Dynamic Multi-path Signal Progression Control Based on Connected Vehicle Technology

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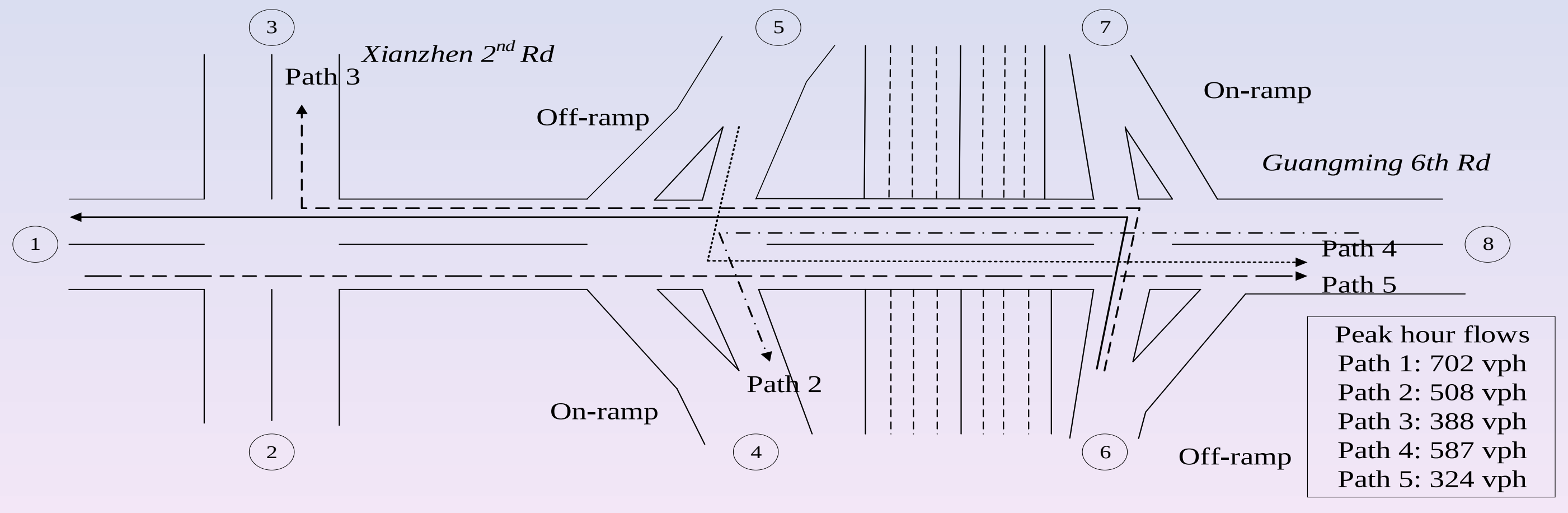
Abstract

- This study proposes a methodology to adaptively control traffic the offsets of signals and to provide dynamic progression bands for multiple critical paths in a CV environment.
- A real-time optimization model is constructed to design coordination plan and the control objective is to provide maximum green bandwidth along the determined critical paths, by optimizing the offsets of all intersections along an arterial.
- To solve this model, a solution algorithm based on dynamic programming is proposed. .
- A simulation-based experimental test is conducted in VISSIM to evaluate the potential and effectiveness of the proposed dynamic signal progression control system.

Problem Nature

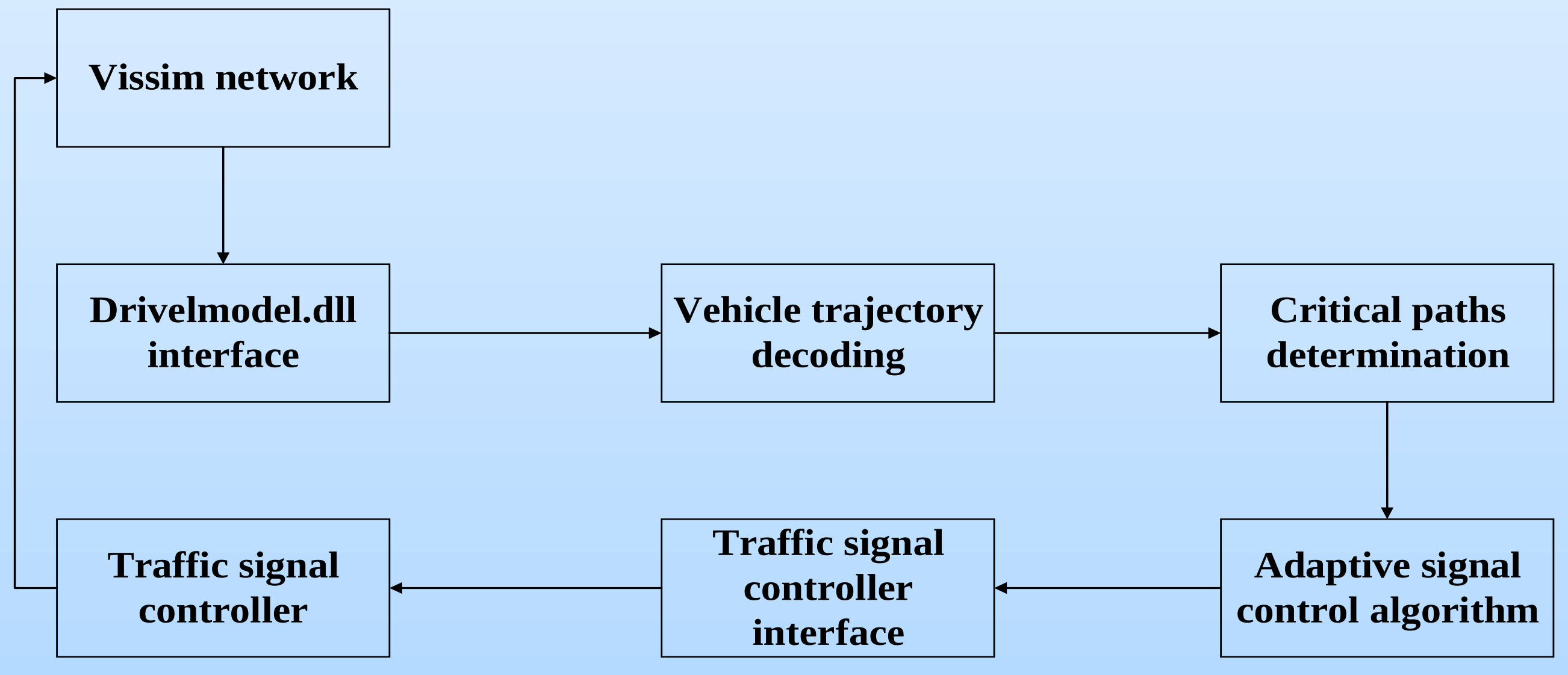
Based on Signal Phase and Timing (SPaT) and Basic Safety Message (BSM), this study proposes a methodology of dynamic signal progression control for arterial coordination.

1. The vehicle trajectory is firstly decoded based on the BSM at the end of each time interval (e.g. 5 min) to calculate the traffic volume for each OD pair and then determine the critical paths.
2. the signal progression control algorithm is applied to optimize the traffic signal timing plan based on the decomposed data and the determined critical paths.



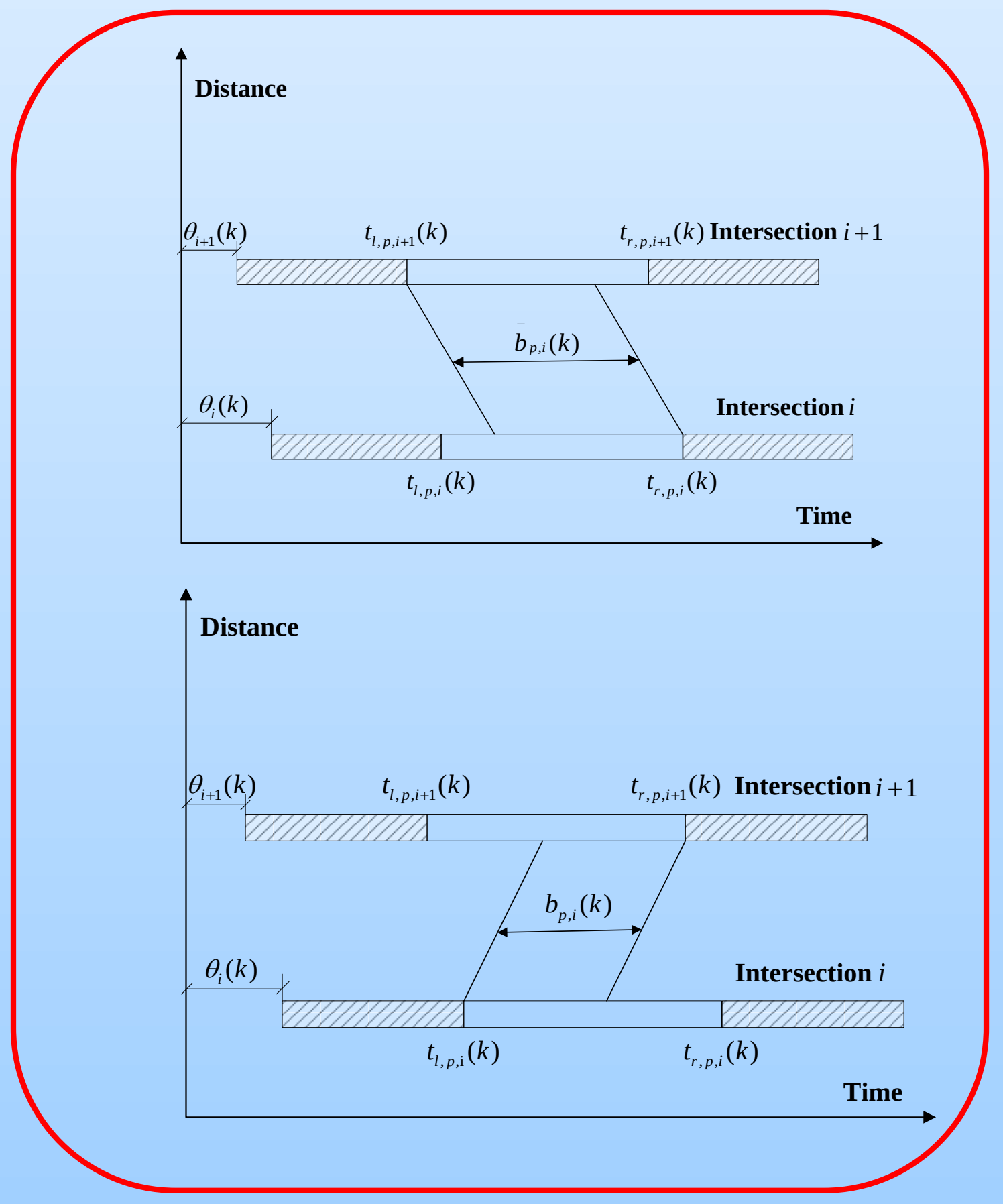
Peak hour flows
Path 1: 702 vph
Path 2: 508 vph
Path 3: 388 vph
Path 4: 587 vph
Path 5: 324 vph

Critical paths of the road network in Chupei, Taiwan



Vissim network
Drivelmodel.dll interface
Vehicle trajectory decoding
Critical paths determination
Adaptive signal control algorithm
Traffic signal controller interface
Traffic signal controller

Flow chart of signal progression control system



Model Development

$$\max\left(\sum_i\sum_p \omega_p(j)b_{p,i}(j)+\sum_i\sum_p \bar{\omega}_p(j)\bar{b}_{p,i}(j)\right)$$

green band for an outbound and inbound path-flow

$$b_{p,i}(j)=max\left(b_{r,p,i}(j)-b_{l,p,i}(j),0\right)$$

$$\bar{b}_{p,i}(j)=max\left(\bar{b}_{r,p,i}(j)-\bar{b}_{l,p,i}(j),0\right)$$

the right bound and left bound of the green band of path p for outbound and inbound

$$b_{r,p,i}(j)=min(t_{r,p,i}(j)+t_{i,i+1}(j),t_{r,p,i+1}(j))$$

$$b_{l,p,i}(j)=max(t_{l,p,i}(j)+t_{i,i+1}(j),t_{l,p,i+1}(j))$$

$$\bar{b}_{r,p,i}(j)=min(t_{r,p,i+1}(j)+t_{i,i+1}(j),t_{r,p,i}(j))$$

$$\bar{b}_{l,p,i}(j)=max(t_{l,p,i+1}(j)+t_{i,i+1}(j),t_{l,p,i}(j))$$

start and end of the green band for critical path

$$t_{l,p,i}(j)=\sum_m\sum_n \beta_{m,p,i}*\varphi_{m,n}*g_{i,m}(j)+\theta_i(j)$$

$$t_{r,p,i}(j)=\sum_m\sum_n \beta_{m,p,i}*\varphi_{m,n}*g_{i,m}(j)$$

$$+\sum_m \beta_{m,p,i}*g_{i,m}(j)+\theta_i(j)$$

ensure the continuity of the green band for a path along multiple intersections

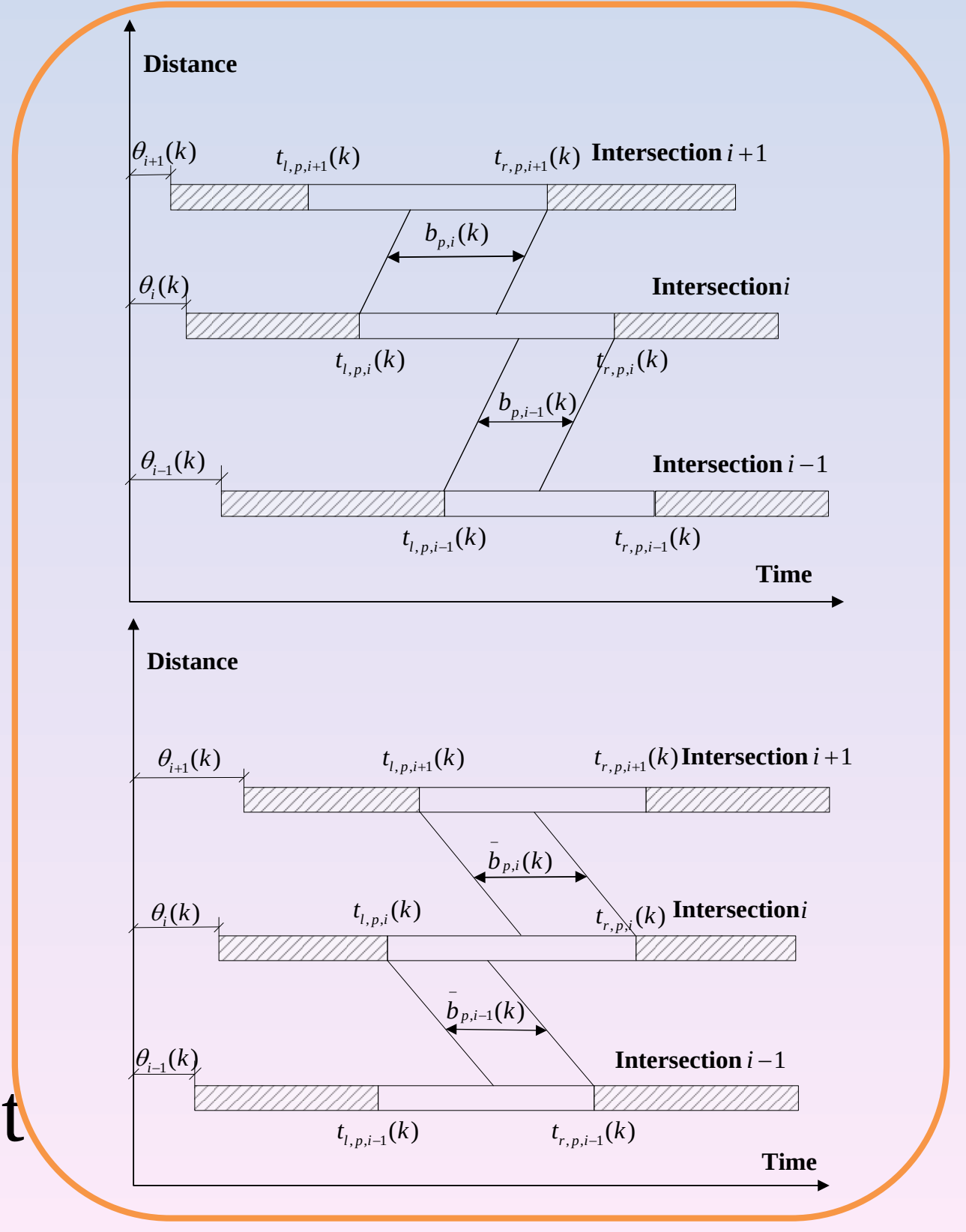
$$b_{l,p,i}(j)<b_{r,p,i+1}(j)-t_{i,i+1}(j)$$

$$b_{r,p,i}(j)>b_{l,p,i+1}(j)-t_{i,i+1}(j)$$

$$\bar{b}_{l,p,i+1}(j)<\bar{b}_{r,p,i}(j)-t_{i,i+1}(j)$$

$$\bar{b}_{r,p,i+1}(j)>\bar{b}_{l,p,i}(j)-t_{i,i+1}(j)$$

$$\theta_{i-1}(j)-\Delta\theta_i\le\theta_i(j)\le\theta_{i-1}(j)+\Delta\theta_i$$ offset adjustment



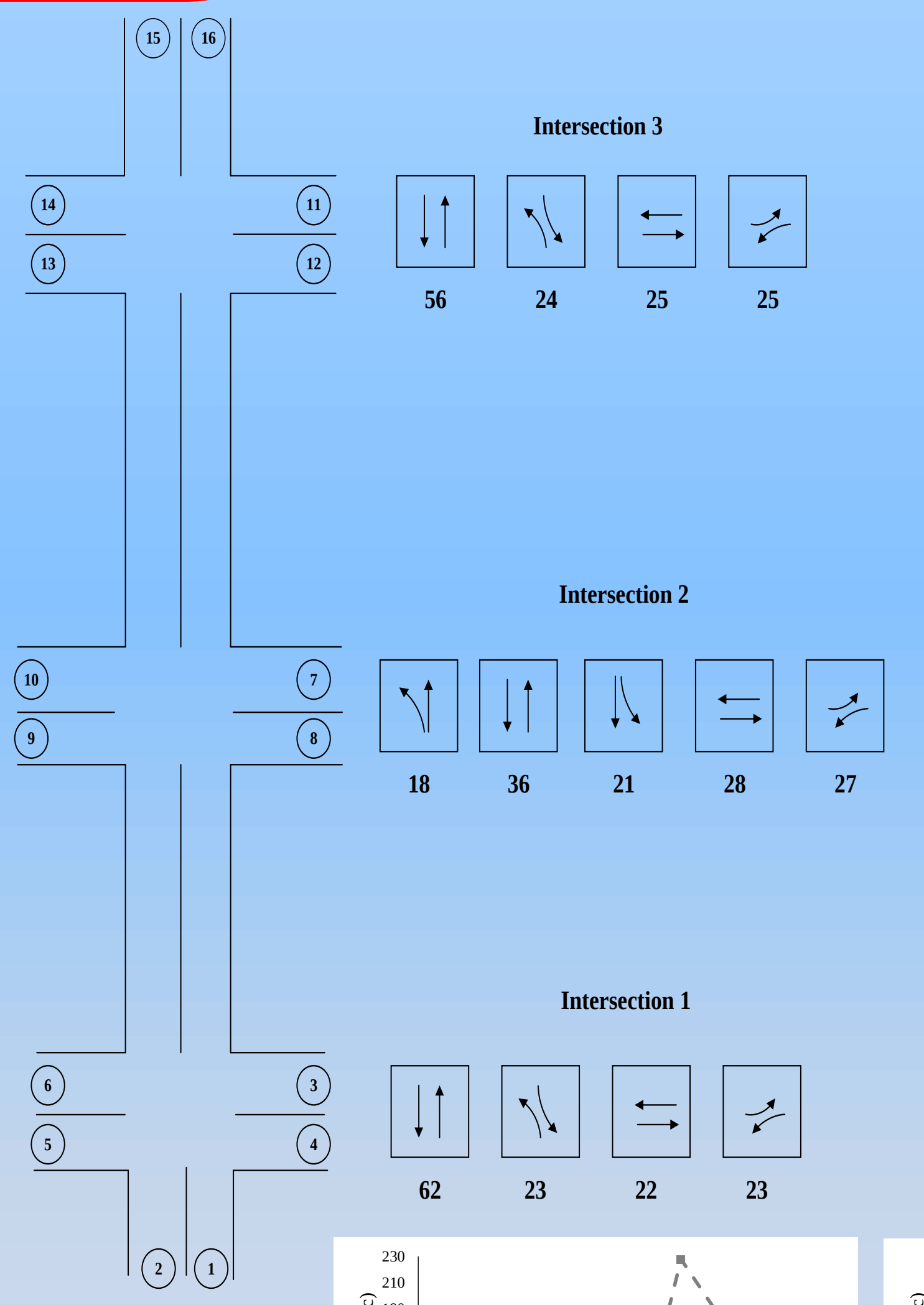
Algorithm

Step 1: define $i=1$, $\theta_1(j)=0$, and $V_i(0)=0$;

Step 2: $i=i+1$; determine the optimal value function $V_i\left(\theta_i^*(j)\right)=min_{\theta_i(k)}\{V_{i-1}\left(\theta_{i-1}^*(j)\right)+B_i(\theta_i(j))|\theta_i(j)\in S_i(j)\}$; Find the optimal solution at this stage, denoted as $\theta_i^*(j)$

Step 3:if $i<N_i$, go to step 2; else trace back to find the optimal solution for each stage.

Case Study



Critical Path of Each Time Period

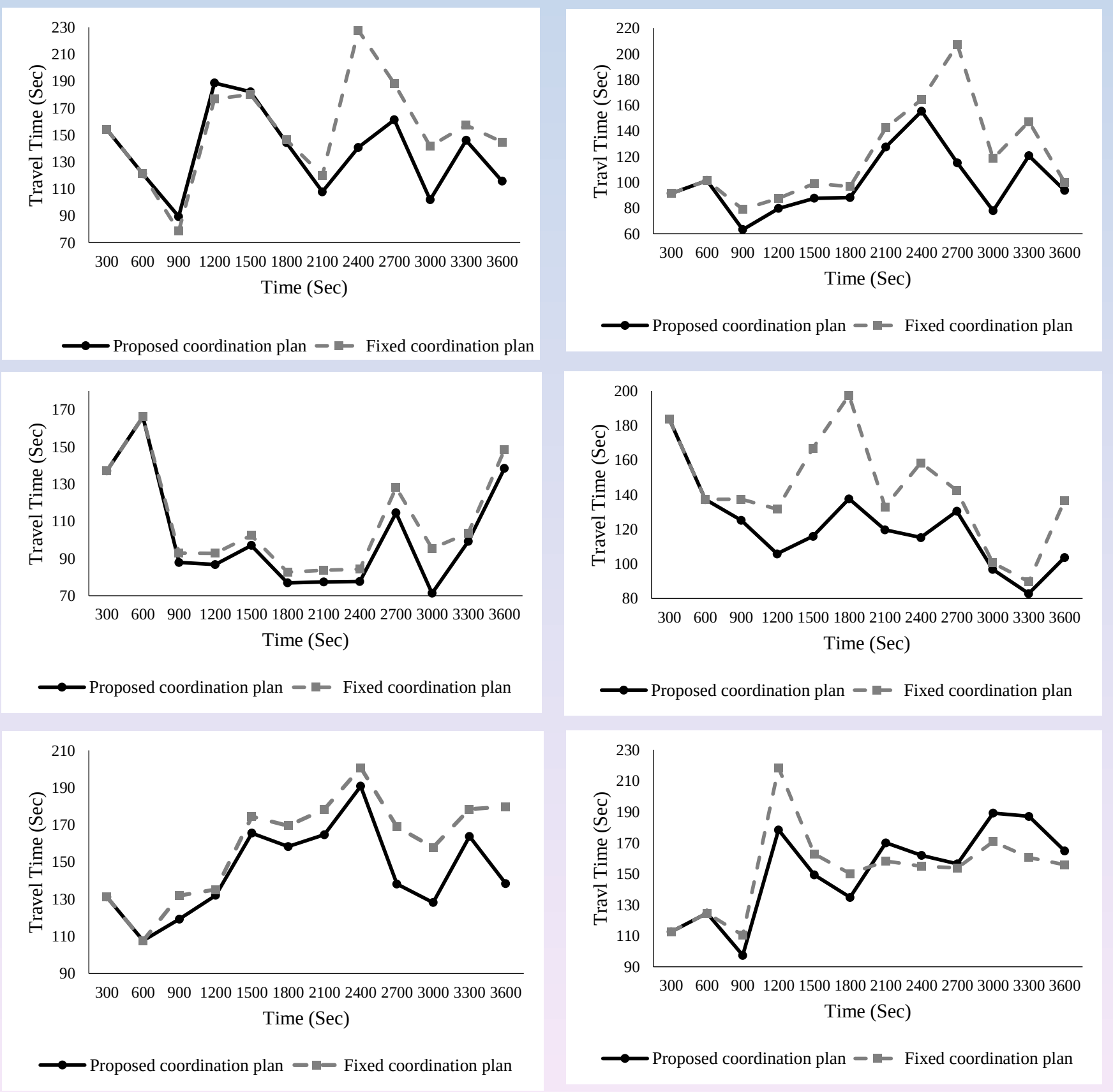
Time (Sec)	0-600	600-1200	1200-1800	1800-2400	2400-3000	3000-3600
Critical path	Node 1 to10 Node 1 to 14 Node 1 to 16 Node 15 to 3	Node 1 to 10 Node 1 to 14 Node 1 to 16 Node 15 to 3 Node 15 to 2	Node 1 to 10 Node 1 to 14 Node 1 to 16 Node 15 to 3 Node 15 to 2	Node 1 to 10 Node 1 to 14 Node 1 to 16 Node 11 to 2 Node 15 to 2	Node 1 to 10 Node 1 to 14 Node 1 to 16 Node 11 to 2 Node 15 to 2	Node 1 to 10 Node 1 to 14 Node 1 to 16 Node 11 to 2 Node 15 to 2

Illustration of Critical Paths During the Simulation Period

Critical path number	Critical path illustration
Path 1	Node 1 to Node 16
Path 2	Node 1 to Node 14
Path 3	Node 1 to Node 10
Path 4	Node 11 to Node 2
Path 5	Node 15 to Node 2
Path 6	Node 15 to Node 3

Arterial and Network Performance with Various Control Plan

MOEs	Fixed coordination plan	Proposed coordination plan
Average critical path delay (Sec)	84.03	73.84
Average number of stops for critical paths	1.63	1.47
Average network delay (Sec)	54.06	50.10
Average number of stops for network	1.00	0.97



The travel time of critical paths depending on simulation time

Conclusions

- This study proposed signal progression control system to control signals dynamically, which aimed to coordinate multiple critical paths along an arterial consumption in a CV environment.
- The proposed system can be more efficiently than the traditional systems based on in-pavement loop detectors or radar sensors.