Study on the Optimization of Engineering during Sponge City Construction

Wanjun Yin [1, a], Shouyuan Chen [1, b], Zengzhen Shao [1, 2, c], Mingguang Ma [1, d]

[1]School of Information Science and Engineering, Shandong Normal University, Jinan, 250014, China

[2]Shandong Provincial Logistics Optimization and Predictive Engineering Technology Research Center, Jinan, 250014, China

[a]13706415811@163.com, [b]shouyuanchen@163.com, [c]shaozengzhen@163.com, [d]mamg1028@163.com

Abstract

During the sponge city construction, a number of projects have been carried out at the same time, which is bound to cause some damage to the original urban road network structure. For the lack of effective implementation arrangements, it will lead to urban traffic congestion and even confusion. In this paper, under the premise of ensuring the time limit of projects' constructions, the travel cost of social residents is reduced as much as possible through the optimization of construction time and method. Finally, Sioux-Fall network is used to verify the model and algorithm, and the optimal construction plan is obtained by optimizing the objective function.

Keywords

Sponge city, The road construction, Travel cost, Construction plan, Optimization of Construction Plan.

1. Introduction

Frequent rainstorm weather brought serious crises and challenges to the development of city. Meanwhile, massive accumulation of water caused the urban waterlogging problems [1].

According to the data from Ministry of Civil Affairs, for the first three quarters of 2015, there were 41 times of heavy rain throughout the country, 320 rivers over the flood line, and 15 medium and small rivers of which flood volume excesses historical record. Waterlogging have occurred in Shanghai, Nanjing, Hefei, Shenzhen and other cities.

As a result, 6540.5 million people were affected, 631 people dead or missing, 232.6 million people were urgently placed [2].in view of all the above, there is a pressing need for city managers to take active and effective measures to solve the problem of city waterlogging. In fact, the United States, Britain, Australia and New Zealand have made remarkable progres in waterlogging problem. In order to deal with waterlogging, Low-impact development storm-water systems, sustainable urban drainage system, the design and development of the water sensitivity and low impact city are employed [3-4]. Domestic scholars believe that establishing a perfect drainage system, and actively promote the pilot work of sponge city are the key to solve the waterlogging problem in China[5]. Sponge city, is a concept of urban storm-water management of new generation, refering to that cities have good "flexibility" in adapting to the environment changes and the natural disasters caused by the rain, also known as "elastic water city"[6]. In October 2015, the general office of the state council issued the guiding opinions on promoting the construction of sponge city to promote the construction of sponge city.

As an important symbol of urban development concept and construction mode, the schedule of China's sponge city construction has been clear and can only be forward[7]. More than 130 cities have developed a sponge city construction program. The core target is, after the sponge city construction, that 80% of the rainfall can be absorbed and used on the spot through the sponge city construction.

During the construction of sponge city, many projects have been carried out at the same time, which is bound to cause damage in a degree to the original urban road network structure. If there is no effective implementation arrangements, urban traffic congestion or confusion will occur. So, how to reasonably arrange the construction of the project? Not only is the time limit of projects' constructions is met, but also disturbance caused by engineering construction for residents is reduced. Therefore, more intelligent, scientific and effective methods are need urgently.

2. The Model Construction of Sponge City

2.1 Problem Description

During the construction of sponge city, we need to arrange the construction of various projects that according to the requirements of the project construction, including the construction of roads, construction time and cost, etc.. In this paper, the relatively large scale of projects are divided into several sub-projects in the unit of road section and each sub-project is nuibmered. For example, as is shown in Fig. 1, 1 to 14 refers to 14 projects, and the labelled section represents the section under construction.

Fig. 1 Engineering schematic

The construction of multiple projects simultaneously will inevitably interfere with the normal travel of social vehicles, causing the increase of travel cost. In order to meet the requirements of the construction of the premise and minimize the travel costs of social vehicles, there is need to optimize the construction scheme.

2.2 Several Definitions

Definition 1 Project: It refers to the construction work which makes a single section of road as a unit. According to the different contents of the construction, each project is divided into three stages. And the construction content as well the amount of work of each stage is determined.

Definition 2 Construction Plan: It means reasonable arrangements made for sarious projects in order to ensure that the project can be completed within the specified time and cost. A construction scheme consists of three parts, namely: the start time, the end time, construction methods.

Definition 3 Construction Method: It refers to a specific form of construction for each project at each stage. Based on the specific case of the project during the sponge city construction, several construction methods is summarized in the following table 1.

Table 1 Construction Methods

EP_i / ECM_i	The first stage (EPi1)	The second stage (EPi2)	The third stage (EPi3)
a	Construction of the inside of the left side (1/2)	Construction of the inside of the right side (1/2)	Semi-closed construction (1)
b	Construction of the inside of the right side (1/2)	Construction of the inside of the left side (1/2)	Semi-closed construction (1)
c	Completely closed construction (2)	Completely closed construction (2)	Completely closed construction (2)
d	Night construction (0)	Construction of the inside of the right side (1/2)	Semi-closed construction (1)
e	Night construction (0)	Construction of the inside of the left side (1/2)	Semi-closed construction (1)
f	Construction of the inside of the left side (1/2)	Night construction (0)	Semi-closed construction (1)
g	Construction of the inside of the right side (1/2)	Night construction (0)	Semi-closed construction (1)
h	Night construction (0)	Completely closed construction (2)	Completely closed construction (2)
i	Completely closed construction (2)	Night construction (0)	Completely closed construction (2)
j	Night construction (0)	Night construction (0)	Completely closed construction (2)

Wherein, *a*-*j* represents of 10 different construction methods.0 represents construction at night; 1/2 representative section of one side half of the number of lanes for construction; 1 representative of each half of the road on both sides at the same time for construction; 2 representative of the entire section of the construction at the same time.

2.3 Symbol Description

A: The set of road section;

N :The set of nodes in the road network;

EP_i :The *i*-th project, $i = 1, 2, 3, 4, \dots, n$;

EP_{ij} : The *j*-th stage of the *i*-th project, $i = 1, 2, 3, \dots, n$; $j = 1, 2, 3, \dots, m$;

ΔT_{ik} : The start time window of project *i* to select the first *k* construction method, $\Delta T_{ik} \geq 0$ and $\Delta T_{ik} \in Z$;

ST_i : The start time of project *i*;

ET_i:The end time of project *i*;

CS_v : The *v*-th construction scheme;

ECM_i:The construction method of project *i*;

GCM_{pq}^d : The construction method of the section of road <*p*, *q*> at *d*-th constructive day;

$\bar{X}_{pq}^d$: The traffic flow on the section of road <*p*, *q*> at *d*-th day;

X_{pq} : The traffic flow on the section of road <*p, q*> under normal circumstances;

$\bar{C}_{pq}^{d}$: The traffic capacity of the section of road <*p, q*> at *d*-th constructive day;

C_{pq} : The traffic capacity of the section of road <*p, q*> under normal circumstances;

$\bar{t}_{pq}^{d}$: The traffic time of the section of road <*p, q*> at *d*-th constructive day;

t_{pq}: The traffic time of the section of road <*p, q*> under normal circumstances;

ST_{min}: The actual earliest start time of all projects, that is $ST_{min} = MIN\{ST_i\}$;

ET_{max}: The actual latest end time of all projects, that is $ET_{max} = MAX\{ET_i\}$;

ST : The planned earliest start time of all projects;

ET : The planned latest end time of all projects;

L : The set of all nodes in the road network;

2.4 Mathematical Model

Based on the above description of the problem, the paper makes the following assumptions:

All research projects are the same type of projects, and each project was divided into three phases of construction. This article assumes that the order of the three stages of construction cannot be changed;

The total of all the start and end time are known;

The earliest start time and the latest end time of each project are known;

The various stages of each project is continuously construction, and there is no construction space in the middle of each other;

Various stages of each construction time span of each project affected by the specific construction deadline and the construction method;

Supposing that the size of each project team and its ability to work are the same.

$$Tol = \frac{\varphi}{ET-ST}\sum_{d=1}^{ET-ST}\{\frac{1}{n}\sum_{k=1}^{n}(t_{pq}^{d} - \bar{t}_{pq}^{d})\} \tag{1}$$

$$ST \le ST_{min} \tag{2}$$

$$ET_{max} \le ET \tag{3}$$

$$\bar{C}_{pq}^{d} = \begin{cases} C_{pq}^{d} & GCM_{pq}^{d} = 0; \\ \frac{1}{4}\ C_{pq}^{d} & GCM_{pq}^{d} = \frac{1}{2}; \\ \frac{1}{2}\ C_{pq}^{d} & GCM_{pq}^{d} = 1; \\ 0 & GCM_{pq}^{d} = 2; \end{cases} \tag{4}$$

$$\bar{t}_{pq}^{d} = t_{p,q}(0)\left[1 + \alpha\left(\frac{\bar{X}_{pq}^{d}}{\bar{C}_{pq}^{d}}\right)^{\beta}\right] \tag{5}$$

Formula (1) is the objective function. By comparing the change of the traffic time before and after the construction of each section of roads, it depicts the average increase in travel costs caused by project constructions. Wherein φ is a regulator, no specific meaning in this article is set to 100. Formula (2) is the earliest start time constraint of the project. Formula (3) is the latest end time constraint of the project. Formula (4) depicts the road traffic capacity of different sections in different construction methods; Formula (5) is a function of the US Federal Highway Administration (*BPR* function), as the each section travel time functions after the construction. Wherein, α, β called the regression coefficients, the typical value of $\alpha = 0.15$, $\beta = 4$, $t_{p,q}(0)$ is the travel time while the flow is same as the free flow.

3. Construction Methods Selection and Traffic Allocation Algorithm

3.1 Calculation of Road Sections Importance

Node betweenness centrality is the number of shortest paths from all vertices to all others that pass through that node. Edge betweenness is equal to the number of shortest paths from all vertices to all others that pass through that edge. A node or edge with high betweenness has a large influence on the transfer of items through the network, and it is an important global geometric quantity, which has a strong practical significance. In this paper, we describe the importance of node by using the betweenness of node and the density index of node, and use the importance of nodes and edge betweenness to describe the importance of the edge.

Betweenness of node p is calculated by the following formula (6):

$$CV_{B-SP}(p) = \sum_{s,e \in L, s \neq e} \frac{\sigma_{se}(p)}{\sigma_{se}} \tag{6}$$

In the formula (6), σ_{se} is the number of the shortest paths that from the node s to the node e, $\sigma_{se}(p)$ is the number of shortest paths through the node p. The greater the number of nodes is, the more important the nodes are in the network.

pd which takes integer from 1 to 4 represents the population density of nodes, followed by a small population, the population is normal, densely populated and very densely populated. When the population density index is larger, the negative impact on the community after the control is also larger. Formula (7) defines the importance of node P indicators.

$$vip_i = \alpha_1 CV_{B-SP}(p) + \alpha_2 \frac{pd_p - avg(pd)}{\max(pd)} \tag{7}$$

In formula (7), pd_p represent the population density index of node p, avg(pd) represent the average population density of all nodes, $\max(pd)$ is the maximum population density index, $\alpha_1, \alpha_2 > 0$,and $\alpha_1 + \alpha_2 = 1$,in general the value of α_1 could be chosen as 0.80,and the value of α_2 could be chosen as 0.20.

The edge betweenness of nodes p to q used to depict the importance of road in the road network, as the formula (8).

$$CA_{B-SP}(p,q) = \sum_{s \neq e, s,e \in L} \frac{\tau_{se}(p,q)}{\sigma_{se}} \tag{8}$$

In the formula (8), σ_{se} is the number of shortest paths between from the node s to e, $\tau_{se}(p,q)$ is the number of shortest paths from nodes s to e which through the section of p to q. Obviously , the larger the edge betweenness, the more importance the position of the road section in the road network. When selecting the type of road traffic control, the number of the side of the road segment, the number of the points and the environmental characteristics should be considered. The importance index of road is defined as formula (9).

$$sip_{p,q} = \beta_1 CA_{B-SP}(p,q) + \beta_2 vip(p) + \beta_3 vip(q) \tag{9}$$

In the formula (9), $\beta_1, \beta_2, \beta_3 > 0$,and $\beta_1 + \beta_2 + \beta_3 = 1$,in general the value of β_1 could be chosen as 0.50,and the value of β_2 and β_3 could be chosen as 0.25. The greater the density of the population around the section of the road, the greater the traffic flow, the more important it is. The greater the importance of the construction of the road, the more likely to take the night construction or local construction, otherwise, the greater the possibility to take full or partical closure construction.

The Construction scheme should be determined based on the following two principles:

According to the limitation of the construction time, determine the feasible construction methods;
1) According to the importance of the construction section, the greater importance of the construction section, the more likely to take the night construction or local construction, otherwise, the possibility of full closure of construction or partial construction is greater.

3.2 The Traffic Flow Assignment Algorithm

According Wardrop user equilibrium principle [8], and satisfying the user optimum equilibrium conditions: Based solely on individual users think the minimum travel time or cost individual users think, travel demand between OD is assigned to for the road network. That is, the path of travel time all the users choose shall not be less than or equal to the selected route travel time. Because the travel time on the road is a function of traffic flow, and on the bases of user equilibrium condition, Backmann [9] presented a mathematical model to solve equilibrium balanced road network traffic flow. 20 years later, LeBlanc and other scholars used the Frank-Wolfe algorithm to solve the Beckmann model [10-11]. Solution step of the model [12] are as follows:

Step1: Seeking initial solution. Find the shortest path between each pair *OD*, and *AON* assignment, get a traffic flow on each section road, and set to x_{pq}^{0}, so that $n = 1$;

Step2: Updated travel time, $t_{pq}^{n} = t_{pq}(x_{pq}^{n}), \forall a \in A$;

Step3: One-way search. According to the t_{pq}^{n} of Step 2 to find the shortest path between each *OD*, and then using *AON* method to assign traffic flow between each *OD*, then we will get the traffic flow of each link, making $v^{n} = y_{pq}^{n} - x_{pq}^{n}$, where v^{n} as the search direction;

Step4: Find the best search step of finding the best φ:

$$\mathrm{Min}_{0\le\varphi\le1} \sum_{(p,q)} \int_{0}^{x_{pq}^{n}+\varphi(y_{pq}^{n}-x_{pq}^{n})} t_{pq}(w)\,dw;$$

Step5: Update each link flow, $x_{pq}^{n} = x_{pq}^{n-1} + \varphi(y_{pq}^{n} - x_{pq}^{n-1})$;

Step6: Check whether the algorithm has converged. If it is satisfies any conditions of $\sqrt{\sum_{(p,q)} x_{pq}^{n} - x_{pq}^{n-1} / \sum_{(p,q)} x_{pq}^{n-1}} \le \varepsilon (\max\{|x_{pq}^{n} - x_{pq}^{n-1}|\} \le \varepsilon)$, then stop; Otherwise, let $n = n + 1$, and turn to Step1.

4. Solving Algorithm

Optimal construction scheme process is an iterative process. Because, there are several construction section (a number of projects), and every projects has various of construction scheme. Meanwhile, the begining and ending time of the construction differ from one another, and the construction period is long. So that it is difficult to solve the problem quickly using the traditional accurate algorithm. Therefore, this paper proposes an improved genetic algorithm. Each step of the Genetic Algorithm is as follows:

Encoding method: using 2 n-bit binary code, the first n-bit represents the start time of the construction, the second n-bit represents the construction method.

Fitness function: this algorithm use the objective function as the fitness function of the genetic algorithm.

Generating initial population: Using heuristic principle to generate initial population. If the road is of great importance, it is proved that the section of the road is more important than the other sections. If the use of the full closure of the construction of the social cost of travel is bound to be high, so the possibility of a large part of the construction method. Conversely, it is possible to choose the full closed construction.

Selecting operator: choosing elites operator.

Crossover operator: choosing the single crossover operator.

Mutation operator: choosing basic mutation operator.

Genetic Algorithm every step of the design is as follows:

Step1: Initialization: Determine the size of the population M and the number of iterations of N, and the construction of the five sections of the importance of the construction of the road from the low to high order;

Step2: Heuristics generate engineering EP_i construction methods ECM_i;

Step3: According to the construction method of ECM_i, generates the time window of the project EP_i in the method of ECM_i, and determine the start and end time of each projects.

Step4: In units of days, to determine the construction scheme of CS_v road network changes day by day, and then use of F-W algorithm re-flow distribution;

Step 5: Calculating the average amount time of social vehicle changes between the rode before construction and after construction.

Step 6: Selection (using elites selecting operator), crossover (using single crossover operator), variation (basic mutation operator);

Step7: Repetitive execute step 4-6, if the number of iterations or the difference between the two target less than$\varepsilon(0 < \varepsilon < 1)$, then end of the algorithm, and outputs the optimal construction scheme.

Specific processes as shown in Fig. 2.

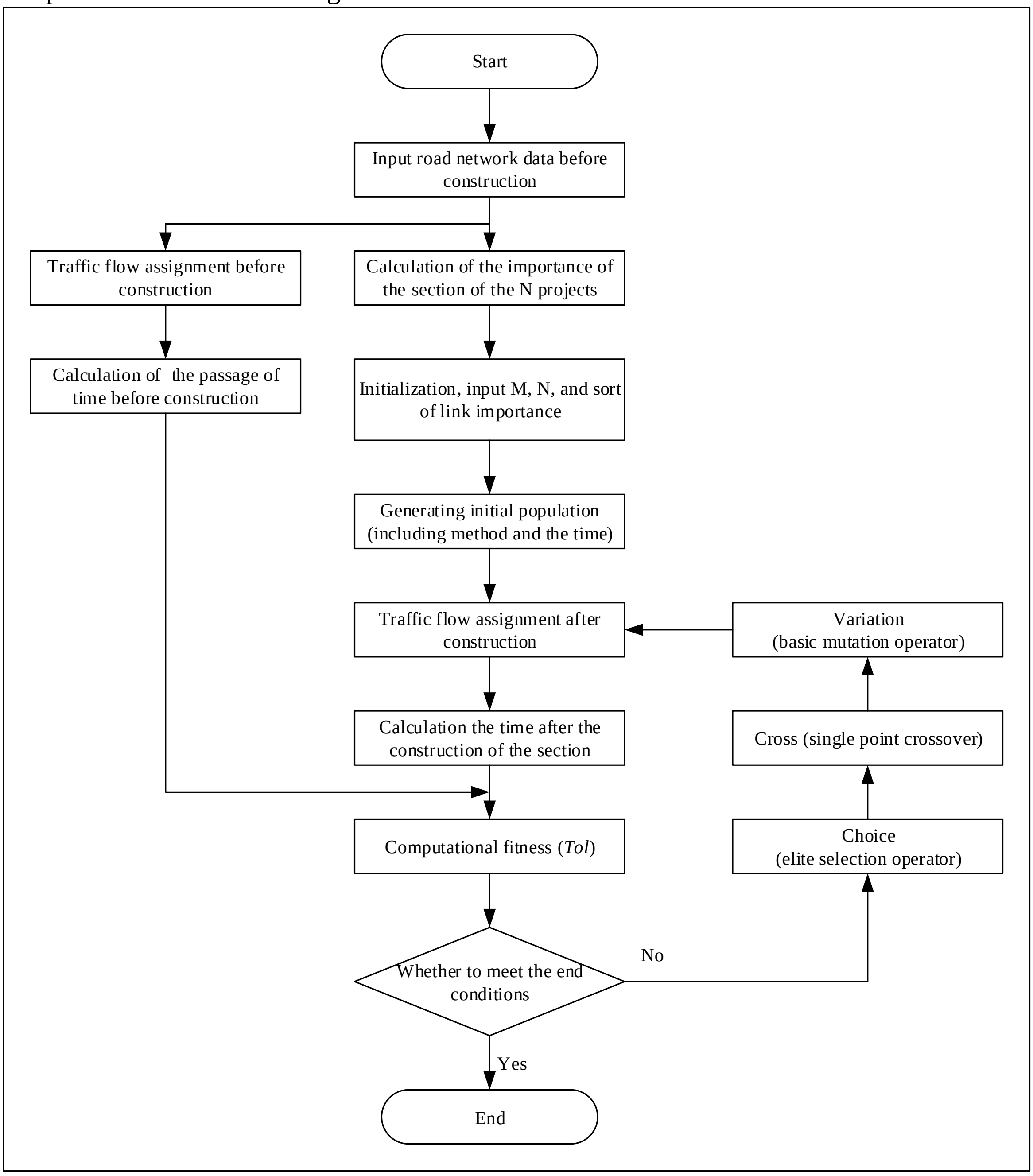

Fig. 2 Algorithm flow chart

5. Example

This article uses sioux-fall road network structure, its topology as shown in Figure 3. In this paper, based on the actual situation of the construction of the sponge city construction, collect the basic data is collected, shown as below.

5.1 Engineering Arrangement

Assume that the total earliest start time of these 5 projects is the first day, the total latest end time is the ninety-second day (a total of 92 days).

Table 2 Detailed Requirements of Each Project Construction

Project	Construction method	Earliest start time	The latest start time	The latest end time	The first stage / day	The second stage / day	The third stage / day	Total construction time / day
1	a	1	29	92	30	30	3	63
	b	1	29	92	30	30	3	63
	d	1	23	92	36	30	3	69
	e	1	23	92	36	30	3	69
	f	1	23	92	30	36	3	69
	g	1	23	92	30	36	3	69
2	a	1	17	92	36	36	3	75
	b	1	17	92	36	36	3	75
	d	1	9	92	44	36	3	83
	e	1	9	92	44	36	3	83
	f	1	9	92	36	44	3	83
	g	1	9	92	36	44	3	83
3	a	1	18	92	35	35	4	74
	b	1	18	92	35	35	4	74
	d	1	11	92	42	35	4	81
	e	1	11	92	42	35	4	81
	f	1	11	92	35	42	4	81
	g	1	11	92	35	42	4	81
4	c	1	67	92	12	12	1	25
	h	1	64	92	15	12	1	28
	i	1	64	92	12	15	1	28
	j	1	61	92	15	15	1	31
5	c	1	43	92	24	24	1	49
	h	1	38	92	29	24	1	54
	i	1	38	92	24	29	1	54
	j	1	33	92	29	29	1	59

The corresponding time windows of various projects under different construction methods are shown in Table 3.

Table 3 Construction time window for each project

Project(EP_i)	The range of the time window ΔT_j
EP_1	$0 \le \Delta T_{1k} \le 29, k = a,b$ $0 \le \Delta T_{1k} \le 23$, $k = d,e,f,g$
EP_2	$0 \le \Delta T_{2k} \le 17$, $k = a,b$ $0 \le \Delta T_{2k} \le 9$, $k = d,e,f,g$
EP_3	$0 \le \Delta T_{3k} \le 18$, $k = a,b$ $0 \le \Delta T_{3k} \le 11$, $k = d,e,f,g$
EP_4	$0 \le \Delta T_{4k} \le 67, k = c$ $0 \le \Delta T_{4k} \le 64, k = h,i$ $0 \le \Delta T_{4k} \le 61, k = j$
EP_5	$0 \le \Delta T_{5k} \le 43$, $k = c$ $0 \le \Delta T_{5k} \le 38, k = h,i$ $0 \le \Delta T_{5k} \le 33$, $k = j$

Among them, $\Delta T_{ik} \in Z$.

5.2 Road Section Construction

The concrete construction of each section of the road network is shown in Figure 3.

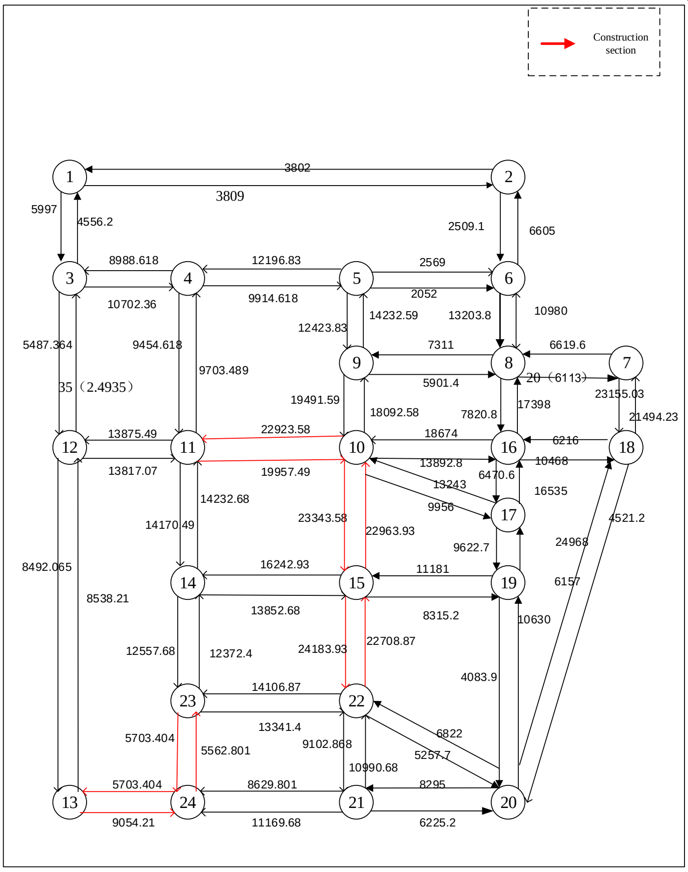

Fig. 3 Road construction schematic

Among them, the red line on behalf of road construction, others are non-construction section.

5.3 Comparison of Different Construction Plans

Different construction schemes correspond to the change of the average daily increment of each road section as shown in Fig. 4.

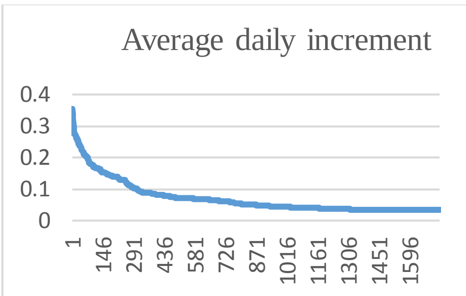

Fig. 4 Change of mean time increment

Wherein the horizontal axis represents the construction program number, and the vertical axis represents the average daily time increments for each road segment of different construction schemes (unit: hour). Figure 4 shows, in time to meet the construction requirements, different construction schedule change a great impact on daily traffic, the pros and cons of the construction plan is directly related to the length of the link travel time. Therefore, the construction program reasonable optimization is very necessary.

This article selected five kinds of optimal construction plan, as shown below in Table 4.

Table 4 Comparison of Different Construction Plan

Scheme number	Project number (EP_i)	Construction method (ECM_i)	Start time (ΔT_{ik})	Construction of each stage (EP_{ij})			Total time increment	Increment per day	Goal (Tol)
				The first stage	The second stage	The third stage			
1	1	g	23	1/2	0	1	238.9944198	2.597765432	3.4181124
	2	f	1	0	1/2	1			
	3	g	12	1/2	0	1			
	4	c	39	2	2	2			
	5	i	21	2	0	2			
2	1	g	22	1/2	0	1	247.9663573	2.695286492	3.5464296
	2	f	6	0	1/2	1			
	3	g	4	1/2	0	1			
	4	c	2	2	2	2			
	5	i	20	2	0	2			
3	1	g	13	1/2	0	1	256.9382948	2.792807553	3.6747468
	2	f	6	0	1/2	1			
	3	g	3	1/2	0	1			
	4	c	36	2	2	2			
	5	i	20	2	0	2			
4	1	g	21	1/2	0	1	267.0734121	2.902971871	3.8196998
	2	f	1	0	1/2	1			
	3	g	7	1/2	0	1			
	4	c	7	2	2	2			
	5	i	21	2	0	2			
5	1	g	22	1/2	0	1	274.8821699	2.987849673	3.9313811
	2	f	1	0	1/2	1			
	3	d	18	0	1/2	1			
	4	c	62	2	2	2			
	5	i	10	2	0	2			

As can be seen from the above table 4, the first plan is the best construction plan. Its specific construction situation like this can be expressed as the following Fig. 5.

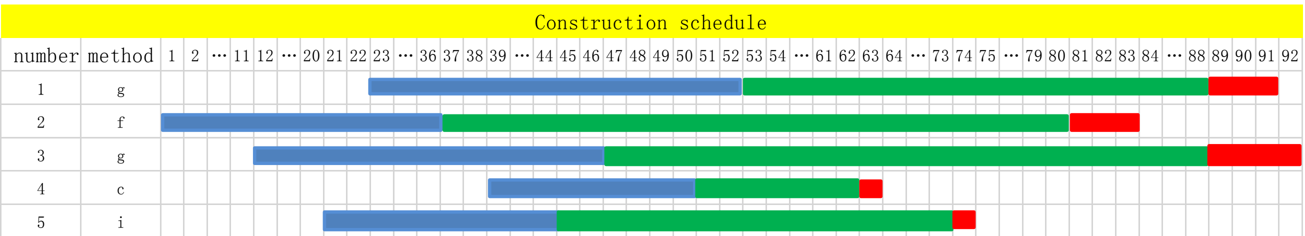

Fig. 5 Construction Progress Table

6. Conclusion

Under the premise of meetting the construction deadline, with the goal of minimizing travel costs residents increments, this paper establishes the model of road construction during construction of a sponge city,and designs a binary coding method based on improved genetic algorithm heuristic principles to solve the model. Study results show that the algorithm can guarantee that under the premise of construction requirements, optimal construction plan can be obtained. Furthrtmore,travel costs incremental of society residents is reduced to the utmost, reducing the disturbance caused by engineering construction for residents. The result of this paper has made a reasonable overall planning for the construction of sponge city, and gives the complete optimal construction scheme, which is of great guiding significance to the construction of sponge City, and can provide reference for city managers.

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