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Traffic Management for Major Traffic Projects During Construction

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ABSTRACT: The transportation situation in Shanghai is a serious problem. Streets, mostly built several decades ago, are crowded with various types of vehicles almost all day long. The urban transportation facilities do not satisfy the needs of economic growth, especially the rapid development of the Pudong economic zone. Recently, this problem has become even sharper. Many major infrastructure projects, which are necessary to improve transportation and the environment and help Shanghai become a center for finance, commerce and trade, are under construction in the downtown area.

In order to minimize the disruption of existing traffic during construction, this paper discusses various schemes of traffic management for major projects. Using mixed qualitative and quantitative methods, various schemes are simulated and analyzed. Each simulation result is evaluated with a multi-objective criterion, which is helpful for decision making. Two successful applications to the Inner Ring Viaduct and the Chengdu Road Viaduct are demonstrated.

KEY WORDS: Traffic Management, Simulation Model, Evaluation

I. Discussion of Traffic Management Schemes

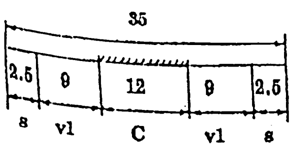
Statistics show that traffic congestion in China is extremely serious. The percentage of road area to total urban area is less than 3.6%, only a fraction of the percentage in developed countries. In Shanghai, the total length of the 300,000 motorized vehicles and 6 million bicycles is over ten times the total length of all roads. Under these conditions, construction of major projects is obviously extremely difficult. Therefore, it is very important to do research on traffic management during construction. We consider a scheme which combines "self-digestion" with traffic diversion.

1. Self-digestion schemes

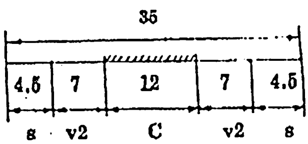
Because of the over-saturation of traffic loading on most roads in Shanghai, it is difficult to accept extra vehicles diverted from a road under construction. A "self-digestion" scheme means that motorized traffic flow is maintained as usual, but the space for bicycles and sidewalks is reduced.

Example 1: The first phase of the Inner Ring Viaduct Project plans to use 12m as the construction width, out of the total available width of 35m. The remaining width should retain four lanes for two-way traffic. We have proposed two kinds of "self-digestion" schemes, as follows:

Scheme A:



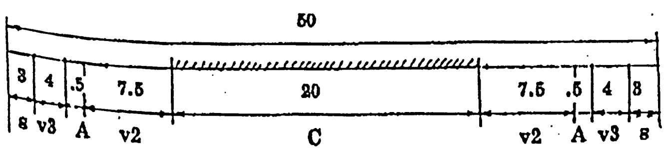
Scheme B:



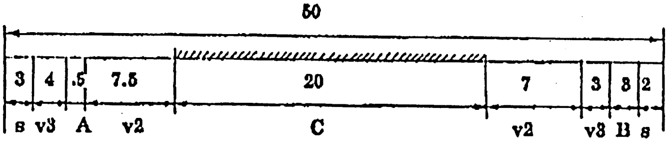
C : Under construction
v_1: Mixed motorized vehicles and bicycles lane
v_2: Motorized vehicles lane
s : Sidewalk

Example 2: Similarly, two schemes for the Chengdu Road Viaduct Project (total width 50m) are as follows:

Scheme A:



Scheme B:



C : Under construction
v_2: Motorized vehicles lane
v_3: Bicycles lane
A : Separation belt
B : Bus stop
s : Sidewalk

2. Traffic flow diversion schemes

It is impossible to maintain the usual traffic flow on some roads. In this case, we must divert some of the vehicles from the original traffic flow. If the traffic loading in the neighbouring area is saturated, we have to build a new path to accept the diverted vehicles. For example, in the first phase of the Inner Ring Viaduct Project, besides the schemes listed in Example 1, we also preset a diversion scheme. According to our statistics from the scene, trucks loading less than two tons constitute about 17% of total motorized vehicles there. We suggest opening a new path between Lan Gao Road and Wu Ning Road to lighten the pressure on Zhong Shan West Road, as well as letting 10% of the vehicles diverge naturally to neighbouring roads.

3. Mixed schemes

If the loading in the neighbouring road network is not too heavy, a scheme combining "self-digestion" with diversion may be better and more practical. In the second phase of the Inner Ring Viaduct Project and Chengdu Road Viaduct Project, we propose several mixed schemes for different roads or regions.

4. Special schemes for intersections crossing railways

Some viaducts must cross a railway. For example, the Chengdu Road Viaduct will coincide with the Gong He Xin Road Overpass which crosses a railway. Every day there are more than 60 pairs of passenger trains, as well as many pairs of freight trains passing this point. It is impossible to interrupt the railway and the overpass for construction. A practical scheme is suggested as follows: constructing bridges for two side ramps first, and linking these bridges to the neighbouring traffic network (Tian Mu Road Overpass and ramps), then removing the original overpass, and finally building the viaduct itself.

5. The influence of public transportation

Buses and trolleybuses are the major transport tools for Shanghai residents. A good scheme should not disrupt the usual public transportation too much. Suggested arrangements include removing some stops, establishing temporary stops, changing routes, etc.

II. Quantitative Analysis of Traffic Management Schemes: Simulation Experiments

We have developed an Urban Traffic Simulation Model (UTSM), which is the key subject of this paper.

1. Characteristics of UTSM

UTSM is a microscopic, stochastic, time-scanning simulation model, programmed in Turbo-PASCAL. It is suitable for any urban traffic flow satisfying the following conditions:

(1) Intersections must be in T-shape or cross shape, with signal control.
(2) Vehicles must be in single lane or double lane.

UTSM has the following features:

(1) As a microscopic model, it simulates the movement of a single vehicle, rather than global variables that describe traffic flow, such as capacity, density, etc. Both motorized vehicles (including cars, trucks, buses, and motorcycles) and bicycles are simulated. For bicycles, we use a batch treatment that converts 4 bicycles into one car.
(2) The basic unit in a road network is a "link" (input link, network link, or output link).
(3) A modular structure is used.
(4) The simulation in UTSM combines discrete events with a continuous system.

2. Simulation experiment

The Model: A proper simulation model must be set up before making an experiment. The scale depends on the planning scale of a project and the practical schemes based on the experience of the engineers and experts who are in charge of the project, as well as the capacity of UTSM.

Validation: The accuracy of a model should also be checked against actual data from field observations. Table 1 shows a comparison between simulated and observed values of traffic flow and speed in the north part of Chengdu Road Viaduct. If the validation is successful, we have confidence to use the model to do other simulations.

Table 1

Link	Segment of Gong He Xin Road	Driving Speed		Traffic Flow	
		Simulated	Observed	Simulated	Observed
7	Liu Ying - Zhong Shan Bei	9.4	-	2185	2455
8	Zhong Shan Bei - Liu Ying	17.4	16.3	1891	2254
14	Zhong Shan Bei - Zhong Xing	17.4	-	756	1048
13	Zhong Xing - Zhong Shan Bei	17.8	15.2	2277	2744
19	Zhong Xing - Tian Mu Xin	15.4	-	1143	1480
20	Tian Mu Xin - Zhong Xin	16.9	-	1036	1280

Output: For each link, certain statistical results, which are the key measures of a scheme, are the simulation output, as follows:

(1) Average travel time: $t = \sum_{k=1}^{K} t_k/k$

where t_k: time duration for kth vehicle passing through the link
K: total number of vehicles during simulation

(2) Average speed: $v = l/t$
where l: length of the link

(3) Average delay time: $d = \sum_{j=1}^{J} d_j/J$

where d_j: delay time of the jth vehicle
J: total number of waiting vehicles during simulation

(4) Average number of stops: $s = \sum_{i=1}^{I} s_i/I$

where s_i: number of stops for the ith vehicle
I: total number of vehicles which stop one or more times

(5) Saturation coefficient: $\lambda = V/kc$
where V: traffic flow
k: number of lanes
c: capacity of a single lane (here we take $c=1312\delta$ [pcu/hr], with δ a reducing coefficient of intersection influence)

(6) Loading coefficient: $\mu = Q/c$
where Q: volume of a single lane at an intersection point
c: capacity of a single lane at an intersection (here we take c=1326 pcu/hr)

Table 2 shows some simulation results for the north part of the Chengdu Road Viaduct.

Table 2

Scheme I: Motorized Vehicles Only

Link	Segment of Gong He Xin Road	Average				Saturation Coefficient
		Speed (km/h)	Delays (s)	Travel Time (min)	Flow (veh/h)	
7	Liu Ying - Zhong Shan Bei	18.0	4	1.80	1211	0.87
8	Zhong Shan Bei - Liu Ying	19.2	1	1.69	1260	0.90
14	Zhong Shan Bei - Zhong Xing	19.5	1	3.03	951	0.68
13	Zhong Xing - Zhong Shan Bei	19.3	2	3.16	924	0.66
19	Zhong Xing - Tian Mu Xi	19.0	2	2.53	1128	0.84
20	Tian Mu Xi - Zhong Xing	19.4	1	2.48	1113	0.80

Scheme II: Motorized and Non-Motorized Vehicles

Link	Segment of Gong He Xin Road	Average				Satura-tion Coeffi-cient
		Speed (km/h)	Delays (s)	Travel Time (min)	Flow (veh/h)	
7	Liu Ying - Zhong Shan Bei	8.9	60	8.65	2105	0.96
8	Zhong Shan Bei - Liu Ying	17.4	1	1.86	1891	0.86
14	Zhong Shan Bei - Zhong Xing	14.1	2	4.32	716	0.83
13	Zhong Xing - Zhong Shan Bei	14.0	4	4.35	2332	1.06
19	Zhong Xing - Tian Mu Xi	11.9	19	4.04	981	0.70
20	Tian Mu Xi - Zhong Xing	14.2	2	3.38	1122	0.51

A comparison of average speeds on Gong He Xin Road between the actual situation and our simulation results for Schemes I and II is given in Table 3. The reduction rates are 8% and 15% respectively.

Table 3

	Motorized Vehicles	All Vehicles
Actual	20.8	15.7
Simulation	19.1	13.4

The above output is just for a single vehicle, which describes the service level of a scheme. We can go beyond this to obtain statistical output for total vehicles, which reflects the benefits of a scheme. The global output is listed as follows:

A. Average measures

Suppose that there are n links and the total length $L = \sum_{i=1}^{n} l_i$, where l_i is the length of the ith link.

(1) Travel time: $T = \sum t_i$
(2) Delay time: $D = \sum d_i$
(3) Mean speed: $V = L/T$
(4) Mean volume: $Q = \sum (q_i l_i)/L$
(5) Capacity: $C = \sum (c_i l_i)/L$
(6) Saturation coefficient: $\lambda = \sum (\lambda_i l_i)/L$

where t_i, d_i, q_i, c_i, and λ_i are the average travel time, delay time, volume, capacity, and saturation coefficient along the ith link respectively.

B. Indices for all vehicles at rush hours

(1) Total travel time: $T_v = \sum_{i=1}^{n} (t_i q_i)$

(2) Total delay time: $S_v = \sum_{i=1}^{n} (s_i q_i)$

III. Evaluation with Multiple Objectives

Suppose that there are n schemes, m links, and k objectives. The evaluation procedure can be described as follows:

Step 1: Set up objective matrices.

$$A_l = \left(a_{ij}^{(l)} \right)_{m \times n} \qquad (l = 1,2,\ldots,k)$$

Step 2: Find an ordering mapping $A_l \to \tilde{A}_l = \left(\tilde{a}_{ij}^{(l)} \right)_{m \times n}$, where $\tilde{a}_{ij}^{(l)}$ are integers and represent the optimal order of $a_{ij}^{(l)}$ in the ith row.

Comparing the magnitude of the elements of in the ith row: $(a_{i1}^{(l)}, a_{i2}^{(l)}, \ldots, a_{in}^{(l)})$, if A_l is an objective matrix of speed, we take the optimal number of 1 for the maximum element of $a_{ij}^{(l)}$, 2 for the second largest one, and so on. If there are two or more elements that have the same value, then they receive the same optimal ranking number. If A_l is some other objective matrix, the procedure is similar, but the minimum element, not the maximum, may be optimal. In any case, the best choice receives value 1, the second best 2, and so on.

Step 3: Find the optimal schemes for each single objective.

Take $\bar{a}_j^{(l)} = 1/m \sum_{i=1}^{m} \tilde{a}_{ij}^{(l)}$ (j = 1,...,n, l = 1,...,k)

Suppose that $\bar{a}_{j1}^{(l)} \leq \bar{a}_{j2}^{(l)} \leq \ldots \leq \bar{a}_{jn}^{(l)}$,

then the best scheme for the lth objective is scheme j1, the second best is scheme j2, and so on.

Step 4: Find the optimal schemes for multiple objectives.

Make an ordering mapping $\{ \bar{a}_j^{(l)} \} \rightarrow \{ \hat{a}_j^{(l)} \}$, where $\hat{a}_j^{(l)}$ is an integer and represents the optimal order of the jth scheme for the lth objective.

Take a weighted summation

$$\lambda_j = \sum_{l=1}^{k} w_l \hat{a}_j^{(l)}, \quad (j = 1,\ldots,n), \quad \text{where } \sum w_l = 1.$$

Suppose that $\lambda_{j1} \leq \lambda_{j2} \leq \ldots \leq \lambda_{jn}$, $(1 \leq jn \leq n)$.

Then scheme j1 is best, scheme j2 is second best, and so on.
We may make an ordering mapping again $\{ \lambda_j \} \rightarrow \{ \tilde{\lambda}_j \}$, where $\tilde{\lambda}_j$ is also an integer, which represents the optimal order of the jth scheme for the multiple objectives.

Consider the Inner Ring Viaduct as an example. We simulated nine schemes with five objectives (average speed, average delay time, average travel time, average number of stops, and coefficients). Denote $P_1, P_2, \ldots, P_8$ as the eight new schemes and P_0 as the current situation. Table 4 shows the results when $w_1 = w_2 = \ldots = w_5 = 1/5$.

Table 4

Scheme	P_0	P_1	P_2	P_3	P_4	P_5	P_6	P_7	P_8
λ_j	5.2	7.6	5.8	4.6	3.4	5.2	2.6	3.4	1.2
$\tilde{\lambda}_j$	5	7	6	4	3	5	2	3	1

In order of priority, the first four schemes are P_8, P_6, P_7, and P_3. If we take the weights as $w_1 = w_3 = 1/4$ and $w_2 = w_4 = w_5 = 1/6$, then we obtain a slightly different result, as shown in Table 5.

Table 5

Scheme	P_0	P_1	P_2	P_3	P_4	P_5	P_6	P_7	P_8
λ_j	5.08	7.58	5.75	4.67	3.50	5.17	2.42	3.42	1.17
$\tilde{\lambda}_j$	6	9	8	5	4	7	2	3	1

In this case, the three schemes of highest priority are still P_8, P_6 and P_7, but the fourth one is P_4 instead of P_3.

We recommended P_8, P_6 and P_7 to Shanghai Municipality. P_8 is a mixing scheme: 7m as motorized vehicle lanes, 4.5m as mixing lanes for manpowered vehicles and sidewalk, natural diversion for 10% of the vehicles, and partial diversion for trucks loading less than two tons. These schemes have already been successfully applied to the first phase of construction of the Inner Ring Viaduct several months ago.

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