# Response of Signal Control Systems to Traffic Variations

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**Abstract** Road traffic system serves as a basis supporting a social economic activity as a means of transfer and transportation. On the other hand, road traffic has also given birth to various problems. They are considered as inherent factors in road transportation. The traffic congestion centering on urban districts, the air pollution caused by the exhaust gas discharged from vehicles,traffic accidents, etc. are some examples of these problems. In order to cope with many such problems, investigation research of the traffic signal control techniques are being conducted. Automatic pattern selection control and automatic generation control mechanisms are regarded as examples of the signal control techniques applicable to the above- mentioned problems.This paper describes the automatic pattern selection control and the automatic generation control for realizing the actual application method corresponding to the feature and the traffic situation of an ideal actual spot of the road network and the research study based on the analyses through simulation experiments. Each control structure has flexible responses to a variety of traffic changes and signal control mechanisms. The simulation experiments were executed on the following model. We built a single independent intersection model which is composed of a main road and a sub-road (crossing road), and vehicles have been generated on each road. The simulation was run according to the specified signal control formulae and we obtained the corresponding results. Thus we analyzed the response differenses resulted from the two signal control mechanisms(automatic pattern selection control and generation control) in the typical situation of congestion generation and its disappearance processes.

## 1.INTRODUCTION

Recently, various traffic problems, such as traffic jams, air pollution due to exhaust gas and accidents, often occur on roads mainly in urban areas.

To solve these problems , intelligent traffic signal (ITS) control systems have been studied and developed by various organizations. However, even if an excellent control system is used, the system must be operated according to actual on-site traffic conditions, to make the most of the features and functions of the system.

The signal control methods currently in wide operation consist mainly of an automatic pattern selection control mode and an automatic adaptation control mode.

This paper describes the functions and the optimum operating settings of each control mode based on the results of analyzing the responses of the signal control systems to traffic variations in simulation experiments.

## 2.SIGNAL CONTROL SYSTEMS

### 2.1 Automatic Pattern Selection Control

Traffic information (traffic volume, occupancy) is collected from vehicle detectors installed at various locations, and a pattern most suitable for traffic conditions at that time is selected from signal control parameters which have been previously entered. In a split pattern selection control mode, the control effect is determined by the relationship between a preference ratio and a split value. Split patterns in use include a main road preferential pattern, a minor road preferential pattern, and an impartial pattern, any one of which is selected depending on the ratio of the amount of traffic on the main road to that on the minor road (preference ratio) calculated from the information provided. When a small preference ratio is selected, the system can sensitively respond to variations in traffic information, and when the ratio is large, the response becomes sluggish.

### 2.2 Automatic Adaptation Control

A cycle and a split are calculated automatically from traffic information (traffic volume, number of cars in traffic jams) transmitted from vehicle detectors.

A split is automatically created by the following formula.

$$Si = \frac{\rho_i}{\Sigma\rho_n} \times 100$$

$$\rho = \frac{\text{Volume of incoming traffic} + \tau\times\text{Jam length}}{\text{Traffic capacity}} \times 100$$

S: Split
i: Aspect number
ρ: Degree of saturation
τ: Congestion ratio

The congestion ratio is a parameter that has a significant effect on the control of an automatic adaptation control system. The congestion ratio (expressed by$\tau$) is given by the proportion of a jam that was not allowed to pass and has to be taken into account for the next timing of the traffic control; if the value of the ratio is 100%, it means all of the remaining jam must be added to the next control period, and 0% means the next control period need only be based on the incoming traffic volume. The incoming traffic volume at this time is not a demand value but the volume of traffic that has passed the signal intersection and been processed, therefore the volume depends on the signal control method.

## 3.OUTLINE OF THE SIMULATOR

Vehicles are generated on the main road and the minor road at a single intersection, and the simulator outputs the results of operation for an assigned signal control system. Details of an output include the length of the traffic jam, travel time, etc. At this time, the length of the jam was used as the index in the analysis. However, losses of vehicles turning left or right were not taken into account in this simulation.

## 4.RESULTS OF THE ANALYSIS

The results of an analysis using the jam length×time as the index, are shown below.

### 4.1 Calculation Conditions

The following conditions were used for the calculations in the automatic pattern selection and automatic adaptation control modes.

(1) Calculation conditions for the automatic pattern selection control mode

(a) Case 1
Preference ratio : 0.9, 1.1 (preference ratio = main road/minor road)
Split value : ±3%
The system responds sensitively to traffic variations with a small range of variations in the split values.

(b) Case 2
Preference ratio : 0.7, 1.3 (preference ratio = main road/minor road)
Split value : ±10%
The system cannot respond sensitively to traffic variations, although the split values vary over a wide range.

(c) Case 3
Preference ratio : 0.8, 1.2 (preference ratio = main road/minor road)
Split value : ±6%
Intermediate status between Case 1 and Case 2

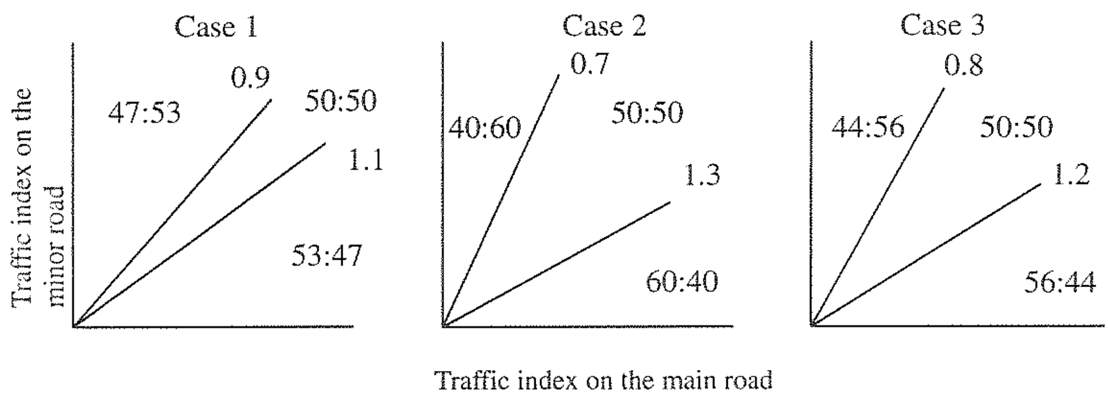


Fig. 1 Split pattern selection charts

(2) Calculation conditions for the automatic adaptation control mode

In the automatic adaptation control mode, $\tau$ was changed from 0% to 100% at 20% intervals, for the analysis.

When $\tau$ was 0%, the parameter was calculated only by the traffic volume, and when $\tau$ was 20%, 20% of the length of the jam which had been produced was added in the calculation. (When there were 10 cars, the calculation was performed with a waiting queue of two cars.) A $\tau$ of 100% means that the total length of a generated jam was added in the calculation.

### 4.2 Analysis of Jam Forming Modes

Differences between the control systems during the process of building up a traffic jam were analyzed, together with an evaluation of the adequacy of the set parameters in each control system.

(1) Traffic volume assumed

The traffic volume assumed was such that the traffic volume was increased to a super-saturated condition and then the volume of traffic continued at a high level. However, the trend in the increase of the traffic volume was assumed to occur about 20 minutes later in the minor road than in the main road. The simulations were carried out for two hours. (Fig. 2)

(2) Comparison of jam lengths

Fig. 2 compares the formation of the lengths of the jams as a function of time.

(3) Results of analysis

The jam length vs. time relationships between the automatic pattern selection control and automatic adaptation control modes are shown below.

(a) Comparison between the automatic adaptation control method and the automatic pattern selection control method

The automatic adaptation control mode provided more advantageous results because the mode sensitively responded to even small traffic variations, and a split value could be calculated freely within a range of upper and lower limits.

(b) Differences due to the preference ratios in the automatic pattern selection control mode

In Case 1, the responses are satisfactory, but the system cannot respond well to large traffic variations, resulting obviously in greater jam length×time values. In Case 2, the responses were so poor that some of the split patterns did not change. However, the jam length×time values are smaller than these of Case 1 because of the larger variations of the split values.

For a traffic flow that is continuously increasing or continuously decreasing in only one sense, it is more advantageous to select a wider range of split values.

(c) Differences due to the value of $\tau$ in the automatic adaptation control mode

In the automatic adaptation control mode, there are no substantial differences in the jam length×time values, which are used as the index values, for different values of $\tau$. In this case, super-saturated traffic conditions occurred in both the main road and the minor road, so the entire intersection had reached its operating limit. Under these circumstances, the traffic volume limits were allocated to the main and minor roads by the split division. Consequently, a significant difference was observed in terms of the balance between the main road and the minor road, although the total volume of traffic was the same. When $\tau$ is 0%, the traffic flow is controlled only by traffic volume, and the traffic volume is the operable volume of traffic which depends on the signal control system, as described above. In the present case, there was more volume of traffic on the main road to begin with, therefore the main road was given preference, and the value of the split increased, resulting in an increase in operating traffic volume; this vicious cycle was repeated without there being any element to make a balance between the main road and the minor road. Therefore, these results were obtained.

### 4.3 Analysis of Dissolving Jams

In the following, the modes are compared with each other for the conditions in which the traffic volume decreases and jams are dissolved.

(1) Assumed traffic trends

First, an initial length of congestion of 1,000m was formed with an initial split of 50:50 then a non-saturated traffic volume including random variations was imposed. The simulations were carried out for one hour. (Fig. 3)

(2) Comparison of jam lengths

Fig. 3 compares time variations as traffic jams are dissolved.

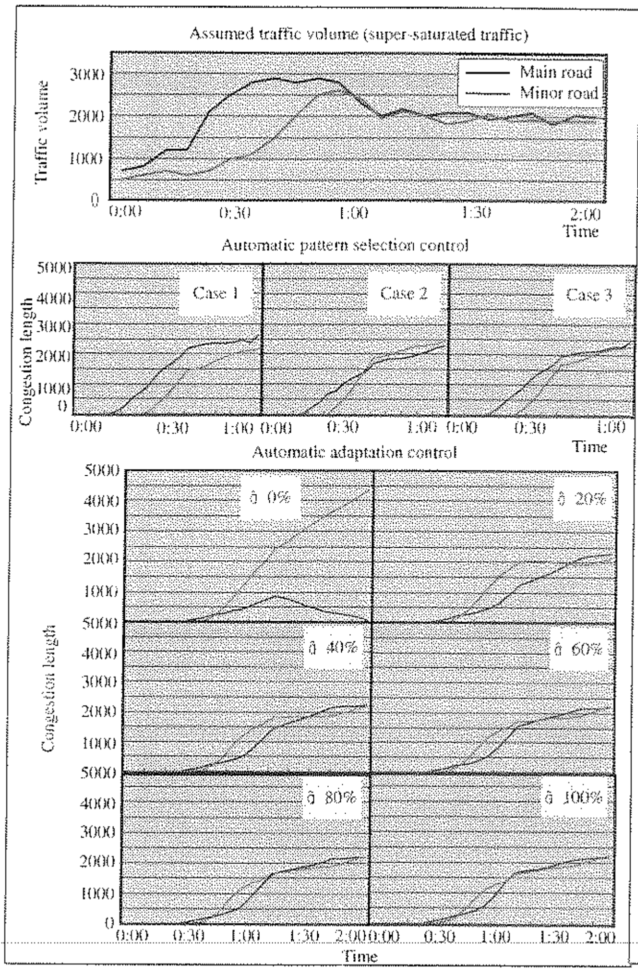


Fig. 2 Assumed traffic volume and lengths of jams (when traffic jams are forming)

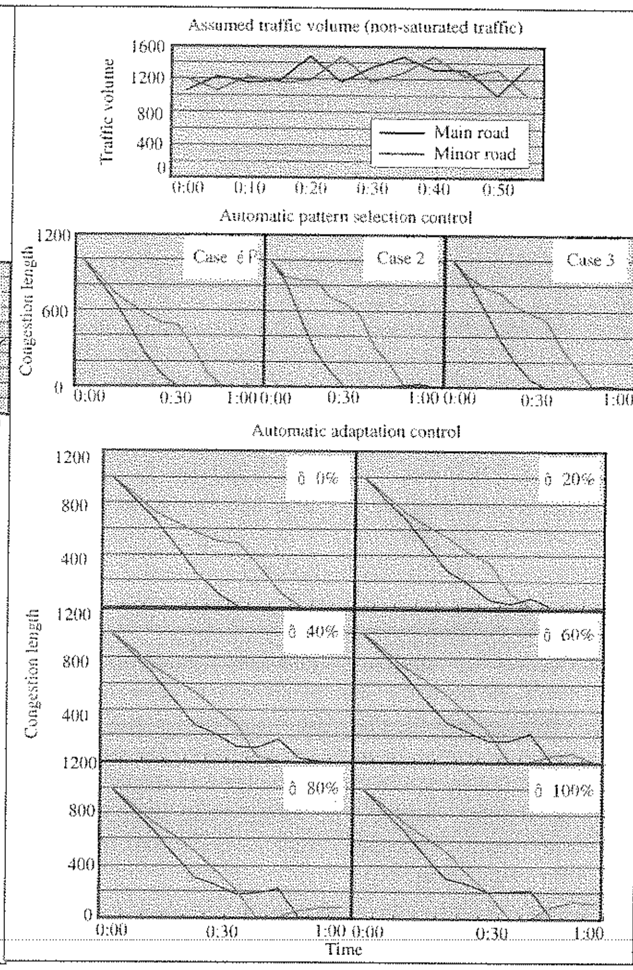


Fig. 3 Assumed traffic volume and lengths of jams (when traffic jams are dissolving)

## (3) Results of the analyses

The jam length×time values are shown below, for automatic pattern selection and adaptation control modes.

(a) Comparison between automatic adaptation control and automatic pattern selection control

The automatic adaptation control mode gives rise to smaller jam length×time values, in the same way as it does when jams are forming.

(b) Differences due to the preference ratio in automatic pattern selection control

In Case 1 the automatic pattern selection

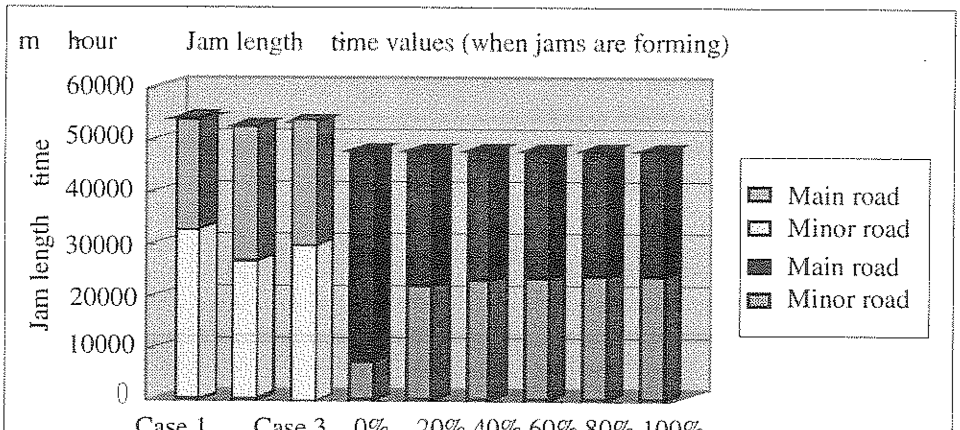


Fig. 4 Comparison of jam length time values (when jams are forming)

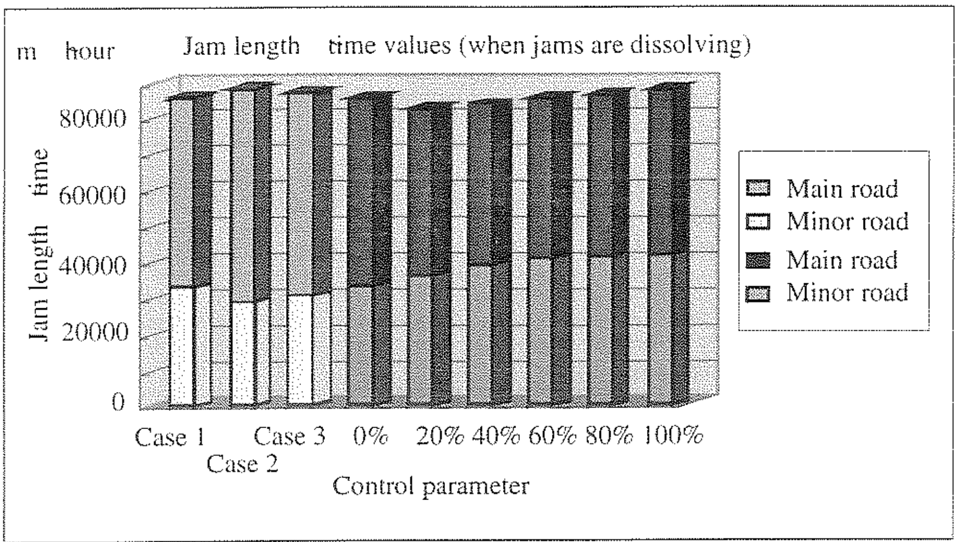


Fig. 5 Comparison of jam length time values (when jams are dissolving)

control is more advantageous. The jam length×time values in this case are similar to the case of automatic adaptation control with τ= 60%, but there is a poor balance between the main road and the minor road.

(c) Differences due to τ in automatic adaptation control
τ= 20% gave the best results for the automatic adaptation control mode.

### 4.4 Precautions when setting parameters

(a) Automatic pattern selection control
In the automatic pattern selection control mode, advantageous results were obtained because the split values changed over a wide range as traffic flow was increasing, although the response to variations was sluggish. However, when random variations were included, the jam length×time values became large because the patterns could not be selected in a stable manner. Therefore, the preference ratio should be made as small as possible, close to the limit where the system does not respond to random variations. Under these conditions, if the range in which the split values can vary is made excessively large, hunting may be caused by controlling the traffic signals, therefore it is necessary that the range of the variation should not be made too large.

(b) Automatic adaptation control
In the automatic adaptation control mode, if τ is 0%, no account is taken of the jam length, and traffic conditions become very unbalanced, therefore it should not be set at 0% unless this is unavoidable. The most advantageous result was obtained with τ= 100% when traffic jams were continuously increasing, from the point of view of the balance between the main road and the minor road. However, when traffic jams were dissolving, τ= 20% exhibited the best result when the congestion length×time value was the criterion. The larger the value of τ, the more the value of the split was changed beyond requirements, so that unstable situations were observed. This effect became more significant as τ approached 100%.

The present analysis predicts that in a practical application, a standard value of 20% should be set and adjusted at the site.

## 5.CONCLUSIONS

The results of this analysis proved the generally observed problems that "the pattern selection control has a poor response because it takes a long time before the reference value for selecting a new pattern is reached" and "the pattern selection control cannot cope sensitively with all traffic circumstances because of the limited number of patterns." The advantages of the automatic adaptation control method are that as well as being superior in respect to the two problems mentioned above there are savings in operation and maintenance, including the fact that signal control parameters do not have to be reconfigured even if traffic conditions change after years of use.

Nevertheless, the results of the present analysis revealed that when $\tau$ is set to 0% in the automatic adaptation control method, that is, if there are no detectors installed for measuring congestion, the characteristics of the traffic control system are poorer than those of a pattern selection control mode using occupancy data. An automatic adaptation control system can only be effective provided the necessary detectors are installed at the same time.

The authors analyzed a single intersection using the jam length×time as the index as described above, however it is also necessary to simulate a number of intersections and analyze the effects produced by an upstream intersection on the downstream traffic flow and travel times using various traffic variation patterns, and traffic indices, in the future.