Effectiveness of Traffic Restraint for a Congested Urban Network: A Simulation Study

AJAY K. RATHI AND EDWARD B. LIEBERMAN

Restricting ("metering") traffic flow on the approaches to an urban street network ("control area") can be considered an application of the concept of freeway ramp metering to surface street systems. In this application, local demand is reduced by metering traffic at the periphery of the control area during peak traffic demand periods. The purpose of this strategy is to maintain a level of traffic density within the control area to avoid congested flow conditions. It is postulated that if this objective is achieved, the performance of traffic will improve significantly within the control area and this improvement will more than offset the disbenefit associated with the possible delay of some traffic at the periphery. That is, the performance of the affected traffic, overall, will be improved. This paper presents the results of a simulation study that evaluated this hypothesis. On the basis of the results obtained in this study, it appears that the peripheral ("external") metering control strategies have the potential to improve the overall performance of traffic in a highly congested control area. The results indicate that it is virtually essential to apply a metering control along the periphery of a control area that is congested to the extent that the ensuing traffic demand cannot be serviced because of overflow queues causing extensive intersection spillback. It has also been shown that the optimal metering control policy to be enacted depends on the traffic condition before the implementation of such control (i.e., base condition) as well as the selected measure of effectiveness.

Traffic restraint consists of measures that are aimed at restricting vehicle use to achieve a significant modification in mode, time, route, or destination of vehicle trips. Restraint measures differ widely in the form and level of restriction they impose. One extreme of traffic restraint is the macroscopic measures that affect demand, such as techniques to reduce trip generation, trip distribution, or mode split, both spatially and temporally. This type of restraint is implemented primarily through fiscal or regulatory measures. The other extreme of traffic restraint is the direct control of demand at the micro level (e.g., individual intersections, approaches to a grid network). This form of traffic restraint is imposed by measures such as physical restrictions (e.g., street closure) or delay-based restrictions (e.g., signal control) and is primarily intended to reduce temporarily the demand for congestion control. One such traffic restraint-based control strategy is the focus of this paper.

A. K. Rathi, Transportation and Systems Research Section, Energy Division, Oak Ridge National Laboratory, Oak Ridge, Tenn. 37831. E. B. Lieberman, KLD Associates, Inc., 300 Broadway, Huntington Station, N.Y. 11746.

BACKGROUND

The problem of urban congestion has received considerable attention recently and for good reason. Traffic congestion is no longer a characteristic only of big cities. Medium-sized cities, such as Charlotte and San Antonio, and even smaller urban areas experience levels of congestion rivaling that in many major metropolitan areas. On the other hand, urban congestion in big cities is reaching such proportions that it is no longer merely a nuisance; it is becoming a critical liability that adversely affects the economic growth of urban areas. The policymakers and administrators of transportation agencies throughout the United States and elsewhere have recognized urban traffic congestion as one of the critical problems facing urban areas. The Executive Committee of TRB has identified congestion of traffic facilities as one of the ten critical issues in transportation (*1*).

Traffic engineering techniques designed to reduce the adverse impacts of urban congestion fall into three general categories:

- Measures designed to increase capacity of the road system,
- Measures designed to maximize use of the available capacity, and
- Measures designed to reduce demand.

Measures designed to increase the capacity of the road system include building additional facilities or physically altering existing facilities to provide additional capacity in the road network. Measures designed to maximize available capacity include traffic engineering techniques aimed at minimizing the capacity-reducing factors (e.g., parking, standing, and stopping control or turn regulations) or at maximizing the use of existing capacity (e.g., improved signal control).

After all possible measures for increasing capacity have been implemented, and the available capacity is optimally utilized, congestion may still occur if traffic demand exceeds system capacity. Under these conditions, congestion is unavoidable unless demand can be reduced through traffic restraints.

TRAFFIC RESTRAINTS

The necessity for traffic restraint was recognized a long time ago. Nearly 25 years ago, in the preface to the book *Traffic in Towns* (*2*) Lord Crowther wrote, "Distasteful though we find the whole idea, we think some deliberate limitation of the volume of motor traffic in our cities is quite unavoidable." Some macroscopic forms of traffic restraints implemented through fiscal or regulatory measures have been tried successfully in some older cities in Europe and are becoming increasingly popular in the large metropolitan areas of developing countries (*3,4*).

However, with one or two exceptions (*5*), policymakers and administrators in the United States and elsewhere have avoided direct control of demand on a micro level (i.e., restricting traffic flow on individual approaches or to a small cohesive area). The reasons for rejection or abandonment of such restraints are many. The major objections are that such measures will be unworkable and ineffective and will have an adverse impact on business in the affected area (*6*). Some minor objections, such as that restraints are unfair to certain groups in society or that they are hard to enforce, are also raised.

Although some of these arguments have their strength and political clout, the arguments in favor of traffic restraints (e.g., efficiency, resource conservation, environmental improvement) have in the past rested on largely unsubstantiated ("intuitive") claims of solving severe traffic problems. That is, these arguments have suffered from a lack of credibility and in many cases there has been no sound technical basis for justification of such restraints. At a minimum, policymakers, administrators, and the public will want to know the resulting transportation effects.

This limitation can now be overcome because sophisticated models are available that can simulate traffic operations in a large urban grid network with the desired degree of detail and precision. Simulation models such as Traf-Netsim (*7*) or TRAFLO (*8*) can be used to predict, with reasonable accuracy, the transportation as well as environmental impacts of traffic restraints in urban areas before their real-life implementation. This paper presents the result of a simulation study that evaluated the effects of applying a traffic restraint at the periphery (hereafter referred to as "external metering control") of a congested area in the New York central business district (CBD).

OBJECTIVE

The policy of external metering consists of applying controls on the periphery of a congested control area to limit the rate of traffic inflow to the area during a period of traffic accumulation (i.e., during the a.m. peak period). The purpose of this strategy is to maintain a level of traffic density within the control area that will avoid congested flow conditions. It is postulated that if this objective is achieved, the performance of traffic will improve significantly within the control area, with a concomitant reduction in vehicle emissions and energy consumption. It is further postulated that the improvement of traffic performance within the control area will more than offset the disbenefits associated with delaying the traffic at the periphery.

As part of a project to examine ways to improve air quality and reduce congestion in the high-density sectors (i.e., highly congested areas) of the New York CBD (*9*), a simulation study was undertaken to assess the feasibility of an external metering-based control strategy. The objective of this study was to evaluate the potential impacts of applying an external metering control during peak traffic demand periods for a congested area in the New York CBD.

SELECTED CONTROL AREA AND METERING LOCATIONS

The control area selected for analysis, as shown in Figure 1, extends from 63rd Street to 54th Street and from First Avenue to Lexington Avenue in mid-Manhattan. Table 1 lists the possible metering locations within this control area. This control area was selected because it is part of one of the high traffic density areas of mid-Manhattan (*10*). This grid area experiences excessive delays for a relatively long time frame during the a.m. peak period and hence offers a potential for reducing aggregate trip travel time during the metering period. Furthermore, the traffic can be metered at almost every entry point by suitably adjusting the signal timing.

PROCEDURE

The Traf-Netsim simulation model (*7*) was used to evaluate the impact of external metering on traffic operations in the control area. The performance of traffic under existing conditions (i.e., without any metering control) was compared with that when different rates of metering were implemented for traffic entering the control area. The analyses were performed for the a.m. peak period.

To use the Traf-Netsim simulation model, the street system within the control area was represented as a network of links and nodes, shown in Figure 2. Data were collected in the field to prepare the input data for the simulation model. The data collected include geometrics, channelization, traffic volumes, turn counts, signal timing, and bus data specific to one control area. Some of these data were obtained directly from the New York City Department of Transportation.

Computer runs were then made to simulate traffic operations under existing conditions as well as for a number of external metering control scenarios. Both restrictive and permissive metering rates were implemented in these experiments. That is, the impacts of restricting the entry of traffic at the periphery of the control area and the impacts of permitting additional traffic to enter the control area were analyzed. Metering was implemented directly by modifying the input traffic volumes at all entry points of the control area to the desired inflow rate. This metering control was implemented in this preliminary study in accord with the following rationale.

1. The same level of metering is implemented throughout the periphery of the control area, so that all entering traffic streams are affected to the same extent.
2. The impact of the metering is uniformly distributed throughout the control area. It is therefore reasonable to assume that no substantive changes in traffic control within the control area are required and that such control measures will have an insignificant or very little impact on traffic assignment.
3. In a congested environment a desired level of metering may not be obtainable through peripheral signal control alone, because the number of vehicles that can enter the control area depends on the traffic conditions within the control area. That

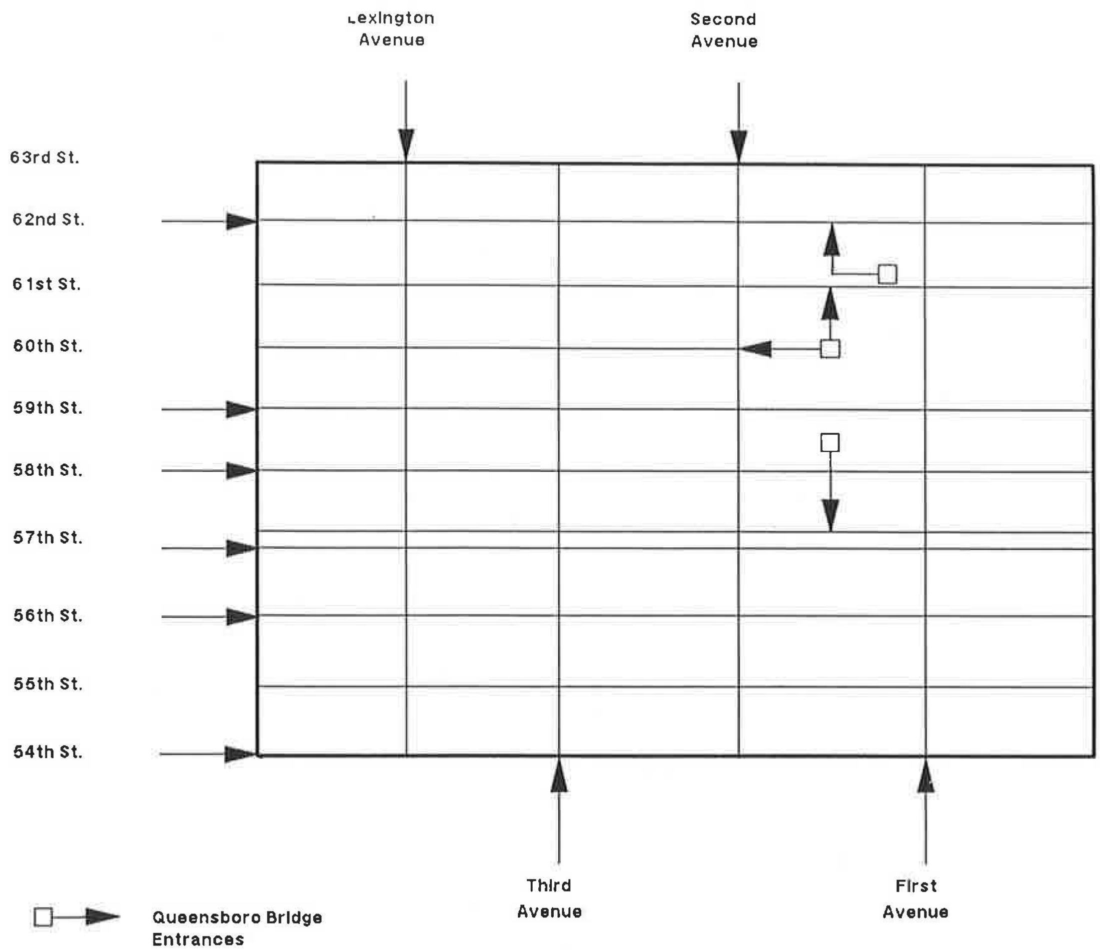

FIGURE 1 Control area.

TABLE 1 POSSIBLE METERING LOCATIONS IN THE SELECTED CONTROL AREA

1.	Southbound Second Avenue and Lexington Avenue at 63rd Street.
2.	Northbound First Avenue and Third Avenue at 54th Street.
3.	Eastbound 62nd, 59th, 58th, 57th, 56th, and 54th Streets at Lexington Avenue.
4.	Westbound 63rd, 61st, 59th, 57th and 55th Streets at First Avenue.
5.	Queensboro Bridge exits at 62nd, 60th and 58th Streets.

is, signal control can specify only the maximum possible inflow rate; the actual inflow rate also depends on traffic conditions within the control area. Specifically, congested conditions within the control area can produce queues that limit the rate of traffic inflow below that permitted by the metering policy.

Simulation studies were undertaken for the following scenarios:

- Scenario 1. Present conditions,
- Scenario 2. A 10 percent reduction in inbound traffic at all entry points in the control area,
- Scenario 3. A 20 percent reduction in inbound traffic at all entry points in the control area,
- Scenario 4. A 40 percent reduction in inbound traffic at all entry points in the control area,
- Scenario 5. A 10 percent increase in inbound traffic at all entry points in the control area,
- Scenario 6. A 20 percent increase in inbound traffic at all entry points in the control area,
- Scenario 7. A 30 percent increase in inbound traffic at all entry points in the control area, and
- Scenario 8. A 35 percent increase in inbound traffic at all entry points in the control area.

SIMULATION RESULTS

The comparisons of traffic performance under the existing control policy versus the metering control scenarios are based on the following networkwide aggregate measures of effectiveness (MOEs): mean speed, production (vehicle trips), delay,

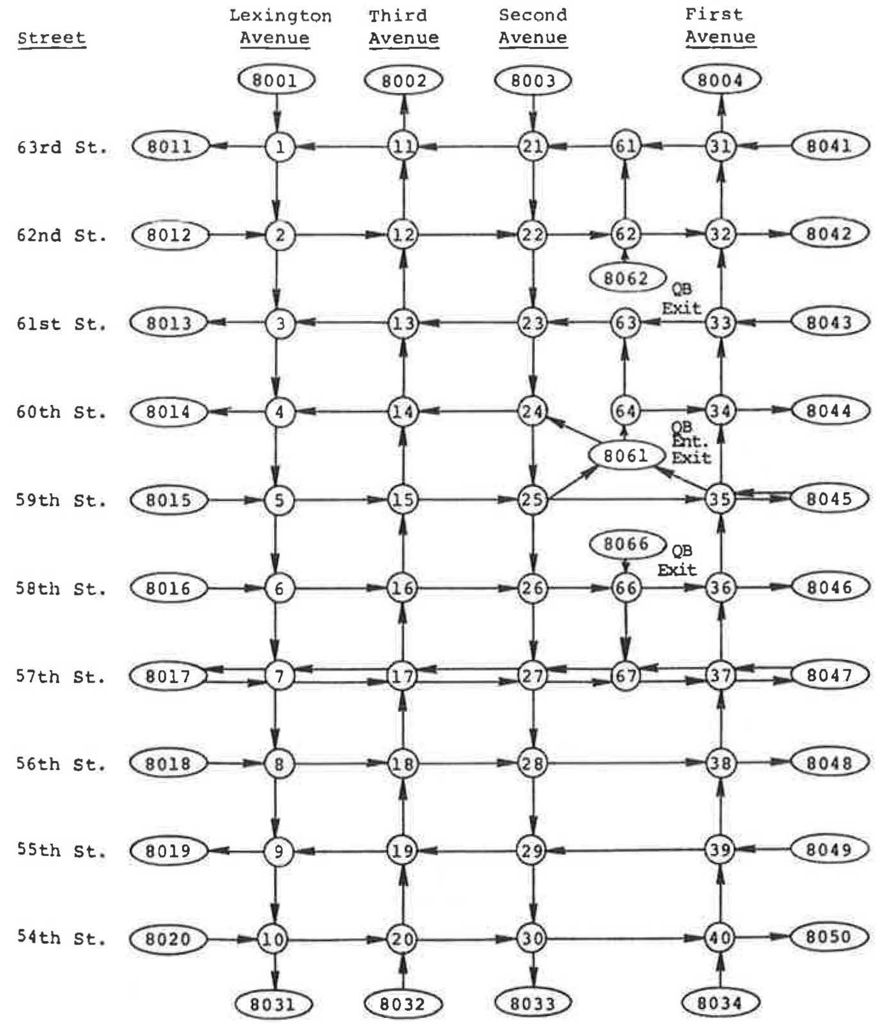

FIGURE 2 Link-node representation of the control area.

total travel time (vehicle hours), and saturation (vehicle content). Throughput, computed as the product of mean speed and vehicle trips, is also considered in analyzing the result.

Table 2 presents the simulation results for Scenarios 1 through 8. It contains the simulated values of the MOEs based on a simulation time period of 12 min following an initialization period of 9 min for each scenario. Scenario 1 represents existing conditions for the control area, and Scenarios 2 through 8 represent the conditions under different levels of metering implemented at the periphery of the control area but with the same signal control policy within the area. For Scenarios 2 through 8, the percent differences—relative to Scenario 1—are also shown (in parentheses) in Table 2 for each MOE. An examination of these simulation results leads to the observations that follow.

Vehicle Trips

When traffic demand attempting to enter the control area is restricted relative to the base condition (Scenarios 2, 3, and 4), the number of vehicle trips serviced on the control area is reduced in almost direct proportion to the implemented metering rates. The results, however, are quite different when a permissive metering allows more traffic to enter the control area than at present. Scenario 6, where a 20 percent permissive metering is implemented, the vehicle trips completed within the control area increased by only 5.5 percent. A further relaxation of the metering rate to permit a 30 percent increase in entering traffic volume produces no additional vehicle trips. When the metering rate is further increased to 35 percent (Scenario 8) relative to the base condition, the number of vehicle trips through the control area actually decreases relative to the 30 percent increase in the metering rate of Scenario 7 (see Table 2).

The changes in completed vehicle trips for individual entry links to the control area indicated that the percent decreases in vehicle trips serviced on entry links along the periphery of the control area for Scenarios 2, 3, and 4 are nearly the same as the percent decreases in metering rate. These results imply that because there is nearly a direct linear relationship between traffic volume entering the control area and traffic volume serviced within the control area, the network is undersaturated at these lower metering rates. There is also some indication that the base condition is, to some extent, reflective of an undersaturated network.

When the metering rate is increased uniformly for all entry links, however, the intrinsic heterogeneity of the network

TABLE 2 SIMULATED TRAFFIC PERFORMANCE—SCENARIOS 1 THROUGH 8

Measure of Effectiveness	Scenario (Metering Rate, Pct.)							
	2 (-10)	3 (-20)	4 (-40)	1 (0)	5 (+10)	6 (+20)	7 (+30)	8 (+35)
Vehicle Trips (veh)	3056.0 (-8.2)	2770.0 (-16.8)	2118.0 (-36.4)	3330.0	3475.0 (+4.3)	3515.0 (+5.5)	3518.0 (+5.6)	3405.0 (+2.3)
Travel Time (veh-hrs)	150.7 (-15.3)	113.6 (-36.2)	77.0 (-56.7)	178.0	208.7 (+17.2)	232.1 (+30.4)	254.5 (+43.0)	279.5 (+57.0)
Total Travel Time (veh-hrs)	226.8 (+9.1)	239.3 (+15.1)	360.4 (+73.3)	207.9	215.4 (+3.6)	232.6 (+11.8)	254.5 (+22.4)	300.4 (+44.5)
Mean Speed (miles/hr)	7.5 (+10.3)	9.1 (+33.8)	10.3 (+51.5)	6.8	5.9 (-13.2)	5.3 (-22.1)	4.9 (-27.9)	4.3 (-36.7)
Delay (veh-hrs)	110.0 (-18.5)	76.5 (-43.3)	48.3 (-64.2)	134.9	164.8 (+22.2)	187.7 (+31.9)	210.3 (+55.9)	236.7 (+75.5)
Content (veh)	761.4 (-15.4)	574.5 (-36.2)	389.5 (-56.7)	899.8	1054.0 (+17.1)	1171.8 (+30.2)	1285.4 (+42.8)	1410.7 (+56.8)
Throughput (veh-miles/hr)	22920.0 (+1.2)	25207.0 (+11.3)	21815.4 (-3.6)	22644.0	20502.5 (-9.5)	18629.5 (-17.7)	17238.2 (-23.9)	14641.5 (-35.3)

Notes: 1) The numbers in parentheses are the percent change relative to Scenario 1.

2) Metering is (restrictive, permissive) if (negative, positive).

3) Total travel time is the sum of Travel Time (within the control area) and the additional travel time outside the control area due to metering relative to Scenario 7.

response becomes apparent. That is, some roadways within the control area exhibit the ability to accommodate additional demand in the control area over the entire range of metering whereas others do not (i.e., they exhibit saturated conditions with small changes in entering traffic volumes). The detailed results are presented elsewhere (*11*).

The inability of some entry points to accommodate additional entering demand, even when metering rates are relaxed to accommodate higher levels of entering traffic, reflects the de facto metering imposed by congested conditions within the control area. That is, the queues formed within the control area preempt, to some extent, the ability of entering traffic on some links approaching the entry points from fully using the available green time provided by the metering policy. Consequently, these queues override the metering policy.

It is seen, for this case study, that there is a strong "asymmetry" in the response of aggregate vehicle trips serviced within the control area to changes in nominal metering rates, M, relative to the base condition, M_o:

- Decreasing metering rates in a restrictive policy (i.e., $M < M_o$), by some percent, p, acts to decrease vehicle trips by approximately the same percentage, p.
- Increasing metering rates (i.e., $M > M^* > M_o$) by some percent, $p \leq p^*$, will increase vehicle trips by a substantially smaller percentage. The percentage, p^*, with the associated metering rate, M^*, is that point beyond which further increase in metering rates, $M > M^*$, does not provide an increase in vehicles serviced and could actually decrease vehicle trips somewhat.

The preceding conclusions apply when $M_o \leq M^*$. Under that condition, application of either restrictive or permissive external metering will change vehicle trips. If, on the other hand, $M_o > M^*$, then restrictive external metering will unconditionally improve traffic operations. It is therefore essential to establish the status of an existing condition, in the sense just discussed, to determine the potential of external metering to provide important benefits in improving traffic operations.

Mean Speed

The previous discussion addressed the quantity of traffic flow serviced. It is also essential to discuss the influence of external metering on the quality of traffic flow. A prominent measure of the quality of flow is mean speed.

Table 2 reveals that mean speed responds in a sensitive way to changes in metering rates. In the cases of restrictive metering (Scenarios 2, 3, and 4), the percent increases in mean speed are greater than the associated percent decreases in metering rate, and they are also greater than the associated percent decreases in vehicle trips. When the entering traffic volume at the periphery is increased (Scenarios 5, 6, 7, and 8), the percent decreases in mean speed are about the same as the percent increases in metering rate. Note that mean speed percentages decrease much more sharply than the corresponding small increases in vehicle trips under permissive changes in metering rates. In fact, both the mean speed and the vehicle trips decrease in Scenario 8 relative to Scenario 7, indicating that, past some point, increasing the metering rates is counterproductive for both vehicle trips serviced and for traffic performance.

It should be mentioned here that because of microcomputer memory limitations, the Traf-Netsim model could not be used to simulate the conditions when entering traffic volume at the periphery is specified at 40 percent above the base condition. For that scenario, the simulation run ended after 8 min of simulation past initialization. On the basis of intermediate output for the first 6 min of simulation, a sharp decrease in vehicle trips completed and in mean speed was observed. These results indicated a pronounced deterioration in operational performance within the control area with high delays and spillbacks throughout the network. Thus, permitting more vehicles to enter the control area at this level (i.e., if $M >> M^*$) sharply exacerbates congestion in every respect. This condition must be avoided.

Delay

The delay within the control area decreases significantly when the entering traffic volume is reduced by restrictive external metering. On the other hand, delay increases as the traffic volume entering the control area increases as a result of permissive metering. As expected, the delay increases sharply at higher traffic volumes as in Scenario 8.

Vehicle Content

Under a restrictive metering policy, relative to the base condition of Scenario 1, the vehicle content of the network decreases (in percent) about 50 percent more than do the associated percent decreases in vehicle trips. Under a permissive metering policy, however, vehicle content increases markedly while the number of trips remains essentially unchanged. This relationship reflects the adverse impact of congestion that increases traffic density but not the service rate.

Throughput

Throughput, p, is a measure that combines two measures, traffic volume and speed, to form a single performance measure:

$$p = \int_{o}^{T} v(t)q(t)dt$$

where

p = throughput (vehicle miles per hour),
v = speed (mph),
q = volume serviced (vph),
t = time (hr), and
T = analysis period (hr).

The Traf-Netsim simulation model provides the value of p directly as the product of networkwide aggregate mean speed and total vehicle trips. This measure, which is comprised of measures describing both the quality and quantity of traffic flow, can therefore serve as an optimizing parameter.

As discussed previously, a permissive metering policy acts to increase slightly vehicle trips (i.e., the number of vehicles serviced) but at higher levels of congestion (delay and vehicle content) and at lower speeds. A restrictive metering policy sharply increases speed and reduces delay but at somewhat lower levels of vehicles serviced. The throughput measure represents a trade-off between the conflicting objectives of increasing the number of vehicles serviced while increasing speed and reducing travel time.

Under permissive external metering (Scenarios 5, 6, 7, and 8) relative to the base condition (Scenario 1), the throughput within the control area is significantly reduced. Under a restrictive metering policy (Scenarios 2 and 3), throughput is increased relative to Scenario 1. Specifically, restricting traffic inflow by 20 percent increases throughput by 11.3 percent in the control area. More restrictive metering of traffic demand, however, is counterproductive because the resulting increase in speed is more than counterbalanced by the decrease in vehicle trips, thereby reducing throughput (Scenario 4).

Travel Time

Travel time is expressed as vehicle hours of travel and is strongly correlated (inversely) with speed. Its value as an optimizing parameter lies in the ability to calculate this measure for traffic operations within the control area and for the effect of metering on the travel time of traffic approaching the control area from outside.

To provide a consistent comparison, it is assumed that the aggregate demand for service over the 12-min simulation analysis period is that associated with Scenario 7—3,518 vehicles. Thus, this demand is serviced over a longer (than 12 min) period for all other scenarios.

For this case study, total travel time is increased for both restrictive and permissive metering policies relative to Scenario 1 (Table 2).

SOME REAL-WORLD CONSIDERATIONS

The discussion of simulation results so far has

- Addressed a single "base condition" (i.e., the existing condition in the control area during an average weekday a.m. peak period); and
- Considered several different measures of effectiveness (e.g., vehicle trips, travel time).

Because traffic volume varies from one peak hour to the next and from one weekday to another, however, it is reasonable to assume that Scenario 1 does not cover the entire spectrum of traffic operations in the control area. That is, Scenario 1 merely represents average weekday a.m. peak period traffic conditions within the control area; at times the system's operational status can be better or worse than that of Scenario 1. At times, the state of traffic operations in the control area can be similar to the conditions represented by Scenarios 2 through 8. It is therefore appropriate to assess the impact of metering control implemented during these conditions—that is, to explore the base condition where traffic in the control area is represented by these scenarios.

Similarly, it is seen that the impact of different metering strategies is not consistent across different MOEs. That is, one metering strategy is better than others for one MOE, but it may not be desirable for other MOEs. For example, Scenario 3 is the best strategy when the selected MOE (or objective) is throughput. It is not the best strategy, however, if the objective is to maximize the vehicle trips. The consequence of this inconsistency is that the optimal metering policy will differ depending on the MOE selected. This relation implies that the optimal metering strategy for a given control area depends on the base condition as well as the selected objective. A simple analysis will illustrate this point.

Consider three base conditions: Scenario 1, Scenario 3, and Scenario 7. For each base condition, we will identify the best metering strategy for each of several specified objectives. The results of this analysis are presented in Table 3. As indicated therein, the optimal external metering policy to be enacted depends on the base condition and the selected objective.

As indicated in Table 3, the objective of maximizing trips would yield a permissive metering policy. This policy would produce a congested environment that just avoids systemwide breakdown within the control area. For the case studied, selecting this objective implies the acceptance of significant penalties in total travel time and throughput.

The objective of minimizing total travel time is intrinsically appealing, particularly when, as in this case, the policy's production (i.e., vehicle trips) is about 95 percent of that provided by the policy that maximizes production. For this policy, the traffic environment is still congested, albeit less so than for the previous policy.

The objective of maximizing throughput produces a traffic environment that is appealing to the motorist within the control area (i.e., moderate density, acceptable speed) but penalizes the motorist on the approaches to the control area. This policy, which produces a stable traffic environment within the control area, may be attractive to policymakers who wish to provide improved service within a control area and are less concerned about delays of traffic attempting to enter the area. That is, although the total travel time for this policy exceeds that for the previous policy, the apportionment of travel time here is such that those inside the control area benefit, while those on the approaches are penalized, relative to the situation attendant to the previous policy.

In summary, with Scenario 1, which minimizes total travel time, as base condition, a metering policy that maximizes trips increases trips by 5 percent, but increases total travel time by 17 percent and decreases throughput by 21 percent. A metering policy that maximizes throughput increases throughput by 11 percent but decreases trips serviced by 17 percent and increases total travel time by 15 percent.

With Scenario 3, which maximizes throughput, as base condition, a metering policy that maximizes trips increases trips by 27 percent but increases total travel time by 2 percent and decrease throughput by 29 percent. A metering policy that minimizes total travel time decreases total travel time by 9 percent and increases vehicle trips by 20 percent but decreases throughput by 10 percent.

With Scenario 7, which maximizes trips, as base condition, a metering policy that minimizes total travel time decreases total travel time by 18 percent and increases throughput by 31 percent but decreases vehicle trips by 5 percent. A metering policy that maximizes throughput increases throughput by 46 percent and decreases total travel time by 6 percent but decreases vehicle trips by 21 percent.

On the basis of the results obtained in this study it appears that a policy designed to maximize trips offers very limited benefits in that respect and penalizes traffic operations to a far greater extent. It appears from this study, then, that the most permissive external policy should be what minimizes total travel time and the most restrictive policy should be what maximizes throughput.

CONCLUSIONS

The objective of this study was to evaluate the potential impacts and feasibility of an external metering control strategy for a congested urban network. According to the results obtained in this study, it appears that the external metering control strategies have the potential to improve traffic operations within and on the approaches to a congested control area. The simulation results for this case study suggest that it is virtually essential to apply an external metering policy along the periphery of a control area that is presently congested to the extent that production (vehicle trips serviced) is reduced because of extensive queue spillback. It has been shown that the optimal external metering policy depends on the base condition as well as the specified objective (i.e., MOE). Thus, an external metering policy can potentially benefit any con-

TABLE 3 EXTERNAL METERING POLICIES FOR THE TEST NETWORK UNDER SEVERAL BASE CONDITIONS

Base condition	Objective	External Metering		Vehicle Trips		Total Travel Time (veh-hrs)		Throughput (veh-mi/hr) x 1000	
		Policy	Pct. Change*	Base	With Metering	Base	With Metering	Base	With Metering
Scenario 1	Maximize Trips	Permissive	+25	3330	3517	207.9	243.6	22.64	17.93
	Minimize Travel Time	-	0	3330	-	207.9	-	22.64	-
	Maximize Throughput	Restrictive	-20	3330	2770	207.9	239.3	22.64	25.21
Scenario 2	Maximize Trips	Permissive	+56	2770	3517	239.3	243.6	25.21	17.93
	Minimize Travel Time	Permissive	+25	2770	3330	239.3	207.9	25.21	22.64
	Maximize Throughput	-	0	2770	-	239.3	-	25.21	-
Scenario 3	Maximize Trips	-	0	3518	-	254.5	-	17.24	-
	Minimize Travel Time	Restrictive	-23	3518	3330	254.5	207.9	17.24	22.64
	Maximize Throughput	Restrictive	-38	3518	2770	254.5	239.3	17.24	25.21

*Percent change in metering rate relative to the specified base condition. Note that interpolation in Table 2 was employed to estimate the optimum policy.

gested area and, furthermore, can be responsive to traffic management policies formulated by the decision makers.

FUTURE WORK

The study discussed in this paper presents an interesting evaluation of the external metering-based control concept. It appears from this preliminary study that such metering control has the potential to improve traffic operations in the affected control area and that this improvement exceeds the disbenefit associated with metering traffic at the periphery of the control area. That is, metering control can lead to an improvement in overall traffic performance. It would therefore be desirable to perform a detailed study identifying optimal metering policies; economic, social, and environmental impacts of such metering controls; behavioral and locational response of the metered vehicles and distributional effects of such restraints; and detection and implementation criteria and procedures for real-life implementation.

In the interests of limiting the extent of the present study and of presenting results in a clear format without introducing confounding factors, only scenarios with a uniform rate of metering at all approaches to the control area were considered. Scenarios with nonuniform metering rates should also be evaluated, however, because a metering control policy should be designed in recognition of the heterogeneity of the traffic environment in the control area. That is, different metering rates should be applied to different approaches to the control area so as to "tailor" the metering rate to the maximum use of available street capacity in the immediate vicinity of the approach.

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