Research of Variable Lane Control Method in the Emergency Evacuation Area

Lili Zheng, Xinyue Hu and Tongqiang Ding

Abstract When unexpected disasters are coming, tens of thousands of people lost their lives because of no emergency aid caused by traffic jam. We need to build an emergency planning based on traffic evacuation. This paper proposes a method of variable lane control based on emergency evacuation area, establishes a bi-level programming model and designs solution algorithm based on harmony search to find the optimal solution quickly. After getting the optimal solution, we build the simulation experiment to verify the feasibility and effectiveness of proposed method according to the comparison of the saturation degree and the total travel time of system.

Keywords Emergency evacuation area · Method of variable lane control · Bi-level programming model · Harmony search algorithm

Introduction

Since the twentieth century, natural disasters in worldwide have been increasing frequently from the earthquake to the tsunami and the hurricane. People have studied urgently with all kinds of typical emergency plans focused on traffic evacuation.

L. Zheng
State Key Lab of Automobile Simulation and Control, Jilin University, Changchun 130022, China

L. Zheng · X. Hu
College of Transportation, Jilin University, Changchun 130022, China

L. Zheng · T. Ding (✉)
Jilin Province Key Laboratory of Road Traffic, Jilin University, Changchun 130022, China
e-mail: dtq8@163.com

W. Wang et al. (eds.), *Green Intelligent Transportation Systems*,
Lecture Notes in Electrical Engineering 419, DOI 10.1007/978-981-10-3551-7_56

Variable lane control which means the variation of the direction of one or more lanes changes all or parts of the lane directions from driving to the affected areas for driving away the affected areas, which can improve the evacuation capability of traffic network greatly and reduce the evacuation time. In 1998, when Florida and Georgia suffered the hurricane, the local administration of America used the variable lane strategy for single interstate road; consequently, the effect is remarkable. In 2005, under the condition of dealing with the evacuation about 3,000,000 people during the hurricane “Rita” in the USA, when the serious congestion occurred (heavy traffic moved 10–20 miles in nine hours), local government implemented variable lane solutions to the interstate 45, interstate highway 290, and interstate 10. The solution solved the jam partly of interstate highway 290, but after a few hours, this solution was forced to be annulled because of the traffic jam around interstate highway 290 [1]. Qiang Sun researched and developed the optimal allocation principles to make a single lane road to adapt to the asymmetry of traffic demand in one day. The capacity of traffic network was improved by the establishment of the most optimized model and the design of the step of dynamic variable lanes [2]. During the process of the practice, even though the fact that reversing local lanes direction could increase the evacuation capacity of part of the road, it could lead to the appearing of traffic bottleneck point in other lanes because of lack of consideration as a whole and reduce the evacuation performance of the whole traffic network. This paper proposes a method of variable lane control based on traffic network, establishes a bi-level programming model, and designs the harmony search to solve the model [3].

The Establishment of the Model of Controlling the Variable Lane Based on Traffic Network

From the point view of the traffic managers, when they adjust the lane, they hope to alleviate traffic jams, named the minimal traffic impedance. From the point view of traffic participants, they choose the shortest path by instinct, named Wardrop balanced principle. Hence, this paper considers the bi-level programming model about the adjustment of variable lane from two aspects [4]. Firstly, in the view of system, the establishment of the upper planning model introduces the minimum of the total impedance of the system. Secondly, in the view of traffic participants, the establishment of the lower-level planning model demands to be applied to the user equilibrium model. After getting each section of the optimal flow distribution of every link, the result will be used in the upper planning model and get the most appropriate lane volume of different directions and the adjustment scheme of variable lane [5].

Considering an urban traffic network consisted of nod-set N and two-way link-net A, each of the two-way traffic links is composed of two sections in the opposite directions [6].

where:

A	Two-way link-net;
a	Any link in the network;
x_a	Flow of any link a;
$f_{\mathrm{p}}^{\mathrm{rs}}$	Flow on path p between r and s;
q^{rs}	Traffic demand between r and s;
n_a	The number of both-way link, $n_a > 0$ as a integer;
k_a	Traffic capacity of single lane on link a;
u_a	Lane number of positive direction in link a after adjustment, value it $[0, \mathrm{n}_a]$ as an integer;
$\delta_{\mathrm{ap}}^{\mathrm{rs}}$	If link a is on the path p between r and s, it act as 1; or 0; and
$t_a(x_a, u_a)$	impedance function of link a.

The function adopts to the famous BPR:

$$t_a(x_a, u_a) = t_0 + 0.15 \times t_0 (x_a / u_a s_a)^4 \tag{1}$$

In order to minimize the total impedance of the whole network system,the department of city traffic management determines the variable lane adjustment scheme according to the situation of the traffic flow on the link. The traffic participants follow a path of least impedance according to the condition of road. The behavior of choosing the path conforms to the Wardrop balanced principle. All above can be described as the bi-level programming model as following:

The upper model:

$$\min_u Z = \sum_{a \in A} t_a(x_a, u_a) \cdot x_a \tag{2}$$

$$\text{s.t. } u_a \in \{0, 1, 2, \ldots, n_a - 2, n_a - 1, n_a\}, \forall\, a \in A \tag{3}$$

The lower-level model:

$$\min_x \sum_{a \in A} \int_0^{x_a} t_a(w, u_a) \mathrm{d}w \tag{4}$$

$$\text{s.t. } \sum_p f_p^{\mathrm{rs}} = q_{\mathrm{rs}}, \forall\, r, s \tag{5}$$

$$x_a = \sum_r \sum_s \sum_p f_p^{\mathrm{rs}} \delta_{\mathrm{ap}}^{\mathrm{rs}}, \forall\, a \in A \tag{6}$$

$$x_a \geq 0, \forall\, a \in A \tag{7}$$

Algorithm Based on Harmony Search

Harmony search algorithm is a new type of the method of the intelligent optimization introduced in recent years with the advantages of small time complexity, wide applicable scope, and simple structure and operation. The arithmetic can be used in both linear integer-programming problem and nonlinear integer-programming problem and have a rather practical value on the application layer for solving NP-hard problem. It can obtain the same or even better solution, compared with the genetic simulated annealing algorithm and hybrid genetic algorithm [7]. The theory imitates the process of playing music. The optimal effect of harmony is attained, according to a few primitive harmony to adjust again and again. Each kind of instruments in band is a variate in the objective function, and tone is the value of variate in the objective function [8]. Same as the musical performance, optimized algorithm is to looking for various optimal states determined by the objective function values such as minimum cost, maximum benefit, or the highest efficiency.

The model in this paper is nonlinear mixed integer bi-level programming problem, which is widely recognized as one of the optimization problems that is extremely difficult to solve. The upper decision variates are integers; the lower decision variates are real numbers. This paper is based on the harmony search algorithm to solve the upper planning and based on the Frank–Wolfe method to design the flow distribution in the lower planning. The following is its basic process:

Step1: Initialize the optimized problem and algorithm parameter. Set the size of harmony memory (HMS) and maximum iterations ($N_{\max}$). Number of HMS should be much smaller than all the feasible solutions.
Step2: Initialize the harmony memory, determine the scope of $u_a[0, n_a]$, and generate HMS solutions of optimized problem randomly, then put these in harmony memory, which expresses as following:

$$\left\{ \left[\begin{array}{ccccc} u_1^1 & \ldots & u_i^1 & \ldots & u_n^1 \\ \vdots & & \ddots & & \vdots \\ u_1^m & \ldots & u_i^m & \ldots & u_n^m \\ \vdots & & \ddots & & \vdots \\ u_1^{\mathrm{HMS}} & \ldots & u_i^{\mathrm{HMS}} & \ldots & u_n^{\mathrm{HMS}} \end{array} \right] \middle| \begin{array}{c} Z(x^1) \\ \vdots \\ Z(x^m) \\ \vdots \\ Z(x^{\mathrm{HMS}}) \end{array} \right\}$$

Among them, $U^m = (u_1^m, u_2^m, \ldots, u_n^m)$ is the mth solution vectors. The corresponding objective function is $Z(x^m)$.

Step3: Generating a new solution. There will be a new solution created $U^{\text{new}} = (u_1^{\text{new}}, \ldots, u_i^{\text{new}}, \ldots, u_n^{\text{new}})$. Among them, the u_i^{new} will be produced by the following three ways:

1. Keep some components in the harmony memory.
2. Generate new components randomly.
3. Disturb the solution generated in the above method.

Keeping some components in the harmony memory and keeping some components in the harmony memory at a certain probability mean the probability that new solution u_i^{new} is from set of ith $U_i = (u_i^1, u_i^2, \ldots, u_i^{\text{HMS}})^{\text{T}}$ in the harmony memory is HMCR. Generate randomly means that the probability that the new solution is from the outside of the feasible solution space in harmony memory is 1-HMCR. Disturb the solution components retained from the above steps u_i^{new} in certain probability (PAR), working on following principle:

$$u_i^{\text{new}'} = u_i^{\text{new}} + 2 \times u \times \text{rand} - u$$

where:

u_i^{new}	The solution before the disturbance;
$u_i^{\text{new}'}$	The solution after the disturbance;
u	Bandwidth; and
r and	A random number valued 0 or 1

$$u = bw \times (gn/\max)$$

The value of bw is between 0.4 and 0.6. gn is the rest of iterative times. $N_{\max}$ is the maximal iterative times. u is rounded down.

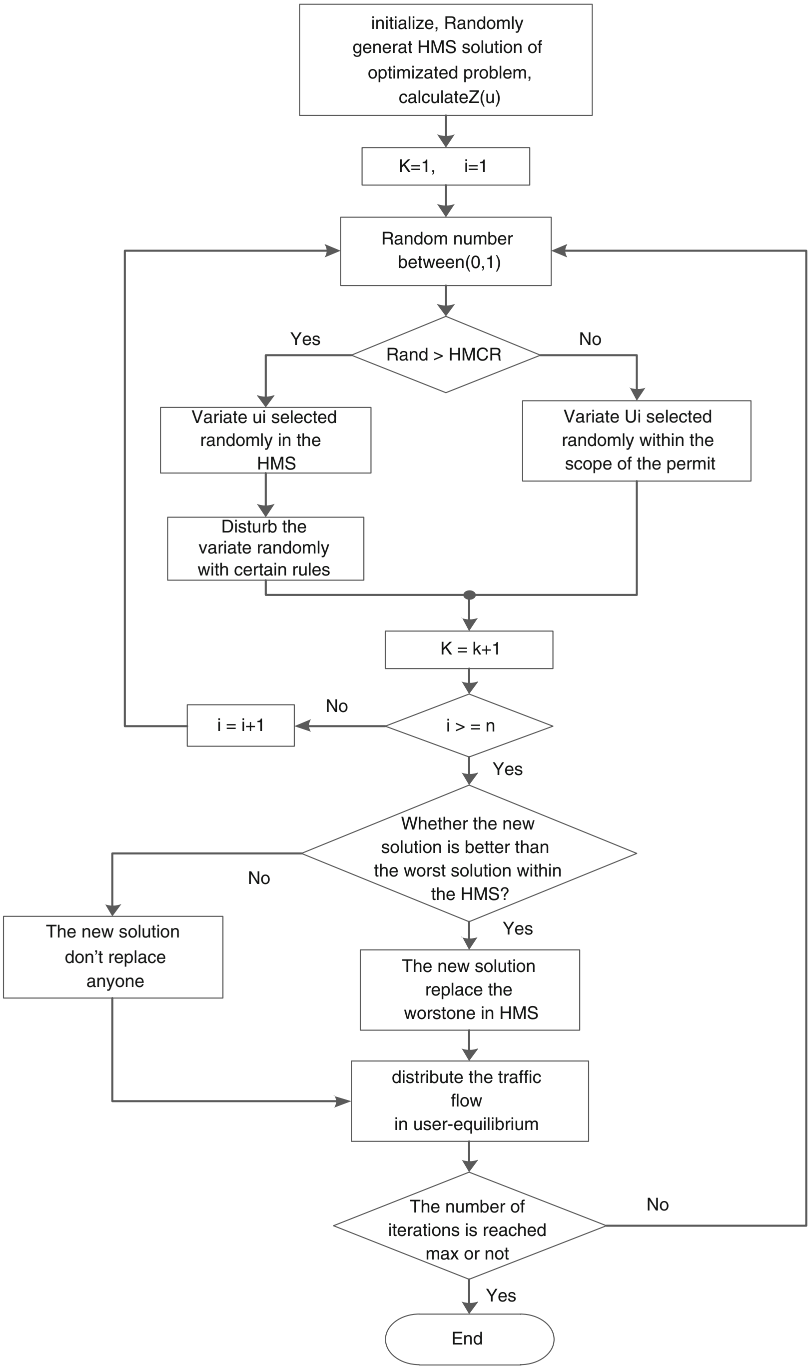
Step4: Update the harmony memory. If the new is better than the worst memory, make the new solution replace the worst one in HMS.
Step5: Distribute the traffic flow in user equilibrium.
Step6: If the outcome fulfills the termination criterion, and n meets the maximal iterative times $N_{\max}$, the optimal solution u_a^* outputs. If not, turn to step3.

Algorithm process is as follows (Fig. 1):

Simulation Verify

Simulation Data Instruction

The road network topology adopted in this paper is as shown in Fig. 2 and the road link data is as shown in Table 1 [9].



◂**Fig. 1** Algorithm process about the V lane control model in emergency evacuation area based on harmony search

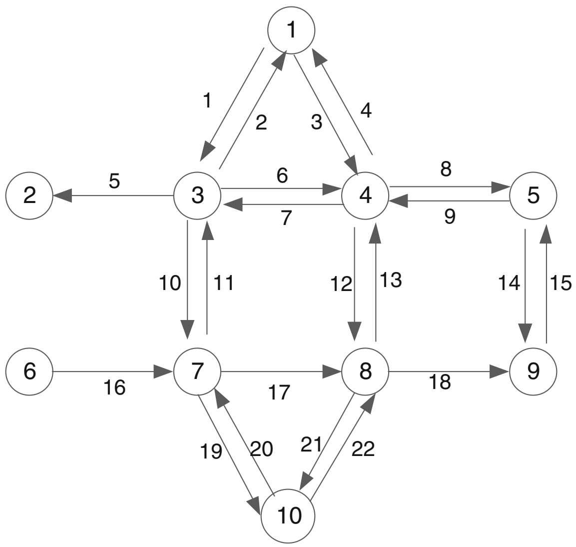


Fig. 2 Road network topology

Table 1 Link data

Link	t_0 unit: s	k_a unit: pcu/h	n_a
1, 2	200	1800	8
3, 4	200	1800	4
5	200	1800	2
6, 7	200	1800	2
8, 9	200	1800	2
10, 11	260	1800	8
12, 13	200	1800	8
14, 15	200	1800	2
16	200	1800	2
17	200	1800	2
18	200	1800	2
19, 20	200	1800	8
21, 22	200	1800	8

There are four couples of O–D: $5 \rightarrow 2$, $6 \rightarrow 9$, $1 \rightarrow 10$, and $10 \rightarrow 1$. Corresponding traffic volume is 1826, 468, 6610, and 1836 pcu/h.

Designing Simulation Environment

1. Build simulation environment.

In the road network, such as Fig. 2, there is a sudden traffic accident at the intersection No. 8, so that the link around the intersection No. 8 cannot work normally.

2. Describing contradistinctive plans.

Program0: Lane directions without any adjustment.
Program1: In the situation of designing simulation, direction of the traffic flow is distributed imbalanced in different direction between node1 and node10. The traffic flow on 1 → 10 is significantly higher than the traffic flow on 10 → 1. Under the above unexpected incidents, the traffic managers adjust the number of lanes artificially in order to avoid the extreme congestion of relevant roads. Adjustment scheme is that link20, link11, and link2 lend a lane to the different direction link, which is link1, link10, and link19;
Program2: Determine the adjustment scheme using the method in this paper.

3. Contrast indexes

The paper selects the saturation of each section and total travel time as contradictive indexes and compares three types of schemes, respectively, from the angle of local and system, in order to evaluate the service level of the road network from different schemes.

Analyze the Outcome of Comparison

Different adjustment schemes are as follows (Tables 2 and 3):

1. The saturation of each section (Table 4)

The data attained from the VISSIM is used to calculate the ratios of each section, as shown in Fig. 3.

Program0: Without any adjustment. Individual sections have been serious congestion, traffic flow is quite unstable.
Program1: After the artificial adjustment, the ratios of some sections have dropped slightly, but the whole ratios remain high. The network is unstable;
Program2: Under the condition of program 2, the whole ratio of network has obvious downward trend and every ratio is between 0.1 and 0.63. The network is in a stable state, according to the evaluation indexes of the HCM.

2. The contrast between total travel time.

Concluding from the histogram as follows, the total impedance of system is the minimum one in program 2 compared with other two schemes. Compared with program1, program2 has better optimization effect (Fig. 4).

Table 2 Adjustment scheme in Program1

Link	1	2	3	4	5	6	7	8	9	10	11
No. of lane	5	3	4	4	2	1	3	1	3	5	3
Link	12	13	14	15	16	17	18	19	20	21	22
No. of lane	4	4	2	2	2	2	2	5	3	4	4

Table 3 Adjustment scheme in Program2

Link	1	2	3	4	5	6	7	8	9	10	11
No. of lane	6	2	4	4	2	1	3	1	3	6	2
Link	12	13	14	15	16	17	18	19	20	21	22
No. of lane	4	4	2	2	2	2	2	6	2	4	4

Table 4 Index of service quality evaluation

Reference value of service quality evaluation (traffic volume/capacity)	
V/C	The characteristics of operation
≤ 0.35	Free-running traffic flow (smooth)
0.35–0.55	Reasonable free-running traffic flow (a little bit delay)
0.55–0.75	Stable traffic flow (receptible delay)
0.75–0.90	Approach instable traffic flow (enduring delay)
0.90–1.00	Unstable traffic flow (crowded)
>1.00	Traffic jam

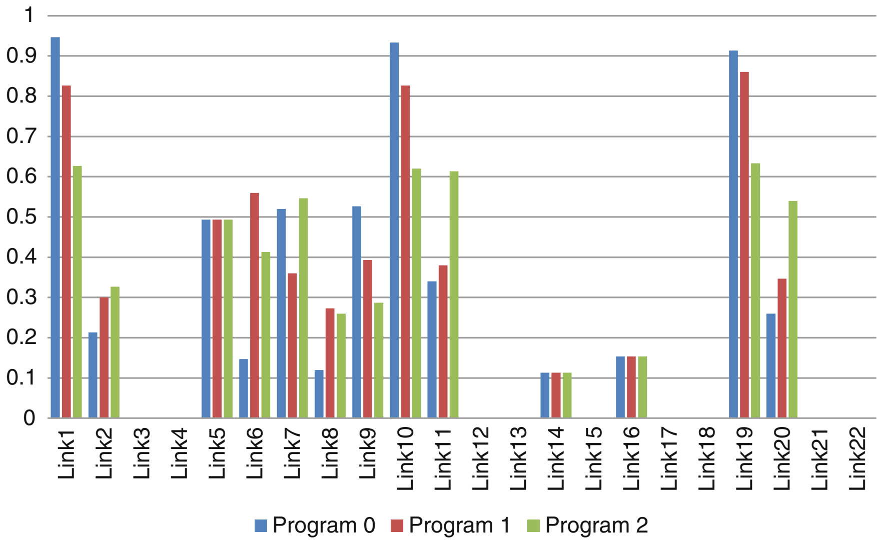


Fig. 3 Contrast figure of saturation in three kinds of solution

In conclusion, the adjustment scheme proposed in this paper reduces the extent of the road congestion and the impedance of the system and makes full use of the resources of the road, which improves the capacity of the network enormously and greatly.

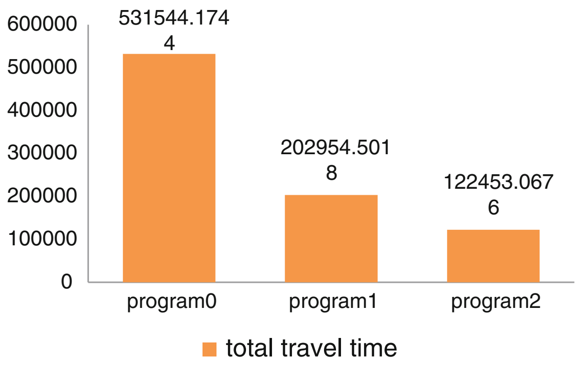


Fig. 4 Comparison about travel time in different schemes

Conclusion

The paper studies the methods of the variable lane controlling which are applied to the emergency evacuation area, then establishes a bi-level programming model—the upper plan that aims at the minimum total travel time and the lower-level plan described by user's equilibrium principle—and designs the solution algorithm based on the harmony search, finally, verifies the proposed method by simulation. Conclusions show that the proposed method is feasible and effective in the traffic emergency evacuation.

Aimed at large-scale traffic network, the author will research the corresponding parallel algorithm in the following study in order to improve the operation efficiency of the algorithm.

Acknowledgements This research is funded by National Natural Science Foundation of China (No. 51308249) and Jilin Province Science and Technology Development Project (20140101070JC). Thank them for the support.

References

1. Kim, Sangho, Shashi Shekhar, and Manki Min. 2008. Contraflow transportation network reconfiguration for evacuation route planning. *Transactions on Knowledge and Data Engineering* 20 (8): 1115–1129.
2. Sun, Qiang. 2009. Research about algorithm of dynamic variable lane optimization. *HIGHWAY* 8.
3. Suwansirikul, C., T.L. Friesz, and R.L. To bin. 1987. Equilibrium decomposed optimization: A heuristic for the continuous equilibrium net-work design problem. *Transportation Science* 21.
4. Huang, Shuai, and Liang Ma. 2014. Solving general integer programming problem by improved harmony search algorithm. *Computer Engineering and Applications* 50 (3).
5. Hao, Wang, Liqun Gao, and Haibin Ouyang. 2014. A modified harmony search algorithm with global crossover. *Journal of Northeastern University (Natural Science)* 35 (8).
6. Zhang, Haozhi, and Ziyou Gao. 2007. Optimization approach for traffic road network design problem. *Chinese Journal of Management Science* 15 (2).

7. Wang, Xiong. 2013. *Bi-level programming model and algorithm of urban roads convertible lanes*. Changsha: Zhongnan University.
8. Gao, Ziyou, Haozhi Zhang, and Huijun Sun. 2004. Bi-level programming models, approaches and applications in urban transportation network design problems. *Journal of Transportation Systems Engineering and Information Technology* 2 (4).
9. Zhang, Peng, Wenquan Li, and Yulin Chang. 2010. Reserve capacity model for urban road network with variable lanes. *Journal of Southwest Jiaotong University* 45 (2).