MINIMIZING GOODS-MOVEMENT IMPACTS ON URBAN MOBILITY THROUGH SIMULATION

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ABSTRACT

This paper describes the use of simulation techniques in the development of standards for off-street loading facilities for goods distribution in the city center. This work uses a simple GPSS model to quantify queues of trucks and also uses a complex traffic simulator to quantify the "congestion" resulting from the formation of queues at inadequately planned and operated off-street loading facilities. This paper is drawn from research sponsored by The Office of University Research, U.S. Department of Transportation.

INTRODUCTION

There are relevant considerations to justify the provision of off-street loading facilities for pickup and delivery (PUD) vehicles in the city center. These include: the reduction in on-street traffic and pedestrian conflicts, the reduction in visual/aesthetic intrusion, and an improvement in security of the goods. There are also relevant arguements against the provision of off-street loading facilities in the city center. These include: increased cost to the developer (and therefore, to the tenants), the potential access (backing-in) problem, and the truck queues that develop because the facilities are not designed or operated efficiently.

This paper presents a new and practical approach to determining the number of off-street loading berths that should be designed into large newly-constructed goods generators in the city center. This approach produces a result that answers the question: how many loading berths are necessary for a specific generator such that the total costs to society (the relevant portions) are minimized.

ECONOMIC CONCEPT

If a new structure is to be built in the city center, then a total cost function could be formulated, with the number of off-street berths remaining a variable. The costs would be the dollar value of the impacts on Society, the relevant portions of which are presented in Table 1 (Figure 1 shows the graphical representation). The cost function would be in the form:

$$C(b) = c_1(b) + c_2(b) + c_3(b) + \ldots.$$

where b is the number of off-street loading berths

$c_1(b)$, $c_2(b)$, $c_3(b)$ are functions relating number of berths to the cost of impact on the interest groups.

TABLE 1-- "SOCIETY" FOR OFF-STREET LOADING

Interest Group	Severity of Impact when Number of Off-Street Berths are: Sufficient*	Insufficient*
The Carrier	Low	High
Local Traffic	Low	High
The Community	Low	High
Street Parking	Low	High
The Developer	High	Low

*In relation to the formation of queues.

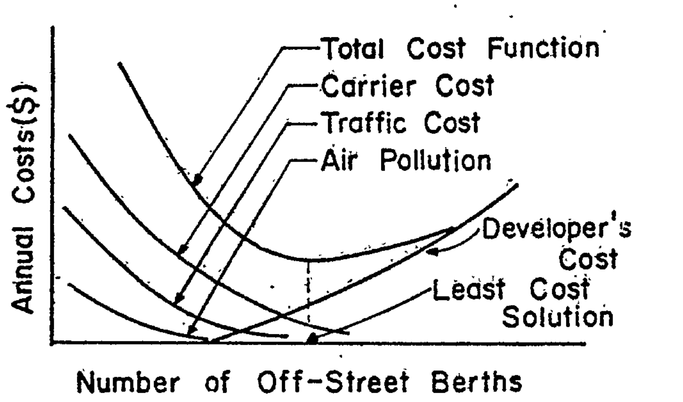


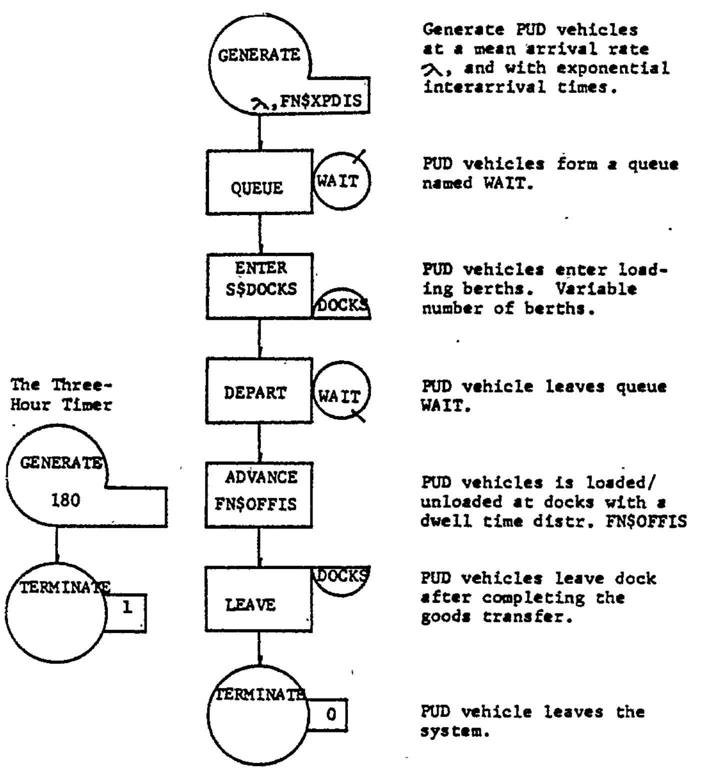
FIGURE 1--TYPICAL COST FUNCTION FOR OFF-STREET LOADING

In order to find the value of "b" that minimizes the above function, one would calculate dC/db, and equate it to zero, solving for "b". However, studies (1,2) have shown that the individual cost functions cannot be expressed algebraically because they are derived from computer simulations. Therefore, "b" is found by solving the above equation for various probable berth conditions and the least cost value would become apparent.

Simulating Carrier Costs

The cost incurred by carriers (and therefore by consumers) at off-street loading facilities is primarily determined by delays while waiting in truck queues. Research (1,2) has shown that the arrival times to loading facilities and the service rate patterns (dwell times) are characteristics of the land use of the specific site. If the dwell time distribution was exponential (or close to it), or if only the one-berth condition is being evaluated, queuing statistics could be generated analytically. However, this is not the case and therefore these queuing statistics must be generated through simulation.

A simple GPSS model was designed for this purpose, the block diagram for which is shown in Figure 2. The use of this type of model provides additional information and data useful in determining costs to other societal elements and will be presented further in this paper.



GPSS MODEL BLOCK DIAGRAM FOR ESTIMATING TRUCK QUEUES

FIGURE 2

The daily queuing statistics are then translated in daily dollars "lost" by using the appropriate value of time. A conservative estimate for this value is $9.00 per hour of delay.

Simulating Developer's Cost

The "cost" to the developer for providing off-street berths includes the construction cost of the facility plus the lost revenue (opportunity lost) had the developer used this space for some revenue generating purpose. The construction cost of the docks minus the construction cost of the revenue-generating facility, when capitalized over the life of the structure is usually not a very sizeable amount and can be neglected in most cases.

The method of calculating developer's cost is to consider that tenants will be willing to pay the cost of providing off-street loading facilities to the extent that these facilities are needed. Thus, the cost to the developer would only be that portion of the business day when the facilities are not utilized. The utilization method for developer's cost would conclude that if a developer provided an off-street loading facility that was occupied 100 percent of the time, the resultant cost would be zero. If the facility was occupied 60 percent of the time, then the cost to the developer would be 40 percent of the opportunity cost.

The GPSS model produces facility utilization statistics that makes calculation of this cost very straight forward. The opportunity cost would be the expected rental charge per square foot, times the area devoted to any specific dock configuration, as well as any normal maintenance and operations cost. In most cities, because docks are on the ground floor, the rental charge is between $10-$20 per square foot. Figure 3 shows typical GPSS output on utilization.

STORAGE	CAPACITY	AVERAGE CONTENTS	AVERAGE UTILIZATION	ENTRIES	AVERAGE TIME/TRAN	CURRENT CONTENTS	MAXIMUM CONTENTS
DOCKS	4	3.877	.969	27	25.851	4	4

QUEUE	MAXIMUM CONTENTS	AVERAGE CONTENTS	TOTAL ENTRIES	ZERO ENTRIES	PERCENT ZEROS	AVERAGE TIME/TRANS	$AVERAGE TIME/TRANS	TABLE NUMBER	CURRENT CONTENTS
WAIT	44	20.783	70	4	5.7	53.442	56.681		43

$AVERAGE TIME/TRANS = AVERAGE TIME/TRANS EXCLUDING ZERO ENTRIES

TYPICAL GPSS OUTPUT FOR UTILIZATION

FIGURE 3

Simulating Traffic Costs

The queuing of vehicles at loading facilities can adversely affect traffic flow, depending on the traffic volume and the street width. Quantifying the impact on traffic is most tedious, and requires the use of the Network Simulation Model UTCS-1(3). The cost of the lane blockages is borne by the affected traffic and the community through increased delay, air pollution and road user costs. It has not been substantiated that accident occurrence increases under these low speed conditions, but one would expect such an increase.

The UTCS-1 simulates the effect of the lane blockage on traffic characteristics for a given set of network conditions, such as traffic volume, block length, cycle length, etc. All impacts are incremental impacts caused by the lane blockage as, in normal traffic, delays are normally encountered. The delays of concern here are the delays over and above those normally occurring.

The increased operating costs due to the incremental congestion are primarily attributable to the increased number of stops and starts caused by the blockage. These increased number of stops result from the maneuvering, as well as from missed progression in the signal system. The UTCS-1 outputs data on the number of stops, as well as average travel speed before, during and after the blockage. Figure 4 is a typical output from UTCS-1 and shows the aggregate statistics for a three minute simulation period.

CUMULATIVE STATISTICS SINCE BEGINNING OF SIMULATION

PRESENT TIME IS 8 15 0. ELAPSED SIMULATED TIME IS 15 MINUTES, 0 SECONDS

LINK STATISTICS

VEH-MILES	VEH TRP	MOV. TIME V-MIN	DELAY TIME V-MIN	M/T	TOTAL TIME V-MIN	T-TIME / VEH. SEC	T-TIME/ VEH-MILE SEC/MILE	D-TIME / VEH SEC	D-TIME/ VEH-MILE SEC/MILE	PCT STOP DELAY	AVG. SPEED MPH	AVG. OCC.	STOPS /VEH
53.3	563	110.4	47.4	0.70	157.8	16.8	177.6	5.1	53.3	20	20.3	10.4	0.12
53.3	563	110.2	25.6	0.81	135.7	14.5	152.8	2.7	28.8	22	23.6	9.0	0.10
53.3	563	110.0	21.7	0.84	131.6	14.0	148.1	2.3	24.4	15	24.3	8.8	0.08
23.7	556	49.4	34.0	0.59	83.4	9.0	211.3	3.7	86.2	58	17.0	5.6	0.21
5.2	554	10.9	17.2	0.39	28.1	3.0	321.1	1.9	196.3	22	11.2	1.8	0.12
23.6	553	48.7	73.0	0.40	121.7	13.2	310.0	7.9	186.0	65	11.6	8.1	0.23
478.4	500	986.9	308.2	0.76	1295.1	155.4	162.4	37.0	38.7	38	22.2	86.3	0.63
46.0	440	95.4	30.1	0.76	125.6	17.1	163.8	4.1	39.3	10	22.0	8.4	0.02

TYPICAL UTCS-1 OUTPUT

FIGURE 4.

The delay and increased operating costs can be translated into their dollar equivalents by using appropriate factors. This work uses $2.20 per person hour for passenger delays. The figure for commercial-vehicle value of time is given previously. For operating costs, values of $6.00 per 1000 stops for autos and $12.00 per 1000 stops for trucks are used. These figures are updates from a 1972 study (4).

Curbside Parking Costs

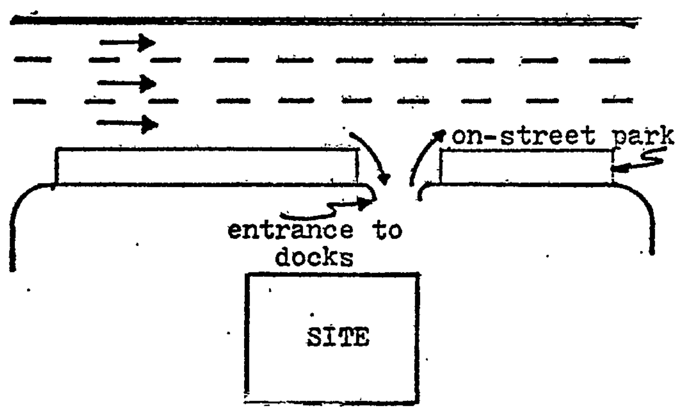
Provision of "standing" space for queued vehicles outside loading docks in order to minimize traffic impact, results in a displacement cost for the curbside auto spaces. As a result, the provision must be made for an equivalent amount of off-street parking spaces, as these vehicles cannot be displaced to other curb space because the supply of these spaces is not expandable. The cost of providing parking spaces for displaced parkers is construction cost, maintenance and operation cost, and land acquisition cost. These off-street parking spaces may be in garages or in parking lots. The annual cost of each displaced auto parking space in the city center is $8,000 to $10,000 per space. The number of spaces would be determined by the truck queuing conditions.

Other Costs

Other costs incurred in this process fall in the category of "unquantifiable". Such aspects as air and noise pollution caused by different dock configurations cannot realistically be translated into dollar equivalents. The same is true for aesthetic considerations.

CASE STUDY

The case study site is an 800,000 square foot office building located on a 600 foot block. The abutting street has three lanes in each direction and has metered parking at curbside. The building generates about 64 trucks on the typical day and the arrival pattern is that typical of office building (2). Figure 5 depicts the case study site.



CASE SITE SKETCH

FIGURE 5

Table 2 is a summary of the calculated annual costs for the case study conditions based on the quantification procedures outlined in this paper. The least-cost solution for this case study is 5 off-street berths. Sensitivity analyses were conducted (2) and showed stable conditions with about one berth need for an increase of 25% in generated trucks.

Number of Berths	Carrier Cost ($)*	Traffic/ Parking Cost ($)	Developer's Cost ($)	Fuel Cost ($)	Total ($) Utilization Cost
2	190,800	67,100	30,000	4700	263,500
3	99,600	40,700	40,000	2000	153,100
4	29,400	14,400	50,000	700	70,400
5	6,300	3,600	60,000	200	43,000
6	-	400	70,000	-	47,900
7	-	1,000	80,000	-	54,600
8	-	-	90,000	-	61,200

*based on $9/hr of waiting

TOTAL ANNUAL COST FUNCTION AND COMPONENTS

TABLE 2

SUMMARY

As a gauge of comparison, if the case study office building was constructed in the Atlanta city center, ten berths would be required by that city's code. If the building were in Pittsburgh six berths would be adequate while, in Cincinnati, four berths would satisfy that city's requirements. Not only does this new approach produce a reasonable result with respect to existing requirements but widespread use will make these highly divergent city standards more uniform.

The next step in this process is the development of a users manual for local planning agencies as the computing facilities to run all models for each newly constructed building is impractical. The Polytechnic is now preparing such a manual.

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