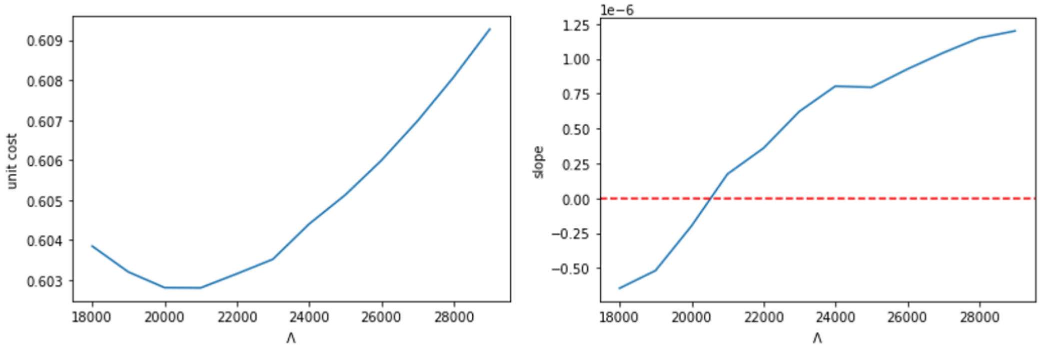
Table 5: Final Outputs

3.4 SENSITIVE ANALYSIS

The concept of scale effects refers to the phenomenon where the per unit cost of a good or service decreases as the scale of production or consumption increases. This is because fixed costs, such as infrastructure and overhead, can be spread over a larger number of units, resulting in a lower average cost per unit.

In this case of public transportation systems, the scale effects come into play when the demand for public transportation services increases. As more people use public transportation, the fixed costs of operating the system, such as the purchase and maintenance of vehicles and the construction and maintenance of infrastructure, can be spread over a larger number of riders. We can see from Figure 6 that when $\Lambda \leq 21000$, the unit cost decreases as demand increases.

Additionally, as the demand for public transportation continuously increases, due to the limitation of road resources and bus capacity, unit cost increases with the increase of demand.



(a) Unit Cost vs. Λ (b) Slope of Unit Cost vs. Λ

Figure 6: Sensitive Analysis (Λ)

4 APPLICATION

The optimal spacing for bus lines has been calculated to be 620 meters. According to the model construction, the bus lines are not equipped with dedicated stops, and all transfers take place at intersections. As the average spacing of arterial roads in Changzhi city exceeds this value, bus routes need to be designed for each arterial road. Our design plan involves the creation of nine bus lines in both the vertical and horizontal directions, with a horizontal spacing of approximately 750 meters and a vertical spacing of approximately 650 meters, within a central grid area measuring approximately 6.0 kilometers (north-south) by 5.2 kilometers (east-west). The north-south lines will be labeled 1-9 from east to west, while the east-west lines will be labeled A-J from south to north.

The grid is then expanded towards the periphery. Chinese cities differ in scale and layout from foreign cities in that foreign cities often exhibit relatively uniform sprawl towards the periphery, resulting in a large overall built-up area. In contrast, Chinese cities typically consist of dense central built-up areas and distant suburban residential areas, with large undeveloped areas in between. Therefore, the central grid of the Hybrid model is generally consistent with the central built-up area, and the built-up area only extends slightly outward. As a result, the radial lines only need to be extended to these distant suburban areas. For the remaining large number of lines that do not require an extension, consider how to connect them in the central city to improve accessibility and satisfy special needs such as new districts and transportation hubs.

Consider first the distant urban areas for which OD data are given. No. 25 corresponds to the Machang Village. The maximum target of OD is District 23 (Hudong North New District) and District 1 (City North Science and Technology Park), and the maximum source of OD is also District 23. District 23 is located on the bus route into the urban area from Machang, so it is straightforward to extend Route 7. District 26 corresponds to the Guxian Village, The maximum target of OD is District 1, so extending the route to Guxian is appropriate. The maximum source of OD is District 23, Route 1 can meet the demand. In addition, there is a large demand for travel between Guxian and Machang. We propose two possible solutions to meet this demand: extending Bus Route 7 to Guxian, or installing a feeder bus between the two locations. Extending Bus Route 7 to Guxian would provide a direct connection between the two locations, while a feeder bus would provide a more flexible and personalized travel solution.

Consider the area corresponding to Huxi New District (No. 24210), which is a small independent industrial area, located between Tunliu District and Luzhou District. Its OD maximum target and source area is District 23, but the value is relatively small so the bus to Tunliu District can meet the travel needs of this district.

The next step is to design other suburban routes into the city based on the distribution of public facilities in Changzhi, as well as the adjustment of routes within the city. The numbers below correspond to the bus routes mentioned above. For transportation hubs, Changzhi Station is located at the end of B, Changzhi East Station (and the new passenger station) at the end of 1, Wangcun Airport at the end of 5, and the passenger center in 8D. Commercial facilities are mainly in 5F, 5I, and 5C, all of which are located on Hero Road, the north-south trunk road. As for health services, the main hospitals are located in 4D, 3B, 6A, 7D, and area 21310 (new area). For other facilities, the sports center is located in District 21510 (New District), and the government center is located in District 21420 (New District). In conclusion, as the new district, District 21 is the major development direction of Changzhi, with many public facilities tilted towards this area; the northeast corner of the city is the main transportation hub; and the main commercial facilities are still concentrated in the old city.

There are several other county-level administrative districts around Changzhi: Tunliu District in the west, Changzi County in the southwest, Shangdang District in the south, Huguan County in the southeast, and Lucheng District in the north. Other counties are not considered for long distances. A qualified bus system needs to minimize the amount of transfers for residents in these areas to get to public places, with less than one transfer on average being the ideal situation. If follow the general Hybrid Model, many of the distant routes into the urban area are still at the edge of the grid area, which is relatively inconvenient. so consider connecting these long routes to grid lines close to the center, thus avoiding some passenger transfers and improving overall efficiency.

However, this step needs to be carried out in conjunction with the road network layout, and buses should take roads that are as straight as possible to reduce the overlap of lines due to missing roads. At the same time, several transit hubs can be set up at the edge of the grid to achieve efficient connections between radial areas. New cities and transportation hubs at the edge of urban areas are given key consideration.

Therefore, design the following bus route. Route F (Yingbin Road, east-west trunk road) is extended to

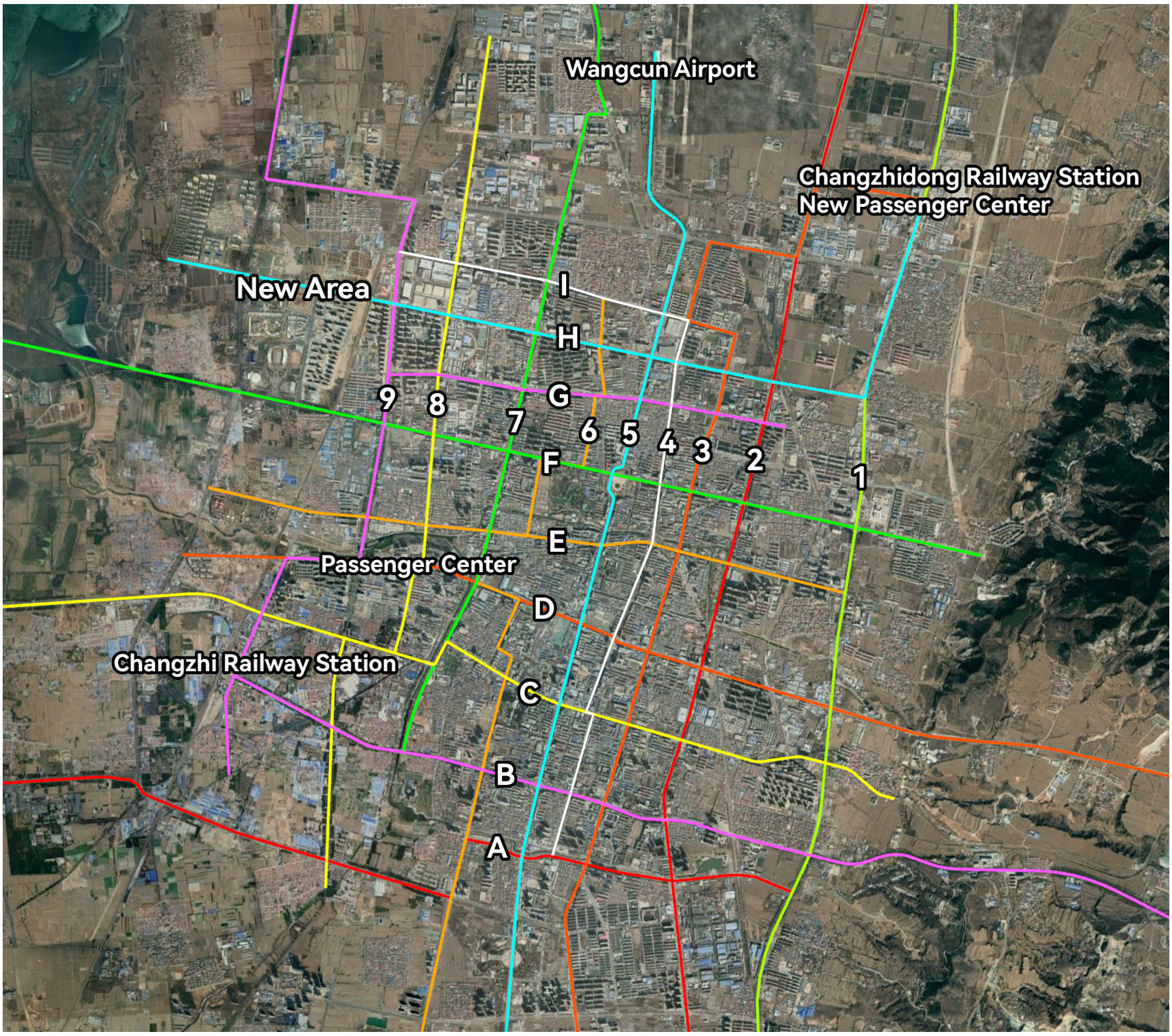


Figure 7: Design Routes Layout

Tunliu District. Route E turns south on the west side and extends to Changzi County via Changzhi Station. Route 5 and 6 are extended south to Shangdang District. Route Route B is extended to Huguan County and extends west to the New District via Changzhi Station. Route D is extended to the east to Happy Taihang Valley. Route 2 and G are extended northward to Lucheng District.

When the road network is completed, Route 4 will be extended to Shangdang District via Changzhi South Station, meet the demand for high-speed rail travel in the southern part of Luzhou District and Shangdang District. The remaining routes are concerned about their relationship with Changzhi East Station, Changzhi Station and New District, and the appropriate routes will be extended to these places without changing the layout of the central grid.

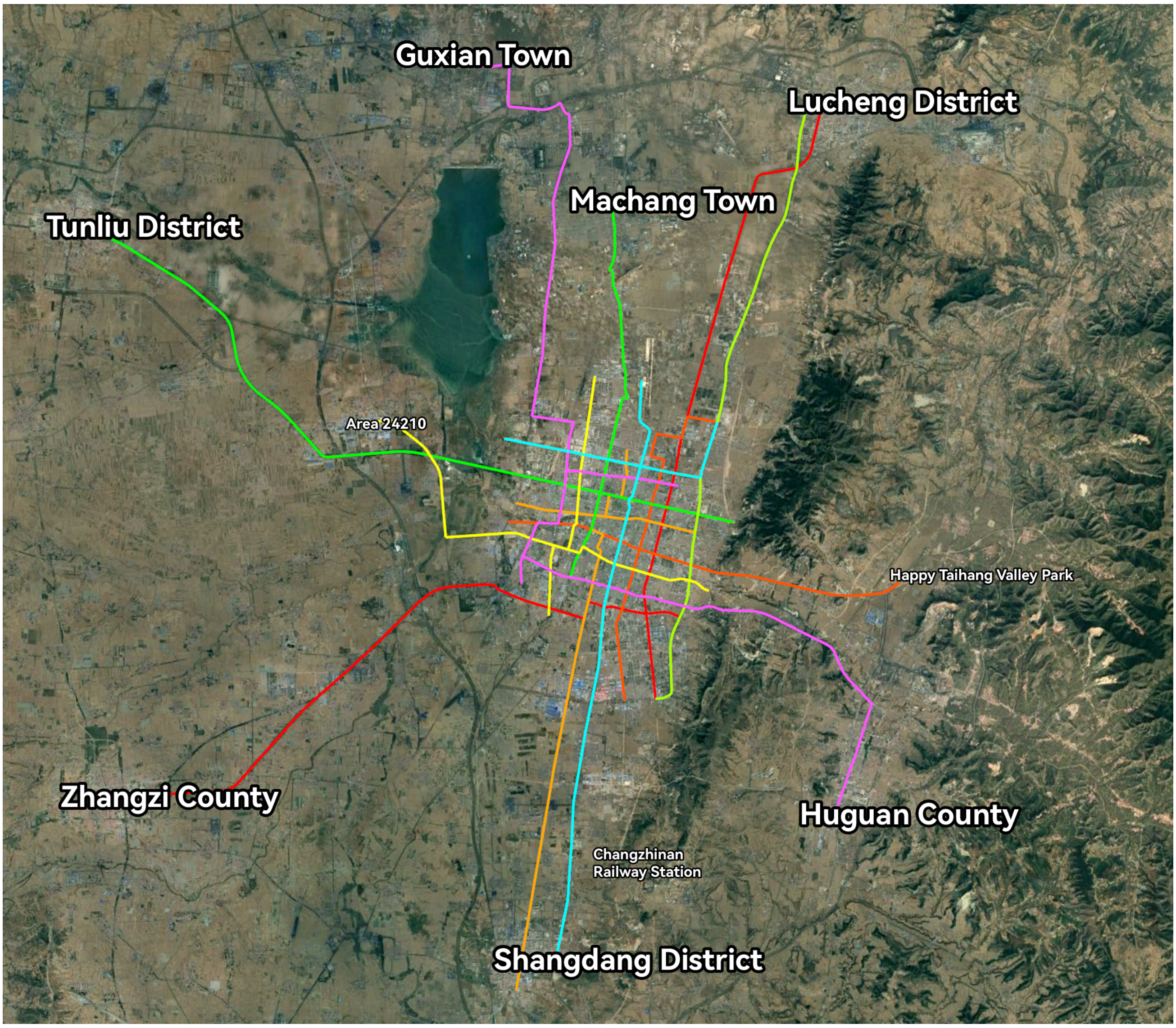


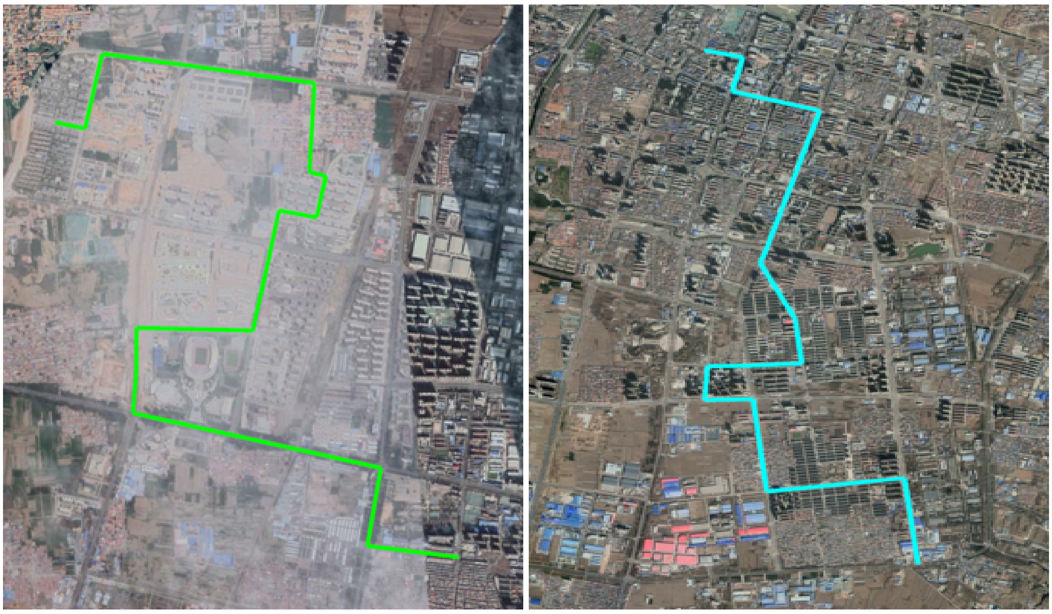
Figure 8: Design Routes Layout - Far View

5

Further Work

The above route design is a simple adjustment based on the existing bus routes. Further optimization is desirable combined with the actual situation. For instance, the West Passenger Stationl is an urban bus hub, there is relatively sufficient capacity for bus pick-up and delivery, but according to the Hybrid Model, no line starts here, resulting in idle function. Therefore, consider the introduction of some of the suburban connection route to the West Passenger Terminal for departure and arrival, and adjust or add some urban bus lines through, to create an interchange hub. For important external hubs such as Changzhi East Station, it is more important to consider the connection with urban residential areas, rather than just extending nearby lines.

There is the design of dedicated bus routes based on the demand for ODs with shorter distances but larger amounts. Thus, for non-uniform OD, our model can be considered as a superposition of the Hybrid Model with such area-based bus routes. the largest OD directions occur within the New District (No. 21) and in the direction of District 19 towards the urban center. Therefore, specialized bus routes are designed based on OD characteristics, and the results are shown in the figure below.



(a) specialized routes 1　　(b) specialized routes 2

Figure 9: Specialized Bus Routes

If traffic demand rises further in the future, a high-capacity rapid public transportation system, such as BRT or rail transit, will need to be designed. The planning of Changzhi City is to lay out a criss-cross backbone network in the main urban area and a radial network to the surrounding counties. Since the scale of the urban area of Luzhou is actually small, the planning of rail transit should focus on the connection between suburban areas, suburban residential areas and commercial areas, functional areas and transportation hubs, and give full play to the guiding effect of rail transit construction on land development.

The Hybrid system designed has a relatively large station distance, the overly long connection distance will reduce passengers' willingness to use the transportation. Therefore, the design of a slow-moving system is considered to realize the connection of bus stops. Changzhi city already has a public bicycle system, so the slow-moving system can be optimized on this basis. The current public bicycle has merely 82 stations, which is a small coverage rate. The subsequent need to encrypt stations and build stations near bus stops to complete the feeder. When the connection is changed from walking to cycling, the connection speed v_a will become larger. Hence, the updated reasonable model result can be recalculated by substituting the new data. It is also possible to set the bicycle stations as separate stations between two interchange stations and calculate the optimal solution in such a case.

A

APPENDIX

During the calculation of the model, according to [Est+11], the user and agency metrics are given by these formulas

$$L = \frac{D_x D_y}{2 s_x s_y}\left(s_x + s_y\right)\left(1 + \alpha_x \alpha_y\right) + \frac{D_x D_y}{2 s_x s_y}\left(s_x - s_y\right)\left(\alpha_y - \alpha_x\right)$$

$$V = \frac{2\alpha_x D_x D_y}{s_y H}\left[1 + \frac{D_x}{2D_y}\left(1 - \alpha_x\right)\right] + \frac{2\alpha_y D_x D_y}{s_x H}\left[1 + \frac{D_y}{2D_x}\left(1 - \alpha_y\right)\right]$$

$$O_y = \max\left(\frac{\Lambda s_y H\left(1 + \alpha_x\right)\left(1 - \alpha_y\right)}{\left(4\alpha_x D_x\right)}; \frac{\Lambda H\left(1 - \alpha_x\right)^2\left(1 + \alpha_y\right)^2}{32} + \frac{\Lambda s_y H\left(4 - \left(1 + \alpha_y\right)^2\left(1 - \alpha_x\right)^2 - 2\alpha_x^2\alpha_y^2\right)}{\left(8\alpha_x D_x\right)}\right)$$

$$O_x = \max\left(\frac{\Lambda s_x H\left(1 + \alpha_y\right)\left(1 - \alpha_x\right)}{\left(4\alpha_y D_y\right)}; \frac{\Lambda H\left(1 - \alpha_y\right)^2\left(1 + \alpha_x\right)^2}{32} + \frac{\Lambda s_x H\left(4 - \left(1 + \alpha_x\right)^2\left(1 - \alpha_y\right)^2 - 2\alpha_x^2\alpha_y^2\right)}{\left(8\alpha_y D_y\right)}\right)$$

$$M = V / v_c$$

$$
\begin{aligned}
A &= \left(\frac{s_x + s_y}{4} + \frac{s}{2}\right) / v_w \\
W &= \left[\frac{H}{6\alpha_x}\left(1-\alpha_x^3\right)\frac{\left(1-\alpha_y\right)}{\left(1-\alpha_x\right)} + \frac{H}{6\alpha_y}\left(1-\alpha_y^3\right)\frac{\left(1-\alpha_x\right)}{\left(1-\alpha_y\right)} + \alpha_x\alpha_y\frac{H}{2}\right]\left(1+P_1\right) + \frac{H}{2}P_2 \\
e_T &= P_1 + 2\cdot P_2 \\
P_0 &= \frac{\left(s_x D_x + s_y D_y\right)}{2D_x D_y}\left(1+\alpha_x\alpha_y\right) + \frac{\left(s_x D_x - s_y D_y\right)}{2D_x D_y}\left(\alpha_y - \alpha_x\right) - \frac{\alpha_x\alpha_y s_x s_y}{D_x D_y} \\
P_1 &= \frac{s_y}{2D_x}\left(-\alpha_y + \alpha_y^2 - 3\alpha_x\alpha_y + \alpha_x\alpha_y^2\right) + \frac{s_x}{2D_y}\left(-\alpha_x + \alpha_x^2 - 3\alpha_x\alpha_y + \alpha_y\alpha_x^2\right) \\
&\quad + \frac{1}{2}\left(1 - \alpha_y^2 - \alpha_x^2 + 4\alpha_x\alpha_y - \alpha_x^2\alpha_y^2\right) + \frac{s_x s_y\alpha_x\alpha_y}{D_x D_y} \\
P_2 &= \frac{1}{2}\left(1 - 4\alpha_x\alpha_y + \alpha_x^2 + \alpha_y^2 + \alpha_x^2\alpha_y^2\right) - \frac{s_y}{2D_x}\left(1-\alpha_y\right)^2\left(1+\alpha_x\right) - \frac{s_x}{2D_y}\left(1-\alpha_x\right)^2\left(1+\alpha_y\right) \\
E(E) &= \left(\frac{\alpha_y^2 D_y^2 + \alpha_x^2 D_x^2 + 4\alpha_x\alpha_y D_x D_y}{4\left(\alpha_x D_x + \alpha_y D_y\right)} + \frac{\left(\alpha_x D_x + \alpha_y D_y\right)}{12\alpha_x\alpha_y D_x D_y}\left(1 - \frac{\alpha_x\alpha_y}{2}\right)\right)\left(1 - \alpha_x^2\alpha_y^2\right) + \\
&\quad + \frac{1}{3}\left(\alpha_x D_x + \alpha_y D_y\right)\left(\alpha_x^2\alpha_y^2\right) + \frac{1}{4}\left(D_x\left(2 - 3\alpha_x + \alpha_x^3\right) + D_y\left(2 - 3\alpha_y + \alpha_y^3\right)\right) \\
1/v_c &= \left[1/v + \tau/s\right] + \left(1 + e_T\right)\Lambda/V\,\tau'
\end{aligned}
$$

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[Dag10] Carlos F. Daganzo. "Structure of competitive transit networks". In: *Transportation Research Part B: Methodological* 44.4 (2010), pp. 434–446. issn: 0191-2615. doi: https://doi.org/10.1016/j.trb.2009.11.001. url: https://www.sciencedirect.com/science/article/pii/S0191261509001325.

[Est+11] Miquel Estrada et al. "Design and Implementation of Efficient Transit Networks: Procedure, Case Study and Validity Test". In: *Transportation Research Part A: Policy and Practice* 45 (Nov. 2011), pp. 935–950. doi: 10.1016/j.tra.2011.04.006.