Transportation System Management Options for Downtown Curbside Pickup and Delivery of Freight

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In downtown areas, freight is picked up and delivered primarily at curbside, either on main streets or on minor cross streets and in alleys. Where excessive demands for freight exist on main arteries, surface traffic problems can become severe. This paper presents operational strategies that address this situation: curb-space management, signal-timing adjustments, signing of curb use and enforcement, restriping of arterial, temporal control of curb lane, relocation of bus stops, control of turns, and land-use control. The tools for evaluation were developed in previous research and are only summarized here. The paper concludes by ranking strategies for effectiveness based on the severity of the traffic problems caused by pickups and deliveries on the arterial.

In downtown areas, freight is picked up and delivered primarily at curbside, either on main streets or on minor cross streets and in alleys. Due to the nature of the principal demand variables for downtown urban freight (primarily consumable products), the freight generators usually front on the main pedestrian arteries (which usually are also the main vehicle arteries). In the downtown areas in which alleys parallel these main arteries, the problems created by conflicts between freight traffic and pedestrian traffic can be minimized. However, when there are no spatial alternatives to solve a goods-movement problem, other measures become necessary.

In this paper I present and evaluate selected low-cost operational (transportation system management, or TSM) strategies directed toward improving traffic conditions while recognizing the need to deliver freight with little or no disruption in service. To date, traffic engineering measures for goods movement have met with limited success (in my opinion) mainly because of an underestimation of the pressure that carriers face to serve their customers efficiently. This paper is based on a project that developed techniques for predicting freight demand, for predicting when pickup-and-delivery (PUD) vehicles would double-park or park in a curbside moving lane, and for determining the impact of lane blockages on arterial level of service. The project used these background capabilities to develop and evaluate TSM strategies for downtown arterial streets, and the results of the efforts of that phase are summarized in this paper.

BASIC TOOLS FOR STRATEGY EVALUATION

In an effort to be brief, this presentation may mislead the reader on the depth of the analysis done to develop the necessary tools for the strategy evaluation. These tools, which are not presented in detail, are

1. Estimation of demand for curbside PUD trips,
2. Determination of how the vehicles will park, and
3. Determination of the impact of a lane blockage on arterial level of service.

Tables 1 and 2 summarize, respectively, the weekly and daily generation equations and hourly arrival patterns of curbside PUD vehicles for various land uses. Figure 1 shows the probability of double-parking as a function of percentage of the blockface devoted to truck space (loading zones, hydrant zones, bus stops, driveways). In addition, the research determined that, under random normal enforcement, 20-25 percent of PUD vehicles that arrive at a blockface will stop in a designated curbside moving lane. Figure 2 was developed to show the relationship between number of double-parkers (or blockages of curbside moving lane), street traffic volume, and expected resultant arterial level of service. Figure 2 gives data for one-way streets (left) and two-way streets (right). With the basic information presented above (plus more not deemed necessary to include here), various strategies will be outlined and analyzed for effectiveness in subsequent sections of this paper.

TSM STRATEGIES FOR IMPROVING ARTERIAL FLOW

First, it is necessary to define the objective of the analysis. For this type of analysis it appears that a specified level of service would be that objective. The recognition that curbside goods movement is a problem related to traffic flow occurs when the state of the traffic on a street approaches or is at that street's capacity. An arterial with freely flowing traffic does not appear (to the traffic engineer) to represent a problem, even though there is some speed reduction due to lane blockages. Therefore, the strategy objectives would be to obtain (a) an upper-limit service level C (C-D boundary) or (b) an upper-limit service level D (D-E boundary) on the arterial (see Figure 2). It is evident that different cities have different objectives in traffic control management; many cities view the D-E border as unsatisfactory, whereas others consider it a realistic level of downtown congestion. Therefore, both the C-D and D-E boundaries will be used as strategy objectives when appropriate, and the option will be available to the traffic engineer or planner to use one or the other as determined by local policy. The strategies addressed include curb-space management, signing of curb use and enforcement of it, signal-timing adjustments, temporal control of the curb lane, demand-reduction methods, and other traffic engineering techniques. These strategies will be applied to specific blocks where goods-movement problems have been determined to exist. It should again be stated that goods-movement problems, though in some cases severe, are isolated, and solutions to these problems should take this into account.

Curb-Space Management

The basic question to be addressed is, for a given traffic-volume level, how much curb space should be allocated as available for PUD use (or rather not available for usual automobile parking). It should be noted that PUD vehicles will look for bus stops, hydrant zones, driveways, or any other available space to load or unload freight, and therefore the existence of such space generally does act as loading-zone space. For a given PUD demand and a given traffic-volume level, curb space would be needed in amounts necessary to reduce conflicts. The data used in this analysis are from Figures 1 and 2. These relate to the estimated percentage of double-parkers for various amounts of allocated PUD curb space and the effects of these double-parkers on level of service of one-way and two-way arterial streets. Tables 3 and 4 show the results.

The procedure followed in the development of Tables 3 and 4 is to

1. Find the maximum number of double-parked PUD vehicles that can be tolerated for a specific traffic volume and level of service,
2. Find the estimated number of vehicles that will double-park for various demands and curb-space allocations, and
3. Select the curb space needed that reduces the number of double-parkers to the tolerable level.

Tables 3 and 4 show that there are traffic-volume levels below which there need not be any designated PUD curb space to obtain a desired level of service--650 vehicles/h of green/lane for level C and 950 vehicles/h of green/lane for level D. These tables also show that one-way streets generally require more total curb space than do two-way streets; this is primarily because of the different blockage patterns. The tables further identify the no-solution (NS) conditions, where all space is allocated and the desired level of service is still not

Table 1. PUD demand equations.

Land Use	Equations for Weekly Generation	Daily Generation	R^2	N
Office	WG = (0.80 x FA) + 2.0	DG = (0.16 x FA) + 0.4	0.93	48
Residential	WG = (0.15 x DU) + 2.27	DG = (0.032 x DU) + 0.45	0.94	87
Hotels	WG = (0.30 x RU) - 12.0	DG = (0.06 x RU) - 2.4	0.96	11
Retail and prepared foods	WG = (1.65 x FA) + (1.21 x E) + 5.2	DG = (0.33 x FA) + (0.242 x E) + 1.04	0.25	44
Light industry and warehousing	WG = (1.28 x FA) + (0.31 x E) + 11.96	DG = (0.26 x FA) + (0.06 x E) + 2.4	0.64	31
Retail and service	WG = (0.30 x E) + 8.2	DG = (0.06 x E) + 1.6	0.74	219

Note: WG = weekly generation; DG = mean daily generation; E = employment; FA = floor area (m^2 000s); DU = dwelling unit; RU = rental unit.

Table 2. Hourly PUD arrival distribution, by percentages.

Time	Land Use: Office	Residential and Hotel	Food	Industry and Warehousing	Retail and Service
6:00-7:00 a.m.	0.1	0.4	2.9	0.2	1.0
7:00-8:00 a.m.	1.4	8.0	7.3	2.4	2.8
8:00-9:00 a.m.	9.6	12.2	11.8	14.0	7.7
9:00-10:00 a.m.	14.4	18.7	19.4	15.4	16.5
10:00-11:00 a.m.	16.6	16.5	19.7	18.1	18.1
11:00 a.m.-12:00 noon	13.4	13.4	15.3	12.4	14.6
12:00-1:00 p.m.	11.0	8.7	7.6	8.6	11.0
1:00-2:00 p.m.	11.4	9.2	7.5	10.8	10.6
2:00-3:00 p.m.	11.9	7.0	4.3	10.0	10.4
3:00-4:00 p.m.	9.9	5.9	4.2	7.4	7.1
4:00-5:00 p.m.	0.3	–	–	0.5	0.2

Figure 1. Probability of double-parking by PUD vehicles.

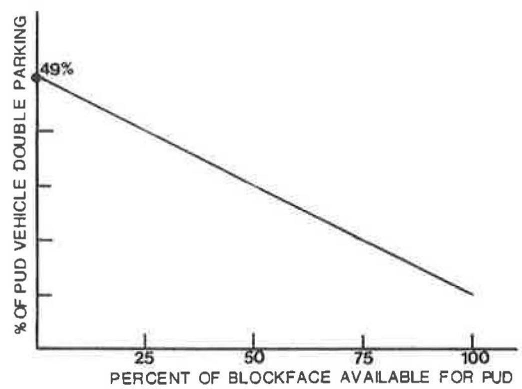

Figure 2. Relationship among number of double-parkers, street traffic volume, and expected arterial level of service.

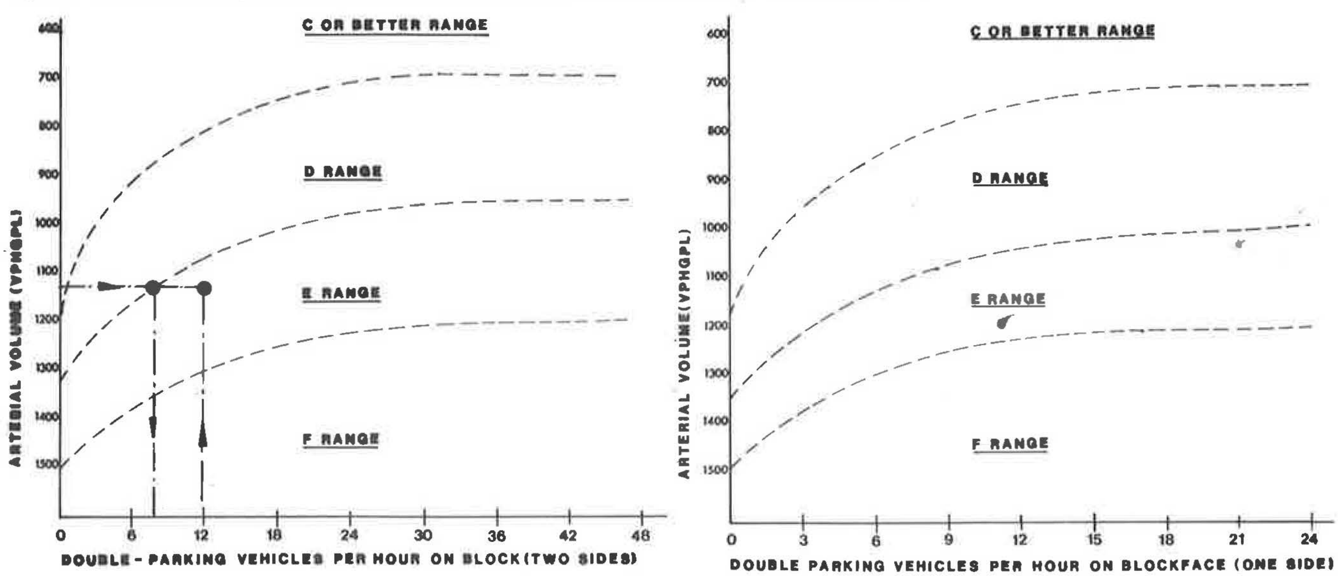

Table 3. Percentage of curb space needed on both sides of a one-way arterial.

Traffic Volume (vehicles/h of green/lane)	Level of Service	PUD Demand (vehicles/h) per Block[a]						
		10	20	30	40	50	60	70
700	C[b]	0	0	0	0	0	10	20
	D[b]	0	0	0	0	0	0	0
800	C	0	0	40	60	70	80	90
	D	0	0	0	0	0	0	0
900	C	0	60	80	90	100	100	NS
	D	0	0	0	0	0	0	0
1000	C	70	100	NS	NS	NS	NS	NS
	D	0	0	0	20	40	60	70
1100	C	100	NS	NS	NS	NS	NS	NS
	D	0	30	60	80	90	100	100
1200	C	NS	NS	NS	NS	NS	NS	NS
	D	50	80	100	NS	NS	NS	NS
1300	C	NS	NS	NS	NS	NS	NS	NS
	D	NS	NS	NS	NS	NS	NS	NS

Note: NS = no solution for conditions.
[a]Both sides of street. [b]Represents the upper limit of each level of service.

Table 4. Percentage of curb space needed on one side of a two-way arterial.

Traffic Volume (vehicles/h of green/lane)	Level of Service	PUD Demand (vehicles/h) per Block[a]						
		5	10	15	20	25	30	35
700	C[b]	0	0	0	0	0	10	30
	D[b]	0	0	0	0	0	0	0
800	C	0	0	20	40	60	70	80
	D	0	0	0	0	0	0	0
900	C	0	30	60	80	90	100	100
	D	0	0	0	0	0	0	0
1000	C	0	60	80	90	100	100	NS
	D	0	0	0	0	0	10	20
1100	C	70	100	NS	NS	NS	NS	NS
	D	0	0	10	30	50	60	70
1200	C	NS	NS	NS	NS	NS	NS	NS
	D	0	30	60	80	90	100	100
1300	C	NS	NS	NS	NS	NS	NS	NS
	D	70	100	NS	NS	NS	NS	NS

Note: NS = no solution for conditions.
[a]One side of street. [b]Represents the upper limit of each level of service.

obtained. Under such no-solution scenarios, additional strategies must be considered.

Example

The field conditions are as follows. The estimated PUD traffic to the block from 9:00 to 10:00 a.m. is 30 vehicles; the street is a one-way arterial that has three through lanes plus parking; the traffic volume is 1850 vehicles/h; arterial G/C = 0.55 (where G = green time and C = cycle time); there is 10 percent available PUD space on one side of the street; there is 30 percent available PUD space on the other side (due to a far-side bus stop); and the block length is 135 m.

To determine the present level of service and find the curb-space PUD needs necessary to achieve service-level-D operation on the arterial during that period, take the following steps:

1. Calculation of traffic volume in vehicles per hour of green per lane gives the following: (1850/3) x (1/0.55) = 1121 vehicles/h of green/lane.
2. By assuming an even distribution of PUD demand on both sides of the street, the estimated number of PUD double-parkers during the hour from Figure 2 is 12. Also, from Figure 2 it is seen that for 12 double-parkers/h and 1121 vehicles/h of green/lane, the one-way arterial operates in the service-level-E range.
3. The review of Figure 2 indicates that only a modest improvement is needed from 12 to 8 double-parkers to reach the service-level-D border. Table 3 shows that, for 30 PUD vehicles/h and 1121 vehicles/h of green/lane, the objective can be reached by providing 60 percent of curb space on both sides of the street for PUD use. Thus, to achieve this modest reduction in double-parkers, a sizeable amount of curb space is required.
4. The allocation of this space should be done on the basis of demand, in which the downstream ends of the block take the highest priority, the upstream ends take second priority, and the midblock section takes the lowest priority for allocation of space. In providing curb space for goods movement, ensuring that a lane blockage does not occur on the downstream approach to the intersection is of critical importance. Therefore space should be allocated there first for maximum effectiveness (1).

The example shown considers that there is about equal PUD demand on both sides of the street. If the PUD demand on one side is significantly higher than it is on the other side (more than 70 percent to 30 percent), the blockage pattern becomes similar to that of a two-way street and Table 4 would be more appropriate for analysis. In addition, the minimum-size curb-space allocation for PUD should be 14.5 m, except at corners, at which the minimum allocation acceptable would be 10 m.

The implementation of this curb-management strategy requires the acquisition of hourly PUD demand data either by using field observers or by using the generation equations and hourly arrival patterns developed with this report. In addition, traffic volumes and signal splits should be known, as well as the use of existing curb space (whether or not it is available for PUD use).

Signing of Curb Use and Enforcement

The conventional method of rationing curb space for PUD use is to designate that space as a truck loading zone by means of the appropriate signing. In New York City, the sign would read NO STANDING EXCEPT TRUCKS LOADING AND UNLOADING. Most cities would have similar signing, whereas some other cities would allocate the curb space just as a loading zone (and not differentiate passengers from freight). The objective of such signing is to provide curb space for the exclusive use of loading or unloading and to allow no parking for any other vehicles and no standing for any nonloading vehicles. There are two main problems with this type of signing that contribute to arterial conflicts, especially in off-peak traffic periods. First, the percentage of trucks in the total vehicle population is rising and is expected to continue to rise into the short-term future. The identification of a truck (except large ones) as a PUD vehicle is not obvious to a parking-enforcement agent, and non-PUD parking in the designated space will continue to occur. Second, when a PUD vehicle stops in a truck loading zone or any other parking space not "pressurized" by a parking meter or other such device, the total dwell time of the stop increases greatly (1). This increase is attributable only to the type of parking. Therefore, since there is increased time of occupancy, the loading zone is less effective.

An objective of curb-space management and control is to minimize the occupancy time of the designated users and eliminate (if possible) the nondesignated users. Elimination of all designated truck loading zones at a problem location appears to be a strategy capable of achieving the desired objective. Those areas intended for PUD use would be signed and controlled (enforced) as no-parking zones. PUD vehicles that are loading or unloading freight would be considered as standing (and therefore legally stopped), whereas all other vehicles would obviously be illegally stopped and subject to a summons. The table below summarizes the research findings with respect to PUD dwell time (1). The introduction of pressurized parking could reduce the mean dwell time in loading zones by about 30 percent and also reduce the non-PUD parking in those spaces. The combination of these improvements would directly result in less PUD double-parking. (The legally curb-parked mode includes truck loading zones.)

Parking Mode	Mean Dwell Time (min)	Sample Size
Double-parked in moving lane	11.5	1398
Curb-parked legally	19.5	5046
Curb-parked illegally	13.8	1697

The proposed strategy would only be implemented in the highest-density areas, and conventional loading-zone signing would remain in other areas. This dual system of signing areas as intended no-parking zones or as designated loading zones has two advantages. First, drivers of PUD vehicles would be able to recognize the existence of the designated spaces (signed LOADING ZONE) and therefore be less likely to use the no-parking zones. The second advantage is that, when drivers need time for personal reasons (coffee break, lunch, telephoning the terminal, etc.), the likelihood that they will take this time at a no-parking zone would be less than it would in a loading zone.

The major disadvantage of the no-parking-zone concept is the fact that all PUD vehicles could be ticketed if the driver is not with or close to the vehicle. However, it is the mere existence of such an enforcement option (even though it may rarely be exercised) that produces the expected operational benefits. The reduction in non-PUD truck parking would also be a positive benefit of the enforcement option.

A loading zone signed with no-parking signs would have at least 30 percent more capacity than a conventionally signed truck loading zone. For the example used in the curb-management section, it was determined that 60 percent PUD-available space was necessary to meet the level-of-service objective, a large increase over the existing 20 percent total. If the new 40 percent loading-zone space were to be signed with no-parking signs, only about 30 percent (40 percent divided by 1.3) would actually be necessary to achieve the desired objective.

The implementation of such a strategy should have the highest priority on main streets in the central business district (CBD) and on blockfaces where existing loading-zone space is fully used. The second priority would be in the CBD on cross streets where loading zones exist at the corners of a major arterial. The third priority would be on cross streets in the CBD where the curb space is designated for use by queued vehicles at loading docks. In all cases, the existence of conventionally signed, designated loading zones must be maintained in noncritical areas.

Signal-Timing Adjustments

The friction because of traffic problems caused by PUD vehicles and pedestrian traffic on a block reduces the intersection service volumes. For many arterials, there is a constant G/C, and for several intersections neither cross-street volume nor pedestrian needs can support this uniformity. The opportunity may therefore exist to increase arterial G/C in order to increase the service volume of a congested block or blocks to the level of upstream and downstream blocks.

The target of this strategy would be to determine the required arterial green per cycle in order to achieve a desired level of service on a problem segment. This level of service should logically be the same as that on the upstream blocks. The material developed in this research has consistently defined volume in vehicles per hour of green per lane. Therefore, the identification of a service volume at various levels of service can readily be translated into a G/C required if the actual traffic volume is known.

Table 5 was prepared to show the traffic volume at upper service levels C and D for various totals of PUD curbside generation and the percentage of available curb space for PUD vehicles. The traffic engineer or planner can therefore use this table to find the necessary amount of arterial green phase necessary to accommodate the actual traffic volume on the street at the desired level of service.

Example

For the same base conditions presented in the curb-management example, the traffic engineer wishes to provide service-level-D operation through signalization. The previous analysis concluded that 1121 vehicles/h of green/lane operated at service level E. The average amount of the block available for PUD use is 20 percent (average of 10 and 30 percent).

Table 5 shows that, for a demand of 30 PUD vehicles/h and 25 percent available PUD space, the service volume at service level D is 1025 vehicles/h of green/lane. Therefore, for an actual volume of 1850 vehicles/h on three through lanes (i.e., 617 vehicles/h of green/lane), the major-street green per cycle should be raised from 0.55 to 0.60 ($617 \div 1025$). In terms of solution scale, this G/C increase would be more attractive than an elaborate curb-space management plan.

There are various combinations of curb-management, signing, and signal adjustments that can produce the desired operating level of service. In order to implement such a signal strategy, it is necessary to inventory (or calculate) PUD hourly demand, count main-street traffic, and determine what curb space is already available for PUD use. These basic inputs will allow the determination of a target service volume from which the required split can be calculated. For computer-traffic-controlled signal systems, programming signal splits for specific periods of the day is facilitated.

Temporal Control of Curb Lane

The need to provide additional lanes to ease peak-period traffic flow is apparent in most downtown areas. The need to provide curbside express bus lanes (or contraflow lanes) is also present in many larger cities (generally those that also have goods-movement problems). In those cities where alleys parallel the main arterials, provision of the curb lane for non-PUD operations is greatly facilitated. In cities where no alternate PUD stopping space exists, the effectiveness of such a curb-lane strategy would be reduced, since all that is needed to disrupt flow is a single blockage per three-block segment. The research on this project also showed a marked variation among cities in terms of compliance

Table 5. Traffic volume (vehicles per hour of green per lane) at service levels C and D on one- and two-way arterials.

PUD Demand (vehicles/h)	Level of Service	PUD Space Available[a] 0	25%	50%	75%	100%
One-Way Arterials						
10	C[b]	900	925	1000	1050	1125
	D[b]	1125	1150	1175	1225	1275
20	C	850	875	900	950	1075
	D	1075	1075	1100	1150	1225
30	C	775	800	850	900	1025
	D	1000	1025	1050	1100	1200
40	C	750	775	800	850	975
	D	975	1000	1025	1075	1175
50	C	725	750	775	825	950
	D	975	1000	1000	1050	1150
60	C	700	750	775	800	925
	D	950	975	1000	1025	1125
70	C	700	725	750	775	900
	D	925	950	975	1025	1100
Two-Way Arterials						
5	C[b]	975	1025	1075	1125	1175
	D[b]	1250	1275	1300	1325	1350
10	C	850	925	950	1025	1125
	D	1150	1200	1225	1275	1325
15	C	800	825	875	975	1075
	D	1100	1125	1175	1225	1300
20	C	750	775	825	925	1025
	D	1050	1075	1125	1200	1275
30	C	700	725	775	850	975
	D	1000	1050	1075	1125	1250

[a] Averages for both sides or one side of the street, depending on whether street is one-way or two-way arterial, respectively.
[b] Represents upper limit of each level of service.

with a no-stopping curb-lane control.

The research has developed general guidelines for implementing a strategy for temporal displacement of the curb lane based on providing the carrier with the option of compliance without rendering the PUD process inefficient. These guidelines apply to cases in which no alley is available.

1. Since traffic does not generally peak in both directions at the same time, PUD operations in the nonpeak traffic direction should be encouraged through the provision of loading zones. This would apply to alternate parallel one-way arterials or to alternate-direction two-way arterials. It should be noted that PUD activity is negligible after 3:00 p.m. and therefore the morning peak period is the one to which the solution should be structured.
2. In addition, for blockfaces that normally generate 5-10 PUD operations/h, 15 m of available curb loading space should be provided at the corners of each cross street. Normal enforcement of parking regulations would suffice.
3. For blockfaces that normally generate more than 10 PUD operations/h during the strategy period, all above space requirements should be implemented, plus heavy enforcement (5-min coverage).
4. For an arterial segment that has more than 20 PUD operations/h on one or more blockfaces, the effectiveness of the strategy would be such that it should generally not be considered for implementation.

PUD Demand-Reduction Methods

The total number of possible conflicts between PUD traffic and pedestrians can also be reduced. This would be either by reducing the amount of curbside PUD operations in a problem period or by reducing the traffic volume in that period. The method generally available for PUD demand reduction is land-use control.

Land-use control is generally a long-term solution. On problem blocks, land use would be promoted that generated lower amounts of PUD trips, provided off-street loading for these trips, or both. For instance, the zoning of a warehousing section to permit loft residential dwelling would drastically reduce PUD demand on that block over time. Conversely, the zoning of that warehousing block to retail or commercial uses would increase PUD demand. An office building reconstructed to provide off-street loading facilities should also reduce curbside demand. The traffic planner should review zoning changes on principal arteries to evaluate their effect on PUD generation and curbside operations.

Short-term land-use control for PUD should concentrate on removing food establishments (retail and prepared) from principal arteries that have PUD-related congestion. The PUD arrival patterns and demand rates associated with this land use put it in direct conflict with the morning peak traffic period. It would be a land-use objective to not allow retail food establishments (supermarkets and drugstores) on principal arterials unless they are accessible from the rear. It would also be a land-use objective to restrict prepared-foods establishments on congested blocks unless access is available from a side street.

If the traffic planner can determine the expected reduction in PUD demand over time (during problem periods), the basic tables and figures presented in this paper will allow estimation of level-of-service changes.

Other Traffic Engineering Strategies

Three traffic engineering strategies are presented in this section: reduce arterial traffic, provide wider parking lanes, and relocate bus stops. Each is presented with a short description and a brief effectiveness evaluation.

Reduce Arterial Traffic

One option to reduce traffic-pedestrian conflicts on arterials is to reduce the number of vehicles without changing the goods-flow process. This can be done by diverting vehicles to parallel arterials by controlling turns in critical periods. That is, vehicles would be allowed to turn off but not onto the arterial in a problem segment. This technique, it is estimated, could reduce volume by 10-15 percent throughout the problem area. Figure 2 shows that such a reduction in volume can translate into real changes in level of service on the arterial. This traffic-reduction measure can be implemented independent of all strategies and therefore compound benefits. In the example being used throughout this paper, in order to achieve service-level-D operation, control of turns to reduce traffic from 1850 vehicles/h to 1780 vehicles/h (4 percent reduction) would be required. The traffic engineer would determine the method of achieving this reduction.

Provide Wider Parking Lanes

The lane striping on arterials could be used to diffuse traffic-pedestrian conflicts by increasing the size of one or both curb lanes to accommodate both the parked automobile and the double-parked PUD vehicle. Due to the fact that fewer than 1 in 20 PUD vehicles are tractor-trailers in the CBD, a 5-m curb lane can accommodate an automobile and an efficiently double-parked PUD vehicle. The increase in curb-lane width would be 2 m. It would be very rare to find an arterial wide enough so that 4 m (enough for two double-parking curb lanes) could be subtracted from the width of the through lanes without reducing the number of these lanes. However, it does appear feasible to provide the wider curb lane on one side of the arterial, the side that generates most of the PUD demand. For a two-way arterial, it would be the side that peaks in the morning. The following example shows the effectiveness of such a double-parking curb lane on one side of an arterial:

Suppose that there is an 18-m-wide one-way arterial with three through lanes and two parking lanes and each lane is 3.60 m. PUD demand in 1 h is 30 vehicles to both blockfaces, split 60-40 percent (18 on one side and 12 on the other), 20 percent of both blockfaces is available for PUD operations, and the volume is 1121 vehicles/h of green/lane. The problem is to find the existing level of service and resultant level of service of a double-parking lane.

Since this example is the same as that being used throughout this paper, the existing arterial operates at service level E. The proposed restriping plan would call for a 5-m double-parking curb lane, three 3.35-m travel lanes, and a 3.25-m parking lane. The 5-m lane would logically be placed on the side of the street with the 18-PUD/h demand. Therefore, the problem would now be reduced to having 12 PUD vehicles operate on one side of an arterial and no blockages on the other side (blockage pattern of a two-way arterial). Figure 2 shows that for a volume of 1121 vehicles/h of green/lane and five double-parkers per hour (12 PUD x 0.41; see Figure 1) the arterial would operate at service level D. Further, Table 4 shows that for a two-way arterial generating 12 PUD/h and at 1121 vehicles/h of green/lane, no curb space is needed to achieve service level D. Therefore, if that level of service is the strategy objective and if the 20 percent available PUD space is really a dedicated truck loading zone, as a part of implementing this strategy that dedicated space could be turned over to curbside automobile parking.

The implementation of such a double-parking lane strategy would produce more-effective results if the PUD demand is consistently biased toward one side of the arterial and would be rendered ineffective with radical shifting of PUD demand from one side to the other over the problem arterial segment. Therefore, a careful inventory of PUD demand should be a prerequisite to considering this strategy.

Relocate Bus Stops

Bus stops are generally placed every three or four blocks on an arterial. The placement of these bus stops is usually on the far side of an intersection, since this results in shorter lengths of required curb space. The use of bus stops for PUD operations is an ongoing process in downtown areas today. Therefore, the question becomes whether a bus-stop location can be coordinated with PUD curb-space needs. Research (1,2) has clearly shown that elimination of the downstream approach-lane double-parker would provide markedly higher benefits than reducing double-parking elsewhere on the blockface. Therefore the ideal placement for a bus stop from the PUD perspective would be at the near side of an intersection.

It can be argued that planning bus-stop space for PUD use is not good practice. However, because this bus-stop space is now being used in some areas and because the value of such space lessens in off-peak periods (when PUD operations peak), then in order to make better transportation use of existing facilities, near-side bus stops must be considered on arterials when PUD problems arise. In order to lessen the interference with right-turning traffic, near-side bus stops should be coordinated with the one-way pattern (if it exists) of the cross streets.

The quantitative effect of near-side versus far-side bus stops cannot be determined here because of the many non-PUD dependent variables, which include enforcement of bus-stop parking regulations, difference in bus drivers' habits in stopping at curbside (which may cause traffic interference), frequency of bus service, as well as the PUD variables such as demand and other available curb space. It is evident, however, that near-side bus stops will lower the probability of the PUD blockages that most adversely affect traffic operations, and therefore implementation of such a strategy would be beneficial to improving speed and level of service.

RANKING OF TSM STRATEGIES

It is clear that the specific problem situation in the field will dictate the most-effective strategy. The basic information provided in this paper allows the traffic engineer or planner to evaluate alternative options for improvement. The strategies presented in this paper are all of very low capital intensity, and the selection of a strategy would not generally be influenced by cost.

The research has pointed out that strategies that tolerate normal PUD characteristics are more effective than those that try to alter these characteristics. In the curb-management example, it was shown that excessive spatial requirements were necessary to achieve the level-of-service objective, whereas subsequent strategies achieved the objective in a more-efficient way. The following is a general ranking of strategies. The ranking is based on the expected effectiveness of the strategy under normal downtown conditions. However, field conditions should dictate to the traffic engineer which strategy is most effective. The ranking is segregated by severity of the problem; however, combinations of the various strategies are highly recommended.

Moderate PUD Problems	Severe PUD Problems
Change signal timing	Provide double-parking lane
Provide no-parking signing	Control turns
Provide double-parking lane	Manage curb space
Control turns	Provide no-parking signing
Relocate bus stops	Relocate bus stops
Manage curb space	Change signal timing

The development and evaluation of strategies by local planners and engineers will be tailored to specific cities and specific problem sites. The data, from which the findings were developed, showed that goods-movement problems are not the same in different parts of the country. The development density of the specific CBD as well as the characteristics of the arterial grid system are the principal differences. Other differences include traffic enforcement, PUD driver habits, and adherence to enforcement. The material presented in this paper is a first step toward understanding and improving the PUD problem; this can markedly improve the surface transportation system in the CBD.

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