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EMERGENCY SUPPLIES DISPATCHING MODEL BASED ON THE OPERATION METHOD ON THE GRAPH

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ABSTRACT: The disaster caused by the tropical cyclone "Mangkhut" in Guangxi Beibu Gulf Economic Zone (GBGEZ) created a problem in dispatching emergency supplies from multiple supply points to multiple demand points. Establishing a fast, efficient, low-cost emergency supplies dispatching (ESD) model is particularly important. Through the characteristics of emergency supplies from multiple supply points to multiple demand points, the traditional provincial → prefecture-level city → county step-by-step emergency supplies dispatching model and provincial → county direct emergency supplies dispatching model were established using the operation method on the graph (OMG). This method can effectively solve the demand for emergency supplies in disaster areas. From the perspective of the total transport tons • km of the two emergency supplies dispatching models, compared with the traditional provincial → prefecture-level city → county step-by-step emergency supplies dispatching model, the provincial → county direct emergency supplies dispatching model based on the operation method of the graph saves 31,031 tons • km, with a saving rate of 16.56%. The provincial → county direct emergency supplies dispatching model based on the operation method on the graph has lower cost, saves limited dispatching resources, and has a better effect. The method can provide a reference for the emergency management departments of Guangxi governments at all levels to formulate emergency supplies dispatching schemes for Guangxi Beibu Gulf Economic Zone.

Keywords: Emergency supplies dispatching, Operation method on the graph, Tropical cyclone disaster, Guangxi Beibu Gulf Economic Zone

1. INTRODUCTION

Guangxi Beibu Gulf Economic Zone (GBGEZ), located in the southwest end of China's coast and the south of Guangxi Zhuang Autonomous Region (Guangxi), comprises six prefecture-level cities, namely Nanning, Beihai, Qinzhou, Fangchenggang, Yulin, and Chongzuo. It covers an area of 42,500 square kilometers and has a total population of 22,976,300 at the end of 2021. On January 16, 2008, the state approved the implementation of the Guangxi Beibu Gulf Economic Zone Development Plan, proposing to build GBGEZ into an important international, regional economic cooperation zone open to ASEAN. Research shows that Guangxi is affected by many tropical cyclones (typhoons) every year, causing many casualties and economic losses in Guangxi. On September 16, 2018, the 22nd typhoon "Mangkhut" entered Guangxi. According to the statistics of the Guangxi Civil Affairs Department, Typhoon "Mangkhut" was the strongest typhoon that landed in Guangxi in 2018. A total of 13 cities and 55 counties (districts) in Guangxi suffered various damage, and 1,479,397 people were affected. It also affected 106,800 hectares of crops, destroyed 371 hectares of arable land, and collapsed 837 farmhouses, causing direct economic losses of 850 million yuan. In GBGEZ, 627,126 people were affected, 122,742 people needed to be relocated urgently, and 35,580.6368 hectares of crops were affected, with a direct economic loss of 31,7734,625 yuan. This typhoon affected a large number of people that was widely distributed in different areas, making it difficult for the relief operation. The government must formulate a quick, low-cost emergency supplies dispatching (ESD) model for relief operations in the affected areas. This paper discusses the establishment of an efficient ESD model using the operation method on the graph (OMG) to carry out effective rescue operations in the affected areas.

2. RESEARCH SIGNIFICANCE

The dispatching of emergency supplies is usually affected by the number of victims, the distribution to emergency supplies storage warehouses, and the transportation route of the affected areas. This study discusses establishing a suitable and efficient ESD model to respond efficiently to a wide range of massive tropical cyclone disasters. Typhoon Mangkhut's 25 affected counties in 6 prefecture-level cities in GBGEZ were taken as the research object of this study. This paper can provide a reference for the emergency management departments of Guangxi and other provinces and cities to formulate ESD schemes.

3. LITERATURE REVIEW

Through the retrieval of papers related to ESD for tropical cyclone disasters, the literature related to this study can be summarized and sorted from two aspects: The tropical cyclone disaster and its impact in Guangxi and the ESD scheme and model.

3.1 Research Literature on Tropical Cyclone Disasters and Impacts in Guangxi

Every year, Guangxi is affected by tropical cyclones, which greatly impact the local economy and people. Typhoon No. 0606 "Papiang" entered Guangxi from Yulin City, causing disaster in 74 counties (cities and districts) in Guangxi, with a total population of 5.706 million, 34 people killed, and a direct economic loss of 7 billion yuan [1]. Typhoon No. 1621, "Salijia," has devastated Guangxi with strong wind and heavy local rainfall [2]. According to the Civil Affairs Department of Guangxi statistics at 20 o 'clock on October 21, 2016, "Salijia" affected 352,100 people in 6 cities and 20 counties (cities and districts), including Beihai, Fangchenggang, Nanning, Qinzhou, Chongzuo, and Guigang. The affected area of crops was 17.76×1000 hm2, and the direct economic loss was 235 million yuan [2]. According to People's Daily Online, China News, International Online, and the official websites of the affected provinces, the losses are mainly concentrated in the following aspects: agriculture, forestry, animal husbandry, fishing, municipal facilities, industrial parks, collapsed residential buildings, as well as transportation, ports, and shipping [2].

3.2 Relevant Research Literature on ESD Scheme and Model

Many scholars have proposed various efficient and feasible research methods for ESD model. Dongqing et al. [3] established the ESD model of a single distribution center and multi-disaster warehouse. They propose the requirement of two-way distribution and significantly improve the efficiency of ESD. Yang et al. [4] reasonably determined the supply quantity of various emergency resources in different disaster-stricken areas by combining various means and methods of major disaster emergency management. Hong X. [5] realized the efficiency of dispatching emergency materials and reduced total emergency and dispatch costs through a dynamic rolling emergency resource allocation model and data mining algorithm service code. Chongchong et al. [6] put forward the problem of route selection for the dispatching and transporting of emergency relief materials from a single supply point to multiple different demand points and disaster relief points and how to assign and select a multi-supply point dispatch plan. According to the time point and cycle of each material dispatch management decision, the management and dispatch of emergency relief materials can be classified into dynamic and static types [6]. Shuhua N. [7] proposed establishing a joint conference system for the emergency supplies reserve to do a good job in the emergency supply reserve and regional division of labor.

There are various modeling methods for emergency supplies scheduling. Douglas et al. [8], Ali A. H. [9], and other scholars proposed to conduct a two-stage study to establish a stochastic network flow planning model to improve the efficiency of ESD. Feihu et al. [10] and Hui et al. [11] stratified the road network, proposed a two-level EMS model of multi-commodity and multi-vehicle with time minimization as the goal, and adopted a genetic algorithm and hierarchical solving method to obtain an optimization scheme. Taking an earthquake disaster as an example, Yuling and Xiaofang [12] obtained the relatively optimal material scheduling scheme by applying the traveling agent theory to the assigned problem. Singhtaun et al. [13] proposes a new mathematical model and a solution method for a heterogeneous fleet open vehicle routing problem. The system collects orders for each target warehouse and creates a cluster of target warehouses and an optimal vehicle route.

For multi-objective models with complex constraints, more efficient algorithms are needed to solve the optimal solutions. Burkart et al. [14] proposed a multi-objective location-routing model, whose objective was the minimum unmet service demand and the cost of open routing of DC and relief materials. Ke et al. [15] established a multi-objective optimization model of relief supply and transport balance constraints, with the objectives of minimizing the sum of construction, maintenance, and transportation costs of protected areas minimizing the overall risk and disaster disposal difficulty. Li et al. [16] proposed a multi-objective emergency medical supplies scheduling model and solved the model by using strategies such as dynamic inertia weight and adding particle perturbation terms to efficiently solve emergency supplies allocation and vehicle routing scheme generation under resource shortage.Yun et al. [17] proposed a multi-dimensional robust optimization model aiming at cost minimization and robustness maximization, aiming at the optimization of cold chain emergency supplies distribution route with multi-demand centers and soft time Windows under the COVID-19 pandemic, as well as the problem of dispatching supplies to medical institutions across the disaster areas. A hybrid algorithm combining Pareto genetic algorithm and improved grey correlation analysis is used to solve the problem.

There are also different solutions to the problem of insufficient or uncertain emergency supplies. Shu-Shun et al. [18] proposed a resource-constrained project Scheduling Problem (RCPSP) model. This is a road network rush repair scheduling model based on constraint programming (CP) as a search algorithm was proposed. Wanbo et al. [19] used the impulse demand fluctuation function and demand prediction formula to build a supply scheduling model to minimize the cumulative sum of unmet material demands at different emergency demand points and obtain the optimal emergency supply scheduling plan. Komarudin et al. [20] takes profit maximization as the objective function and adopts mixed integer programming method to design liner shipping logistics network under multi-period programming level.

3.3 Summary

The above literature analysis shows that there are many studies on emergency logistics. However, there is a particular gap between Guangxi and other provinces in emergency logistics, and few studies on emergency logistics in GBGEZ. The GBGEZ is deeply affected by tropical cyclones every year and does not have much research on the ESD model. The lack of scientific plans for the overall ESD can be affected by time and distance. Several factors can also affect the quantity of emergency supplies stored in governments' emergency supply storage in GBGEZ and the emergency supplies required by the temporary resettlement sites in the affected areas. In view of the impact of tropical cyclone disasters in GBGEZ, It is necessary to establish an efficient and low-cost ESD scheme to provide a reference for governments at all levels in GBGEZ when dealing with tropical cyclone disasters.

4. METHODOLOGY

To solve the problem of ESD, linear programming, production-marketing balance, mileage saving, shortest path, and OMG can be adopted. This paper uses the OMG to solve the problem of ESD based on the principle of linear programming, and the scheme obtained is the optimal one. The OMG plan and calculate the transportation network diagram of ESD to minimize the tons•kilometers of emergency supplies running and reduce the cost and time. The traffic network diagram can be distinguished into two types: the traffic network diagram without circles and the traffic network diagram with circles.

4.1 Operation Method on the Graph Without Circle

The non-circular OMG adopts the principle of "nearby transport." If there is no convection and roundabout transport phenomenon in the scheme, it is the optimal scheme. The situation of emergency supplies transportation of the operation method is illustrated in Fig. 1. The supply point of emergency supplies is represented by "○", the quantity of emergency supplies supplied is recorded in addition to "○" (unit: ton), the demand for emergency supplies is represented by "×", the quantity of emergency supplies received is recorded next to "×" (unit: ton), and the distance between the two points is marked on the route (unit: km). The total emergency supplies equal the total demand for emergency supplies.

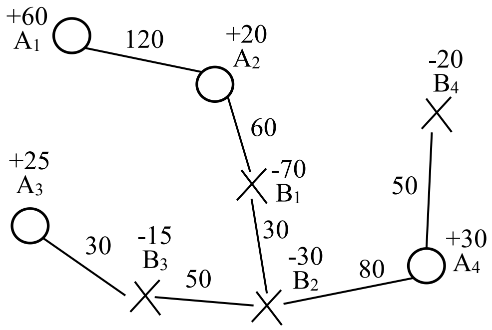

Fig. 1 Traffic network diagram of OMG without circles

According to the OMG, the emergency supplies should first meet the emergency supplies demand of the neighboring demand point and then meet the other demand points. From the A_1-A_2-B_1-B_2 branch line, the Supply of A_1 and A_2 is 80 tons, and the demand for B_1 is 70 tons. Therefore, 70 tons are transferred from A_1 and A_2 to B_1, and the remaining 10 tons are transferred to the next nearest demand point, B_2.

Looking at the A_3-B_3-B_2 branch line, A_3 is transferred to B_3, the nearest demand point, totaling 15 tons, and the remaining 10 tons are shipped to B_2.

Finally, look at the branch line B_4-A_4-B_2. At this time, only two demand points B_4 and B_2, have not met the demand. 20 tons of A_4 should be transferred to B_4 and 10 tons to B_2.

Fig. 2 shows the flow diagram of the final emergency supplies transportation plan. Where "→" represents the flow direction of emergency supplies, and the number on "→" represents the number of emergency supplies transported.

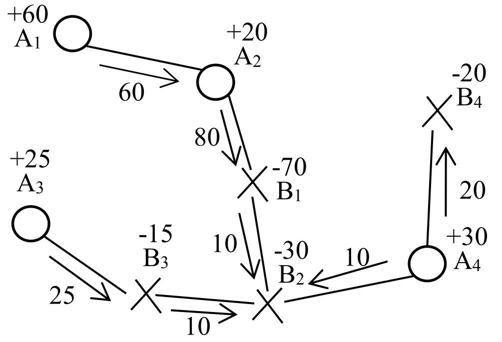

Fig. 2 Flow diagram of emergency supplies transfer scheme of the OMG without circles

According to the ESD situation in Fig. 2, the optimal ESD scheme of the OMG without circles is obtained, as shown in Table 1.

Table 1 The optimal emergency supplies transfer scheme of the OMG without circles

	B_1	B_2	B_3	B_4	Supply (tons)
A_1	60				60
A_2	10	10			20
A_3		10	15		25
A_4		10		20	30
Demand (tons)	70	30	15	20	135

The total tons • km S_1 dispatching of its transportation scheme is:

S_1=60*120+10*60+10*（60+30）+10*（30+50）+10*80+15*30+20*50=11750（tons• km）

4.2 Operation Method on the Graph With Circle

The traffic network diagram with a circle needs to be transformed into a traffic network diagram without a circle. The method is to sum the flow lines of the inner and outer circles of the feasible scheme, respectively, and judge whether they are more than half of the total circumference of the whole circle. The scheme is optimal if the total length of the flow line of the outer ring exceeds half of the circumference of the whole ring. The specific adjustment method is to choose the circle flow line in the smallest adjustment, in more than one-half of the full circle minister of the inner (or outer) circle. The above method is applied until the sum of the flow lines of empty vehicles in the inner and outer circles is less than half of the circumference, and then the transportation scheme obtained is the optimal scheme. According to the OMG of emergency supplies transportation in the circle in Fig. 3, the total supply of emergency supplies is equal to the total demand for emergency supplies.

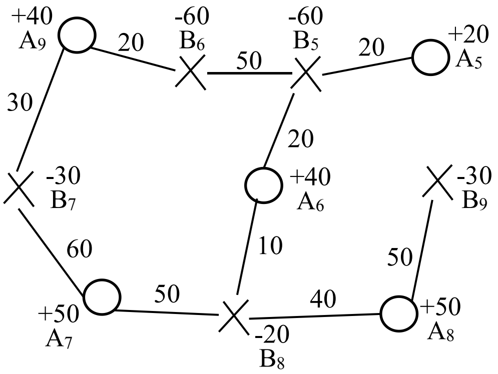

Fig. 3 Traffic network diagram of emergency supplies transfer with circle

The circled emergency supplies transportation diagram is changed into an uncircled diagram. Assuming that the route between A_7 and B_7 is not feasible, the initial transportation scheme is obtained according to the principle of "nearby transportation," as shown in Fig. 4.

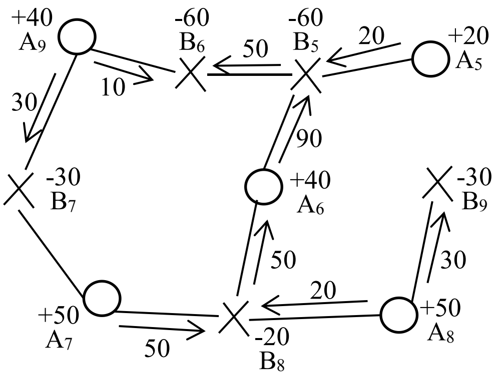

Fig. 4 Flow diagram of initial emergency supplies transportation scheme with circle

Test the initial scheme:

Circumference：

C_1=60+50+10+20+50+20+30=240（km）

Half of the circumference：

$C_1/2$=240/2=120（km）

The inner circuit length：

C_{inner1}=20（km）

The outer circuit length：

C_{outer1}=50+10+20+50+30=160（km）

From this, we can see that $C_{inner1} < C_1/2$, $C_{outer1} > C_1/2$, so it's not optimal. After adjusting the initial scheme according to the adjustment method described above, the final transport scheme, as shown in Fig. 5, can be obtained.

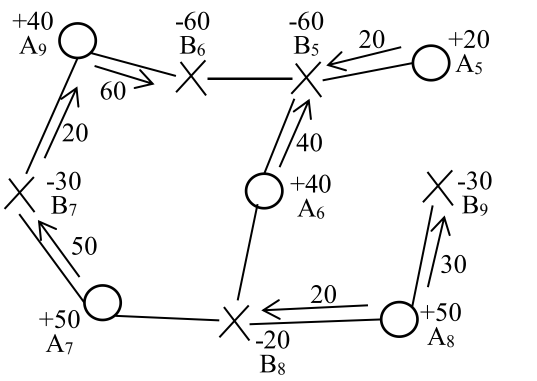

Fig. 5 The flow diagram of the emergency supplies transfer scheme with a circle after adjustment

To test:

C_{inner2}=60+30+20=110（km）

C_{outer2}=20（km）

So, $C_{inner2} < C_1/2$, $C_{outer2} < C_1/2$, so the adjusted scheme is the optimal scheme.

The optimal emergency supplies distribution scheme of the OMG with circles is shown in Table 2.

Table 2 Optimal scheme of emergency supplies distribution of the OMG without circles

	B5	B6	B7	B8	B9	Supply (tons)
A5	20					20
A6	40					40
A7		20	30			50
A8				20	30	50
A9		40				40
Demand (tons)	60	60	30	20	30	200

The minimum tons•km S_2 is:

S_2=20*20+40*20+20*(50+10+20+50)+30*60+20*40+30*50+40*20=8700(tons•km)

The resulting minimum tons•km is multiplied by the road freight rate to get the minimum transport cost.

5. RESULTS

5.1 Disaster Situation and Emergency Supplies Requirements

According to the population data survey of 6 prefecture-level cities in GBGEZ affected by Typhoon "Mangkhut," 25 counties (districts and county-level cities) in these 6 prefecture-level cities where more than 500 people need to be urgently relocated and resettled. The remaining disaster victims in other counties (districts or county-level cities) where no more than 500 people need to be urgently relocated are counted into neighboring counties. A total of 122,742 people need to be urgently relocated and resettled in 6 prefecture-level cities. The detailed disaster data of each city and county are shown in Table 3.

The maximum time for the autonomous region's financial assistance to people in need of emergency relocation and resettlement should not exceed 10 days, according to the circular on natural disasters by the Guangxi government. All emergency supplies shall be converted into 1kg per person per day. Table 3 shows the number of emergency supplies needed by cities and counties for emergency relocation and resettlement. Other disaster losses can be saved through cash subsidies.

According to the survey data of Guangxi's emergency supplies reserve pool, A_1 Guangxi Disaster preparedness Center is the provincial emergency supplies reserve and supply place, A_2-A_7 of the six prefecture-level city emergency management Bureau of GBGEZ is the prefecture-level city emergency supplies reserve and supply place. The emergency Management Bureau of 25 counties in need of emergency relocation and resettlement of more than 500 people under the jurisdiction of 6 prefecture-level cities B_1-B_{25} receive places for relief materials. The 25 counties' need to supplement emergency supplies (991 tons) is equal to the emergency supplies needed by the counties for emergency population relocation (1227.42 tons) minus the emergency supplies reserves of (236.42 tons). Emergency supplies of prefecture-level cities (255 tons) can only be given priority to those under their jurisdiction for disaster relief. Insufficient emergency supplies are supplied by the provincial emergency supplies reserve center (736 tons). See Table 3 for information on the disaster situation of each city and county, the amount of emergency supplies reserves, and the supply of supplementary emergency supplies.

5.2 The Distance Between the Place of Supply and the Place of Receiving

The distance between the provincial emergency supplies reserve center of Guangxi (A_1) and the emergency supplies reserve repositories of disaster-stricken prefecture-level cities (A_2-A_7) and the emergency supplies reserve repositories of counties (districts and county-level cities) (B_1-B_{25}) can be queried through the transportation map of Guangxi and Baidu map (unit: km). The transport routes selected for emergency supplies are the shortest to ensure the rapid delivery of emergency supplies to the disaster area. The distances between the places where emergency supplies are supplied and the places where they are received are shown in Table 4.

Table 3 Disaster situation and emergency supplies demand of 6 prefecture-level cities in GBGEZ caused by Typhoon "Mangkhut"

No.	Name of the disaster area	Affected population (persons)	Emergency transfer and resettlement Population (persons)	Emergency transfer and resettlement population demand emergency supplies (tons)	Emergency supplies reserve (tons)	Supplementary emergency supplies (tons)
A_2	Nanning City	322606	23978	239.78	50	119
B_1	Qingxiu district	1078	678	6.78	4.78	2
B_2	Xixiangtang District	9174	9144	91.44	20.44	71
B_3	Liangqing district	5581	842	8.42	5.42	3
B_4	Yongning district	5078	735	7.35	4.35	3
B_5	Wuming district	8594	3201	32.01	10.01	22
B_6	Long 'an County	9889	929	9.29	4.29	5
B_7	Binyang County	60315	3573	35.73	10.73	25
B_8	Hengzhou City	222897	4876	48.76	10.76	38
A_3	Beihai City	20360	17353	173.53	40	97
B_9	Haicheng district	7402	4670	46.7	10.70	36
B_{10}	Yinhai district	6449	6449	64.49	10.49	54
B_{11}	Tieshan port area	895	895	8.95	4.95	4
B_{12}	Hepu County	5614	5339	53.39	10.39	43
A_4	Qinzhou City	25827	19683	196.83	45	112
B_{13}	Qinnan district	4154	4154	41.54	10.54	31
B_{14}	Qinbei district	4540	3229	32.29	8.29	24
B_{15}	Lingshan County	6997	4699	46.99	10.99	36
B_{16}	Pubei County	10136	7601	76.01	10.01	66
A_5	Fangchenggang City	11910	5027	50.27	20	17
B_{17}	Defense district	7175	3308	33.08	8.08	25
B_{18}	Shangsi County	4735	1719	17.19	5.19	12
A_6	Yulin City	225677	47842	478.42	80	333
B_{19}	Fumian district	61859	1206	12.06	5.06	7
B_{20}	Rongxian County	60272	6050	60.5	10.50	50
B_{21}	Luchuan county	15630	4672	46.72	10.72	36
B_{22}	Bobai County	37571	26130	261.3	20.30	241
B_{23}	Xingye county	25356	3761	37.61	8.61	29
B_{24}	Beiliu city	24989	6023	60.23	10.23	50
A_7	Chongzuo City	20746	8859	88.59	20	58
B_{25}	Fusui County	20746	8859	88.59	10.59	78
	Total of 6 cities	627126	122742	1227.42	491.42	736
A_1	Guangxi	1479397	137910			736

5.3 Construction of the Traditional Provincial → Prefecture-Level City → County Step-by-Step ESD Model Based on the OMG

5.3.1 Dispatching model assumptions

Based on the disastrous impact of Typhoon "Mangkhut" on 6 prefecture-level cities and counties (districts and county-level cities) in GBGEZ, as well as the management system of Guangxi's emergency supplies reserve at the provincial, prefecture-level city, and county levels, emergency supplies shall be dispatched step by step according to the traditional province → prefecture-level city → county. The following assumptions are set up to complete better the dispatch of emergency supplies in the emergency supplies reserve of governments at all levels.

(1) The six prefecture-level cities are respectively responsible for the relief and resettlement of the disaster victims in the disaster-stricken counties (districts and county-level cities) within their respective jurisdictions. That is to say, all emergency supplies stored in the emergency reserves of the prefecture-level cities can only be supplied to the disaster-stricken counties (districts and county-level cities) within their respective jurisdictions as a matter of priority.

(2) The emergency supplies needed by disaster-stricken counties (districts and county-level cities) that cannot be met by the prefecture-level cities shall be first centrally transferred to the prefecture-level city emergency supplies reserve pool and then supplied by the prefecture-level city emergency supplies reserve pool to the counties.

(3) The provincial emergency supplies reserve center must have enough emergency supplies to supply the insufficient emergency supplies needs of the cities and counties. However, the equilibrium of supply and demand is crucial to avoid wasting over supplies.

Table 4 Distances between the places where supplied and received

	A_1	A_2	A_3	A_4	A_5	A_6	A_7
A_2	12						
A_3	224						
A_4	116						
A_5	135						
A_6	274						
A_7	125						
B_1	14	3					
B_2	25	15					
B_3	8	9					
B_4	21	18					
B_5	68	60					
B_6	115	105					
B_7	91	98					
B_8	129	119					
B_9	220		3				
B_{10}	220		3				
B_{11}	231		36				
B_{12}	194		28				
B_{13}	131			15			
B_{14}	117			3			
B_{15}	127			103			
B_{16}	167			152			
B_{17}	130				11		
B_{18}	94				105		
B_{19}	283					9	
B_{20}	255					50	
B_{21}	336					42	
B_{22}	302					46	
B_{23}	184					36	
B_{24}	231					21	
B_{25}	68						75

5.3.2 Construction and solution of provincial → prefecture-level → county-level ESD model

Combined with the data in Table 3 and Table 4, according to the actual locations of the six prefecture-level cities and their subordinate counties in GBGEZ, the OMG is adopted to obtain the transport network diagram of three-level dispatch from province to the prefecture-level city to county, as shown in Fig. 6.

The above traffic network diagram of the provincial → prefecture-level → county-level ESD model shows a traffic network diagram that does not contain circles. The OMG without circles can be used to solve the lowest-cost transportation scheme. The lowest-cost transportation scheme obtained is shown in Fig. 7.

According to the flow diagram of the provincial → prefecture-level city → county-level ESD scheme obtained using the OMG in Fig. 7, there is no convection and roundabout phenomenon in this scheme which means this scheme is the optimal dispatching scheme. The optimal dispatching scheme, A_1-A_7, is the supply place of emergency supplies. Meanwhile, A_2-A_7 emergency supplies reserve prefecture-level cities serve as the intermediate transfer station. It also receives emergency supplies from A_1 provincial emergency supplies reserve center, and the B_1-B_{25} of emergency supplies demand area receives emergency supplies from higher prefecture-level cities. The optimal provincial → prefecture-level city → county-level ESD scheme is shown in Table 5.

Table 5 Optimal plan of ESD by province, prefecture-level city and county

	A_1	A_2	A_3	A_4	A_5	A_6	A_7	Demand (tons)
A_2	119							119
A_3	97							97
A_4	112							112
A_5	17							17
A_6	333							333
A_7	58							58
B_1		2						2
B_2		71						71
B_3		3						3
B_4		3						3
B_5		22						22
B_6		5						5
B_7		25						25
B_8		38						38
B_9			36					36
B_{10}			54					54
B_{11}			4					4
B_{12}			43					43
B_{13}				31				31
B_{14}				24				24
B_{15}				36				36
B_{16}				66				66
B_{17}					25			25
B_{18}					12			12
B_{19}						7		7
B_{20}						50		50
B_{21}						36		36
B_{22}						241		241
B_{23}						29		29
B_{24}						50		50
B_{25}							78	78
Supply (tons)	736	169	137	157	37	413	78	1727

As seen from Table 5, the total supply equals the total demand, which is 1727 tons, reaching a balance between supply and demand. Table 5 shows the 736 tons of emergency supplies from the provincial emergency supplies reserve center. A_1 was first transferred to A_2-A_7 and then from A_2-A_7 of the prefecture-level city to B_1-B_{25} of the county. The supply and demand of the 736 tons of supplies in Table 5 were calculated twice. The total amount of emergency supplies transferred from A_1-A_7 is 1727-736 = 991 tons, and the total amount of emergency supplies needed to be replenished from B_1-B_{25} counties is also 991 tons. If the total number of tons•kilometers transferred in the optimal plan for the province → prefecture-level city → county step-by-step ESD is S_3, S_3 is equal to the actual transport volume transferred in the optimal plan for the province → prefecture-level city → county step-by-step ESD in Table 5 multiplied by the distance between the corresponding supply place and the receiving place in Table 4. Substitute the corresponding data in Table 5 and Table 4 to obtain: S_3= 187,439 (tons•km).

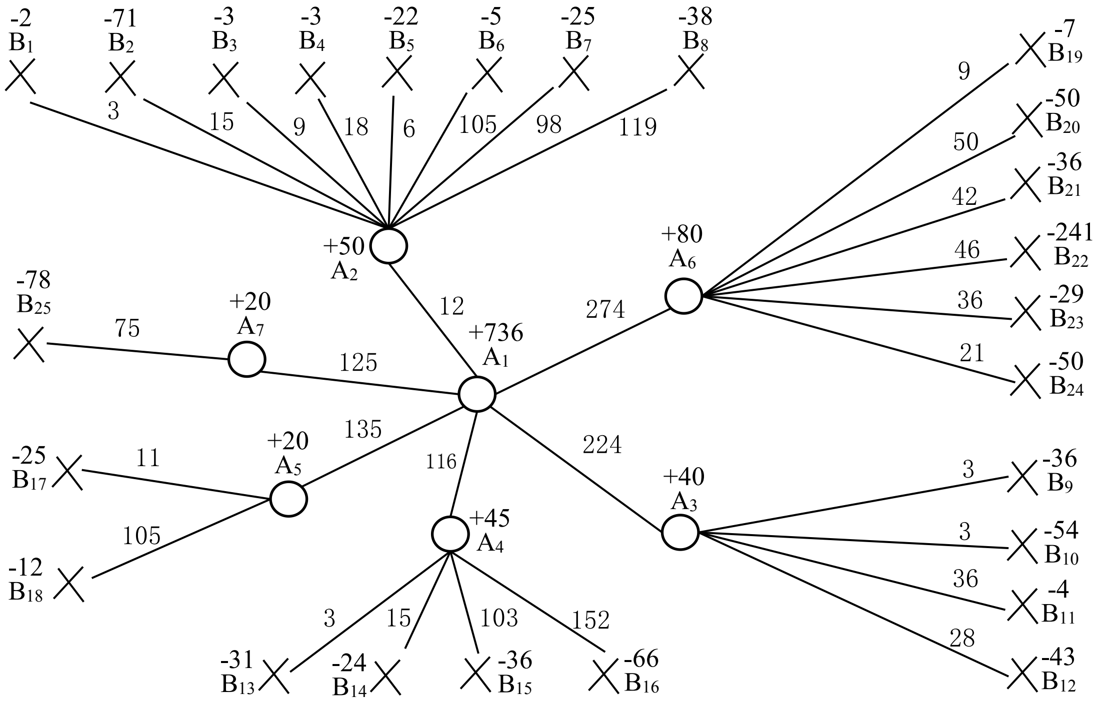

Fig. 6 Traffic network diagram of Provincial → prefecture-level → county-level ESD model

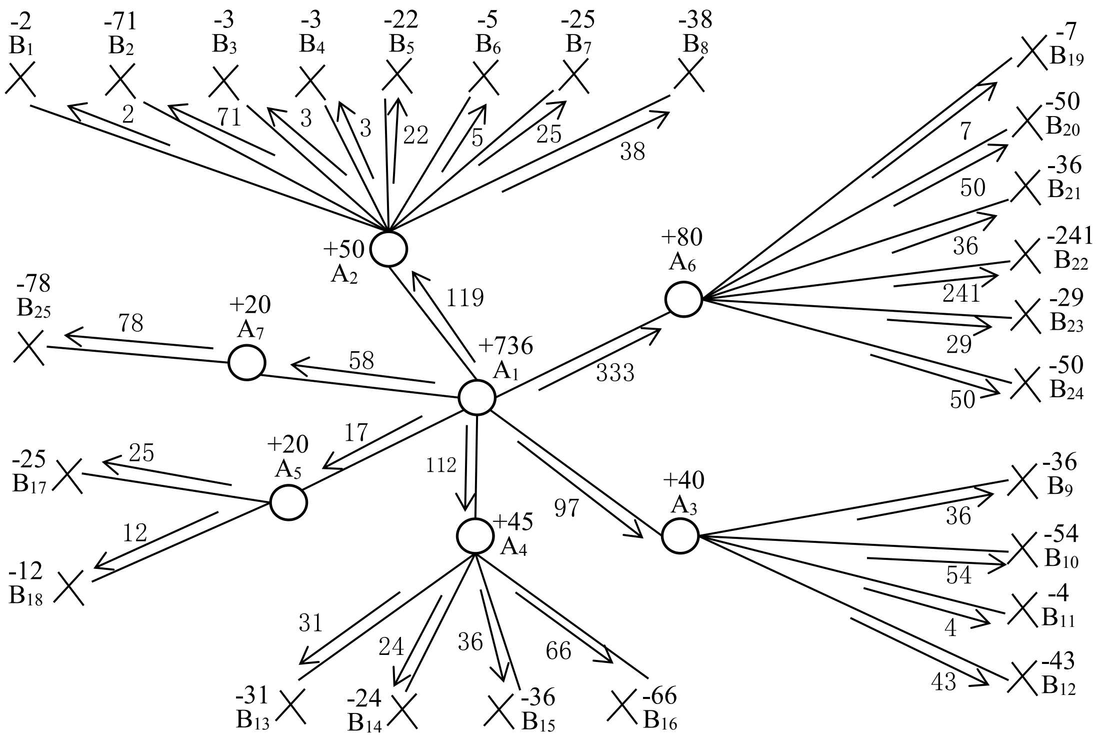

Fig. 7 Flow chart of ESD scheme at provincial → prefecture-level city → county level

5.4 Construction Of Provincial → County Direct Supply ESD Model Based On The OMG

5.4.1 Problems existing in the traditional provincial → prefecture-level city → county-level ESD model

The disastrous impact of Typhoon "Mangkhut" on 6 prefecture-level cities and counties (districts and county-level cities) in GBGEZ can be seen from the traditional provincial → prefecture-level city → county (districts and county-level cities) level-by-level dispatching traffic network diagram. Part of the emergency supplies needed by disaster-stricken counties are first shipped from the provincial emergency supplies reserve center to the prefecture-level city emergency supplies reserve pool, and then transferred from the prefecture-level city to the county emergency supplies reserve pool. There is a circuitous problem in this traditional emergency supplies transfer route, which increases the transportation cost. From this situation, this paper puts forward an improved scheme that can dispatch emergency supplies directly from the provincial emergency supplies reserve center to the emergency supplies reserve of the disaster-stricken county (district or county-level city).

5.4.2 Assumptions of the improved provincial → county direct supply ESD model

In order to improve ESD in the emergency supplies reserve of governments at all levels, the following assumptions are established. First, the six prefecture-level cities are responsible for the victims' relief and resettlement. Under their respective jurisdictions, the emergency supplies stored in the emergency reserves of the prefecture-level cities can only be supplied to the disaster-stricken counties on a priority basis. Second, the emergency supplies needed by the affected counties can be directly supplied to the affected counties by the provincial emergency supplies reserve center without first transferring them to the emergency supplies reserve repositories of prefecture-level cities. Then they are transferred from the prefecture-level city emergency warehouse to the disaster-stricken county's warehouse. Lastly, the provincial emergency supplies reserve center should have enough emergency supplies to supply the needed by cities and counties. The amount of supply and demand must be in equilibrium to avoid oversupply.

5.4.3 Construction and solution of provincial-county direct supply ESD model

The traditional transportation network diagram of ESD at the provincial → prefecture-level city → county (district or county-level city) level was improved, and two approaches of prefecture-level city → county (district or county-level city) supply emergency supplies and province → county (district or county-level city) supply emergency supplies directly were obtained. Fig. 8 shows the traffic network diagram improved by the OMG.

The traffic network diagram contains many circles, as reflected in Fig. 8. The emergency supplies stored in the emergency supplies reserve of each prefecture-level city can only be preferentially dispatched to the county (district or county-level city) under its jurisdiction. When the emergency supplies stored in each prefecture-level city are distributed but cannot meet the needs of the county needs, they must be dispatched from the provincial emergency supplies reserve center. Therefore, a relatively independent circle is formed between each prefecture-level city emergency reserve pool, its subordinate counties, and the provincial emergency supplies reserve center. Each relatively independent circle is a small circle composed of four nodes connected to each other.

It is required that the optimal dispatching scheme of the provincial → county direct supply ESD model can be completed by using the OMG with a circle. For example, the large circle formed by A_1, A_4, B_{13}, B_{14}, B_{15}, and B_{16} is selected, and then the small circle formed by A_1, A_4, B_{13}, and B_{14} is selected from the large circle. Assuming that the $A_1 \rightarrow B_{13}$ line is blocked, the "nearby transfer" principle is adopted. All 31 tons of emergency supplies needed by B_{13} will be supplied by A_4 (according to the principle of transferring emergency supplies in the right direction, this line belongs to the inner circle, with a length of 3km), and the remaining 14 tons of emergency supplies in A_4 will be supplied to B_{14} (this line belongs to the outer circle, with a length of 15km).

At this time, 45 tons of emergency supplies stored in A_4 of the prefecture-level city have been distributed. Of the 24 tons of emergency supplies needed by B_{14}, only 14 tons can be obtained from A_4, and the insufficient 10 tons can only be supplied by A_1, the provincial emergency supplies Reserve center (this line belongs to the inner circle, with a length of 117km). At this time, emergency supplies needed by B_{13} and B_{14} in the small circle formed by A_1, A_4, B_{13}, and B_{14} have been met. The transport scheme of this small circle is tested as follows:

Circumference: C_2=3+131+117+15=266 (km)

Half of the circumference: $C_2/2$=266/2=133 (km)

The inner ring length: C_{inner3}=3+117=120 (km)

Outer ring length: $C_{outer\ 3}$=15 (km)

$C_{inner3} < C_2/2$, $C_{outer3} < C_2/2$, so this transportation plan is the optimal transportation plan.

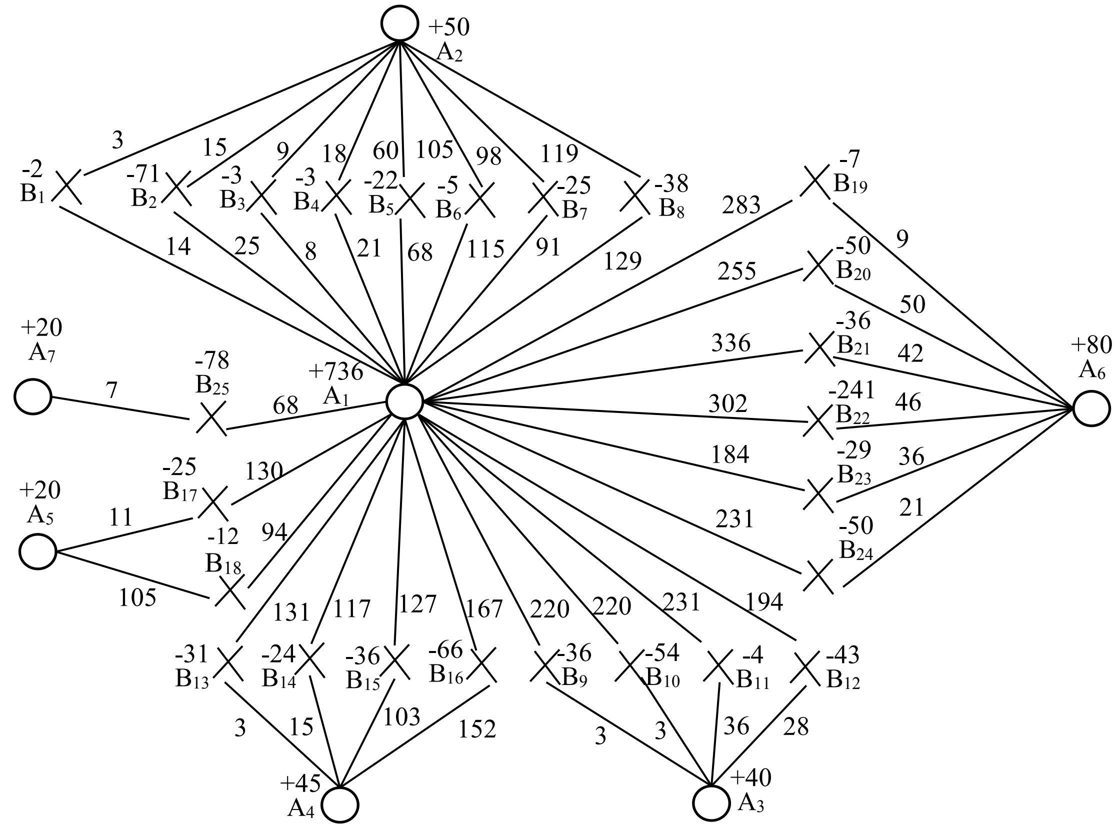

Fig. 8 Traffic network diagram of provincial → county direct supply ESD model

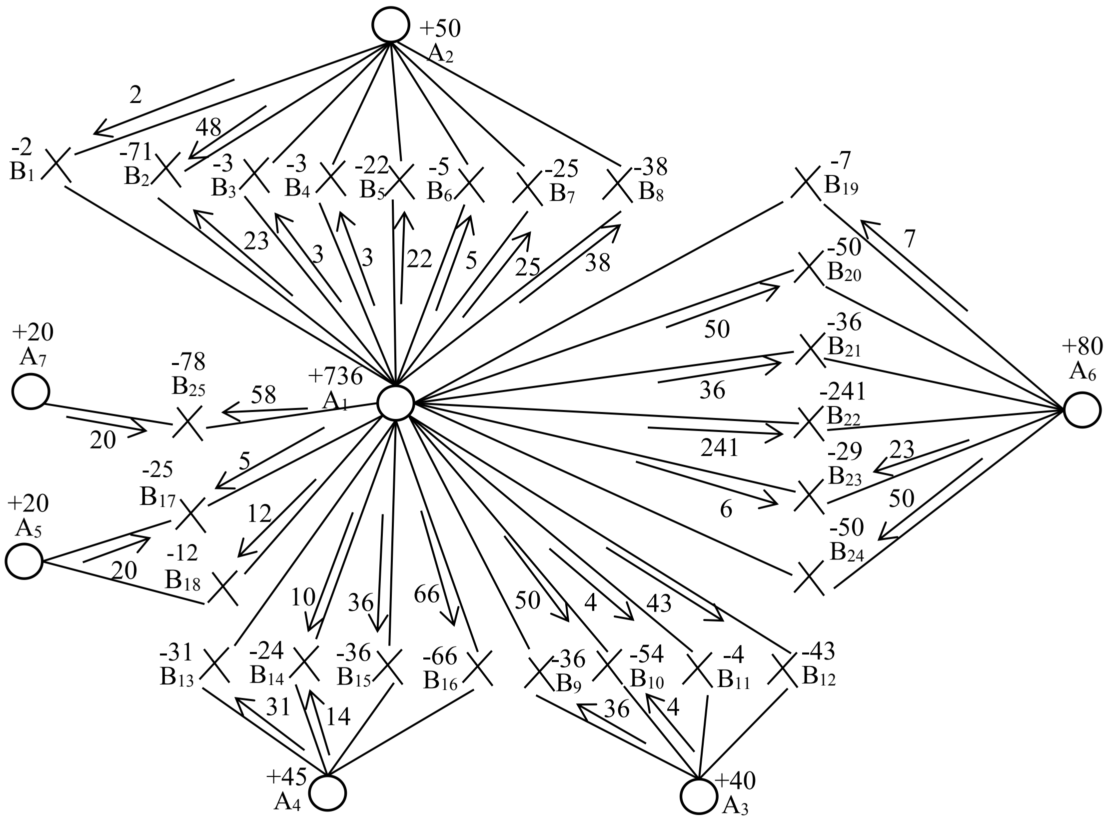

Fig. 9 Flow diagram of optimal dispatching scheme of provincial → county direct supply ESD model

At this time, 45 tons of emergency supplies stored in A_4 of the prefecture-level city in the big circle have been distributed, and the emergency supplies needed by B_{15} and B_{16} can only be supplied by A_1 of the provincial emergency supplies reserve center. A_1 shall supply 36 tons of emergency supplies to B_{15}, and supply 66 tons of emergency supplies to B_{16}. At this time, B_{13}, B_{14}, B_{15} and B_{16} in the big circle formed by A_1, A_4, B_{13}, B_{14}, B_{15} and B_{16} have all received the needed emergency supplies, and the total number of tons and kilometers of this transportation plan is the smallest. Other prefecture-level cities and their subordinate counties can refer to this scheme to solve the optimal transportation scheme, and the flow diagram of the optimal dispatching scheme of the final provincial-level → county direct supply ESD model can be obtained according to this method, as shown in Fig. 9.

According to the flow diagram of the optimal dispatching plan for the provincial → county direct emergency supplies model in Fig. 9, the emergency supply places in the dispatching plan are A_1-A_7. And the emergency supply demand places B_1-B_{25} receive emergency supplies from A_2-A_7 of the superior prefecture-level city or A_1 of the provincial emergency supplies reserve center. The optimal provincial → county direct supply ESD scheme is shown in Table 6.

Table 6 Optimal plan of direct supply emergency supplies dispatch from province to county

	A_1	A_2	A_3	A_4	A_5	A_6	A_7	Demand (tons)
B_1		2						2
B_2	23	48						71
B_3	3							3
B_4	3							3
B_5	22							22
B_6	5							5
B_7	25							25
B_8	38							38
B_9			36					36
B_{10}	50		4					54
B_{11}	4							4
B_{12}	43							43
B_{13}				31				31
B_{14}	10			14				24
B_{15}	36							36
B_{16}	66							66
B_{17}	5				20			25
B_{18}	12							12
B_{19}						7		7
B_{20}	50							50
B_{21}	36							36
B_{22}	241							241
B_{23}	6					23		29
B_{24}						50		50
B_{25}	58						20	78
Supply (tons)	736	50	40	45	20	80	20	991

Table 6 shows the balance between supply and demand, which is a total of 991 tons. The total number of tons•kilometers transported in the optimal plan for direct supply of emergency supplies by province→county as S_4, then S_4 is equal to the actual transport volume in the optimal plan for direct supply of emergency supplies by province→county as shown in Table 6 multiplied by the distance between the supply place and the receiving place of emergency supplies as shown in Table 4. Substitute the corresponding data in Table 6 and Table 4 to obtain:

S_4=156408 (tons•km).

6. DISCUSSION

Based on the above introduction of research methods and empirical analysis, this paper adopted the OMG to establish the emergency height model with the advantages that it is efficient and feasible for ESD and easy to understand. The operation method's key point is to clarify the supply of the emergency supplies at the supply place and the demand place and the actual distance to draw the traffic network diagram of ESD according to the position relationship between the supply point and the demand point. The optimal dispatching scheme can be gradually obtained according to the method and ideas of the operation method.

Comparing the results of the two supply dispatching models carried out during the disaster caused by tropical cyclone "Mangkhut" in GBGEZ. The traditional provincial → prefecture-level city → county ESD model established by the OMG was adopted. The total number of tons•km transported was 187,439 tons•km. The total number of tons•km transported by the provincial → county direct supply ESD model established by the OMG is 156,408 tons•km. Compared with the traditional provincial, prefecture-level, or county-level ESD model, the total transportation volume of 31,031 tons•km was saved, with a saving rate of 16.56%. It can be seen from the calculation results that the provincial → county direct supply ESD model established by the OMG has lower cost, saved limited dispatching resources, and achieved better results.

7. CONCLUSIONS

From the complex problem of ESD during the tropical cyclone "Mangkhut" in GBGEZ, the analysis of this paper came up with the following conclusion. Accurate disaster data, emergency supply reserve, and the type and quantity of emergency supply demand in disaster-stricken areas are the prerequisite for developing an efficient ESD model. It is also necessary to obtain the accurate location information of emergency supplies storage warehouses of governments to develop an efficient ESD model and screen out the optimal dispatching routes and distances between emergency supplies storage warehouses at all levels. In times of the ESD problem of multi-supply points to multi-demand points, choosing the method of establishing the dispatching model is vital. For the two ESD models established using the OMG, the provincial → county direct supply ESD model saves 16.56% of dispatching cost compared with the traditional provincial → prefecture-level city → county step-by-step supply ESD model, with lower cost, saving limited dispatching resources and better effect.

8. ACKNOWLEDGMENTS

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