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Research on the Construction of Underground Logistics Network

-- Comparative analysis of economy and timeliness with truck transportation

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ABSTRACT

E-commerce industry continues to expand to promote urban express demand explosive growth, the current domestic urban goods distribution is highly dependent on fuel trucks road transport, the model brings traffic congestion, logistics cost escalation, tailpipe noise pollution and other multiple "big city disease". 2024 national highway freight turnover amounted to 76,847.5 billion tons kilometers, the number of goods vehicles exceeded 33.58 million shortboards. In 2024, the national road freight turnover will reach 7684.75 billion tons kilometers, and the number of trucks will exceed 33.58 million, and the short boards of diesel trucks with high emissions and low traffic efficiency will continue to magnify the pressure of urban governance. The urban subway network has the advantages of independent underground right of way, large capacity, all-weather stable operation, and low-carbon power drive, which can divert the pressure of ground freight transportation and build a multi-level underground logistics system. This paper takes Chongqing rail transit network as the research carrier, compares the ground truck transportation mode, and quantitatively demonstrates the economic and efficiency advantages of underground logistics system; adopts K-means clustering algorithm with improved Haversine formula to complete the siting of first and second level logistics nodes, matches the transit nodes of subway stations relying on Floyd algorithm, and solves the shortest transportation path between subway stations by Dijkstra algorithm, and establishes the shortest transportation path with the total transportation distance, and establishes the shortest transportation path with the total transportation distance. The shortest transportation path between subway stations is solved by Dijkstra's algorithm, which establishes a multi-level underground logistics optimization model with the goal of minimizing the total transportation distance. The empirical results show that compared with the traditional truck road distribution, the subway underground logistics network constructed in this paper reduces the comprehensive transportation cost by 32%~41%, shortens the average distribution time of a single batch of goods by 54%, and reduces the carbon emission of a unit of goods by 85%; relying on the existing subway stock resources without the need for large-scale construction of new corridors, which is of great value for popularization. The study can provide a quantitative reference and technical framework for underground logistics planning in mountainous and high-density rail transit cities in China.

KEYWORDS

Urban underground logistics; Dijkstra's algorithm; K-means clustering; Floyd's algorithm; truck road transportation; cost-benefit comparison; rail transportation logistics

1. INTRODUCTION

1.1. Research Background and Existing Pain Points of Ground Truck Transportation

Domestic e-commerce industry has been expanding at a high speed for more than ten years, and the volume of national express delivery business exceeded 132 billion pieces in 2023, and the demand for short-distance delivery in the same city has continued to surge, and the flow of goods within the city relies on the completion of light and medium-sized diesel trucks almost exclusively. National Bureau of Statistics data show that in 2024 the national highway freight turnover of 7684.75 billion tons of kilometers, firmly in the second largest mode of freight transport; the national cargo vehicle ownership of 335,894,000 vehicles, the vast majority of diesel-powered vehicles, compared with gasoline passenger cars, trucks tailpipe particulate matter, nitrogen oxides emissions 2-3 times higher, the engine continues to seriously interfere with engine noise in the residential areas of the life of the Xinhua News Agency Beijing Channel.

There are four irreconcilable shortcomings in the road freight transportation model:

First, traffic congestion pushes up time and fuel costs. First and second-tier cities in the morning and evening peak road traffic efficiency decreased by more than 60%, Chongqing as a mountainous city, the main urban area, a large number of two-way two-lane roads, trucks passing speed is less than 15km / h; truck restriction policy forcing the distribution of vehicles to bypass the single trip distribution mileage increased by an average of 25%, fuel, vehicle depreciation, and labor costs rose simultaneously. Research data show that domestic logistics enterprises in large and medium-sized cities, the additional cost of congestion accounted for more than 35% of the total distribution costs.

Secondly, the capacity to carry the upper limit is low, the scale of transportation is not economical. Light truck single-vehicle cargo capacity of only 0.8 ~ 2 tons, large quantities of the same city express need to be diverted, vehicle scheduling, loading and unloading labor, road access costs superimposed on the unit of goods transport costs remain high; a standard subway passenger line idle time can carry 10 ~ 15 tons of express, capacity equivalent to 10 light trucks, intensification of the advantages of a significant.

Third, the external cost of the environment is outstanding. Diesel trucks are the main source of PM2.5 and noise pollution in the city, and carbon emissions from urban logistics trucks accounted for 28% of the total traffic emissions in the city in 2024; vehicle idling under congested road conditions will increase pollutant emissions by 40%, and the city needs to invest a lot of money each year in atmospheric management and noise control, and the hidden social costs are high.

Fourth, by the weather, road accident constraints, distribution stability is poor. Heavy rain, fog, road construction, traffic accidents will directly interrupt highway distribution, the delay rate of express delivery in the same city is always maintained at about 15%, and the cost of fresh food, medicine and other time-sensitive goods wear and tear has increased significantly.

The "Outline for the Construction of a Strong Transportation State" and the "14th Five-Year Plan for Scientific and Technological Innovation in the Field of Transportation" explicitly propose to promote the integration of rail transportation and urban intelligent logistics, and to utilize the idle capacity of metro to share the ground freight. As of the end of 2024, 43 cities across the country opened the subway, with a total operating mileage of 9507.8 kilometers; Chongqing rail transit operating mileage of 575 kilometers, 13 lines, 263 stations, 45 transfer stations, 2024 express business volume of 2.055 billion pieces, an increase of 31.73%, huge logistics demand and improve the underground rail network for the subway to provide the basis for the landing of the logistics of the subway conditions. The huge logistics demand and perfect underground rail network provide the basic conditions for the landing of underground logistics in metro.

1.2. Underground Logistics System Connotation and Comparative Advantages

Underground logistics system (ULS) relying on tunnels, rail transit and other underground space, the use of automated carriers to complete the distribution of urban goods, this paper focuses on the subway passenger and cargo underground logistics mode, the use of the subway at night, midday passenger flow during the trough time plus hanging freight carriages, special circulating carriers to complete the transportation of express delivery, to build the "first-level logistics park - second-level transit station - third-level subway station transit - end demand point" three-level network system Logistics Park - secondary transfer station - tertiary subway station transfer - end demand point" three-level network system.

Comparison with the ground truck transport, the core advantages of subway metro logistics can be quantitatively summarized:

Stability of time: independent right of way of the subway is not subject to ground congestion interference, the average operating speed of 60 ~ 100km / h, the average speed of the truck peak of 12 ~ 20km / h, the same distribution zone subway time-consuming shortened by more than 50 percent, the rate of order delays tend to be close to 0;

Economic Cost Advantage: Relying on the existing subway infrastructure, without the need for new freight corridor, power-driven energy costs. Economic cost advantage: relying on existing metro infrastructure, without the need for new freight corridors, power-driven energy costs only diesel trucks 1/3, the scale of operation after the integrated distribution costs down 30% ~ 50%, Jinhua, Zhejiang, Wuxi metro express pilot have verified the conclusion;

low-carbon environmental benefits: power-driven no exhaust emissions, unit of carbon emissions per 100 kilometers of goods only diesel trucks 15%, which can significantly reduce the city's atmospheric governance inputs;

space resource saving: the goods transport Space resource saving: transferring cargo transportation to underground, reducing the occupation of parking lots and temporary loading and unloading points of trucks in the main urban area, and releasing commercial and public space on the ground.

1.3. Research Ideas and Innovations

Existing underground logistics research focuses on qualitative analysis of feasibility or single path optimization, and seldom models the complete combination of K-means clustering node siting + Floyd transit matching + Dijkstra's shortest path, and at the same time, lacks the quantitative cost and time comparison with the traditional trucking. The innovations of this paper are as follows:

introduce Haversine spherical distance correction K-means clustering, adapt to the geographic characteristics of Chongqing mountainous area in latitude and longitude, and accurately classify the three-level logistics nodes;

add ground truck transportation control measurement, quantitatively comparing the two modes of transportation from the five dimensions of transport distance, time, fuel, manpower, and carbon emission;

construct the total distance minimization optimization model, and build a complete model. Construct a total distance minimization optimization model to build a complete underground logistics network with the whole link of "Park - Stage - Subway Station - Demand Point", and the method has urban universality.

1.4. Thesis Structure Arrangement

This paper is divided into five parts: the first part of the introduction describes the pain points of ground truck transportation and the research value of underground logistics; the second part of the literature review compares the results of domestic and foreign underground logistics, rail freight transportation, and path optimization, and compares the shortcomings of the existing researches; the third part of the paper builds a multilevel mathematical model for underground logistics, specifies the assumptions, the definition of the symbols, and the objective function, and establishes a control index for truck transportation; the fourth part of the paper takes Chongqing as a base to build the total distance optimization model. The fourth part completes the model solution with the metro data of Chongqing main city, outputs the results of node siting, transit matching and optimal path, and horizontally compares the indicators of truck distribution; the fifth part summarizes the research conclusions and points out the limitations of the model and the direction of future optimization.

2. LITERATURE REVIEW

2.1. Foreign Underground Logistics and Rail Freight Transportation Practice Research

Underground logistics prototype originated in 1865 in Berlin pneumatic pipeline freight transportation system, the total length of the pipeline is 297km for mail, securities rapid transit; in 1927, London built an underground postal rail transportation system, relying on a small railcar to divert ground postal trucks, effectively alleviating the traffic congestion of the old city of London. Paris, France, landed in 2017 TramFret tram freight, the use of "common line trailer" mode, passenger cars after hanging additional freight cars synchronized loading and unloading; later upgrade "common line separation" mode, night, low peaks, pure freight metro train, to achieve Passenger and cargo completely separate, measurement shows that the mode can reduce the center of the city 42% postal truck traffic Xinhua Beijing Channel.

European and American scholars focus on measuring the comprehensive benefits of rail freight compared to highway trucks: London metro freight project data show that the same express transportation scale, rail logistics annual fuel, vehicle maintenance costs reduced by 37%, road congestion accidents reduced by 68%; Berlin underground pipeline logistics system compared to trucks, noise pollution reduced by 50%, the concentration of regional air pollutants decreased by 22%. Overseas research has confirmed that rail transportation freight in the intensive, low-carbon, stable distribution level is better than traditional truck transportation, but the model is more adapted to the plains city, the lack of mountainous cities with many undulating road network adapted algorithms.

2.2. Domestic Underground Logistics Feasibility and Mode Research

Domestic academician Qian Qihu firstly proposed to build underground three-dimensional logistics network in megacities by relying on rail transportation, and argued the feasibility of rail freight transportation to relieve congestion by using the Beijing subway as a carrier; Meng Fang took Wuhan subway as an object, and compared the truck distribution in terms of cost, environment, and operation dimensions, pointing out that the long-term operation cost of subway logistics is lower; Zhao Yao used hierarchical analysis to evaluate the landing conditions of Taiyuan subway logistics, and proved that subway logistics in mountainous cities is superior to traditional truck transportation. Zhao Yao uses hierarchical analysis to evaluate the landing conditions of metro logistics in Taiyuan, which proves that mountainous cities also have the potential of rail freight; Chen Ziyu proposes that metro logistics is an important alternative to the increase in distribution costs due to the restriction of trucks based on the SWOT analysis of Nanjing Metro.

Huang Oulong system summarizes the core value of underground logistics compared with truck transportation: reduce ground land occupation, reduce oil consumption and exhaust emissions, transport strong anti-interference, relieve congestion, disaster prevention performance is outstanding; Wang Xiaolin, Hu respectively in Xi'an, Beijing, measured long-term benefits, underground logistics to save congestion management, environmental protection management costs far more than the rail freight transport transformation input.

2.3. Research on Logistics Node Siting and Path Optimization Algorithm

Underground logistics network research is divided into three levels: network hierarchical structure, node siting, path optimization.

At the level of network layout, Huang Oulong divided the underground logistics structure into five categories: line, ring, grid, tree, and hybrid; Yan Haolong built a three-tier logistics network (out-of-town park - in-town distribution center - community end); and Zhou Ailian screened the core transshipment nodes using the comprehensive evaluation method.

At the level of node siting algorithm, Yu Shujun utilizes entropy value TOPSIS to identify the importance of subway transit nodes; Dong Suqin applies the center of gravity method to complete the siting of underground logistics sites; and Fang Longxiang compares the effect of node siting using 0-1 integer planning and greedy algorithm respectively, and both algorithms do not incorporate the correction of geographic sphere distance, which makes the adaption to the mountainous cities inaccurate.

At the level of path optimization, Zhou Bing uses Dijkstra to solve the shortest path of underground distribution; Zhang Chen builds a genetic algorithm model with time window to adapt to passenger and cargo transportation; Li Chengyu uses ant colony algorithm to optimize the multilevel transfer path.

2.4. Existing Research Review and This Paper To Fill The Gaps

existing literature has confirmed the feasibility of underground logistics, but there are three obvious shortcomings:

most of the research is only qualitative description of rail freight is better than trucks, the lack of multi-dimensional quantitative comparative measurement, the lack of complete cost and time data support;

K-means clustering is rarely applied to multi-level underground logistics node delineation, the traditional Euclidean distance clustering does not fit the geographic coordinates of the mountainous area in Chongqing; the complete series "K-means clustering" is not used in underground logistics. Geographic coordinates;

less integrated models with "clustering site selection - Floyd transit matching - Dijkstra path optimization", which can not form a grounded urban underground logistics planning program.

Based on the above gaps, this paper introduces Haversine formula to improve K-means to complete the clustering of the first and second level nodes, Floyd matches the third level transit nodes of the subway, Dijkstra solves the shortest path of the site, and builds a truck transportation control measurement system to quantify the gap between the two modes with real operation data.

3. MODELING

3.1. Problem Description and Benchmarking of Truck Transportation

3.1.1. Chongqing Logistics and Transportation Status Quo

Chongqing as an inland municipality, southwest logistics hub, 2024 express business volume of 2.055 billion pieces, an increase of 31.73% year-on-year; Chengdu-Chongqing China-European liner Chongqing originates and departs accounted for 47% of the annual value of more than 120 billion yuan; the main urban area of the mountainous terrain of the road is narrow, trucks pass the constraints of the strong, the ground distribution of the existence of the three major pain points:

lorries are prohibited from entering the city in the morning and evening peaks, only the early morning, lunchtime can pass In the main city, trucks are prohibited from entering the city in the morning and evening peaks, and can only pass in the early morning and midday, the distribution window is short, and the cost of manpower scheduling rises;

mountain roads have many curves and slopes, and trucks' fuel consumption is 28% higher than that of plain cities, and the mileage of a single vehicle per distribution is inflated;

small districts and business districts have scarce loading and unloading spaces, and trucks can easily cause congestion by temporary parking, which results in an additional overtime fine.

In this paper, the design of the three-level subway underground logistics network:

Level 1 node: city periphery integrated logistics park (out-of-province goods distribution, highway access to secondary nodes);

Level 2 node: urban area of the Rookie Bird Stage class transit station (temporary goods sorting and storage, highway access to the three-level subway station);

Level 3 node: rail transit station (subway trunk line transportation to the demand site, complete the end of the underground distribution).

One or two, two or three short-distance connection between the use of small new energy trucks, three-level nodes to the end of the demand point of the whole subway transportation, and the whole chain of medium-sized diesel trucks directly to the distribution of the formation of a contrast, the measurement of the two types of mode total distance, total cost, total time consumed, carbon emissions.

3.1.2. Truck Transportation Against The Benchmark Model

Traditional ground truck distribution process: out-of-province goods are uniformly transported to the peripheral logistics parks in the city, relying on the direct loading of medium-sized diesel trucks, and directly reaching the end demand points along the urban highway network, with no underground rail transportation, no subway transit, and all sorting, transportation, loading and unloading relying on the ground to be completed.

Comparison indicators include: total transportation mileage, fuel cost, vehicle depreciation cost, labor hour cost, congestion delay time, total carbon emissions.

3.2. Basic Assumptions of the Model

All subway stations are uniformly regarded as cargo demand points, and the spatial coordinates of truck distribution demand points and subway demand points are identical to ensure the fairness of the comparison;

Logistics parks, stagecoaches, and subway lines can be operated normally in all-weather, and the equipment maintenance stoppages are not taken into account;

The one-way flow of cargoes: logistics parks→secondary stagecoaches→third-level subway stations→demand points, with no reverse unladen transportation; the mode of ground trucks is one-way transportation from parks directly to demand points; the mode of ground trucks is one-way transportation from parks to demand points. Unidirectional transportation of goods: logistics park → secondary station → tertiary station → demand point; unidirectional transportation of ground truck mode for the park directly to the demand point;

Only take spatial distance as the core optimization target, and simultaneously extend the measurement of time, cost and carbon emission auxiliary indexes;

Highway connection uniformly adopts small-scale new energy distribution trucks, and only uses medium-sized diesel trucks for the whole chain control mode;

The subway makes use of the unused capacity to carry out freight transportation at noon from 10:00-16:00 and at night after 22:30 without interfering with the daily passenger transportation.

3.3. Description of Model Symbols

3.3.1. Underground Logistics Network Symbols

U_1: set of first-level logistics parks; U_2: set of second-level transit stages; U_3: set of third-level subway station transit nodes; U_4: set of end-demand sites; q_{ij} : 0-1 variable, q_{ij}=1 represents the transportation of goods from park i to secondary stage j, otherwise 0; z_{jc}: 0-1 variable, z_{jc}=1 represents the transportation of goods from stage j to tertiary metro station c, otherwise 0; h_{cg} : 0-1 variable, h_{cg}=1 represents goods distribution from metro station c to demand point g, otherwise 0; d_{ij}: spherical distance from park i to highway of station j; d_{jc}: spherical distance from highway of station j to metro station c; d_{cg} : subway station c to demand point g subway track spherical distance.

3.3.2. Truck Control Mode Measurement Symbol

D_{ig}: logistics park i direct demand point g truck road sphere distance; C_{oil}: diesel truck unit mileage fuel cost; C_{car}: truck unit mileage depreciation and maintenance cost; T_{traf}: average length of congestion delay per kilometer for trucks; E_{co2}: carbon emissions per unit mile for diesel trucks; C_{ele}: electricity energy cost per unit mile for metro; E_{sub}: carbon emissions per unit mile for metro.

3.4. Objective Function and Constraints

3.4.1. Objective Function for Minimizing The Total Distance of Underground Logistics

$$MinS = \sum_{i\in U_1}\sum_{j\in U_2} q_{ij}d_{ij} + \sum_{j\in U_2}\sum_{c\in U_4} h_{cg}d_{cg} \tag{1}$$

Eq. (1) is divided into three distances: the road distance from the park to the secondary stage, the road connection distance from the stage to the tertiary metro station, and the metro transportation distance from the metro station to the point of demand, to minimize the total transportation distance of the whole link as a whole.

Constraints:

$$\sum_{j\in U_2} q_{ij} = 1, \forall i \in U_1 \tag{2}$$

$$\sum_{c\in U_3} z_{jc} = 1, \forall j \in U_2 \tag{3}$$

$$\sum_{g\in U_4} h_{cg} = 1, \forall_c \in U_3 \tag{4}$$

Equation (2)(3)(4) ensures that each level of node cargo transits only to the next single node, with a unique transportation path and no repeated round trips.

3.4.2. Truck Distribution Total Distance Control Function

$$S_{truck} = \sum_{i\in U_1}\sum_{g\in U_4} D_{ig} \tag{5}$$

Struck is the total highway mileage for all-truck distribution, which is used for a side-by-side comparison with the total underground logistics distance S. The distance is combined to further convert the cost, timeliness, and emissions metrics.

3.5. Supporting Measurement Formulas

3.5.1. Transportation Cost Measurement

Comprehensive Cost of Underground Logistics:

$$Cost_{sub} = (\sum q_{ij} d_{ij} + \sum z_{jc} d_{jc}) C_{new} + \sum h_{cg} d_{cg} C_{ele} + C_{man1} \tag{6}$$

C_{new} is the new energy feeder van unit mileage cost and Cman1 is the subway sorting labor fixed cost.

All-van distribution cost:

$$Cost_{tuck} = S_{truck}(C_{oil} + C_{car}) + C_{man2} \tag{7}$$

Cman2 is the cost of truck driving, loading and unloading labor.

3.5.2. Measurement of Total Distribution Time

Total time spent in metro mode includes road connection time + metro rail transportation time without congestion delays; truck mode is superimposed on road congestion delay time:

$$T_{truck} = \frac{S_{truck}}{v_{truck}} + S_{truck} \cdot T_{traf} \tag{8}$$

3.5.3. Carbon Emission Measurement

$$E_{sub}(\sum q_{ij} d_{ij} + \sum z_{jc} d_{jc}) E_{new} + \sum h_{cg} d_{cg} E_{sub} \tag{9}$$

$$E_{truck} = S_{truck} \cdot E_{co2} \tag{10}$$

4. MODEL SOLVING AND QUANTITATIVE COMPARISON ANALYSIS OF TRUCK TRANSPORTATION

Based on the latitude and longitude data of 263 stations in Chongqing main urban metro area, the model solving is completed in six steps, and the control index of full truck distribution is calculated synchronously, so as to visually show the advantages of economy and convenience of underground logistics system.

4.1. Improve K-means Clustering To Determine The First-Class Logistics Park (First-Class Node)

Haversine spherical distance correction contour coefficient method to determine the optimal K value of clustering, measured contour coefficient peak corresponds to K = 3, all the demand sites in the main urban area is divided into three clusters, after the completion of the initial clustering of the second clustering of the remote site of the discrete downward dimensionality, to eliminate the mountainous topography coordinates of the discrete error. Combined with the location of existing logistics parks, highway entrances and exits, and railroad freight hubs in Chongqing, three first-level nodes are selected:

Airport Baowan Logistics Park (106.679433, 29.785057), which serves cluster 1;

BaoShiTong Logistics Park (106.555313, 29.624217), which serves cluster 2;

HengTong Logistics Park (106.43741, 29.624217), which serves cluster 2;

HengTong Logistics Park (106.43741, 29.418342), serving Cluster 3.

If traditional trucks are used for distribution, the three parks need to directly dispatch trucks to 263 demand points, with an average distribution highway distance of 21.7km for a single point. Underground logistics relies on clustered zoning, with the parks only transferring to a small number of secondary stations in the corresponding clusters, and the average connecting highway distance for a single point is reduced to 7.2km, with a reduction in short-distance highway mileage by 66.8%.

4.2. Cluster K-means Clustering Screening of Secondary Transfer Stations (Secondary Nodes)

Recalculate the optimal K value of the three first-level clusters: Cluster 1K=3, Cluster 2K=2, Cluster 3K=5, and select the corresponding area of the clustering center of the Raider station as the secondary transfer node, with a total of 10 secondary stations, with the geographic coordinates as shown in Table 3. Difference in van comparison: traditional van mode has no layered transit, the park directly reaches the end demand point, the single loaded goods are scattered, and the empty load rate is high; underground logistics second-level station centralizes the sorting of express mail in the same area, and batch transshipment is carried out to the subway station, which increases the load rate of the goods by 75%, and greatly reduces the number of times of round trips of the connecting vehicles.

4.3. Floyd Algorithm Matching of Three-level Subway Station Transit Nodes

Using Floyd multi-source shortest path algorithm, calculate the spherical distance matrix between 10 secondary stations and all the surrounding subway stations, screen the nearest stations with convenient transfer as the three-level logistics transit nodes, and output the distance matrix of the alternative stations to ultimately determine the 13 three-level subway stations as the core transshipment points of underground logistics. There is no fixed transfer hub for truck distribution, each truck plans its route independently, and a large number of repetitive road sections cause mileage waste; the 13 three-level stations of underground logistics cover all the main urban areas, and the metro trunk lines are connected in a network, so there is no repetitive detour for rail transportation.

4.4. Dijkstra Algorithm Solves The Shortest Track Path From Subway Station To Demand Point

Extract the latitude and longitude of all subway stations, calculate the spherical distance of the track between stations by Haversine formula, and construct the adjacency matrix;

Take the 13 three-stage transit subway stations as the starting point, and the 263 demand stations as the end point, and cyclically call Dijkstra algorithm to solve the shortest path of a single source to output the complete track transportation routes of each area. Summarize the total distance S of all underground logistics links and compare it with the total mileage Struck of direct trucking.

Mileage Comparison Core Data:

Total transportation distance S of all underground logistics links: 12,763km;

Total transportation distance Struck of all diesel trucks: 37,241km;

Conclusion: The total mileage of underground logistics is reduced by 65.7% compared with the truck mode, which significantly reduces the pressure on fuel, depreciation and emission caused by vehicle traveling.

4.5. Multi-dimensional Quantitative Comparison: Underground Logistics VS Ground Truck Transportation

Based on the measured data of Chongqing main urban area, the quantitative comparison is completed from the five dimensions of cost, timeliness, carbon emission, capacity and stability, and the data are all in line with the measured parameters of the domestic rail freight transportation pilot.

4.5.1. Comprehensive Transportation Cost Comparison (Monthly Equivalent Express Scale 2 Million Pieces)

Table 1. Comprehensive Transportation Cost Comparison

Indicators	All-diesel truck distribution	Metro underground logistics network	Magnitude of variance
energy costs	42.7	11.3	Reduction 73.5%
maintenance	28.3	7.6	Reduction 73.1
labor	36.5	24.8	Reduction 32.1%
others	12.1	0	eliminate
total cost	119.6	43.7	Reduction 63.5%

Van mode high fuel, vehicle wear and tear, congestion additional cost is the core expenditure; underground logistics only short-distance feeder use new energy car, subway relying on existing lines, no new road access, restriction of fine costs, scale operation after the economic advantage is significant. Jinhua subway express pilot data synchronization verification, rail logistics single-ticket distribution costs down more than 40% Xinhua Beijing Channel.

4.5.2. Comparison of Distribution Timing

Average speed of trucks: 22km/h at peak, 13km/h at peak, average congestion delay 0.42h/10km; Average speed of subway: 75km/h, no congestion, no weather delay, punctuality 99.2%;

Cross-regional distribution case of the same area (Yubei Airport to Dadukou):

Truck mode: total time consumed with congestion: 3 hours 17 minutes Subway underground logistics mode: 1 hour and 28 minutes for feeder + rail;

54.3% shortening of the time limit, and a significant reduction in the loss rate of fresh food, medicine and other high time-sensitive goods.

4.5.3. Comparison of Carbon Emission and Environmental Benefits

Monthly total carbon emission of 2 million pieces of express transportation: diesel truck mode: 147.2 tons of CO_2; subway underground logistics mode: 21.6 tons of CO_2;

Carbon emission decreased by 85.3%, subway electric drive is almost free of tailpipe particulate matter and nitrogen oxides emission, and at the same time, it reduces the noise nuisance of the trucks and lowers the financial investment of the city's atmospheric control.

4.5.4. Capacity and Urban Traffic Mitigation Effect

1 medium-sized truck single load 1.2 tons, 1 subway freight formation single load 12 tons, a single subway line idle time daily can run 6 freight, a single day equivalent replacement of 60 trucks on the road;

This paper builds the Chongqing underground logistics network can divert 42% of the main city city with the city's freight vehicles, the peak of the road congestion index decreased by 27%, the ground private car, The efficiency of public transportation is synchronized to improve, alleviating the contradiction of the shortage of road resources in the mountain city.

4.6. Complete Flow Process of Underground Logistics Network

The goods outside the province are allocated to three first-level logistics parks according to the area, and then transferred to the corresponding cluster second-level station through new energy short-distance trucks to complete the sorting; the goods at the station are again connected and transported to the matching third-level transit subway station; the subway is utilized to run freight grouping in off-peak hours, and then distributed to the various demand stations along the shortest rail line solved by Dijkstra; and the final station completes the last 100 meters of distribution through a small unmanned vehicle. Small unmanned vehicles complete the last 100 meters of distribution, forming a complete underground closed loop.

Only two short distances of new energy trucks are used in the whole process, and the core trunk line relies on the underground track, completely avoiding all the short boards of ground truck transportation.

5. CONCLUSION

5.1. Main Research Conclusion

This paper takes Chongqing mountainous rail transportation network as a carrier, builds a multilevel underground logistics optimization model based on improved K-means, Floyd, Dijkstra combination algorithm, and compares the whole process with traditional diesel truck road distribution, and comes up with three major core conclusions:

5.1.1. Node Clustering Algorithm Adapts to the Mountainous City, And Greatly Reduces The Total Transportation Mileage

Haversine spherical distance correction K-means algorithm is used to divide the first and second level logistics nodes, compared with the non-hierarchical truck direct mode, the total transportation mileage of the whole chain is reduced by 65.7%; K-means clustering is easy to calculate, has strong adaptability to dense subway stations, and has a higher computing speed than the intelligent algorithms of genetics, ant colony, etc, which is convenient for the rapid landing planning of various large cities.

5.1.2. The Economy and Timeliness of the Underground Logistics System Comprehensively Surpasses That of Truck Transportation

Under the same express size, the monthly comprehensive distribution cost of subway metro logistics is reduced by 63.5%, the cross-regional distribution time is shortened by 54%, and the carbon emission is reduced by 85.3%; it eliminates the additional costs brought by truck restrictions, congestion and detours, and is not subject to interference by extreme weather such as rainstorms and fog, so that the stability of distribution is greatly improved. Relying on the existing subway stock resources, there is no need to build new freight tunnels, low investment in preliminary transformation and significant long-term benefits.

5.2. Limitations of the Study

The distance measurement adopts spherical straight-line distance, which is not fully matched with the actual mileage of Chongqing's mountainous highway and subway climbing, and there is a small theoretical deviation in the results; the model is optimized only with a single objective of transportation distance, and it does not incorporate the multi-objective constraints of cargo loading and unloading transit time, subway freight wagon reconstruction investment, and nighttime operation cost; it fails to consider the embargoed cargo categories such as bulky goods, flammable and explosive goods, and is modeled for standard express and small goods only. The modeling is only carried out for standard express small pieces; some elevated subway stations in mountainous areas have a large difference in height from the ground, and the cost of terminal connection and loading and unloading is not included in the cost measurement system.

5.3. Future Optimization Direction

Construct a multi-objective comprehensive optimization model, synchronously incorporate multi-dimensional weights of transportation distance, transit time, construction and operation cost, and carbon emission to form a comprehensive evaluation system; revise the distance calculation formula by combining the actual alignment of Chongqing's mountainous roads and subways, and introduce traffic simulation software to simulate the real traffic and cargo flow, so as to enhance the accuracy of the measurement; subdividing the cargo categories, and distinguishing between the design of fresh food, documents, and ordinary parcels. Differentiated passenger and cargo transportation scheme; combined with unmanned distribution vehicles, intelligent three-dimensional warehousing to improve the end connection, build "rail + unmanned vehicle" fully automated underground logistics system; measure the long-term social benefits of underground logistics, quantify the hidden economic value of reducing congestion, reducing pollution, saving road construction, and provide data support for the formulation of urban rail transportation freight policy. Provide data support.

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