

Research on the Cooperative Optimization Mechanism and Methods for Urban Regional Traffics

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Abstract

With the rapid development of urban traffics, recently many big cities have established lots of modern traffic networks extended in all directions, but there are still some severe problems caused by traffic congestions and traffic accidents. So for improving these unsatisfactory states in the urban traffic, inspired by the immune cooperative phenomenon from the biologics, firstly the regional traffic cooperative objective function is purposefully constructed, then special immune cooperative optimization schemes for urban regional traffics are particularly designed and discussed based on dynamic sub-area priorities and niche techniques, and at last some traffic state data are elaborately analyzed and verified in a simulation, thereby this research may be very helpful for promoting the regional traffic travel capacity and improving the adaptation to the dynamic urban traffic tasks.

Keywords: urban region traffic, cooperation, optimization

1. Introduction

In recent 20 years, traffic congestions, traffic accidents, and environment pollutions have led to huge material and economic losses of society, so some urban traffic control systems have been developed considerably for a better urban traffic running condition [1-2]. However, most of these systems are performed with a single point multi-periods control and are shortage in the coordination with other traffic crosses in the same traffic region. Biology studies show that, facing with virus groups with different characteristics, various immune molecules, immune cells and immune organs can cooperatively promote the biological immune system into an adaptive evolution to generate the defense behaviors against the dynamic environment, parts of their special characteristics have widely aroused researchers in different engineering domains, such as the immune study, adaptation, evolution, self-organization. So to reduce the delay time and stop times of vehicles through crosses in an urban region, different crosses are needed to be connected into a group by a real-time way, some information about the traffic control, vehicles' data, crosses' status, and emergency events are needed to gather into one regional traffic information environment.

At present, the study of combining the artificial immune system with a traffic control is still in the developing stage, the immune theory has been employed to many areas, i.e. the signal point timing, traffic time division, traffic event monitoring, and traffic state analysis [3-8], partly including, Mengmeng Zhang built a mathematical model of traffic flow, Daikun Li solved the layout optimization based on an immune clone algorithm, Okamoto Takeshi used an immunity-based anomaly detection system for a network traffic. But there is still little research in the adaptive combination of the immune cooperation and regional traffic. So in this thesis, a special way of the "objective cooperation" and "evolutionary fusion" among different crosses may be considered inside

an integrated and cooperative traffic network, which is in the aim of cooperatively constructing a kind of “dynamic cooperative relationship” and of improving this traffic real-time condition in this urban region, expectedly a better adaptive ability will be achieved through the “dynamic study” and “cooperative evolution” of a regional traffic signal system, thereby, the vehicle oriented induction and traffic capacity will be enhanced in a central urban region, which have been partly proved in the cities with a notable regional traffic.

2. Analysis on the Immune Cooperative Mechanism in Urban Regional Traffics

2.1. Immune Cooperative Mechanism Description

The biological immune system is a natural and defensive system, while a new kind of antigen emerges, relative defensive cells automatically evolve to be as antibodies exterminating the antigen, and this immune process are dynamically adaptive to the environment through related immune cells’ evolution, which is similar to the dynamic regional traffic adaptation [9]. Thus, a cooperative traffic control network can be constructed and be dynamically reconfigured for regional traffic adaptive tasks, by the use of some intelligent immune agents in general characteristics of all immune cells. Figure 1 is a simple description of an immune evolution process on a regional traffic control network, which is composed of different immune cells in charge of different regional traffic sub-tasks and is designed in the distributed sub-network form to dynamically, cooperatively and adaptively deal with current regional traffic tasks.

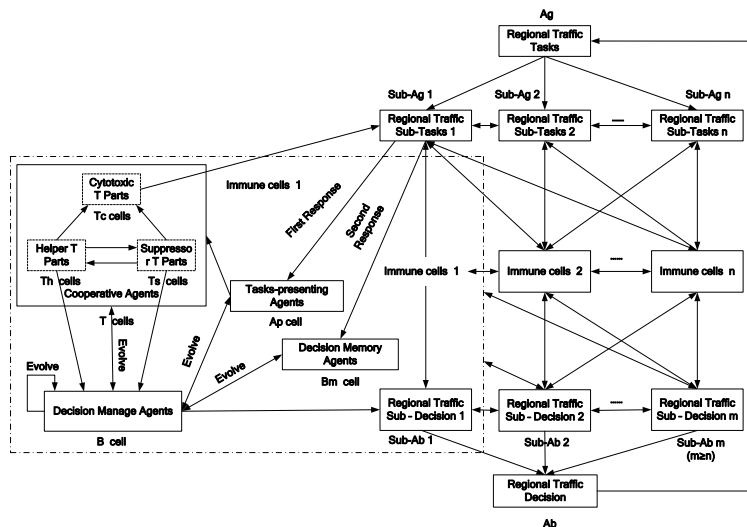


Figure 1. Immune Regional Traffic Process Description

This regional traffic control network in Figure 1 is dynamically designed and reconfigured by a few regional traffic immune agent control units (RTIACU) composed of above different immune functional agents, mainly including task-presenting agents, cooperative agents, decision memory agents, evolution agents and decision manage agents [10], which are respectively in main forms of the antigen, antibody, antigen-presenting cell, B cell, memory B cell, helper T cell, suppressor T cell, and cytotoxic T cell respectively, and are differently present of A_g , A_b , A_p , B , B_m , T_h , T_s , and T_c .

While new regional traffic tasks emerge as some unknown A_g s, thus cooperative agents are on main duties of implementing a first immune response to these unknown antigens,

which are needed to coordinate all functional agents in this RTIACU based on some immune mechanism, and thus a mutual cooperation or exclusion can be achieved among various functional immune agents in this RTIACU, lastly a new regional traffic control decision can be made as a new antibody by an evolved decision manage agent of new B cells, and new re-constructed RTIACUs may be created by evolved immune functional agents to improve adaptabilities to special regional traffic tasks in this regional traffic control process [5,11-13].

2.2. Regional Traffic Cooperative Objective Based on Dynamic Sub-Area Priorities

In the urban regional traffic signal control distributed with multi-crosses, it is expected to carry out a cooperative control on this regional traffic signal system, and to obtain an ideal traffic performance, so traditionally, three basic traffic parameters at least on a single traffic cross should be cooperatively managed in this regional traffic control, namely the traffic cycle, traffic split, and traffic phase difference, a designed regional traffic cooperative objective should be created and analyzed based on all these traffic parameters from all crosses in this traffic region. To strengthen the traffic capacity and efficiency of passing vehicles, the sum of vehicles' delay in all crosses need to be the minimum, so which can be viewed as a general and basic regional traffic cooperative objective.

Inspired by the immune cooperative phenomenon, different crosses and all traffic condition in this region are analyzed intensively and systematically, moreover for a better cooperative efficiency, one big regional traffic can be further dynamically divided into different smaller sub-areas controlled with adaptive methods due to current states. Thus, under the concern of one adapting dynamic sub-area priority and one regional traffic optimization vector(RTOV), this regional traffic cooperative optimizing objective in the m^{th} period can be considered as the equation listed [3,14-15], which is composed of common signal cycles for each traffic sub-area, and green phase start times of each crosses.

$$\begin{aligned}
 AFI(RTOV) &= \sum_{t=0}^{m^{\text{th}}} AFI(RTOV)_t = \min \sum_{h=1}^{CSN} d^h = \min \sum_{h=1}^{CSN} \sum_{i=1}^{n^h} d_i^h = \min \sum_{h=1}^{CSN} \sum_{i=1}^{n^h} \sum_{j=1}^{k_i} (dg_{ij}^h + dr_{ij}^h) \\
 &= \min \sum_{h=1}^{CSN} \sum_{i=1}^{n^h} \sum_{j=1}^{k_i} [(bg_{ij(m-1)}^h + \sum_{u=1}^{T_{in}^h - T_{ij}^h} q_{iju}^h - vrate_{ij}^h \cdot T_{ij}^h) + (\sum_{l=1, l \neq j}^{k_j} (bg_{il(m-1)}^h + \sum_{u=1}^{T_{in}^h - T_{ij}^h} q_{ilu}^h))] \\
 \text{note: } m^{\text{th}} &= \max(m_1^{\text{th}}, m_2^{\text{th}}, \dots, m_h^{\text{th}}, \dots, m_{CSN}^{\text{th}})
 \end{aligned}$$

This traffic cooperative optimizing objective function can be viewed as a multi-objective optimizing integration from different sub-area priorities in the same regional traffic community, which is proposed to achieve the minimum vehicles' delay in all crosses [16-17]. Due to dynamic sub-area priorities, in this traffic cooperative optimizing objective function, regional traffic control parameters mainly include: CSN is of total numbers of adapted dynamic sub-area priority, n^h is of total numbers of crosses in the dynamically divided h^{th} sub-area priority in this traffic region, where total numbers of crosses is n , k_i is of planed phase numbers of the i^{th} cross, d^h is of total delay of uplink and downlink vehicles in a traffic cycle from the dynamically divided h^{th} sub-area priority, and which is equal to all sums of d_i^h on the total delay of uplink and downlink vehicles through the i^{th} cross in a traffic cycle from the h^{th} sub-area priority, dg_{ij}^h is of vehicles' delay on the green light way in the m^{th} period of the j^{th} phase through the i^{th} cross from the h^{th} sub-area priority, dr_{ij}^h is of vehicles' delay on the red light way in the m^{th} period of the j^{th} phase through the i^{th} cross from the h^{th} sub-area priority, $bg_{ij(m-1)}^h$ is of vehicles' retention number at the green light' end in the $(m-1)^{\text{th}}$ period of the j^{th} phase through the i^{th} cross from the h^{th} sub-area priority, q_{iju}^h is of vehicles' arriving number at the u^{th} second in the j^{th} phase at the i^{th} cross from the h^{th} sub-area priority, $vrate_{ij}^h$ is of vehicles' number rate on the green light way in the j^{th} phase through the i^{th} cross

from the h^{th} sub-area priority, T_{im}^h is of the time length on the m^{th} period of the i^{th} cross from the h^{th} sub-area priority, and T_{ij}^h is of the time length on the green light signal at the j^{th} phase of the i^{th} cross from the h^{th} sub-area priority.

3. Immune Cooperative Decision Mechanism Schemes

3.1. Immune Cooperative Mechanism Description

In this traffic signal control of urban regions composed of multi-crosses with different objectives, the resources and ability of a single cross control individual are limited, traffic crosses' cooperation in the same traffic region can be cooperatively organized and similarly described as the interactive improvement and suppression of various immune cells from different cell population [18-19]. In this regional traffic immune cooperative evolution, a binary logic coding method is adopted in presentation of regional traffic control patterns from this RTIACU, a current regional traffic task is made as an immune antigen, and some possible regional decision patterns from this RTIACU are used as possible antibodies, the regional traffic cooperative optimizing objective has been defined as AFI (RTOV), thus the affinity refers to the matching degree between anti-bodies and antigens, the affinity function of anti-body may be defined as AFF (RTOV), listed as following [20].

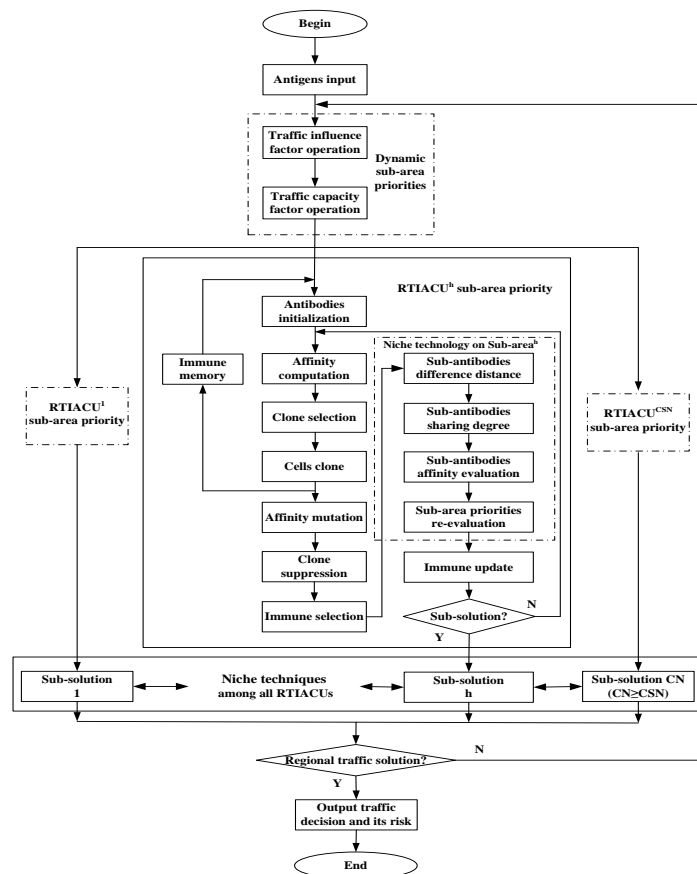


Figure 2. Regional Traffic Immune Cooperative Scheme

Based on this framework of the constructed regional traffic cooperative operation and conventional immune algorithm [21], Figure 2 shows the designed regional traffic immune cooperative scheme.

This scheme is specially designed for solving the optimization of the regional traffic cooperative objective function, it is very important to make the evaluation on different individual affinity with the consideration of other populations, and moreover for keeping the diversity of immune population in the maximum degree on the multi-objective optimizing in the same traffic community, two functional operations are specifically designed for achieving the dynamic sub-area priorities operation and the traffic immune niche techniques operation, on the base of proposed conventional operations [20] on the immune system.

3.2. The Dynamic Sub-Area Priorities Operation Design

In main regional traffic, environment state information can be classified into the regional traffic space location information and the regional traffic time capacity information, so two specialized operation may be defined of the traffic influence factor operation and traffic capacity factor operation, which are used to achieve the dynamic sub-area priorities operation [22-25].

A traffic influence factor group of TIF can be composed of the traffic space location information of the crosses' traffic distance, the crosses' traffic direction and the current traffic tasks domain, which is presented as a listed form(n is the number of all crosses in the regional traffic).

$$TIF = \{tif_1, tif_2, \dots, tif_i, \dots, tif_n\}, tif_i = \{ctd_i, ctr_i, cctd_i\}, i = 1, 2, \dots, n$$

So, these designed traffic influence factor operation rules are listed as following in which, L_{min} is the minimum cooperative crosses' distance, L_{max} is the maximum cooperative crosses' distance, R_λ is the minimum cooperative crosses' direction, TD_λ is the maximum current traffic tasks domain degree.

$$i, L_{min} < |ctd_i - ctd_j| < L_{max}, corss_i \cup cross_j \subseteq sub-area^h$$

$$ii, |ctr_i - ctr_j| < R_\lambda, corss_i \cup cross_j \not\subseteq sub-area^h$$

$$iii, |cctd_i - cctd_j| > TD_\lambda, corss_i \cup cross_j \not\subseteq sub-area^h$$

$$normally\ recommendal: L_{max} = 800m, L_{min} = \frac{traffic\ flow(t)}{0.80 * lanes' number} * vehicles' length$$

A traffic capacity factor group of TCF can be composed of the traffic time capacity information of the crosses' current traffic modes, the crosses' current traffic parameter periods, the crosses' current traffic queues and the crosses' traffic widths, which is presented as a listed form(n is the number of all crosses in the regional traffic).

$$TCF = \{tcf_1, tcf_2, \dots, tcf_i, \dots, tcf_n\}, tcf_i = \{cctm_i, cctp_i, cctq_i, ctw_i\}, i = 1, 2, \dots, n$$

So, these designed traffic capacity factor operation rules are shown as following, in which, the capacity _{i} is the all vehicles in the i^{th} cross, SA_λ is the minimum cooperative crosses' capacity degree.

$$i, cross_i \cup cross_j \subseteq sub-area^h$$

$$ii, capacity_i = cctq_i \times ctw_i$$

$$iii, \|tcf_i - tcf_j\|_{hammin\ g} < SA_\lambda, corss_i \cup cross_j \not\subseteq sub-area^h$$

Therefore, while a regional traffic task happens currently, this traffic area may be dynamically divided into some sub-area priorities with different optimizing objectives and different priority of ω_n , which should be cooperatively integrated in the regional traffic multi-objective optimizing process.

$$\begin{aligned}
 traffic_area &= sub-area^1 \times \omega_1 + \dots + sub-area^h \times \omega_h + \dots + sub-area^{CSN} \times \omega_{CSN} \\
 \omega_1 + \dots + \omega_h + \dots + \omega_{CSN} &= 1, \quad \omega_h : traffic \text{ priority of } sub-area^h
 \end{aligned}$$

3.3. The Traffic Immune Niche Techniques Operation Design

To immune niche techniques [17, 26], it is a key to how to design a sharing degree evaluation mechanism for this regional traffic tasks. In the proposed immune cooperative scheme, there are two kinds of adopted immune niche techniques, one is among various sub-area priorities, another is among different evolutionary cell population in the RTIACU^h sub-area priority, though for different traffic population, but this sharing degree evaluation mechanism may be designed to be non-different in the form of a traffic population symptoms' fitness regulation based on their analyzed and calculated sharing degree. For describing this, traffic population symptoms of various sub-area priorities and evolutionary cell population in the RTIACU^h sub-area priority may be respectively described in two group of SUP and ECP_SUP^h, which can be designed and shown as following,

$$\begin{aligned}
 &supposed, SUP = \{sup_1, sup_2, \dots, sup_h, \dots, sup_{CSN}\}, h = 1, 2, \dots, CSN, \\
 &or, ECP_SUP^h = \{ecp_1, ecp_2, \dots, ecp_k, \dots, ecp_{CN^h}\}, k = 1, 2, \dots, CN^h \\
 &i, sd_{ij} = \|\sup_i - \sup_j\|_{hammin} \text{ or } cd_{ii}^h = \|ecp_i - ecp_j\|_{hammin} \\
 &ii, tssh(sd_{ij}) = \begin{cases} 1 - (\frac{sd_{ij}}{s\sigma_{sh}})^\alpha, & sd_{ij} < s\sigma_{sh}, \text{ or, } tecpsh(cd_{ij}^h) \\ 0, & \text{others} \end{cases} = \begin{cases} 1 - (\frac{cd_{ij}^h}{c\sigma_{sh}})^\alpha, & cd_{ij}^h < c\sigma_{sh} \\ 0, & \text{others} \end{cases} \\
 &ii, tssh(sup_i) = \sum_{j=1}^{CSN} sd_{ij}, \text{ or, } tecpsh(ecp_i) = \sum_{j=1}^{CN^h} cd_{ij}^h \\
 &iv, AFI_{nk}(sup_i) = \frac{AFI(sup_i)}{tssh(sup_i)}, \text{ or, } AFI_{nk}(ecp_i) = \frac{AFI(ecp_i)}{tecpsh(ecp_i)}
 \end{aligned}$$

In which, sd_{ij} is the hamming distance between the i^{th} sub-area priority and the j^{th} sub-area priority, cd_{ij}^h is the hamming distance between the i^{th} evolutionary cell population in the RTIACU^h sub-area priority and the j^{th} evolutionary cell population in the RTIACU^h sub-area priority, $tssh(sd_{ij})$ is the traffic sub-sharing degree of the i^{th} sub-area priority and the j^{th} sub-area priority, which is related to the sub-area sharing radius of $s\sigma_{sh}$ and the sub-area parameter of α (often $\alpha=1$ or $\alpha=2$), $tecpsh(cd_{ij}^h)$ is the traffic evolutionary cell population sharing degree of the i^{th} evolutionary cell population in the RTIACU^h sub-area priority and the j^{th} evolutionary cell population in the RTIACU^h sub-area priority, which is related to the cell population sharing radius of $c\sigma_{sh}$ and the sub-area parameter of α (often $\alpha=1$ or $\alpha=2$), $tssh(sup_i)$ is the traffic sub-sharing degree of the i^{th} sub-area priority, $tecpsh(ecp_i)$ is the traffic evolutionary cell population sharing degree of the i^{th} evolutionary cell population in the RTIACU^h sub-area priority, $AFI_{nk}(sup_i)$ is the regulated traffic affinity of the i^{th} sub-area priority based on the initial traffic affinity of $AFI(sup_i)$, by use of the traffic immune niche techniques operation among all sub-area priorities, $AFI_{nk}(ecp_i)$ is the regulated traffic affinity of the i^{th} evolutionary cell population in the RTIACU^h sub-area priority based on the initial traffic affinity of $AFI(ecp_i)$, by use of the traffic immune niche techniques operation among all evolutionary cell population in the RTIACU^h sub-area priority.

3.4. Traffic Decision Simulation

In a traffic area there are six crosses, which are located from west to east respectively and can be simply named as the Cross 1, Cross 2, Cross 3, Cross 4, Cross 5, and Cross 6.

Through a long time observation [15, 22-26], all average traffic rates of all crosses have been listed in Table 1.

Table 1. Traffic Rates of all Crosses

Cross	East import flow			West import flow			South import flow			North import flow		
	Right	Straight	Left	Right	Straight	Left	Right	Straight	Left	Right	Straight	Left
1	83	420	130	215	348	198	104	305	95	145	297	116
2	83	396	130	123	385	85	215	285	105	89	325	79
3	115	430	87	112	396	125	160	290	110	48	365	73
4	202	450	85	62	418	215	85	255	135	100	260	115
5	190	460	125	73	460	119	85	215	118	82	280	213
6	82	455	135	115	520	135	160	320	86	265	320	169

Taking Cross 1 as a start position, location distance between different crosses are 480m, 290m, 530m, 620m and 300m from west to east respectively, so for more effectively improving this regional traffic, these six crosses are dynamically classified into different traffic sub-areas and should be cooperatively regulated [15, 22-26].

Step i calculation on signal cycles of all crosses in this regional traffic. The single cross's signal cycle can be achieved on the base of the Webster calculation formula of optimal signal cycle, which is $C_0 = (1.5L + 5) / (1 - Y)$.

Step ii division on dynamic traffic control sub-areas. As proposed methods, dynamic sub-area priorities of all traffic control sub-areas are made by use of the defined traffic influence factor operation and the defined traffic capacity factor operation.

Step iii cooperative optimization of regional traffic parameters. For the best regional traffic cooperative optimizing objective, discussed immune niche techniques are adopted, this designed cooperative decision vector variable is composed of common signal cycles for each traffic sub-area, and green phase start times of each crosses.

This cooperative regional traffic simulation process is shown in Figure 3. In this simulation, the evolution population size is fixed at 1000, the clone selection rate α_s is 0.15 the clone restraint radius β is 0.10, the density restraint radius γ is 0.15 and the iteration number of times Φ is 50, the sub-area sharing radius of σ_{sh} and the cell population sharing radius of $c\sigma_{sh}$ are equal to 45.

So, learning from Figure.3, in order to achieve the best traffic state, these six crosses in the regional traffic can be further subdivided into for two sub-areas of the sub-area 1 and sub-area 2, the sub-area 1 are composed of Cross 1, Cross 2, Cross 3 and Cross 4, the sub-area 2 are composed of other two crosses. The best common signal cycle of the sub-area 1 and sub-area 2 are respectively 111s and 118s, green phase start times of four crosses in the sub-area 1 are respectively 42s, 101s, 108s and 45s green phase start times of two crosses in the sub-area 2 are respectively 78s and 21s. If adopting different calculation parameters, only the calculation speed or time maybe be influenced in the observation, thus this simulation is effective and verified.

4. Conclusions

Regional traffic congestion and traffic accidents have become severe issues that many cities widely face, so it is very important of improving these unsatisfactory states in the urban traffic, on the base of relevant immune mechanisms, this research specially makes a further study on the immune regional traffic cooperative scheme, which mainly includes:

- i* The regional traffic cooperative objective function is purposefully constructed, and the regional traffic immune cooperative mechanism is explicitly described.
- ii* Some special cooperative operations are detailed designed, analyzed and verified on regional traffics, which make RTIACUs be conventionally regulated and reconstructed for being adaptive to current regional traffic tasks.

This study aims to provide an effective method for meeting demands in dynamic regional traffic managements, thereby which may be very helpful for promoting the regional traffic travel capacity and improving the adaptation to the dynamic urban traffic tasks.

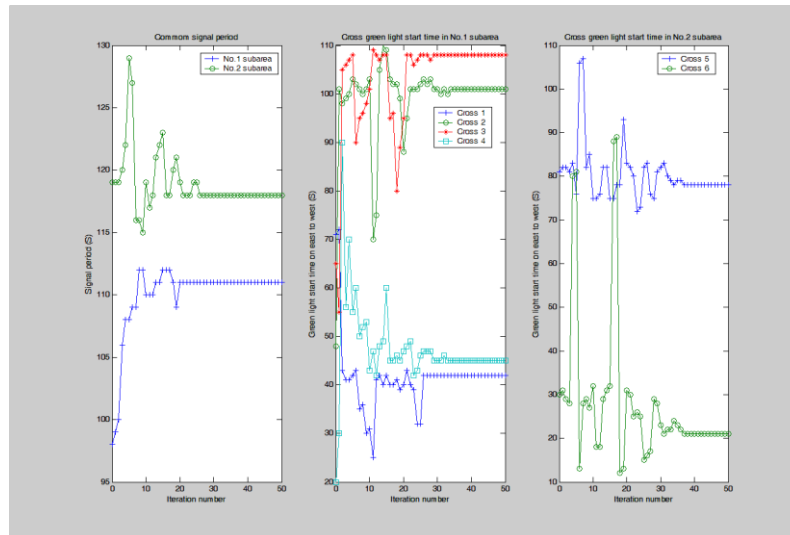


Figure 3. Regional Traffic Simulation Process

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