DETECTOR SETTINGS FOR REAL-TIME TRAFFIC SIGNALS

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Abstract

The effectiveness of real time traffic signals depends to a great extent on the number and the location of the installed detectors. The primary objective of this paper is to develop a framework to identify the best detector placement mostly suitable for different operation conditions of real time traffic signals. The paper presents a heuristic-based real-time responsive signal control system for green time splitting. It studies the effect of detector setting on the system performance (captured by travel time and delay) under various operational conditions of link speeds, traffic flows and approach lengths. Several scenarios of real-time and pre-timed controllers are studied and analyzed using a microscopic simulator.

Keywords: Traffic signal control, pretimed, real time, detector settings, microscopic simulation.

Presenting Author's biography

Yaser Hawas currently serves as a professor at the department of Civil and Environmental Engineering at the UAE University. He also serves as the Director of the Roadway, Transportation and Traffic Safety Research Center (RTTSRC) at the UAE University. He obtained his Ph.D. from the Civil Engineering Department at the University of Texas at Austin in 1996, and joined UAE University in 1998.

Prof. Hawas has published more than 50 international journal papers, and conference papers. He carried out several professional studies and consultancy works for several local and international agencies including the Texas Department of Transportation (US), The Federal Highway Administration (US), Holden vehicle manufacturers (Australia), and United Nations (ESCWA) among many others in UAE.

1 Introduction

Recent advances of ITS techniques for Traffic responsive control strategies are increasingly implemented to improve intersection performance. The study on signalized intersections has been carried out by various methods; however, still the benefits of signal control have not been fully realized. The literature on real-time signal control is quite extensive. Herein, we highlight some of the most recent literature. The methodologies for signal control are many including for instance: Fuzzy Logic [1], Neuro fuzzy logic [2], Genetic algorithms [3], Expert systems [4], Ad hoc or heuristics procedures [5], Cell transmission modeling approach [6] and Classical optimization models [7].

The effectiveness of real-time signal controllers is recognized to depend heavily on the location of the traffic detectors, and the extent of information received via such detectors [8]. Nonetheless, very few research attempts were made to investigate the issue of detector optimization and sensitivity of effectiveness with respect to detector settings. In literature, several simulation models were reported with capabilities of modeling traffic detectors, and subsequent signal operation/control in response to detector data. Virtually all these models depend on single detectors; i.e. each signal phase is linked to one detector reading. In the well-known CORSIM/NETSIM [9], each phase is actuated by individual detector activation. Moreover, these models do not allow an open source code access or scripting tools to test various signal setting methodologies in response to variant detector arrangements.

In developing the framework for detector placement, sensitivity analysis is needed to test the relationship between the detector settings and the signal performance outcome under various operational conditions (link flows, speed, length, etc.) For actuated controllers, conventionally detectors are located close to the intersection stop lines, and usually act as passage detectors whose actuation "extends" the green time of the active phase via some preset vehicle extension. The intersection performance (e.g. delay time) might be improved by altering the detector location. Furthermore, using single detector (in deciding the green extension or termination) might be problematic in case of detector malfunctions. Furthermore, in congested situations, the detectors (close to the stopline) are frequently blocked by queued vehicles, and as such leading to inaccurate or inefficient signal switching decisions. Multiple detectors would provide better estimates of vehicular flow, occupancy and other traffic measures, resulting in better control decisions and system performance. A compromise between the detectors cost and the added system performance is to be sought in deciding the "optimal" detector. This research work is not intended to provide conclusive recommendations on "optimal" detector settings, but rather to illustrate the methodology and simulation tools used in carrying out the sensitivity analyses to establish the detector arrangement and system performance relationship.

The aim of this paper is to develop a framework to identify the detector placement configurations mostly suitable for different operation conditions of real time traffic signals. A heuristic-based real-time signal logic is presented herein for testing purposes. It is to be noted that the devised framework is not merely limited to the devised heuristic logic; rather, any real-time logic can be used instead.

The specific paper objectives include (1) the development of some simple heuristic-based real-time signal control system for testing purposes, and (2) to carry on sensitivity analyses aiming at studying the relationship between the signal control performance and the detector location under various operational conditions (link flows, speed, and length). The paper is divided in six sections. Section 2 highlights the mathematical formulation of a pretimed signal controller (a benchmark) for comparative testing. It also includes the formulation of the heuristic-based real-time signal controller. Section 3 presents the simulation-based framework. The simulation-based experimental set-up and sensitivity analyses results are discussed in sections 4 and 5, respectively. Some concluding remarks and further work are included in Section 6.

2 Signal Control Formulations

Consider a signalized intersection located at node i. The upstream side of the decision node i represents the incoming links to the decision node; each link is representing a separate phase. Conventionally in the literature, the traffic conditions along the upstream links are captured by single detector readings; each link is assumed to have a single detector. Such arrangement does not provide enough accuracy to capture the vehicular flow spatial and temporal variability along the link, and as such might lead to inefficient signal control decisions.

Hawas [8] introduced the so-called knowledge estimators, which process the raw detectors' readings, transfer them into traffic measure "knowledge", which are then used as input to the signal control fuzzy logic. The knowledge refers to the estimated traffic measures beyond the raw detector counts such as queue length, link blockage, truck composition, etc. The knowledge measures are utilized to estimate the so-called green weight for each phase, which is subsequently used in the green split allocation among all intersection phases. The approach is quite promising in the sense that it can incorporate multiple detector readings for each phase, and hence improve the knowledge upon which the signal control decisions are based. Herein, the same approach is used in a more a simpler manner aiming at investigating the effect of the detector locations on the controller efficiency.

The pre-timed signal control (PTSC) assumes that signal green time split is proportional to the *average* hourly demand volume of the phase it controls. As such, the phase splits are kept fixed among all cycles within the analysis period. The real-time signal control (RTSC) re-estimate new green splits in each cycle based on the actual traffic volume gathered by the installed detectors.

2.1 Pre-timed signal control (PTSC)

The PTSC takes into account the average volume of the link to determine the associated signal green split, as a percent of the intersection total green time. PTSC keeps green splits fixed during network running time. More specifically, for any signalized intersection, *i*, PTSC sets the green split of phase ϕ, $g_{i,\phi}$ offline as follows:

$$G_i = C_i - \sum_{\phi=1}^{\phi=\Phi}(Y_\phi + AR_\phi) \qquad (1)$$

Where:

G_i : total actual green time at intersection *i*

C_i : preset cycle length of signal *i*,

Y_ϕ : amber (yellow) time interval of phase ϕ

AR_ϕ : all-red time interval of phase ϕ,

Φ : the total number of served phases (upstream links)

$$g_{i,\phi} = G_i * \frac{V_\phi}{\sum_{\phi=1}^{\Phi} V_\phi} \qquad (2)$$

Where:

$g_{i,\phi}$: actual green time allocated to phase ϕ at intersection *i*

V_ϕ: critical hourly volume (flow) on the link representing phase ϕ.

Note that the average hourly vehicular flow is a fixed value for each phase (to be determined prior to the actual signal implementation), and does not depend on the online detector readings.

2.2 Real-time signal control (RTSC)

The proposed RTSC provides variant signal splits based on the on-line passage detector readings. The green splits are assumed to change every cycle time, which is assumed to be fixed (and preset) for the proposed ad-hoc controller. The phase splits vary based on the accuracy of the detector readings, affected by the number of detectors, their locations along the links, traffic congestion levels, observed link speeds, link lengths, etc. The estimation of the green splits is quite analogous to that of the PTSC, with the difference that the link vehicular flow varies from one cycle to another, as captured by the raw detector readings.

In this paper, we assume that each phase link is equipped by two passage (counting) detectors; one is located at the downstream end of the link (close to intersection *i*), and one is located some distance upstream the link. The difference between the two detector readings of a specific link, at any specific time, represents the number of vehicles on the link at that time.

At any time *t* (at discrete intervals of cycle time), the RTSC estimates the green split, $g_{i,\phi,t}$, of any phase , ϕ, at intersection *i*, as follows:

$$g_{i,\phi,t} = G_i * \frac{v_{\phi,t}}{\sum_{\phi=1}^{\Phi} v_{\phi,t}} \qquad (3)$$

Where:

$v_{\phi,t}$: vehicular flow of phase ϕ at time t, and estimated as follows:

$$v_{\phi,t} \cong \frac{(N_{\phi,u,t} - N_{\phi,d,t})}{\Delta t} \qquad (4)$$

$N_{\phi,u,t}$: accumulative number of vehicles passed the *upstream* detector at time t,

$N_{\phi,d,t}$: accumulative number of vehicles passed the *downstream* detector at time t,

Δt: time interval between any two successive updates of a specific detector reading

In the RTSC, Δt is assumed equal to the cycle time, C_i. Note here the approximation in estimating the vehicular flows from two successive detectors. As known, the vehicular flow is conventionally estimated at a specific *point* in space as the rate of passage over time. Using a single detector reading might then be misleading in urban networks, especially if the link queues spill back to the detector, indicating false fully *zero* link flow.

The number of vehicles between the two detectors (at time *t*) are assumed to reach the downstream end of the link (and hence passing the signalized intersection) during the time interval Δt. In other words, the link flow is assumed to be *approximated* by the number of vehicles between the two detectors divided by the time interval, Δt. The validity and accuracy of this assumption depend on several aspects including the link length, speed, congestion level, vehicle composition, detector spacing, etc. As such, sensitivity analyses would be needed to assess the effectiveness of such signal control, and provide recommendations on suitable detector arrangements for different operational conditions.

Based on all the above, equation 3 can be re-written as follows:

$$g_{i,\phi,t} = G_i * \frac{(N_{\phi,u,t} - N_{\phi,d,t})}{\sum_{\phi=1}^{\Phi}(N_{\phi,u,t} - N_{\phi,d,t})} \qquad (5)$$

It should be noted that the *flow* terms (in all the above equations) indicate *passenger car* flows. For simplicity in this paper, the experimental setup was done assuming traffic streams of 100% passenger cars.

3 i-SIM-S Simulation Framework

Both signal control systems (*PTSC* and *RTSC*) are embedded in the i-SIM-S - a microscopic simulation component of an integrated system for incident management [10]. Either algorithms (*PTSC* or *RTSC*) can be called at the beginning of any simulation instance.

The paper is essentially tackling the ad-hoc signal system effectiveness. For more details on the i-SIM-S simulator's structure, mathematical formulation and calibration, the reader is referred to [10]. i-SIM-S is an object oriented program. Each object is composed of data that represents the current values of object parameters, and methods (or functions) which could be applied on the object (for example, add vehicle or remove vehicle for the lane object). i-SIM-S is a hierarchical model in the sense that main or larger objects contain the sub (or smaller) objects. For example, each street object composes several lane objects, and each of these lane objects contains the vehicle objects (running on that lane).

4 Experimental Set-ups

To test the traffic performance under the control of the *RTSC* and *PTSC*, an analysis period *T* is defined as 60 minutes. Both systems are simulated over the analysis period using i-SIM-S. The overall network travel time and delay time are obtained for comparative analysis of effectiveness by the end of each time cycle C; set as 2 minutes. At the beginning of the analysis period *T*, details of the network structure, connectivity and characteristics, vehicle source volumes and links properties are provided as input to the simulator. For the *PTSC*, green splits are set before the simulation starts and kept fixed throughout the entire analysis period. For the *RTSC*, signals green splits are reset every cycle.

A simple intersection with four phases was selected for testing. The intersection is represented by a decision node and four incoming links (A, B, C and D). Three experimental sets were considered. The first experimental set combines variations of link flows as well as detector locations. The second set of experiments is intended to study the effect of the link (approach) speed. The third set of experiments is intended to study the effect of the link length. In all the experimental runs of the *RTSC*, each link is equipped with two detectors, the front one is located at the stop line (close to the decision node), and the back detector location is varied as specified in tables 1, 2 and 3.

5 Results Analysis

5.1 Link flows simulation runs

For the *RTSC*, four different scenarios representing various locations of the back detector were tested (End, 1/2, 1/4th, and 1/8th of link). For the PTSC, additional scenario was considered assuming no link detectors. This makes a total of five scenarios. Additionally for *RTSC* and *PTSC*, three different conditions of link flows were tested representing low, medium, and high congestion levels (200, 1000, and 2000 veh/hr). Each link is assumed to have three lanes. Other network properties (speed and link length) are kept the same for all runs.

Figure 1 illustrates results of the 15 runs to test the effect of the detector location and link flows. The figure shows a 2x3 graph matrix; the first row represents the average travel time graphs and the second represents the average delay time graphs. Each column represents a traffic flow condition. Each graph shows the result; namely, average travel time or average delay time in minutes in three time intervals (first, mid, and last 10 minutes) of the one-hour simulation analysis period. For example, graph B-2 represents the average delay time (min) for the five scenarios and the medium link flow condition (1000 veh/hr), throughout the three time intervals of simulation (first, mid and last ten minutes).

Tab. 1 Configurations of First Experimental Set of Runs (Detector Locations and Volume Variations)

Scenarios		Scenario 1	Scenario 2	Scenario 3	Scenario 4	Scenario 5
Properties	Back Detector Location	End of Links	1/2 of Links	1/4th of Links	1/8th of links	N/A
	Speed	80 km/hr				
	Link Length	300 m				
	Link Flow Conditions	1: Low = 200 veh/hr, 2: Medium = 1000 veh/hr, 3: 2000 veh/hr				

Run Configuration															
Run #	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Scenario	1	1	1	2	2	2	3	3	3	4	4	4	5	5	5
Link Flow Condition	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3
Control	RTSC												PTSC		

Tab. 2 Configurations of Second Experimental Set of Runs (Link Speed Variations)

Scenarios		Scenario 6	Scenario 7	Scenario 8	Scenario 9	Scenario 10	Scenario 11
Properties	Links Speed (km/hr)	A = 40 B = 60 C = 60 D = 60	A = 60 B = 60 C = 60 D = 60	A = 80 B = 60 C = 60 D = 60	A = 100 B = 60 C = 60 D = 60	A = 80 B = 80 C = 80 D = 80	A = 100 B = 100 C = 100 D = 100
	Back Detector Location	Upstream End of Link					
	Link Length	300 m					
	Link Flow	1000 veh/hr					

Run Configuration												
Run #	16	17	18	19	20	21	22	23	24	25	26	27
Scenario	6	7	8	9	10	11	6	7	8	9	10	11
Control	RTSC						PTSC					

Tab. 3 Configurations of Third Experimental Set of Runs (Link Length Variations)

Scenarios		Scenario 12	Scenario 13	Scenario 14	Scenario 15	Scenario 16	Scenario 17
Properties	Link Length (m)	A = 300 B = 400 C = 400 D = 400	A = 400 B = 400 C = 400 D = 400	A = 500 B = 400 C = 400 D = 400	A = 600 B = 400 C = 400 D = 400	A = 500 B = 500 C = 500 D = 500	A = 700 B = 700 C = 700 D = 700
	Speed	80 km/hr					
	Link Flow	1000 veh/hr					
	Back Detector Location	Condition1: End of Links Condition 2: at 150 m upstream the intersection NA: Not applicable (case of *PTSC*)					

Run Configuration																		
Run #	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45
Scenario	12	12	12	13	13	13	14	14	14	15	15	15	16	16	16	17	17	17
Back Detector Location Condition	1	2	NA	1	2	NA	1	2	NA	1	2	NA	1	2	NA	1	2	NA
Control	RTSC		PTSC	RTSC		PTSC	RTSC		PTSC	RTSC		PTSC	RTSC		PTSC	RTSC		PTSC

Variability among the five scenarios is mostly noticeable in the first ten minutes of simulation, specifically for the conditions of low and medium link flows (Graph A-1, A-2 and B-1, B-2). The first ten minutes are usually regarded as a warming up period. As the volume increases, scenario 4 (back detector located at 1/8th of the link) gives almost best performance among all studied runs with high link flows (Graph C-1, C-2).

For the condition of medium link flows, the best result is given with the detector arrangement of scenario 2 (back detector located at 1/2 of the link) (Graph B-1, B-2). *RTSC* performs better than *PTSC* in all scenarios of detector arrangements and all links flows conditions.

5.2 Link speed simulation runs

The link speed scenarios (as shown in Table 2) are introduced to test the interaction effect of link speed and detector location on the effectiveness of the *RTSC*. Three scenarios consider constant and fixed speed for all incoming links (60, 80 and 100 km/hr for scenarios 7, 10 and 11, respectively). Three other scenarios are introduced introducing variability in link speeds among the various links (scenarios 6, 8 and 9). In these speed scenarios, the speed of one link is increased/decreased, while other link speeds are kept at 60 km/hr. A total of 12 simulation runs are made (six for *RTSC* and six for *PTSC*). All runs were made for the same intersection, fixing the location of the back detector to the upstream end of the link, the link length to 300 m and the link flow to 1000 veh/hr. Figure 2 shows the link speed simulation results, summarized in six different graphs; one for each scenario. The y-axis of any graph shows the average travel times (minutes). For scenarios 7, 10 and 11 (which represents equal link speeds), *RTSC* shows slight better performance than PTSC (Graphs A, E and F). For scenarios 8 and 9 (where one link speed is set higher than the others), *PTSC* performs more effectively (Graphs C and D). For scenarios 6 (where one link speed is set lesser than the others), *RTSC* performs more effectively (Graph B).

5.3 Link length simulation runs

The link length scenarios (as shown in Table 3) are introduced to test the interaction effect of link length and detector location on the effectiveness of the *RTSC*. Three scenarios consider constant and fixed length for all incoming links (400, 500 and 700 m for scenarios 13, 16 and 17, respectively). Three other scenarios are introduced introducing variability in link lengths among the various links (scenarios 12, 14 and 15). In these link scenarios, the length of one link is increased/decreased, while other link lengths are kept as 400 m. For the back detector location, two conditions were considered; one at the upstream end of the link and the other is mid link length. A total of 18 simulation runs are made (twelve for *RTSC* and six for *PTSC*). All runs were made for the same intersection, varying the location of the back detector between the two conditions. All link speeds were fixed to 80 km/hr, and all the link flow to 1000 veh/hr. Figure 3 shows the link lengths and detector location simulation results, summarized in six different graphs; one for each scenario. Each graph illustrates three different curves; one for the PTSC, and one for each of the RTSC detector's conditions. The y-axis of any graph shows the average travel times (minutes). In general, a better performance is presented by *RTSC* with back detectors located at mid link in most of the runs. As compared to *PTSC*, the *RTSC* illustrates better performance for all scenarios except for scenarios 12 and 14.

6 Concluding Comments and Future Works

This paper presented an ad-hoc real-time signal control system as an ATMS (Advanced Traffic Management Systems) that can be applied in road traffic networks effectively. Simulation experiments were performed to assess the effectiveness of the *RTSC* vis-à-vis *PTSC*. The experiments indicate that *RTSC* is expected to yield lesser travel and delay times with highly congested intersections, and that there is a "best location" for back detectors in different congestion conditions. Moreover, experiments prove that *RTSC* would perform more effectively compared to *PTSC* in the majority of the studied runs. As the results indicate, the location of the back detector plays an important role in determining the effectiveness of the *RTSC*.

Variants of this research would involve using the detector data in a more sophisticated way; other than simple counts. Extracting useful knowledge from several detectors on each link can help achieve smart signal control decisions. Other areas under consideration include using variant detector arrangements. Further work would also involve the development of general guidelines that allow operators the selection of optimal settings for field detectors based on the prevailing traffic conditions.

7 References

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Acknowledgment

This research was funded by the Roadway, Transportation and Traffic Safety Research Center (RTTSRC)- Research Affairs of the United Arab Emirates University.

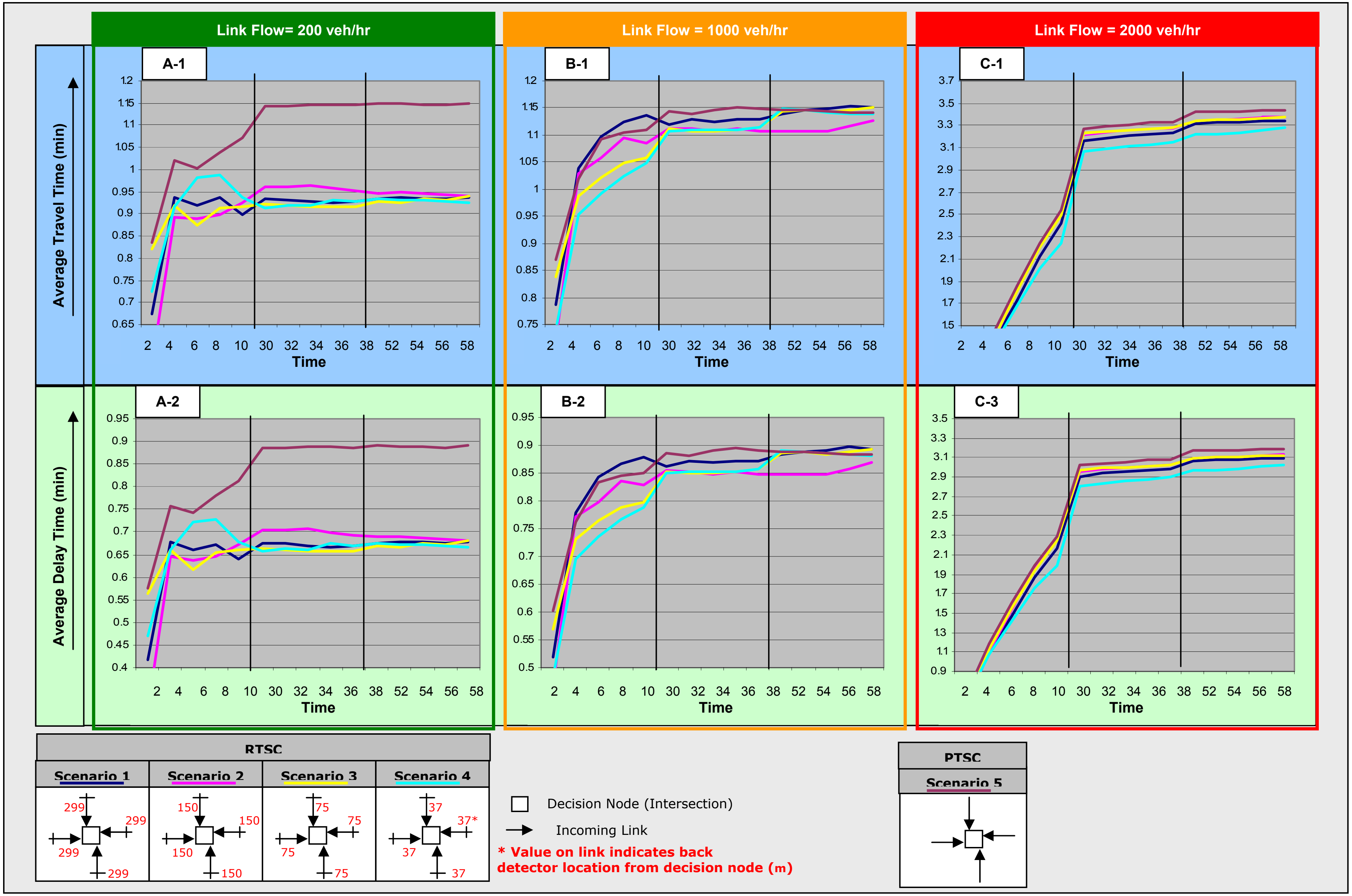


Fig. 1 Detector Locations Experiment Results

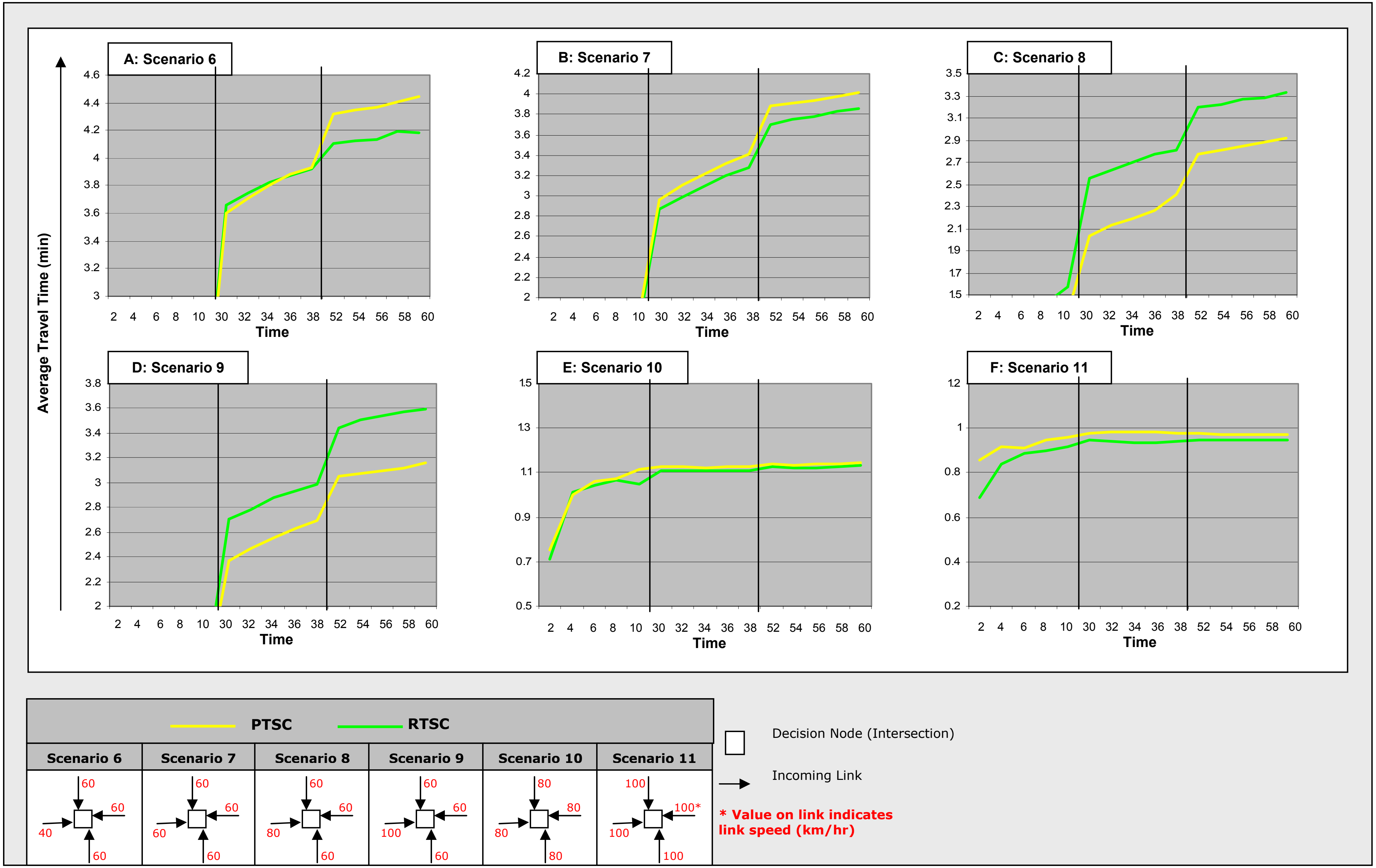
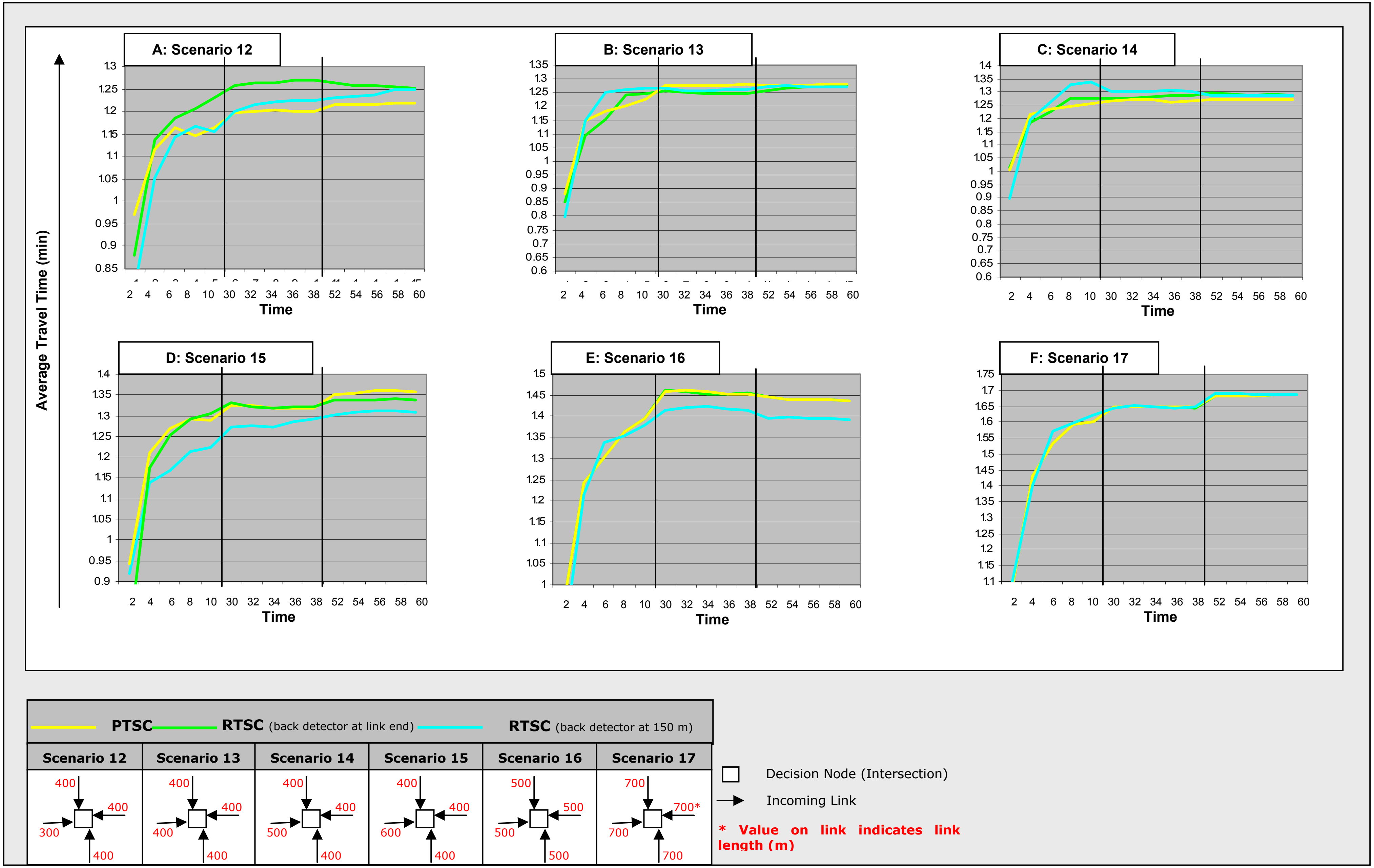


Fig. 2 Link Speed Experiment Results



* Value on link indicates link length (m)

Fig. 3 Link Length Experiment Results