MODERATO (Management by Origin-DEstination Related Adaptation for Traffic Optimization)

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SUMMARY

Due to an increase in traffic demand, we have many traffic accidents and constant traffic jams in the cities of Japan. Thus, we reconsidered the present traffic control systems which are used in each prefecture and developed the next generation traffic control system making use of the latest intelligence networks. We named it MODERATO. It has the following functions:

- Information collection
- Traffic control

These functions are part of the ITCS (Integrated Traffic Control System). ITCS is the nucleus of UTMS21

CONCEPT OF MODERATO

MODERATO is a real-time signal control system that is aimed at alleviating traffic congestion, distributing traffic, and reducing the number of traffic accidents. MODERATO is applicable to all traffic conditions, from undersaturation to oversaturation. The concept of control is explained below.

1) The traffic control function consists of a macro control function, which operates every 2.5 minutes, and a micro control function, which operates every second. The macro control function is run on the central computer and determines the signal parameters based on detector information and congestion information. The micro control function runs on the signal controllers and finely adjusts the green light time based on detector information from nearby intersections. Its main functions are such local actuated controls as right (left) turn controls, public transportation priority controls, and dilemma controls which aim to reduce the danger of rear-end collisions during the signal changing period.
2) When there is light traffic, MODERATO aims not only to reduce delays and stoppages but also to allow the traffic to flow safely by moderating vehicle speed. Therefore, it uses ROC (Real-time Offset Control). The ROC functions to calculate offset, which is considered as offering safety and smoothness using the latest traffic information.
If there are some traffic accidents, such as rear-end collisions, during the signal changing

period in intersections, they are controlled by the dilemma control.
3) When traffic demand is nearly saturated, MODERATO curbs congestion by improving the efficiency of green light time at critical intersections and maximizing traffic capacity. To realize these objectives, MODERATO directly calculates the split and cycle length based on the queue and traffic volume calculated from vehicle detector information.
MODERATO also incorporates a micro control function as the right turn vehicle actuation which is run every second by a signal controller at each critical intersection.
4) When traffic demand is oversaturated, MODERATO runs strategic controls for competing traffic flows at critical intersections. There are two policies in strategic control. One is equality of travel time for competing traffic flows, and the other is priority control for either of these flows. If there is an intersection in which the flow rate changes every cycle, it is controlled by a flow rate maximization control, which is a micro control function.
5) It is possible that public transportation is controlled by Priority Control, which gives it green light time priority.

OUTLINE OF TRAFFIC CONTROL SYSTEM

Figure 1 shows a basic system configuration.

Information Collection

The traffic information is collected by vehicle detectors installed at roadside. There are various kinds of vehicle detectors. Previously most vehicle detectors have been the ultrasonic type, but recently an image processing type and an infrared type for measuring all lanes have been developed. The image-processing detector can measure not only traffic volume and occupancy, which are collected by the ultrasonic type, but also a vehicle queue on the street, using image-analyzing technology. And an infrared beacon has two functions. The main function is two-way communication for VICS (Vehicle Information & Communication System) and PTPS (Public Transportation Priority System), and the other function is the collection of traffic volume and occupancy. This traffic information is sent to the central computer system through leased telephone lines.

Central Computer System

The central computer system analyzes the traffic information, and calculates the traffic signal time, to control signal lights so those vehicles can pass though smoothly. It also provides traffic data to advanced mobile information systems such as VMSs(Variable Message Sign), information service by telephone or facsimile, VICS and so on.

Basic System Configuration

The basic system configuration consists of the central system, standardized communication methods and local equipment.
In regards to the central system, it can be configured with some distributed functional

modules such as signal control, information provision, man-machine I/F, and so on. All central equipment can be connected with a local area network and wide area network when you operate the system remotely.

In the communication method between the central system and roadside modules, standardized communication methods such, as TCP/IP, are applied in addition to Japanese original protocols. For physical levels of communication, ISDN digital networks and telephone lines can be used, as well as leased lines.

At the roadside, various types of local equipment can be connected together through communication lines.

System Scale

Some traffic control centers use MODERATO in Japan. MODERATO is adaptable to a great variety of control centers, such as large and medium sized and PC-based systems. Large sized traffic control centers control more than 1,000 signals. We also have a small sized system, which is based around a PC. Recently the performance of Personal Computers has been increasing, as has bandwidth, while communication fees are decreasing. Small sized systems control a maximum of 128 signals.

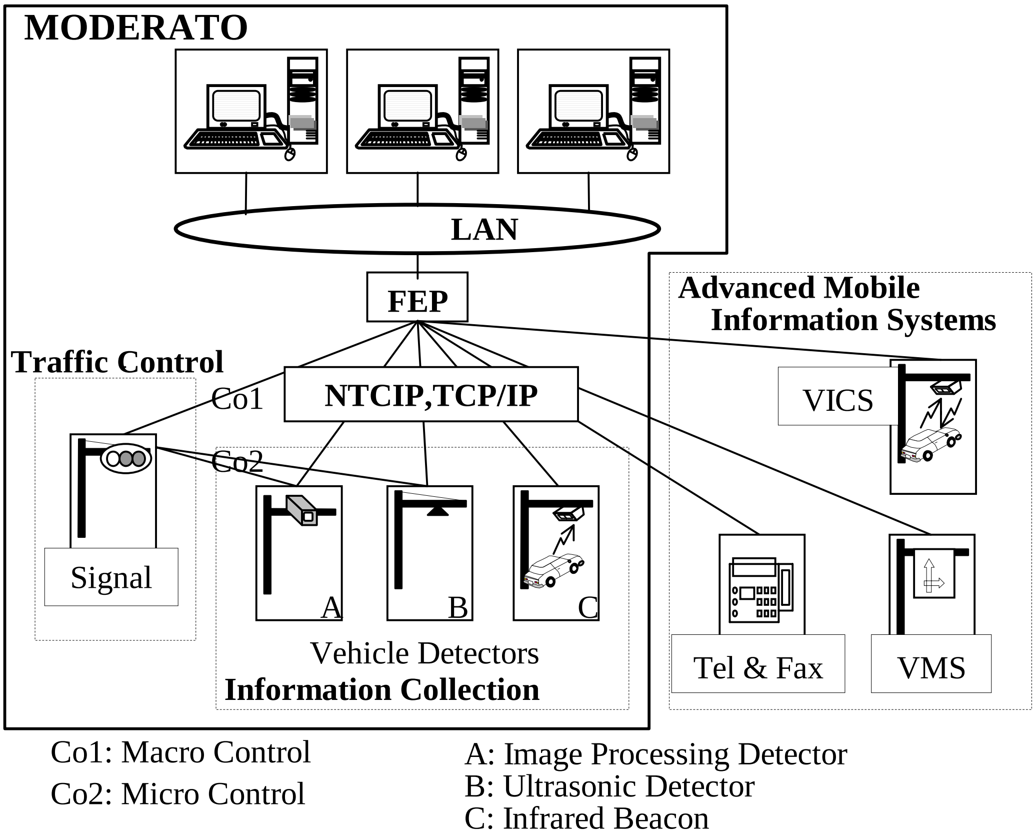

Figure 1. Basic system configuration

ARRANGEMENT OF VEHICLE DETECTORS

Figure 2 shows a standard arrangement of vehicle detectors on an approach at a critical intersection. The detectors, which measure the traffic volume and saturation flow, are positioned in all lanes at a distance of 150m (or 30m) from the stop line at an intersection. In the intersection, when the traffic volume of right turn vehicles are changeable every cycle, the detector is placed 30m from the stop line in the right turn bay, and it is used not only for measuring the traffic volume but also for right turn vehicle actuation. If the congestion length and the travel time are estimated, detectors are placed at distances of 150m, 300m and 500m from the stop line. And when traffic jams occasionally lengthen to more than 500m, they are placed at intervals of 250m in areas close to the city center and at intervals of 500m in the suburbs.

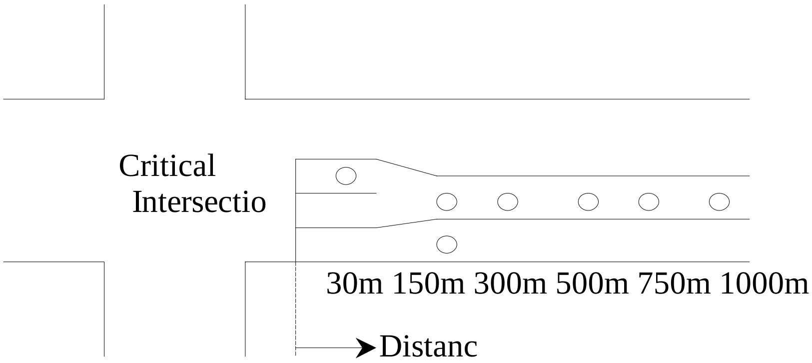

Figure 2. Arrangement of vehicle detectors

SIGNAL CONTROL METHOD

Macro Control Function

The macro control function is run on the central computer and determines the signal parameters based on detector information and congestion information. It is explained in detail below.

Split Control

The split at a critical intersection is a parameter that has the most influence on traffic processing capacity. Allotment of suitable green light time is the most important factor for delaying congestion growth at near-saturation.
Also, it is necessary that main and cross traffic is controlled in accordance with traffic policies during congested conditions.

The following section discusses how MODERATO handles split control at a critical intersection. The split at an ordinary intersection is selected in connection with the cycle length.

1) Load ratio. In realtime control, the amount obtained by adding the vehicles in queue to the inflow must be used in order to handle near-saturation. This amount is called the load demand. The load ratio is defined as the ratio of load demand to saturation flow, and load ratio (Lr) for each traffic movement on each approach is expressed by the following equation:

$$Lr = (Q_{in} + r*k*E)/s \quad (1)$$

Where

Q_{in} : Inflow [veh/2.5or5.0 min]

E : Vehicles in queue [veh]

s : Saturation flow [veh/2.5or5.0 min]

k :Usage ratio of E (0< k=<1) [1/2.5or5.0 min]

r : Usage ratio of E when vehicles are queued ahead (0 =< r =< 1)

The way in which the system handles the type of measurement shown in Figure 3 is explained below.

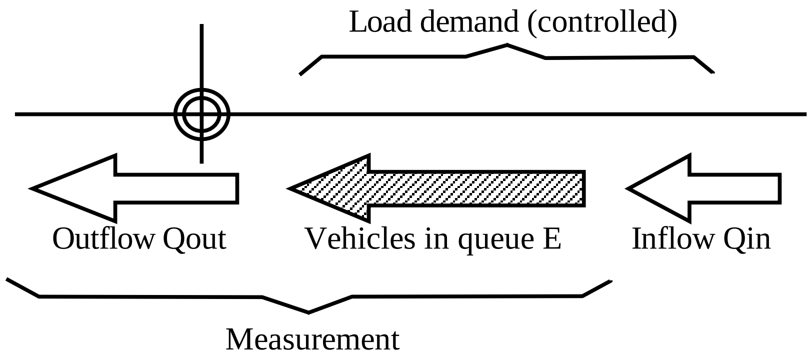

Figure 3. Measurement of load demand

When there is a queue, it is difficult to measure inflow Q_{in} directly. Therefore, Q_{in} is calculated according to the following equation using outflow Q_{out} that can be measured.

$$Q_{in} (t_n \sim t_{n+1}) = Q_{out} (t_n \sim t_{n+1}) + [E (t_{n+1}) - E(t_n)] \quad (2)$$

$t_n \sim t_{n+1}$: the interval between time t_n and t_{n+1}

The number of vehicles in queue E is found by dividing the congestion length by the average space headway. Actually, average space headway is a function of outflow, but in this system it is a constant of 10 [m/veh].

Saturation flow s is measured during congested conditions, and the set value is adopted at undersaturation.

2) Calculating split. The split for each phase is calculated based on the load ratio of each traffic movement as shown simply by the following equation:

$$Lr_i= Max (Lr_{i1}, Lr_{i2})$$

$$g_i =Lr_i / TLr \quad (3)$$

Where

Lr_{ij} : Load ratio of movement j on an approach in phase i

Lr_i : Load ratio of phase i

TLr : Load ratio (Lr) of the intersection

g_i : Split of phase i

This method has the following important functions:

- It performs processing required when one traffic movement corresponds to several phases. This processing is omitted from the above equation.

- During congested conditions, the phase load ratio Lr_i in equation (3) is modified as the following equation shows according to the priority of each phase p_i ($0 =< p_i =< 1$).

$$Lr'_i = Lr_i / Lr + p_i (Lr_i - Lr_i / TLr) \qquad (4)$$

- The cycle length is increased and/or the split is compensated so that green light time is at least equal to the minimum green light time.
3) Features. The features of this control method are as follows:
- Since the number of vehicles in the queue is included in the load ratio of each movement, the system can provide continuous control from undersaturation to near saturation.
- The control method can be applied to multi-phase intersections, since it calculates the split directly.
- During congested conditions, traffic can be controlled in accordance with traffic policies. That is, when p_i in equation (4) are all 0, this method controls congestion of critical movement in each phase equally (equalizes travel time through congestion). If a different p_i has been set for each phase, the phase whose p_i value is greatest is given priority.
- Since the load ratio of a movement drops in accordance with coefficient r in equation (2) when the system detects congestion downstream, the split for competing phases increases and the total outflow volume of the intersection can be increased.

Controlling the Cycle Length

The aim of controlling the cycle length as part of coordinated control is to minimize delay and stops along a route and create a safe traffic flow at undersaturation, and to maximize the traffic processing capacity at critical intersections at oversaturation. A theoretical calculation method for providing this type of control in real-time has not yet been established. In MODERATO, the cycle length is set between the preset upper and lower limits as explained below. The cycle length is determined for each sub-area unit. When the difference in the cycle length between two adjacent sub-area units is smaller than the set threshold value, MODERATO controls the two sub-area units as one sub-area and recognizes the greater cycle length. The cycle length for each sub-area unit is calculated using equation (5) based on the load ratio of a critical intersection within the sub-area unit.

$$C = (a_1 * L + a_2)/(1 - a_3 * TLr) \qquad (5)$$

Where:
L : Loss time
TLr : Load ratio of the intersection (Total of Lr_i)
a_1, a_2 and a_3 : Coefficients

The coefficients $a_1 = 1.5$, $a_2 = 0$ and $a_3 = 1.0$ are usually set so as not to give an excessive cycle length. During peak morning hours, the coefficient $a_3 = 1.2$ is assumed so that the control method can cope with the rapid increase in traffic. This control method includes the following functions:
.It compensates the cycle length by increasing it when the split calculated according to

equation (3) is not feasible from the point of view of guaranteeing the minimum green light time.
The maximum value of one change when the cycle length is falling is set to 10 seconds to enable the control method to cope with fluctuations in the load ratio.

Offset Control

During undersaturation, Offset is calculated by ROC (Real-time Offset Control). The ROC has a function which can calculate the offset to minimize the index EI (Evaluation Index) by simulation using the information of cycle length, split, and traffic volume.

$$EI = delay + k1 * stoppages + k2 * degree\ of\ risk \quad (6)$$

It is very dangerous to calculate the offset of a group of vehicles approaching the intersection during the signal-changing period. In this equation (6), the degree of risk is the term to decrease that danger. Figure 4 shows the image of degree of risk. When a signal changes from yellow to red, the degree of risk is highest, and it decreases after and before timing. The total of A and B is approx.10 seconds.

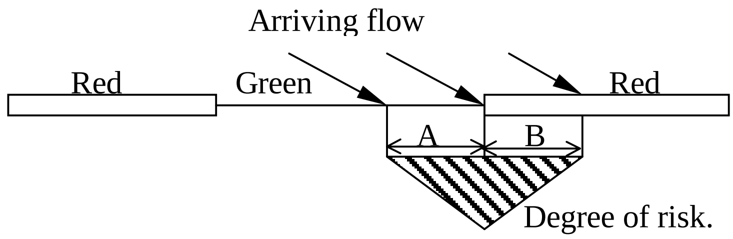

Figure 4. Image of degree of risk

During congested conditions, the inflow of traffic from an intersecting road at an intersection within the congestion can be controlled by the offset. If the opposite direction of traffic flow is not congested, giving priority to the direction can minimize delays and stoppages. This type of control during congestion is implemented by detecting the congestion and selecting the offset for each link.

Micro Control Function

The micro control function runs on the signal controllers and finely adjusts the green light time based on detector information from nearby intersections. Its main functions are as follows.

Right Turn Vehicle Actuation

In the intersection, when the demand for right turns by vehicles increases, the bay for right turn vehicles is given and those vehicles are controlled by the phase for a right turn. The interval of the phase is calculated from the ratio of historical right turn volume to total volume in the intersection.
However, in case the number of right turn vehicles during the cycle length are more

than capacity, which flows out during the phase, surplus right turn vehicles overflow into the lane for straight vehicles and the flow rate of those vehicles decreases.

On the other hand, when the number of right turn vehicles is less than capacity, there is some green light time with no cars flowing. The aim of the actuation is to allocate appropriate green light time for right turn vehicles and to make the total number of vehicles in the intersection clear.

A vehicle detector is placed 30m from the stop line and gaps between each vehicle are recorded by the detector.

Flow Rate Maximization Control

During congested conditions, there is a possibility that the flow rate at the stop line decreases in the latter half of the green period. The origins of decrease are probably car stoppage or shape of the road in the upper stream. The aim of this control is to maximize the flow rate at the stop line every cycle. In this control, the flow rate is predicted from information of the detector, which is set up aprox.150 m above the stop line. In this case, we can predict the flow rate until a few seconds later. When the flow rate from green start to a few seconds later is maximal, this control decides the end of the green light period.

Dilemma Control

The aim of the dilemma control is to decrease rear-end collisions just after the yellow signal start and collisions between vehicles that have jumped the red signal and entered from a crossroad. In this vehicle actuation, a dilemma zone and an optional zone are defined as follows:

- Vehicles in the dilemma zone find it difficult to stop with safe deceleration and pass the stop-line before the yellow signal ends.
- Vehicles in the optional zone can stop and pass.

These zones are the regions encircled by the curved line L1 and L2.

$$L1=R*V + V^2 / (2d) \qquad (7)$$

$$L2=Y*V \qquad (8)$$

Where

V: Vehicle speed (km/h)

R: Response time (sec)

d: Deceleration rate (m/sec^2)

Y: Yellow time (sec)

In the Fig.5

R=1.0sec, d=2.5m/sec^2, Y=4sec

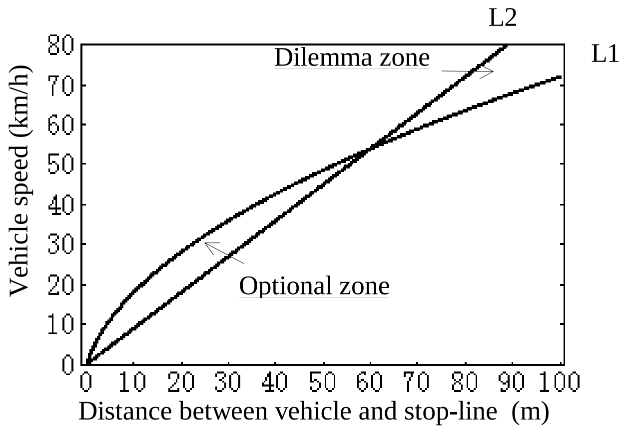

Figure 5. The dilemma zone and the optional zone

When there are some vehicles in the dilemma or optional zone, there is a possibility that each driver has a different decision whether to go or not. It causes the probability of rear-end collisions to increase. Furthermore, when a vehicle in the dilemma zone

goes into the intersection by force, probability of collisions between that vehicle and those entering from the cross roads increase.
In this actuation, location of vehicles are estimated using information of vehicle detectors set up the upstream road, and the actuator decides the end of the green light when there are no vehicles in these zones.

Public Transportation (Bus) Priority Control

This actuation allows buses, which are public facilities, to pass through the intersection with priority. They are estimated using information of infrared beacons when buses approach the intersection. There are two functions in the actuation and they are as follows:
-When buses approach the intersection just before the end of the green light period, the actuation extends the green light period.
-When buses approach the intersection just before the green light period starts, the actuation closes the red signal.
This control is one part of PTPS (Public Transportation Priority Systems) in UTMS.

Cross road Vehicle Actuation (The Semiactuated Control)

This actuation decreases the delay of main road vehicles, when the number of cross road vehicles are by far less than that of the main road. The green light period needs to be lengthened so pedestrians may cross the intersection. Generally speaking, when there are no pedestrians and few vehicles in the phase, we can shorten the time of the green light period compared to that when pedestrians are present.

1) The intersection which has few pedestrians:
The actuator gives the green light period for vehicles as usual, but when a pedestrian presses the button, it lengthens the time.
2) The intersection which has few pedestrians and vehicles:
The actuation doesn’t usually give a green light for the crossroads, but when a pedestrian presses the button or the detector senses a vehicle, it gives a green light period.

CONCLUSION

Several traffic control systems have been controlling heavy traffic with MODERATO in Japan. From these results we have confirmed that MODERATO is effective in reducing congestion, and that during congested conditions competing traffic flow was handled more equally than with the previous control system.
We hope that this paper serves as a reference for all cities that have traffic congestion problems.

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