845

TRANSPORTATION RESEARCH RECORD 845

Transportation System Management and Parking

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TRANSPORTATION RESEARCH BOARD
NATIONAL RESEARCH COUNCIL

NATIONAL ACADEMY OF SCIENCES
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Contents

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Estimating Users and Impacts of a Regional Alternative Work Schedule Program

EMERY J. HINES

This paper presents the findings of a study that estimates (a) the number of firms in the Baltimore metropolitan area that might implement an alternative work schedule program and (b) the reduction of vehicle miles of travel, emission of automobile pollutants, and gasoline consumption that could occur if alternative work schedules were implemented on a large-scale basis in the Baltimore area. The assumptions used to estimate the market for new alternative work schedule users and potential impacts were based on the survey responses of 828 Baltimore area firms and the alternative work schedule experiences of other cities. Employer responses to the regional survey show that nearly 25 percent of the firms are not using alternative work schedules, but it would be possible for them to change their schedule. Based on these responses and the experiences of other areas that have implemented areawide alternative work schedule programs, an estimated 260 firms in the Baltimore metropolitan area that employ 100 or more people could implement a flextime, staggered work hours, or compressed workweek program. As many as 84 000 employees could be involved in these alternative work schedule programs. These employees might reduce the distance that they commute annually by 26 million miles. This, in turn, would reduce the amount of (a) hydrocarbon emissions by 36 Mg, (b) carbon monoxide emissions by 313 Mg, (c) nitrogen oxide emissions by 57 Mg, and (d) gasoline consumption by 1.2 million gal.

Commuters in the Baltimore metropolitan area face the effects of peak-period or rush-hour congestion twice a day, five days a week. Streets and highways are filled with bumper-to-bumper traffic. Buses are crowded beyond capacity. Elevators, corridors, and parking lots are overcrowded. Noise and noxious odors abound. A trip on the Jones Falls Expressway (I-83), the beltway (I-695), or a ride on a local bus during rush hour makes one wonder how the rush hour got its name. Alternative work schedules (AWS) offer potential solutions to some transportation problems related to congestion.

AWS

AWS are options that can be used by employers to change the traditional times when employees report to and leave from work. AWS options may change one or more of the following:

1. Starting time,
2. Quitting time,
3. Number of hours in a day, and
4. Number of days in a week.

The most popular AWS strategies are the compressed workweek (CWW), flexible work hours (FWH), and staggered work hours (SWH).

CWW

Under a CWW system, employees work longer days and shorter weeks. The following are the most widely used forms of CWW:

1. Four-day workweek, 10-h days;
2. Three-day workweek, 12-h days; and
3. Five-four-nine plan, 9-h days; employees work five days one week and four days the next week.

A one-year CWW experiment in the Denver area was recently completed. The project involved more than 7000 employees at 35 federal agencies. Key findings of the Denver experiment (1) were that peak period arrivals and departures were reduced by 25 percent. Weekly household vehicle miles of travel (VMT) were reduced by 16 percent. Weekend automobile emissions were reduced by 28 percent, and nonwork VMT were also reduced. The study concluded that traffic flow in the central business district (CBD) could be improved if the CWW concept were extended to a larger number of CBD employers.

FWH

Flexible work hours (FWH), or flextime as it is often called, provides employees an opportunity to choose their work hours. The typical FWH system uses two types of time: coretime and flextime. Coretime is when all employees are required to be on the job. Flextime contains preestablished limits (e.g., 7:00 to 9:30 a.m. and 3:00 to 5:30 p.m.) from which employees can select their starting and quitting times.

A flextime experiment conducted at the Social Security Administration's Woodlawn office in Baltimore County (2) found that productivity improved by 21.6 percent. Overtime hours were reduced by 63 percent. The use of annual leave for short absences declined substantially, and 68 percent of employees liked their job better after the flextime experiment began. Social Security Administration management personnel were so happy with the success of the Woodlawn experiment that flextime has been extended to all of their other Baltimore area offices.

SWH

Under a SWH system the starting and stopping times of groups of employees within a firm or groups of firms within a given area are varied to avoid having the entire work force arrive and depart at the same time. The time intervals are fixed and determined by the employer.

One of the early SWH experiments was implemented in New York by the Downtown Lower Manhattan Association and the Port Authority of New York and New Jersey. This SWH program involved 220 000 employees at 400 firms. Some of the key findings of this project (3) were that travel demand was reduced by 26 percent during the peak 10-min period in the morning. Travel demand during the peak 15-min period in the evening was reduced by 25 percent. Eventually, the evening peak demand was flattened to the same level for approximately 45 min. About 22 percent of the work force reported an increase in job effectiveness. This experiment was so successful that it has become a national model for SWH implementation.

Key Results of Regional Employer Survey

Approximately 30 percent of the survey respondents are currently using some type of AWS. Nearly 25 percent of the firms reported that, although they are currently not using an AWS, it would be possible for them to change their current work schedule. The survey results seem to indicate that larger firms are more willing than smaller firms to change their work schedules.

According to the survey respondents, the peak period of arrivals in the morning extends from 7:00

to 9:00 a.m., and in the evening the peak period of departures extends from 3:30 to 5:00 p.m. The greatest number of arrivals during a 15-min interval in the morning occurs between 8:00 and 8:15 a.m. (Actual on the road peak-period traffic begins earlier and stops later than the peak arrival and departure times referenced in this report.) The evening peak-within-the-peak occurs between 4:00 and 4:15 p.m. Although recommendations for reducing peak travel demand at a particular location must by necessity be site specific, there appears to be a significant potential for flattening the morning peak.

Potential AWS Impacts

Based on the survey results and the experiences of other areas that have implemented areawide AWS programs, as many as 84 000 employees at 260 firms could become new AWS users. Also, as a result of increased opportunities to rideshare, VMT during peak commuting periods could be reduced by as much as 103 000 miles daily or nearly 26 million miles yearly.

The estimated VMT savings could also result annually in the following reductions:

1. 36 Mg of hydrocarbons,
2. 313 Mg of carbon monoxide,
3. 57 Mg of nitrogen oxides, and
4. 1.2 million gal of gasoline.

EMPLOYER SURVEY

A survey of 1785 employers was conducted to assess the potential for implementing AWS in the Baltimore metropolitan area. A primary objective of the survey was to investigate employer attitudes concerning AWS. The survey also sought to (a) assess the potential for implementing employer-based parking management practices and (b) identify general transportation concerns of the business community in the Baltimore area. In addition, the survey sought to identify employee starting and quitting times, employer attitudes toward various AWS strategies, and subareas or corridors where it might be useful to implement an AWS project.

Survey Methodology

Three inventories were used to select the firms that were surveyed:

1. COMPUTERIDE's list of major employers;
2. Mayor's Office of Manpower Resources' report, Industrial Parks of Metropolitan Baltimore; and
3. Regional Planning Council's master establishment file (MEF).

COMPUTERIDE, the regional ridesharing program, has compiled a list of 100 major employers for use in its outreach efforts. Each firm on the list has a minimum of 500 employees. A key contact person (often the president or highest executive officer) has been identified at each of these firms. A letter from the Regional Planning Council's executive director was sent to each of these businesses to request that the firm complete the questionnaire and return it within 10 days in a postage-paid envelope.

Since AWS can be implemented effectively at multiple-employer sites, major industrial parks in the Baltimore region were also surveyed. A major industrial park was defined as a site that (a) is listed in Industrial Parks of Metropolitan Baltimore, (b) is operational in 1978, and (c) contains a minimum of 10 firms and 1000 employees.

Ten industrial parks were identified that met these criteria:

1. Sinclair Lane Industrial Park (Baltimore City),
2. Baltimore-Washington Science and Industry Center (Anne Arundel County),
3. Parkway Industrial Center (Anne Arundel County),
4. Chesapeake Park, Inc. (Baltimore County),
5. Hunt Valley Business Community (Baltimore County),
6. Meadows Business Park (Baltimore County),
7. Owings Mills Industrial Park (Baltimore County),
8. Security Industrial Park (Baltimore County),
9. Guilford Industrial Park (Howard County), and
10. Oakland Ridge Industrial Center (Howard County).

In addition, the state office complex at Preston and Eutaw Streets was surveyed as a multiple-employer site.

After the 10 industrial parks were selected, Stewart criss-cross directories were used to verify addresses for the survey's mailing. The telephone directory for state agencies was used to verify mailing addresses for agencies located in the Eutaw-Preston Streets office complex. A total of 575 questionnaires were sent to the 11 multiple-employer sites.

MEF was used to identify the final group of survey participants--firms that employ 20 or more persons. The MEF is a tool used by the Regional Planning Council to inventory and monitor the number, type, and location of businesses in the Baltimore metropolitan area. The MEF inventories all firms that have salaried employees and represents the universe of employers in the Baltimore metropolitan area.

The MEF was used to identify a stratified (by jurisdiction) random sample of employers in the Baltimore Region that have more than 20 employees. Twenty employees was established as a minimum category of firm size for two reasons. First, firms of this size account for more than 81 percent of the total regional work force (see table below). Second, alteration of the work schedules at firms with less than 20 employees would probably have a negligible impact on the regional transportation system (unless these firms are located at multiple-employer sites). Also, the smaller the firm, the less likely the chance that the employer would be willing to alter the work schedule.

	Firms		Employees	
Size	No.	Percent	No.	Percent
<20 Employees	30 875	82.3	166 379	18.8
>20 Employees	6 644	17.7	719 128	81.2
Total	37 519		885 507	

The next task was to determine how many of the 6644 firms that have 20 or more employees should receive questionnaires. By using the formula (4, p. 110-115)

$$n = [Z\sqrt{p^* (1 - p^*)}/(\bar{p} - p^*)]^2 \quad (1)$$

where

n = sample size,
Z = 1.96 (equals confidence level of 95 percent),
p^* = 0.5, and
$\bar{p} - p^*$ = 0.05 (equals sampling error of ±5 percent),

it was found that 385 responses would produce survey results that could be accepted with 95 percent confidence that the sample error would be ±5 percent. The survey response rate was expected to be about 33 percent. This meant that questionnaires should be mailed to 1167 firms to ensure receiving at least 385 responses. After the 1167 firms had been selected, 57 firms were found to be duplicates from the earlier COMPUTERIDE and industrial park lists. These firms were striken from the random sample list and not replaced.

The sample was weighted in favor of the less-populous jurisdictions to ensure an adequate return from these outlying areas. For instance, 3.68 percent of the 6644 firms that have 20 or more employees are located in Harford County. If this actual percentage were used to determine the number of Harford County survey participants, only 43 firms would be selected. About 14 of these firms would be expected to return their questionnaires--not enough to be significant. The following table compares the jurisdictional composition of the actual employer population (those who have 20 or more employees) with the sample population.

	Actual		Random Sample	
Jurisdiction	No.	Percent	No.	Percent
Baltimore City	3039	45.74	330	28.26
Anne Arundel County	872	13.12	153	13.15
Baltimore County	1975	29.72	315	26.97
Carroll County	183	2.75	123	10.54
Harford County	245	3.68	123	10.54
Howard County	330	4.96	123	10.54
Total	6644		1167	

Survey Results

A total of 828 firms responded to the regional parking and alternative work schedule questionnaire. This represents a response rate of nearly 50 percent. The number of responses to the AWS questions (see Table 1) range from 493 (question 14) to 824 (question 1). As mentioned earlier, the responses to any question answered by 385 firms can be accepted with 95 percent confidence that such responses are representative (within 5 percent) of the entire population. The table below lists the number of responses per jurisdiction.

	Responses	
Jurisdiction	No.	Percent
Baltimore City	221	26.7
Anne Arundel County	96	11.6
Baltimore County	298	36.0
Carroll County	53	6.4
Harford County	53	6.4
Howard County	106	12.8
Total	827	-

The relatively large number of responses from Howard County was the result of a high response rate from two Howard County industrial parks: Guilford Industrial Park and Oakland Ridge Industrial Center.

The 828 survey respondents employ approximately 250 000 employees, nearly 30 percent of the regional work force. Twenty-seven percent of the survey respondents employ fewer than 20 people. Fifty-one percent of the respondents employ between 20 and 199 people; 15 percent have more than 200 and fewer than 1000 workers; and the remaining 7 percent have more than 1000 employees (see Table 2). Of the three firms that employ more than 10 000 people, two are governmental installations and one is a manufacturing concern.

Existing AWS Use and Easiest AWS Strategy to Implement

Nearly 30 percent of the survey respondents are currently using some type of AWS. The table below indicates that the largest percentage of firms that use AWS are located in Baltimore County and Anne Arundel County. Carroll County has the lowest percentage of AWS use.

	Firms Use AWS		
Jurisdiction	No	Yes	Total
Baltimore City	145	70	215
Anne Arundel County	61	29	90
Baltimore County	211	81	292
Carroll County	35	11	46
Harford County	38	13	51
Howard County	75	29	104
Total	565	233	798

When asked to identify the type of AWS that would be easiest for their firm to implement, 54 percent of the survey respondents chose SWH. The CWW was chosen as the easiest to implement by 21.5 percent. Table 3 compares the preferred alternative work option with the respondents' type of business. As would be expected, staggered hours is considered the easiest strategy to implement by manufacturing firms. Firms that engage in finance, insurance, and real estate (F.I.R.E.) consider staggered hours the most difficult strategy to implement. The CWW is considered the easiest strategy to implement by construction firms, but retail firms believe that the CWW would be the most difficult option to implement. FWH are considered the easiest strategy to implement by F.I.R.E. firms. The flexible hours strategy is most difficult to implement by firms engaged in manufacturing.

The easiest to implement (used as a proxy for preferred) AWS option responses were also examined in light of whether or not a firm was currently using any of the AWS options. Nearly two-thirds of the firms that are currently using some type of AWS think that staggered hours is the easiest AWS option

Table 1. Responses per question.

Question	No. of Responses	Response Rate (%)
1[a]	824	99.6
2[a]	819	99.0
3	822	99.4
3a	590	71.3
4	803	97.1
4a	164	19.8
5	200	24.2
6	739	89.3
6a	194	23.4
7	815	98.5
7a	274	33.1
8	751	90.8
8a	267	32.2
9	808	97.7
9a	78	9.4
9b	80	9.7
10	810	97.9
11	787	95.1
11a	221	26.7
12[a]	495	59.8
13[a]	798	96.5
13a[a]	516	62.4
13b[a]	611	73.9
14[a]	493	59.6
15	159	19.2

[a]Question relates to alternative work schedules.

Table 2. Responses by employer size.

Jurisdiction	Responses: 1-19 Employees No.	Percent	20-199 Employees No.	Percent	200-999 Employees No.	Percent	1000-9999 Employees No.	Percent	>10 000 Employees No.	Percent	Total
Baltimore City	35	16	97	44.5	54	24.8	32	14.7	0		218
Anne Arundel County	18	19.4	54	58.1	16	17.2	5	5.3	0		93
Baltimore County	116	39.1	131	44.1	39	13.1	9	3	2	0.7	297
Carroll County	14	26.4	34	64.2	3	5.7	2	3.7	0		53
Harford County	6	11.5	40	76.9	4	7.6	1	2.0	1	2.0	52
Howard County	33	31.1	62	58.5	8	7.5	3	2.9	0		106
Total	222	27.1	418	51.0	124	15.1	52	6.3	3	0.5	819

Table 3. Easiest AWS strategy to implement by type of business.

Type of Business	Compressed Workweek No.	Percent	Staggered Work Hours No.	Percent	Flexible Work Hours No.	Percent	Total
Retail	16	21.3	41	54.7	18	24.0	75
Government	14	28.0	23	46.0	13	26.0	50
Service	19	27.9	29	42.6	20	29.4	68
F.I.R.E.	7	20.0	11	31.4	17	48.6	35
Transportation and utilities	3	16.7	14	77.8	1	5.6	18
Construction	14	42.4	16	48.5	3	9.1	33
Manufacturing	25	23.4	73	68.2	9	8.4	107
Wholesale	7	18.9	20	54.1	10	27.0	37
Agriculture	0	0.0	0	0.0	0	0.0	0
Mining	1	100	0	0.0	0	0.0	1
Other	15	21.4	40	57.1	15	21.4	70
Total	121	24.5	267	54.0	106	21.5	494

to implement (see table below).

AWS Option	Preferred by AWS Users No.	Percent
Compressed week	25	13.3
Staggered hours	123	65.7
Flextime	39	21.0
Total	307	

Nonusers of AWS preferred staggered hours 1.5 times more than their second choice--CWW (see table below).

AWS Option	Preferred by Non-AWS Users No.	Percent
Compressed week	96	31.3
Staggered hours	144	46.9
Flextime	67	21.8
Total	307	

A comparison of the above tables reveals that the percentage of AWS users that prefer SWH is much higher than the percentage of non-AWS users who prefer staggered hours. The percentage of firms that prefer flextime is about the same for both AWS users and nonusers. Non-AWS users; however, are more predisposed toward CWW than AWS users.

Reasons for Not Changing Schedules

Question 13b asked the survey respondents to choose those factors that would prevent them from changing work schedules at their firms. The most often selected factors were (a) decreased efficiency and productivity, (b) difficulties in coordination with other firms, and (c) difficulties in coordination with suppliers.

The list of choices and responses is presented in Table 4. Some of the employer concerns about using AWS could be reduced by a marketing campaign that emphasizes the positive experiences of employers who have implemented an AWS program.

Employee Arrival and Departure Times

As mentioned earlier, a key objective of the survey was to identify when the surveyed work force reports to and leaves from work. The purpose of this objective is to determine the extent to which existing work schedules contribute to peak-period congestion.

Nearly 60 percent (493) of the survey respondents completed the requested information on work schedules. The responses are stratified by jurisdictions and subarea for both total day and peak period. The temporal characteristics described in the following pages are those of approximately 156 500 employees--

Table 4. Reasons why firms cannot change schedules.

Reason	No.	Percent
Difficulties in coordination with other firms	104	17.0
Difficulties in coordination with suppliers	78	12.8
Difficulties in coordination with customers	60	9.8
Difficulty and expense of conversion to another schedule	60	9.8
Decreased efficiency and productivity	120	19.6
Facilities idle for longer periods	19	3.1
Union resistance	42	6.9
Fatigue or negative effects on employees	31	5.1
Other	97	15.9
Total	611	

about 18 percent of the regional work force.

Seventy-one percent of the surveyed work force starts work between 7:00 and 9:00 a.m. Of the remaining work force, 1.2 percent report between 9:01 a.m. and 1:59 p.m., 15.5 percent report between 2:00 and 4:49 p.m., 8.3 percent report between 5:00 p.m. and midnight, and 4.0 percent report between 12:01 and 6:59 a.m. These arrival frequencies are depicted in Figure 1.

Sixty-seven percent of arrivals during the 2-h morning peak period and 47 percent of all arrivals occur between 8:00 and 9:00 a.m. Thirty-three percent of the peak-period arrivals occur between 7:00 and 7:59 a.m. The greatest number of arrivals during a 15-min period occurs between 8:00 and 8:15 a.m., when 34.3 percent of peak-hour arrivals and 24 percent of all arrivals take place. Only 2.6 percent of peak-period arrivals occur between 8:46 and 9:00 a.m. The nine-to-five schedule is clearly not the predominant shift among the survey respondents. Figure 2 depicts the morning peak-period arrivals.

Approximately 65 percent of the surveyed work force depart from work between 3:30 and 5:00 p.m. The remainder of the work force leaves between 5:01 and 6:30 p.m. (1.8 percent), 6:31 p.m. and midnight (13.9 percent), 12:01 a.m. and 2:59 p.m. (12.7 percent), and 3:00 and 3.29 p.m. (6.4 percent). The work force departure frequencies are found in Figure 3.

Approximately 70 percent of departures during the 1.5-h evening peak period and 34 percent of all departures occur between 3:30 and 4:30 p.m. Thirty percent of the evening peak-period departures occur between 4:31 and 5:30 p.m. According to the survey results, the greatest number of employee departures during a 15-min period occur between 4:00 and 4:15 p.m., when 29.2 percent of peak-hour departures and 20 percent of all departures take place. Only 2.2 percent of peak-period departures occur between 5:01 and 5:30 p.m., and only 3.3 percent of peak-period departures take place between 4:31 and 4:45 p.m. Figure 4 depicts the peak-period departures in the evening.

A comparison of Figures 2 and 4 reveals the following information:

1. The evening peak period lasts for 1.5 h (3:30-5:00 p.m.); however, the morning peak period lasts for 2 h (7:00-9:00 a.m.);
2. A large shoulder exists at the end of both peak periods and at the beginning of the morning peak period;
3. The peak 30-min interval in the evening occurs between 4:30 and 5:00 p.m., when 34.2 percent of all employees leave work; and
4. A significant number of employees (approximately 24 300) have to report to work during the evening peak period.

The reported starting and stopping times for a jurisdiction or subarea often varied significantly from the regional averages. For example, although

Figure 1. Frequency of employee arrival times.

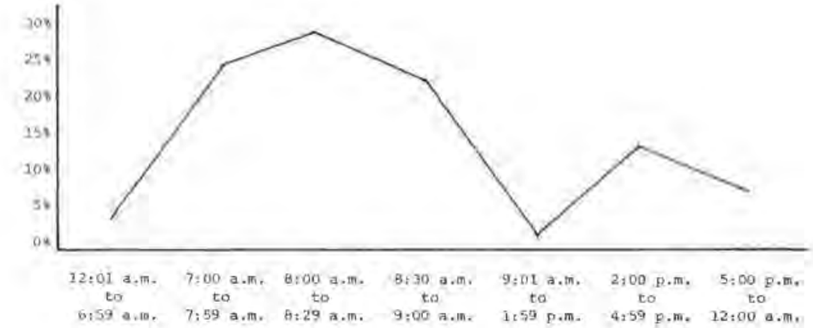

Figure 2. Morning peak-period arrival times.

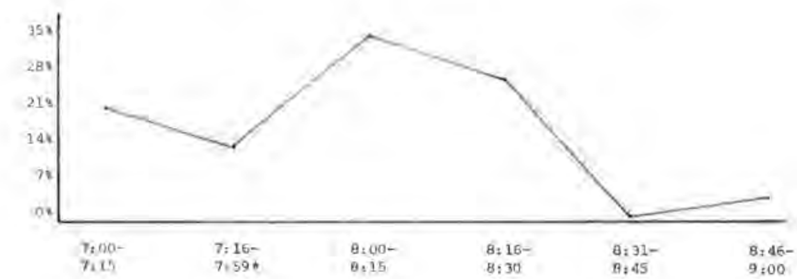

Figure 3. Frequency of employee departure times.

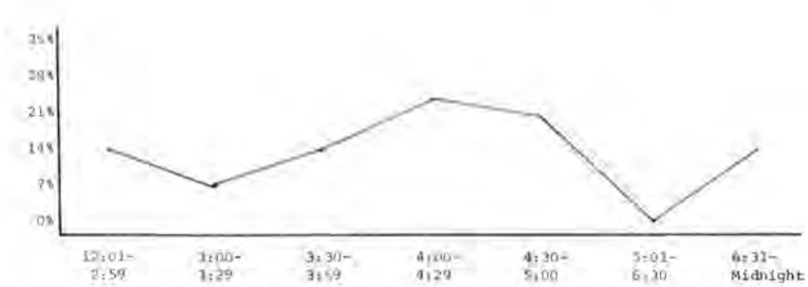

Figure 4. Evening peak-period departure times.

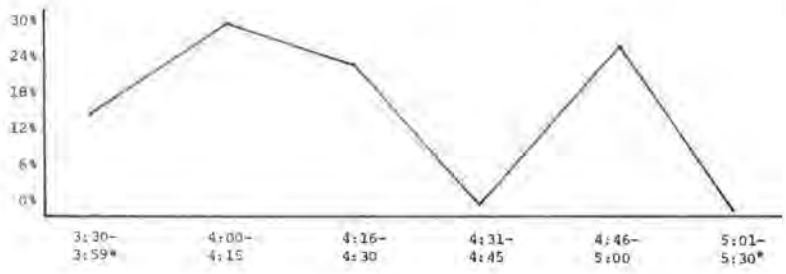

Table 5. Comparison of jurisdictional arrival and departure times.

Time	Baltimore City (%)	Anne Arundel County (%)	Baltimore County (%)	Carroll County (%)	Harford County (%)	Howard County (%)
Arrival						
12:01-6:59 a.m.	6.9	1.8	2.0	2.2	5.3	0.9
7:00-7:59 a.m.	20.5	23.9	24.9	17.0	24.8	38.3
8:00-8:29 a.m.	23.2	23.9	26.1	39.6	49.2	8.3
8:30-9:00 a.m.	23.6	31.6	15.6	10.2	10.1	39.9
9:01 a.m.-1:59 p.m.	1.8	0.7	0.7	1.0	1.0	1.4
2:00-4:59 p.m.	15.9	13.1	18.3	19.7	6.9	9.0
5:00 p.m.-midnight	8.1	5.0	12.4	10.3	2.6	2.2
Departure						
12:01 a.m.-2:59 p.m.	17.2	5.5	12.9	12.6	8.5	4.2
3:00-3:29 p.m.	6.9	6.8	6.2	1.6	16.5	2.4
3:30-3:59 p.m.	13.2	11.8	5.0	14.8	8.3	26.6
4:00-4:29 p.m.	9.6	19.7	35.9	27.4	10.4	9.9
4:30-4:59 p.m.	22.9	13.8	12.0	20.5	40.7	6.8
5:00-5:30 p.m.	18.6	28.4	8.8	3.6	8.7	41.0
5:31-6:30 p.m.	0.1	0.1	0.3	0.4	0.1	1.6
6:31 p.m.-midnight	11.5	13.9	18.9	19.0	6.7	7.6

Table 6. Ability to implement AWS by employer size.

	No		Yes		
No. of Employees	No.	Percent	No.	Percent	Total
1-19	117	76	37	24	154
20-199	217	82.2	47	17.8	264
200-999	44	58.6	29	41.4	70
1000-9999	7	46.7	8	53.3	15
10 000	0		0		0
Total	392	75.9	121	24.1	503

regionally 4 percent of all employees started work between 12:01 and 6:59 a.m., less than 1 percent started during this time period in Howard County and nearly 7 percent started work during this time period in Baltimore City (see Table 5). In the region, between 7:00 and 7:59 a.m., 24 percent started work; however, nearly 40 percent of the Howard County work force started work during this time period. Between 8:00 and 8:29 a.m., 25 percent started work; about 50 percent of the Harford County work force started during this period, as opposed to only 8 percent in Howard County.

Regionally, 20 percent of the work force leaves work between 4:00 and 4:29 p.m. Thirty-six percent of employees in Baltimore County leave work during this period as opposed to 10 percent of employees in Baltimore City. Between 5:00 and 5:30 p.m., 18 percent leave work; however, 41 percent of the Howard County and 4 percent of the Carroll County work force leave during this time period. Between 12:01 a.m. and 2:59 p.m., 13 percent leave work; but only 4 and 5.5 percent leave during this time period in Howard and Anne Arundel Counties, respectively. Between 4:30 and 5:00 p.m., 34 percent leave work; however, nearly 60 percent of the Metrocenter employees leave during this time period. Nearly 12 percent of all employees in the region leave work between 3:30 and 3:59 p.m.; only 2.4 percent of Towson area employees leave work during this time.

Potential AWS Use

Of the firms that do not currently use AWS, nearly 25 percent can change their shift times (see table below).

	Able to Implement AWS		
Jurisdiction	No	Yes	Total
Baltimore City	97	39	126
Anne Arundel County	34	16	50
Baltimore County	148	41	189
Carroll County	27	4	31
Harford County	31	4	35
Howard County	56	18	74
Total	383	122	505

Although the results are inconclusive, larger firms might be more willing to change their work schedules than smaller firms (see Table 6). Forty-three percent of the firms that employ 200 or more persons say that it is possible to change their work schedules; only 24 percent of the firms that employ less than 200 people indicate that they can change their schedules.

ESTIMATING REGIONAL TRAVEL, AIR QUALITY, AND ENERGY IMPACTS

Based on the results of the survey of regional employers, approximately 25 percent of the employer population, or about 9400 firms in the Baltimore metropolitan area, might be able to implement an AWS program. However, this estimate probably overstates the amount of AWS activity that reasonably can be expected to occur because this estimate assumes that approximately 7750 firms that employ fewer than 20 people will change their work schedules. Many of these smaller firms are not likely to change their

Table 7. Estimated regional AWS impacts at firms that have 100 or more employees.

Item	Level A[a]	Level B[b]	Level C[c]
Estimated actual market for AWS			
Firms	155	233	264
Employees	61 861	92 791	106 163
Estimated new AWS users	43 303	69 593	84 130
Automobile driver trips before AWS[d]	31 741	51 011	61 667
Automobile passenger trips before AWS[e]	6149	9883	11 946
Transit trips before AWS[f]	5413	8699	10 517
Automobile driver trips after AWS[g]			
With 3 percent reduction in automobile driver trips	30 442	48 924	59 143
With 9 percent reduction in automobile driver trips	27 844	44 748	54 096
Automobile passenger trips after AWS[h]			
With 3 percent reduction in automobile passenger trips	6842	10 996	13 293
With 9 percent reduction in automobile passenger trips	8220	13 223	15 985
Transit trips after AWS[i]			
With 3 percent reduction in transit trips	6019	9673	11 694
With 9 percent reduction in transit trips	7231	11 622	14 049
Estimated daily peak VMT reduction			
With 3 percent reduction in automobile driver trips	17 666	28 383	34 326
With 9 percent reduction in automobile driver trips	53 000	85 177	102 966
Estimated daily reduction of pollutants (Mg)			
HC			
With 3 percent reduction in automobile driver trips	0.026	0.039	0.047
With 9 percent reduction in automobile driver trips	0.074	0.118	0.143
CO			
With 3 percent reduction in automobile driver trips	0.215	0.345	0.417
With 9 percent reduction in automobile driver trips	0.645	1.04	1.25
NOX			
With 3 percent reduction in automobile driver trips	0.040	0.062	0.075
With 9 percent reduction in automobile driver trips	0.117	0.187	0.227
Estimated daily gasoline savings (gal)			
With 3 percent reduction in automobile driver trips	837	1345	1627
With 9 percent reduction in automobile driver trips	2512	4037	4880

Note: The number of firms in the area that employ more than 100 people is 1235. The number of employees of these firms is 494 884. If we assume that the estimated potential for AWS is 25 percent, then 310 firms that employ 123 721 people have the potential for AWS.

[a]Level A assumes a 50 percent rate of employer participation and 70 percent of their employees participate.
[b]Level B assumes a 75 percent rate of employer participation and 75 percent of their employees participate.
[c]Level C assumes an 85 percent rate of employer participation and 85 percent of their employees participate.
[d]Calculation is based on 73.3 percent of all trips being automobile driver trips.
[e]Calculation is based on 14.2 percent of all trips being automobile passenger trips.
[f]Calculation is based on 12.5 percent of all trips being transit trips.
[g]Calculation is based on 70.3 percent of all trips being automobile driver trips.
[h]Calculation is based on 15.8 percent of all trips being automobile passenger trips.
[i]Calculation is based on 13.9 percent of all trips being transit trips.

work schedules without some type of assistance, encouragement, or incentive from an AWS promotional campaign. Also unlikely is that a promotional campaign would receive enough funds to conduct an outreach program aimed at 9400 employers, of which nearly 8000 employ fewer than 20 people.

Potential Trip Reductions

A more realistic approach to estimating the number of establishments that might implement an AWS program is to examine the AWS potential at firms that employ 100 or more people. It is financially realistic to assume that an outreach program could be designed to reach this segment of the employer market. The estimated impacts from implementing a regional AWS program at firms that have 100 or more employees have been calculated in Table 7.

In the Baltimore region, 1235 firms employ more than 100 people. These firms have a combined work force of nearly 0.5 million people. Approximately 30 percent of these firms (370) currently have some type of AWS, and approximately 45 percent (555) cannot use AWS due to scheduling difficulties. The remaining 25 percent (310) represent the maximum number of employers who could be persuaded to implement an AWS project. Let us assume that the percentage of employees likely to be affected by a regional AWS program will be the same as the number of firms (i.e., 25 percent, or 123 721 employees.

Even with an extremely aggressive AWS outreach effort, it is unlikely that all of the employers that are candidate firms for implementing an AWS project will do so. For this reason, three different levels of employer participation of less than 100 percent were assumed. The first level (level A) of estimated employer participation assumes that 50 percent of those employers eligible to implement an AWS program will do so. The second and third levels are more optimistic and assume that between 75 and 85 percent, respectively, of the employers who can implement an AWS program will do so. Under these assumptions, the estimated number of firms in the Baltimore metropolitan area that might implement a new AWS program ranges from approximately 150 to

Table 8. Change in automobile driver trips at selected AWS sites.

City	Change in Automobile Driver Trips (%)	Type of AWS
Boston	-6.4	Flexible
Cambridge	-3	Flexible
Denver	-2.2	4-day week
Richmond, VA	+1	Flexible
Sacramento	-20	Flexible
San Francisco	-2.4	Flexible
Seattle	-9.6	Flexible
Toronto	-2	Staggered

Table 9. Estimated annual reduction of pollutants and gasoline use.

Level	3 Percent Reduction in Automobile Driver Trips				9 Percent Reduction in Automobile Driver Trips			
	HC (Mg)	CO (Mg)	NOX (Mg)	Gasoline (gal)	HC (Mg)	CO (Mg)	NOX (Mg)	Gasoline (gal)
A	6.5	53.7	10	209 250	18.5	161	29	628 000
B	9.7	86.2	15.5	336 250	30	260	47	1 009 250
C	11.7	104.2	18.7	406 760	36	313	57	1 220 000

275. The number of affected employees could range from 62 000 to 105 000 (see Table 7).

Firms that implement AWS often do not allow their entire work force to adopt an AWS. In fact, only about half of the firms that implement AWS put their entire work force on the new schedule. For this reason, the analysis assumes three different levels of employee participation at firms that implement AWS programs. Each of the three levels assumes that half of the firms put their entire work force on AWS, while the remaining firms put between 40 and 60 percent of their work force on AWS. As a result, level A assumes that a total of 70 percent of the affected work force is allowed to participate in an AWS program. Levels B and C assume that a total of 75 and 85 percent, respectively, of the affected work force will be allowed to participate in their employers' AWS programs. Under these assumptions, the total number of employees whose work trips might be affected by implementation of an AWS program is approximately 43 300 for level A; 69 600 for level B; and 84 100 for level C.

Estimating AWS Impacts

The transportation system management, energy, and air quality improvement benefits of AWS are derived from estimated reductions in automobile driver trips. Reductions in automobile driver trips can occur regardless of the type of AWS program implemented. However, these reductions are generally more pronounced when a FWH program is implemented. For this reason, the impact analysis assumes that the predominant AWS strategy is some type of FWH program. Data from feasibility studies, pilot studies, and long-term projects indicate that persons on FWH programs tend to reduce automobile use. The reductions in automobile driver trips range from 2 to 20 percent (see Table 8).

Based on the experiences of AWS users in other areas, the implementation of an AWS strategy in conjunction with a ridesharing and transit marketing effort could reduce automobile driver trips of participating employees by at least 3 percent and perhaps by as much as 9 percent (1,5-11).

The next step of the impact analysis uses the estimated automobile driver reductions to adjust the modal shares by subtracting the estimated reductions from the existing percentage of automobile driver trips. The reductions are then added to the automobile passenger and transit mode shares (see Table 7). The range of regional automobile driver work trip reductions is 1300-7600. The estimated 1300 trip reductions assumes a minimum level of participation by employers (level A) and a 3 percent reduction in automobile driver trips. At a 9 percent level of reduction, almost 4000 level A automobile driver trips could be saved. At level B, 21 000 automobile driver trips would be saved at the 3 percent level of reduction and 6300 could be saved at the 9 percent level. At level C, an estimated 7600 work trip reductions assumes a 9 percent reduction in automobile driver trips; at 3 percent the reduction is almost 2500 trips.

The estimated daily VMT is derived by multiplying the trip reductions in Table 7 by the average (two-day) work trip length of 13.6 miles. The estimated peak VMT savings could be as low as 18 000 or as high as 103 000 daily (see Table 7). These VMT savings could reduce the region's hydrocarbon emissions burden by as much as 36 Mg annually (see Table 9) and save more than 1.2 million gal of gasoline.

CONCLUSIONS

Between 155 and 264 firms in the Baltimore metropolitan area that employ 100 or more people could implement a flextime, staggered work hours, or compressed workweek program. (This estimated market is between 13 and 21 percent of the employers who have a work force of 100 or more.) The number of work-related automobile trips could be reduced by as few as 1300 or as many as 7600 if employers implemented AWS on a wide-scale basis in the Baltimore area.

The estimated travel, air quality, and energy impacts that could result from implementation of a regional AWS program are not of mammoth proportions. However, the estimated impacts would be beneficial to the region and could assist the area in meeting its travel, air quality, and energy objectives. In addition, AWS generally has a positive impact on ridesharing and transit use and its benefits would probably be increased if it were implemented as a package along with other transportation system management measures.

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San Francisco Joint Institutional TSM Program Evaluation

IRA FINK AND JON TWICHELL

The San Francisco joint institutional transportation systems management (TSM) program began out of conflict in the mid 1970s between institutions, who thought they needed to grow to survive, and neighborhood groups, who thought they had to defend their neighborhoods against the negative impacts of growth. One of the main impacts of growth was traffic congestion and lack of on-street parking. With the sponsorship of the San Francisco Department of City Planning, the joint institutional TSM program was started in 1979. Fourteen major hospitals, colleges, and a private employer were asked to participate in the program; all agreed. A four-phase program was developed for planning, training, implementation, and evaluation. The Urban Mass Transportation Administration granted $163 000 to support the program. Evaluation, based on a 1980 resurvey of employees and analysis of broker and institutional efforts, showed outstanding results. Single-occupant automobile use decreased from 57 to 49 percent from 1979 to 1980. During this same period, ridesharing increased from 17 to 22 percent. This paper presents the results of the evaluation of the program conducted following the first year of program implementation.

The San Francisco joint institutional transportation systems management (TSM) program began out of conflict in the mid-1970s between institutions, who thought they had to grow to survive, and neighborhood groups, who thought they had to defend their neighborhoods against the negative impacts of growth. One of the main impacts of growth was in transportation--traffic congestion and lack of on-street parking.

As a result of this conflict in San Francisco, an institutional master plan requirement was passed by the City Board of Supervisors. Also, growth at the University of California at San Francisco (UCSF) resulted in legal challenges by its neighbors. UCSF met its transportation challenge by developing and implementing a TSM plan, designed to make more efficient use of present transportation resources and lower the number of single-occupant automobile trips. As a result of analysis of the institutional master plan submissions and the efforts of UCSF, the San Francisco Department of City Planning organized a series of joint meetings with other institutions in San Francisco to discuss common transportation problems and solutions. Out of this effort the joint institutional TSM program was started.

Fourteen major hospitals, colleges, and a private employer were asked to participate in the program; all agreed. The criteria for participation were based on (a) location in a neighborhood area, (b) perception of conflict with neighbors about traffic, and (c) institution had to be of significant size.

A grant application was prepared and approved for $163 000 in funding from the Urban Mass Transportation Administration (UMTA). A four-phase program was developed for planning, training, implementation, and evaluation. Planning efforts included the development by consultants of a separate TSM plan for each institution and an overall planning report. Training of the employer-designated transportation brokers was accomplished through a 10-week, half-day per week training class. Implementation was the responsibility of each of the individual institutions, assisted by an organization the brokers set up, the Joint Institutional Transportation Brokers Association (JITBA). Evaluation, based on resurvey of employees and analysis of broker and institutional efforts, showed outstanding results.

In general, the participating institutions were located in San Francisco neighborhoods rather than the downtown area. The implications of this include difficult transit access, lack of parking, spillover effects on the streets and adjacent neighborhoods, unusual work schedules, the perception of being out of scale with the neighborhoods, and considerable political and legal opposition to further growth. In a city where only 20 percent of downtown workers drive alone to work, 57 percent of the employees of the 12 institutions who participated in the total program drove alone to work in 1979 prior to the start of the TSM program.

The findings of the effectiveness of joint institutional TSM plans instituted at 12 institutions (universities, medical centers, and a private insurance company) in San Francisco from October 1979 through October 1980 were significant. (Some of the results exclude two institutions, Children's Hospital and the University of California, San Francisco, who evaluated their TSM programs separately from the overall joint institutional program.)

1. Employment at the institutions showed minor change. Overall, the 12 institutions employed 23 170 in 1979 and 23 830 in 1980; an increase of 3 percent.
2. Generally, the distribution of employees by geographic area remained consistent between 1979 and 1980. Collectively, nearly 14 000 employees of the 12 institutions (58 percent) lived in San Francisco in both 1979 and 1980. The remaining 9000 employees were almost evenly divided among East Bay communities, North Bay communities, and the Peninsula.
3. The institutions, although experiencing normal job turnover and employment fluctuations, had a labor force that remained fairly constant in its residual distribution; thus, changes in residence were of minor importance as a motivation for employee changes in transportation patterns.
4. The effect of the TSM program on reducing employee reliance on the automobile from 1979 to 1980 was significant. At the 12 institutions, use of single-occupant automobiles declined, on an average, from 57 to 49 percent. Overall, the number of single-occupant drivers was reduced from 13 100 to 11 650.
5. The decline in the use of single-occupant automobiles was accompanied by significant increases in the number of employees who shared rides, which increased from 17 to 22 percent. In 1979, 4050 shared rides; by 1980 the number had increased to 5200.
6. Use of transit as a means of commuting to work also showed gains. In 1979, 16 percent of the employees (approximately 3750) used public transit; by 1980, transit use increased to 18 percent, or 4250 employees.
7. Changes occurred in other transportation modes, including walking and bicycling. In 1979, 10 percent of the employees (2300) walked or bicycled to work; in 1980, 11 percent or nearly 2700 did so.
8. Considerable annual employee turnover occurred at the institutions--approximately 12 percent at the universities and 19 percent at the medical centers.
9. Although it was anticipated that the individual institutional transportation brokers would be able to devote a large percentage of their work time to TSM activities, in actuality, this did not occur. Brokers spent an average of 18 percent of the their time in TSM activities, or approximately 7-8 h/week.

10. Nearly one out of four of the new employees (persons employed less than one year) changed their mode of transportation between 1979 and 1980. Among the employees who had worked from 1 to 10 years, approximately one out of five changed their mode of transportation. Among employees who had worked 11 or more years, approximately one out of nine changed transportation modes.

11. More than 6 out of 10 employees indicated that they were aware of their employer's transportation programs. At only two institutions did fewer than one-half of the employees indicate that they were aware of the employer's program.

12. More than one-third of the employees who responded to the transportation resurvey asked for additional transportation information and provided their name and work phone number on the survey form to receive more information.

13. According to the resurvey, an untapped market of employees who were not only ready to change transportation modes but who were also willing to consider changing immediately, existed. For example, 30 percent of all employees who currently drive alone to work said they would be willing to consider changing to a carpool, 20 percent to vanpools, and 16 percent to public transit. However, 51 percent of the single-occupant automobile drivers indicated no interest in or willingness to consider changing transportation modes.

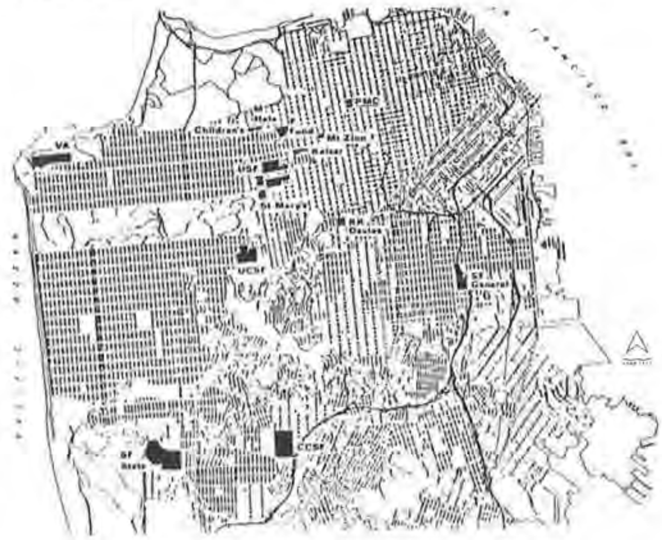
14. One of the most visible and tangible results of the TSM program was the spontaneous formation of JITBA. The effectiveness of JITBA's collective voice was demonstrated in legislation enacted to provide preferential on-street parking for carpools; in proposed San Francisco Municipal Railway (Muni), San Mateo County Transit District (SamTrans), and Golden Gate transit improvements; and in providing mutual support for the institutional brokers' activities.

In summary, the joint TSM programs were the first of their kind in the nation and a test case for potential application to other cities throughout the country. Although the programs have been effective, the reasons for the significant results in reducing employee reliance on the single-occupant automobile are difficult to pinpoint. However, a number of factors were at work. First, the institutions had comprehensive plans for encouraging employees to reduce reliance on the single-occupant automobile; second, the cost of commuting by automobile increased as gasoline prices rose to approximately \$1.35/gal by fall 1980; third, parking management programs were implemented at many of the institutions, including preferential parking for carpools, and greater restrictions were placed on obtaining parking stickers for existing parking; fourth, the institutions themselves made transportation management a high priority and publicized it through new and existing employee-orientation sessions and through newsletters, transportation fairs, and other forms of publicity and marketing to the employees; fifth, each institution had an appointed transportation broker on whom employees could call for transportation information and also who served to encourage commute alternatives to the employees. Thus, a combination of timing, resources, alternatives, and priorities led to the impressive TSM gains.

EXISTING CONDITIONS

The San Francisco Department of City Planning and a consortium of 14 major institutions [see Figure 1 (1)] located in neighborhood districts participated

Figure 1. Location of San Francisco joint institutional TSM program institutions.



Source: "Final Report of the San Francisco Joint Institutional Transportation Systems Management Study," DeLeuw, Cather, et al., October 1979, Page 7.

in the San Francisco joint institutional TSM program, which began in 1979:

1. Children's Hospital,
2. Kaiser Permanent Medical Center,
3. Marshal Hale Memorial Hospital,
4. Mt. Zion Hospital and Medical Center,
5. Pacific Medical Center,
6. Ralph K. Davies Medical Center,
7. San Francisco General Hospital,
8. St. Mary's Hospital and Medical Center,
9. Veteran's Administration Hospital,
10. Fireman's Fund Home Offices,
11. City College of San Francisco (CCSF),
12. San Francisco State University (SF State),
13. University of California, San Francisco (UCSF), and
14. University of San Francisco (USF).

The objectives of the TSM program were to reduce automobile parking and traffic impacts at each institution by means of low capital cost measures, such as ridesharing, public and private transit services, parking management, and marketing incentives, and to achieve greater impact through cooperative efforts with the other participating institutions. The primary goal was to reduce the number of single-occupant automobile commute trips to work (2). The first step in development of the program was to gain a clear understanding of the nature of each institution, the transportation system that serves it, and existing transportation use by institutional employees and visitors. This was needed not only for identifying potential for TSM improvements but also to provide before data for postimplementation evaluation.

At all but two institutions, the single-occupant automobile was the predominant means of commuting by employees in 1980. In most cases, public transit, particularly Muni, was the second most frequently reported means of commute.

Residence Locations

The nature of transportation services available to employees was dependent on residence location. In

1979, nearly 60 percent of the employees lived within San Francisco. The greatest use of single-occupant automobiles for commuting was by employees who live outside the city, particularly on the San Francisco Peninsula. This reflects the lengthy and difficult transit access from these outlying points.

Parking

Although all institutions provide some employee or visitor parking, the number of spaces provided and policies on their use vary widely. In general, the university campuses have the greatest numbers of parking spaces on-site; this is consistent with their comparatively large site populations.

At all institutions, on-site parking was observed or reported to be heavily used during the peak periods, and parking frequently spilled over onto neighboring streets. The amount of spillover varied greatly, depending on the net deficiency of on-site parking and availability of transportation alternatives.

Public Transit and Ridesharing

The San Francisco Bay Area has an extensive public transit network. However, the institutions in the program shared a common problem of being located away from the downtown focal point of local and regional transit service. As a result, although all of them have at least one transit route that provides direct service, connections to some areas of the city and to some regional transit systems are inconvenient and time consuming.

Carpools operated at all of the institutions, but the degree to which carpooling was encouraged varied considerably. Vanpools operated at three of the institutions. Buspools operated only at two institutions.

Recommended TSM Efforts

The planning effort resulted in plans for all of the participating institutions and an overall final planning report (1).

The recommendations focused on the following activities:

1. Ridesharing--internal carpools, internal and joint vanpools, new buspool service, in-house matching services, and preferred on-site parking;
2. Parking management--priority and free or low rates for registered pools, higher all-day rates, no additional on-site parking, and cooperation with neighborhood parking programs;
3. Transit--sale of monthly transit passes, transit information availability, and work with transit operators for improved service;
4. Marketing--information available, transportation bulletin boards, new employee orientation, and flextime;
5. Administration--designation of the transportation broker, joint coordination, employee transportation committees, and program monitoring and evaluation; and
6. Traffic operations--various low-cost operational improvements.

In addition, specific numerical goals for modal shifts were developed for each institution. These were based on a combination of present habits, surveyed employee interest, and site conditions. All of the goals were ambitious and were meant to be implemented and met over several years.

PROGRAM IMPLEMENTATION AND EVALUATION

Program implementation began in late 1979 with the completion of a transportation brokers' training class and the publication of the individual TSM reports. Basically, the implementation involved initiation and continuation of proposed TSM actions. The actions included activities that required immediate action, short-range plans, or long-range plans.

Immediate-action plans included ridesharing promotions and the marketing of transit efforts, coordination among the various institutions to promote carpools and vanpools, improvements in parking management, and the creation of employee transportation committees. Short-range program elements depended on other agency resources, particularly the public transit districts, including Muni, SamTrans, and the Golden Gate Bridge District. Individually and collectively the institutions were asked to take immediate action in requesting and lobbying for transit improvements, although transit improvements were not expected until the second or third year of the program. The short-range proposals included modifications of transit routes in the Muni five-year plan, Muni reverse express service to the institutions from the AC Transit Trans Bay Terminal and Bay Area Rapid Transit (BART), and rerouting of the Golden Gate transit service onto Geary Boulevard. Other short-range activities included recommendations for off-street preferential parking for carpools, and implementation of a Muni shuttle service to link the outer Mission District of San Francisco with some of the institutions.

Long-range plans, basically those that would occur between the third and fifth year of the program, related primarily to new transit services, such as the new Muni Route 33 and other suggested transit improvements. Although it will take several years to implement all the TSM plans fully and to accomplish the TSM goals, much of the ground work was to be accomplished during the first year.

The program evaluation phase included both program monitoring and evaluation. At the outset of the TSM program, the city reserved funds to evaluate program effects after approximately one year of implementation. The firm of Ira Fink and Associates of Berkeley, in association with David Bradwell and Associates of San Francisco, was selected by the city in Fall 1980 to conduct the evaluation of the effectiveness of the TSM plans at each institution (3).

The steps involved in the TSM program evaluation included first, a resurvey, in October 1980, of employee transportation patterns at 10 of the participating institutions (UCSF and Children's Hospital conducted employee surveys separately, the Ralph K. Davies Medical Center and the San Francisco General Hospital dropped out of the joint institutional program and were not included in the resurvey or evaluation). Interviews were conducted with the institutional brokers at each of the participating institutions. A review was made of all recommended TSM programs at each institution to document those that were accomplished in 1980 and those that were not accomplished. Meetings were held between the consultant, the transportation broker, and his or her immediate administrative supervisor to review the progress of the TSM program at each institution and to discuss the results of the employee transportation surveys. Final evaluation reports were prepared for each of the 10 institutions and an overall evaluation summary, including the other two institutions, was also prepared.

JOINT INSTITUTIONAL TSM MODE SPLIT GOALS

The primary purpose of the TSM program was to reduce reliance on the single-occupant automobile as a mode of transportation from home to work. At the start of the TSM program, the single-occupant automobile was the predominant means of commuting by employees at all institutions except for Fireman's Fund and UCSF. At most institutions between 51 and 66 percent of the employees arrived in single-occupant automobiles. Overall, an average of 57 percent of the employees drove to work in single-occupant automobiles in 1979. This is shown in Table 1.

The effect of the TSM program in reducing employee reliance on the automobile during 1980 was significant. As shown in Table 1, use of single-occupant automobiles declined to an average of 49 percent. In other words, whereas in 1979, 6 out of 10 employees drove to work, in 1980 only 5 out of 10 did so. Overall, the number of single-occupant drivers was reduced from 13 100 to 11 650.

The hoped for decline in the use of the single-occupant automobile was accompanied by significant increases in the number of employees who shared rides. In 1979, 17 percent of the employees (4050) shared rides; by 1980, the percentage who shared rides had increased 22 percent and the number increased to 5200. In other words, in 1979 one out of six employees shared rides; in 1980, more than one out of five did so.

Use of transit as a means of commuting to work also showed gains. In 1979, 16 percent of the employees (3750) used public transit; by 1980 this had increased to 18 percent, or more than 4250 employees. In addition, increases occurred in other transportation modes, including walking and bicycling. In 1979, 10 percent of the employees (2300) walked or bicycled to work; in 1980, 11 percent (2700) did so.

Overall, the effect of the TSM program in reducing employee reliance on the single-occupant automobile was impressive. Automobile use, as measured by the percentage of employees who drove to work at each of the institutions, showed a significant decline. As illustrated in Table 2 (1, p. 27), many of the institutions reached the TSM target transportation goals suggested in the 1979 institutional plans. These goals, set separately for each of the institutions, were based on the factors of existing transportation patterns, availability of institutional resources to change these patterns, alternative means of transportation to the institutions, institutional parking policies, and anticipated improvements in transit services that serve the institutions. The 1980 data in Table 2 were from the employee transportation survey conducted by Ira Fink and Associates and David Bradwell and Associates in October 1980.

Because of the considerable annual turnover of employees at these institutions (approximately 12 percent for the universities and 19 percent for the medical centers), TSM marketing activities that led to reduced use of automobiles must continue uninterrupted. If not, employees may revert to earlier forms of transportation behavior. Thus, to maintain the impressive TSM gains requires continuing work, because of the ease with which employees can shift from one commute alternative to another. Once an employee learns to commute to work with an alternative other than the single-occupant automobile, the probability is high that the employee will not revert to single-occupant automobile use if continued emphasis is placed on commute alternatives.

PERCENTAGE OF EMPLOYEES WHO CHANGED TRANSPORTATION MODES

There are two measures of employee changes of transportation modes. The first is a measure of the change of mode by the years of service at the institution; the second is the change of mode by type of transportation. These measures are based on the more-extensive evaluation at 10 of the 12 institutions conducted by Ira Fink and Associates and David Bradwell and Associates.

Table 1. Primary modes of employee transportation.

	Drive Alone		Shared Ride		Public Transit		Walk or Bicycle		
Year	No.	Percent	No.	Percent	No.	Percent	No.	Percent	Total
1979	13 105	57	4030	17	3740	16	2295	10	23 170
1980	11 640	49	5215	22	4265	18	2710	11	23 830
Difference	−1 465		+1185		+525		+415		+660

Table 2. Progress made by 1980 in reaching transportation mode goals set forth in 1979 TSM plans at joint TSM institutions.

	Drive Alone (%)			Shared Ride (%)			Public Transit (%)			Other[a]		
Institution	1979	Goal	1980	1979	Goal	1980	1979	Goal	1980	1979	Goal	1980
Kaiser Permanent Medical Center	58	38	57	24	37	18	10	17	17	8	8	8
Marshal Hale Memorial Hospital	56	30	45	15	30	21	20	31	21	9	9	9
Mt. Zion Hospital	65	42	49	5	21	18	25	32	25	5	5	8
Pacific Medical Center	52	34	45	14	28	18	23	27	25	11	11	12
St. Mary's Hospital	56	39	52	17	31	20	19	22	18	8	8	10
Veteran's Administration Hospital	66	59	47	14	19	27	7	9	17	13	13	9
Fireman's Fund Insurance	42	26	33	39	52	45	15	18	18	4	4	4
CCSF	86	81	68	2	6	13	10	11	15	2	2	4
SF State	63	55	57	13	20	17	16	17	16	8	8	10
USF	53	30	42	17	17	18	19	27	24	11	26	16
Avg	60		51	16		21	16		19	8		9
Children's Hospital	59		45	15		23	16		16	10		10
UCSF	46		44	22		25	16		14	16		17
Avg	57		49	17		22	16		18	10		11

[a]Includes walking and riding.

One of the basic tenets of the Joint Institutional TSM plans was the introduction of employee orientation programs for new employees to alert the employees to transportation or commute alternatives on their trip from home to work. As shown in the table below, turnover of employees is considerable.

No. of Years of Employment	Avg (%)
<1	16
1-2	22
3-5	13
6-10	20
>11	29

The effectiveness of the TSM programs is shown in the table below. Nearly one out of four of the new employees changed their mode of transportation between 1979 and 1980. Among the employees who had worked from 1 to 10 years, approximately one out of five changed their mode of transportation. Among employees who had worked 11 or more years, approximately one of nine changed their mode.

No. of Years of Employment	Changed Transportation Mode (Avg %)
<1	24
1-2	21
3-5	19
6-10	20
≥11	11
Avg	18

The new employee, who, at the time of employment, can be induced to change his or her mode of transportation, offers the greatest single opportunity for long-term improvement in commute alternatives to the institution. However, since the longer-term employees represent five out of six employees at the institutions, existing employees need also to change transportation modes and, once they have changed from a single-occupant automobile mode, to stay in the alternative mode.

In view of the turnover among employees and that many employees change places of residence during the year, some employees will change to driving to work. However, this amount of change was minimal. Of the employees who reported driving alone to work in 1980, 13 percent (one of seven) indicated that they had changed to this mode of transportation. This resulted in approximately 1100 added drivers. This potential increase was offset by a reduction of 2700 employees who changed to other modes with the net result of 1300 fewer cars being driven to work at the TSM institutions.

Among those who rideshared, 30 percent indicated that they had changed to this mode of transportation within the past year. At those institutions that have aggressive ridesharing programs, the results were most impressive: 37 percent of the ridesharers at both Mt. Zion and at Fireman's Fund indicated that they had changed to this mode in 1980.

Of the more than 3300 ridesharers, the 30 percent change meant that more than 1000 employees became ridesharers in 1980. As a result of the increase in ridesharing, the percentage of ridesharers at all institutions increased from 16 percent in 1979 to 21 percent in 1980.

Gains were also made in percentage increases in the number of employees who changed to public transit. An estimated 60 public transit users changed from public transit to another mode of transportation, and 615 changed to using public transit. Overall, the net gain was 555 transit users. At individual institutions transit use increased between 20 and 70 percent. Overall, the percentage of all employees who use transit increased from 2600 (16 percent) to 3100 (19 percent).

Finally, some employees chose either to walk or bicycle to work instead of driving or using transit. Gains were made at 9 of the 10 institutions in this regard. Overall, an estimated 20 employees changed from walking or bicycling to some other mode of transportation, and more than 270 changed from some other mode to walking or bicycling. In sum, the number of walkers or cyclists increased from slightly more than 1200 (8 percent) to nearly 1500 (9 percent) between 1979 and 1980.

As the above data indicate, employees, regardless of the length of time on the job, were willing to change to alternate modes of transportation. Of the nearly 16 300 employees at the 10 institutions, more than 3000 of the employees, or nearly 20 percent, indicated that they had changed their mode of transportation between 1979 and 1980. These modal shifts clearly favored alternatives to the single-occupant automobile.

EMPLOYEE AWARENESS OF EMPLOYER'S TRANSPORTATION PROGRAMS

One of the key components of the TSM plans was to set forth marketing strategies to inform new and existing employees about their transportation alternatives for commuting to work. All institutions had such programs written into their work plans. However, implementation of the marketing strategies was easier at some institutions than others because of the variation in the ease with which the institutional administrations could communicate with the employees. At some institutions weekly, biweekly, or monthly newsletters are distributed in house. At others, such as Kaiser Permanent Medical Center, the employee newsletter is a regional newsletter distributed to all Kaiser employees throughout the Bay Area. At some institutions, such as City College, which has a large part-time faculty who are on campus infrequently and for short periods of time, it is difficult to communicate with them or to establish mechanisms for them to work out commute alternatives.

Notwithstanding the above, and as shown in the table below, in 1980 more than 6 out of 10 of the employees were aware of their employer's transportation programs. At three of the institutions, Marshal Hale Memorial Hospital, Veterans Administration Medical Center, and Fireman's Fund Home Office, more than 85 percent of the employees were aware of the transportation programs or received information about them. At only two institutions, Mt. Zion and City College of San Francisco, did fewer than one-half of the employees indicate that they were aware of the employer's transportation programs.

Employee Awareness of Transportation Programs	No.	Avg (%)
Aware	10 116	62
Not aware	6 154	38
Total	16 270	
Want transportation information	5 792	36

With so many of the employees indicating that they were aware of the programs, one would expect them to be fully informed about their transportation alternatives. However, more than one-third of the employees who responded to the survey asked for additional transportation information and provided both their name and work phone number to receive it.

Moreover, that employees asked for additional information indicates that, although significant gains

Table 3. Employee willingness to consider changing to another transportation mode among car drivers only at joint TSM institutions, 1980.

	Willingness to Change Mode									
	Carpool		Vanpool		Public Transit		No Interest or Response			
Institution	No.	Percent	No.	Percent	No.	Percent	No.	Percent	Car Drivers	Total[a]
Kaiser	278	26	203	19	171	16	599	56	1070	1 465
Marshal Hale	49	27	41	23	25	14	86	48	180	264
Mt. Zion	378	35	259	24	119	11	529	49	1080	1 619
Pacific Medical Center	238	34	147	21	84	12	364	52	700	994
St. Mary's	299	34	202	23	106	12	378	43	880	1 267
Veteran's	159	23	113	17	68	10	401	59	680	790
Fireman's Fund	156	38	111	27	49	12	226	55	410	632
City College	347	34	204	20	204	20	643	63	1020	1 653
SF State	510	28	364	20	400	22	801	44	1820	2 621
USF	127	27	61	13	75	16	207	44	470	546
Total	2521	30	1705	21	1301	16	4234	51	8310	11 851

Note: The responses from employees interested in changing to shuttles or buspools have been excluded from the above table. These results are contained in the individual institution's final TSM evaluation report.

[a]Total responses exceed the number of car drivers because some of the drivers indicated a willingness to consider changing to more than one other mode of transportation.

have been made in the past year, there is still an existing untapped market of employees who are not only ready to change transportation modes but are also willing to consider it immediately.

For example, based on an employee transportation survey (October 1980) conducted by Ira Fink and Associates and David Bradwell and Associates, 30 percent of all employees who currently drive to work alone would be willing to consider changing to a carpool (see Table 3). This level of interest was consistent among all institutions, even at institutions that have a high percentage of ridesharers, such as Fireman's Fund. At Fireman's Fund, 45 percent of employees currently share rides, yet 38 percent of the car drivers indicated that they would be willing to consider a carpool alternative.

Interest in vanpools was also apparent, but not as high as in carpools. Overall, more than one out of five employees who drove to work alone indicated that they would be willing to consider changing to a vanpool. Again, the level of interest was consistent among all 10 institutions.

Interest in public transit did not fare as well. Among current automobile drivers, only one out of six said they would be willing to consider changing from driving the automobile to using public transit. The highest level of interest was expressed among employees at the universities--City College of San Francisco, San Francisco State University, and the University of San Francisco. In each of these cases between 16 and 22 percent of car drivers said they would be willing to consider changing to public transportation modes.

At the medical centers the level of interest in changing to public transit was somewhat lower, which is understandable because of the variation in employee starting times, especially among the nursing staff. Also, many of the shifts start or end the work period in nondaylight hours. In conversations with the transportation brokers and their administrators, employees' concerns about public transit were less related to convenience and schedule and more related to their personal safety both en route to work and between the transit stop and their place of employment.

Of interest is that, of all of the single-occupant automobile drivers, about one-half indicated no interest in or willingness to consider changing transportation modes. Thus, of the more than 8300 single-occupant automobile drivers, the most apparent market is for about 4100 to be willing to consider changing and actually changing to a different transportation mode.

JITBA

The unique JITBA organization was formed by the institutional brokers on the completion of their broker training in mid-1979. JITBA has provided an important ingredient that the individual institutions could not accomplish on their own--the ability to provide a single voice for transportation and transit improvements to agencies that provide transportation and transit services. For example, JITBA and its members sponsored and wrote new legislation for the City of San Francisco to allow for preferential parking for carpools in designated areas around institutions. The members appeared before the various committees of the Board of Supervisors, bird-dogged the legislation, and now share both in the glory of its effectuation and the benefits of its implementation, which started in January 1981 (4).

Similarly, the brokers association and its representatives have appeared before Muni, SamTrans, and the Golden Gate Bridge District. In all three cases, transit improvements resulted. One such improvement is the Muni reverse-express-bus service from the downtown AC Transit and BART terminals to the institutions. Service began on a pilot basis in April 1981; 3000 of the employees who live in the East Bay could avail themselves of this service.

The SamTrans system has indicated interest in providing express-bus service from the Peninsula to the institutions and is currently conducting a survey of institutional interest in such a route. At present 3700 of the joint institutional employees live on the Peninsula. The Golden Gate Bridge District, with support from JITBA, has prepared a position paper on providing service by its buses along Geary Boulevard in San Francisco. Such service would be of considerable interest to the institutions in that more than 3200 of the employees of the JITBA institutions live in the North Bay area and are now served by the Golden Gate Bridge District transit system. This spontaneously formed organization has been one of the most visible and tangible results of the TSM program.

It was anticipated at the outset of the program that the transportation brokers would be able to devote a large percentage of their time to the TSM activities. In actuality, this has not occurred. Many of the brokers have other primary responsibilities at their institutions, including serving as security officers, managers of the parking systems, or directors of internal transportation programs.

As a result, the brokers themselves report spending as little as 5 percent of their time in the TSM activities to as much as one-third of their time. This is shown in the table below:

Distribution of Broker's Time	Avg (%)	Hours per Week
TSM program	18	7.3
Parking management	18	7.3
Police or safety	32	13.0
In-house transportation	16	6.2
Other	16	6.2

On average, the brokers spend about 18 percent of their time in TSM activities, or approximately 7-8 h/week.

HOW THIS PROGRAM DIFFERS FROM OTHERS

The joint institutional TSM program has a number of positive and negative features. On the negative side, it deals with institutions whose irregular working hours made ridesharing particularly difficult. Also, the program is a collection of sites bound together by function rather than proximity. On the positive side, the program has the benefit of a number of vital factors:

1. A clear and thorough four-part program,
2. Specific numerical goals for modal split at each institution,
3. Designation and training of the transportation brokers,
4. On-going broker organization,
5. A comprehensive approach to the problem rather than piecemeal focus on one or two elements,
6. Low cost,
7. The gasoline crisis of 1979,
8. Clear political pressures on the institutions,
9. Clear political and employee payoffs for the institution, and
10. A consensus on clearly effective strategies.

Each of the pieces of the program was vital in its own way. The planning effort gives each institution a detailed list of solutions to their particular problems. The training of the brokers clearly fixes responsibility at each institution on a particular person, and that person was brought up to the state of the art. The continuing brokers association provides a professional forum, joint problem solving, mutual support system, and joint measuring stick. The implementation term was long enough (one year) to provide results but still left time to catch up to the long-term schedule. The evaluation was very clear; there was an obligation to progress toward the specific, numerical goals set in the initial plans. Everyone knew the evaluation was coming, and they had to produce. All participants produced a lowered rate of single-occupant drivers. By 1980, eight institutions produced a drive-alone rate under 50 percent compared with two in 1979.

One of the most telling results was that one of the most promising institutions, in terms of location and potential, produced the least. The transportation broker was replaced, the new broker's responsibility was upgraded to a middle-management level, and the new person went through subsequent training courses and developed an aggressive, improved plan of attack for that particular institution.

The brokers association, in recognition for its results, received the San Francisco Bay Area Transportation Commission's grand award for 1980 for "significant efforts...in support of public transit."

Although the gasoline shortage, which came during this program, certainly heightened everyone's awareness of the costs and perils of commuting alone, this factor cannot be given primary credit. The results of the program varied widely from institution to institution, not in any specific pattern other than the amount of time, energy, and thought put in by the broker. Less promising locations did better than more promising ones in a number of cases.

The program served to reinforce two conclusions. First, personalized service is the key to maximum success. Shifts away from driving alone to work are the result of personal decisions to make a change in travel habits; the more a broker deals on a personal, individual basis, the more likely he or she will get results. Second, results do not come dramatically but are accumulated over time. All of the commute alternative success stories across the country, such as the Tennessee Valley Authority and 3M Company, are the results of years of accumulated effort. The joint institutional program accumulated 8 percent change in the first full year of effort, and will likely accumulate more over the next several years, despite the difficulty of dealing with hospital and college work shifts and locations.

A coordinated, multifaceted program is more likely to succeed than a TSM program focused on a single strategy. Programs fixed on just vanpools or parking management did not produce the results, for instance, that the overall approach does.

A major result was the clarification of TSM as an employer strategy and a clarification of just what strategies seem to be effective. The most-effective strategies included the following:

1. Transit--on-site sale of monthly commuter passes, availability of route maps and schedules, and personal trip planning;
2. Ridesharing--personal assistance in getting carpools and vanpools together and maintaining them; free or reduced-rate, reserved on-site parking; and joint ridesharing where a pool cannot be formed onsite;
3. Parking management--preference for ridesharing vehicles, increased rates for single-occupant automobiles, and limitations on increasing the number of available parking spaces;
4. Marketing--new employee orientation, transportation day, transportation bulletin boards, and continual use of in-house newsletter to promote program; and
5. Administration--coordinate all activities, emphasize on the personal touch, and regular recycle of all activities, especially marketing, parking enforcement, ridesharing drives.

A very business like approach was taken to the situation. Because the whole enterprise was taken seriously, it worked. In sum, the six-part approach is an essential--specific goal-setting, a mix of governmental carrots and sticks, institutions that can see the political and employee benefits, a clear, personalized set of various TSM strategies, a mutual support group of brokers with consulting or professional assistance through the implementation period, and an evaluation they have to answer to. Each area around the country has differences in situation, cooperation, and public opinion; however, the joint institutional formula can be applied.

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Reducing Work Trip Length Through Home Mortgage Subsidy Incentives

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This paper presents research in progress at Princeton University that examines the potential of geographically restricted mortgage subsidies to encourage people to live closer to work and thus reduce work trip travel and automobile-related energy consumption and air pollution. A preliminary analysis is made of the effect of a mortgage-subsidy program at Princeton University. The Princeton plan offers a 1.5 percent mortgage subsidy to eligible employees of Princeton who buy a home within an 8-mile radius of campus. Preliminary analysis indicates that the mortgage subsidy has produced significant reductions in work trip travel in comparison with employee work trips of similar employers in the Princeton area. Implementation of mortgage subsidies in the private sector is also investigated. We propose that the U.S. Environmental Protection Agency's emissions offset policy can provide industry with a financial incentive for implementing geographically restricted mortgage-subsidy programs. This policy is proposed as a means of increasing an industry's flexibility in meeting pollution regulations. It also provides the benefit of significant energy conservation.

This paper reports preliminary results of research in progress at Princeton University that examines the potential of geographically restricted mortgage subsidies to reduce vehicle miles of travel (VMT) in urban areas. At Princeton, mortgage subsidies are available to eligible employees who are willing to live within a specified distance of the work place. This research examines the effect of the Princeton University mortgage-subsidy program in reducing the length of employee work trips. Work trip comparisons are made between employees at Princeton and employees of three other major employers in the area.

At this point in the research the data are highly aggregated. This limitation is currently being overcome by collecting data via a detailed questionnaire. However, the preliminary analysis suggests that the Princeton plan has been effective in reducing Princeton employees' work trip VMT significantly.

This paper presents the benefits of a geographically restricted mortgage loan policy and the theoretical support for such a policy. The initial empirical results of the Princeton plan are given. We propose that the U.S. Environmental Protection Agency's (EPA) regulatory policies be used as incentives to induce participation of the private sector in providing geographically restricted mortgage-subsidy programs.

PROBLEM DEFINITION

The problems of excessive energy consumption and air pollution emerged during the last decade as major facets of the urban transportation problem. Automobile travel is a major contributor to both energy consumption and air pollution. Automobile travel accounts for about 40 percent of the U.S. consumption of oil, two-thirds of which is consumed in urban areas (1). Pollutant emissions from mobile sources produced 75 percent of the ambient carbon monoxide (CO), 55 percent of the ambient hydrocarbons (HC), and 50 percent of the ambient nitrogen oxides (NO_x) in urban areas in 1973. Reduction in these levels of energy consumption and air pollution has been mandated by legislation such as the 1975 Energy Policy and Conservation Act and the Clean Air Act of 1970, as amended. However, large-scale solutions by the public sector to these problems appear to be decreasingly feasible as the public increasingly embraces fiscal austerity and rejects governmental regulation of private industry.

To date, the approaches to solving the problems of excessive energy consumption and air pollution from mobile sources have been characterized by both a technical dimension and a political dimension. The technical dimension distinguishes between transportation supply and transportation demand solutions. Supply solutions include the construction of new mass transit facilities or the increasing of the capacity of existing transit facilities and improvement of the fuel efficiency and emissions levels of automobiles. Supply solutions generally try to accommodate existing or projected demand for transportation; they represent the traditional approach of transportation planners and engineers to transportation problems.

On the other hand, demand solutions focus on the reduction or redistribution of VMT, which in turn reduces or redistributes vehicular emissions and reduces energy consumption. Demand solutions include automobile and gasoline taxes, staggered work hours, increased parking fees, congestion pricing, and influencing the location of travel-producing or travel-attracting activities. This last option may offer the greatest potential for reducing automobile-related energy consumption and air pollution, but it is difficult to implement due to American traditions in land use development (2). Demand solutions have gained popularity in recent years, at least within the academic community.

Potential solutions can also be categorized along a political axis. The political dimension distinguishes between distributive and restrictive solutions, to borrow Altshuler's useful dichotomy (1).

Distributive solutions are those that confer financial or other benefits to various groups in order to implement transportation proposals. Restrictive solutions constrain choice and include such measures as regulation of product performance, consumer regulations such as gasoline rationing, and pricing measures to reduce VMT or gasoline consumption. In general, distributive measures are feasible politically but are expensive to implement; restrictive measures involve less direct expense but are politically difficult to implement.

Any particular solution participates in both dimensions at once. For instance, construction of a new transit facility is a supply-oriented, restrictive measure. Demand-oriented, distributive measures, which are potentially the most-effective combination, have not as yet been proposed. Our intention here is to make a preliminary case for one such measure--mortgage subsidies to households that are willing to live close to work.

Future efforts to reduce automobile-related air pollution and energy consumption will probably focus on improved vehicular efficiency and reduction of VMT. With regard to improved automobile performance, the federal government has made full use of its regulatory powers. The machinery has been set in motion, and, with vigilance, the automobile fleet will become more energy efficient and less polluting.

Little, however, has been done with respect to VMT reductions. Carpooling and transit have so far failed to produce significant reductions in VMT. This indicates that other nontransportation measures to reduce VMT should be considered.

Transportation seeks to eliminate the spatial separation of people and activities. By shortening the journey-to-work, which accounts for 40-60 percent of urban travel, spatial separation is decreased and VMT reduced. If people could be induced to live closer to work, this objective could be realized. The potential energy savings from such a policy would outweigh the effect of any other policy except for the utopian carpooling policy.

Evidence suggests that for the past 25 years transportation has placed little constraint on the major household decision of housing location. Although accessibility of the work place and urban rent structure are theoretically and empirically related, most researchers have found that other factors, such as cost, dwelling unit aspects, and neighborhood quality, are more important factors than distance to work in individual decisions about housing location.

As a result, the work trip can be quite long. One Chicago survey, for instance, found that the mean maximum acceptable length of the work trip was 58 min (3). Furthermore, work trip length seems to be increasing over time (4).

These increasing work trip lengths are symptomatic of the sprawl that has characterized metropolitan areas since the 1950s. Without redirection, this sprawl will probably continue. Given the extraordinarily high mobility of the U.S. population, policies that encourage people to voluntarily choose housing closer to where they work could be effective in reducing transportation needs.

Offering lower-interest home-mortgage loans to home buyers willing to live within a specified distance of their work places is an attractive policy for accomplishing this goal. Just as home-mortgage policies contributed to decentralization and overconsumption of transportation in the 1950s and 1960s, the above mortgage policy could lead to reduced energy consumption and strong economic growth in the 1980s and 1990s. Such a policy has a number of advantages:

1. It provides incentives rather than disincentives,
2. It tends to result in conservation and to complement programs that seek greater fuel efficiency and less pollution,
3. It provides long-term results with continuing benefits,
4. It does not necessarily imply highor low-density land use,
5. It produces land use patterns conducive to transit and carpooling, and
6. It is demand-oriented and distributive.

THEORETICAL DEVELOPMENT

A review of the literature concerning residential location revealed no previous theoretical analysis of the effects of a mortgage subsidy in reducing work trip length. However, two related areas of study are applicable to this topic: (a) trade-off theories of urban land rent and (b) residential mobility and migration studies. A brief examination of this literature supports the conclusion that a geographically restricted mortgage subsidy could result in reduced work trip VMT.

Trade-Off Theories of Land Rent

Trade-off theories of urban land rent (5-8) are based on the assumption that housing and accessibility to work are purchased jointly. These models assume a hypothetical city on a flat, homogeneous plane where all employment is concentrated at the center. The price any urban location commands is solely a function of its accessibility to the city center. Due to the cost of traveling, which is assumed to increase with distance from the city center, central locations command a higher unit price than do less central locations. Thus, the model derives a declining unit land rent curve for the urban area, which has the highest land rents at the point of greatest accessibility [the central business district (CBD)].

Households maximize their utility by trading off higher commuting costs for lower unit rents. Households that prefer lower-density housing, for instance single-family, detached houses, will travel farther in order to purchase housing at a lower unit price (9). The land rent model suggests that (assuming that higher-income households have a higher preference for land than for accessibility) households that can afford to do so will consume more housing, locate where unit prices are lower, and commute farther to work (10).

The land rent model has been the subject of much empirical analysis in the 1960s and 1970s. Most empirical studies have found site rent to be highly correlated with some aggregate measure of accessibility (11), although a number of researchers disagree (10,12-13). However, it seems clear that higher-income households (such as homeowners) consume less accessibility and more space (14) and tend to commute farther (9).

The trade-off rent models support the assertion that a geographically restricted mortgage policy could result in VMT reductions. Were a household to receive a mortgage subsidy without a geographical restriction, the household would buy more housing. How much more housing, and whether the household moves closer to the work place, stays at the same distance, or moves farther away will depend on the household's relative preferences for housing and accessibility. However, if the subsidy is restricted to sites within a given distance of the work place, the model suggests that at least some households will be better off by relocating closer to work, assuming that the mortgage subsidy does not affect the market rent curve.

Residential Mobility and Migration Studies

The literature on residential mobility and migration examines factors that influence the choice of housing at particular locations and conceptualizes the mobility process for individual households and aggregates of households. Trade-off models consider only generalized work place accessibility, household income, and lot size in developing an aggregate urban land rent curve. Given this land rent curve, how individual households select housing depends on a number of factors, including

1. Locational attributes, such as neighborhood quality and demographic composition, local taxes, public services, and parking availability;
2. Housing attributes, such as age of structure, dwelling quality, garage, structure type, and lot size;
3. Spatial attributes, such as accessibility to work and family, friends, shopping, and other nonwork destinations; and
4. Socioeconomic characteristics, such as household income, race, household size, number of workers, education, and marital status (15).

The relative importance of the journey to work as a factor in the housing decision seems to be small. Recent studies have concluded that convenience to work is only of marginal importance in the location decision (14,16,17) and that the journey to work is becoming less important as a determinant of residential location (4). Thus, the desire to save commuting costs no longer appears to be an important incentive to live close to the work place. The mortgage policy proposed in this paper supplants this incentive with a more potent financial incentive to live close to work.

Availability of mortgage funds and affordability of housing also affect the housing choice. However measured, the percentage of families able to afford a median-priced new home is decreasing (18). One study, based on 1976 data, found that between 17.5 and 40 percent of families could afford a median-priced new home, when affordability was based on current income. When current home equity was included in family income, 60 percent of the families could afford a new home (18). This percentage is probably lower in today's economy. By making housing affordable to more families, it therefore seems that the effectiveness of a mortgage subsidy in influencing household location is further reinforced.

Conceptualizations of the mobility process (19-21) typically use a cost-benefit approach to moving from one location to another. In these approaches, households consider moving due to dissatisfaction. Dissatisfaction occurs when a perceived gap appears between actual and optimal levels of housing satisfaction (22). Thus, dissatisfaction could occur due to the availability of a mortgage subsidy at a location other than the current household location. Dissatisfaction does not necessarily result in household relocation, however, because moving entails substantial search and relocation costs. Households move when the expected benefits (monetary and nonmonetary) from a new location exceed the moving costs (monetary and nonmonetary) of moving to that location. Thus, if the benefits that accrue from a mortgage subsidy are greater than the moving costs entailed in qualifying for that subsidy, at least a significant percentage of households should move to subsidized locations.

Although current research has not yet allowed us to measure these benefits and costs, we hope that these can be measured through a survey currently being administered. In the findings presented, only the percentage of subsidy and the corresponding amount of VMT are known; individual household benefits and costs are unknown.

EMPIRICAL ANALYSIS OF THE PRINCETON PLAN

Description

The Princeton University mortgage loan program, "The Princeton Plan", is part of the university's effort to provide close, affordable accommodations for its employees. The plan's objective is to ensure that Princeton University remain a residential university by offering incentives to faculty and senior-level staff to purchase a home in the vicinity of Princeton. The plan offers home-mortgage loans at an annual percentage rate approximately 1.5 points below the prevailing local commercial interest rate for home-mortgage loans at the time written application is made. To qualify, an eligible university employee must buy a house located within 8 miles of the central campus.

Begun in 1958, the plan applies to first mortgages only on homes purchased to be the principal residence of the eligible employee and his or her family. Refinancing of existing mortgages, second-mortgage loans, and home-improvement loans are not allowed. The effect of these restrictions is to associate the mortgage program directly with the housing-location decision.

The primary incentive offered by the plan is the reduced mortgage rate. However, other incentives provided by the plan are a lower down payment (10 percent) and a longer payback period (40 years). Also, the very availability of mortgage funds in a tight market situation is an incentive to eligible home buyers to participate in the program.

About 40 percent of all eligible employees hold home mortgages obtained through the Princeton mortgage-loan program. When only professors, associate professors, and assistant professors are considered, participation increases to 55 percent. About 70 percent of full professors participate in the program.

Plan-Induced VMT Reductions

The impact of Princeton University's home-mortgage loan program on residential location and work trip length has been assessed by comparing work trip length distributions between (a) university employees eligible to participate in the program and those who are ineligible and (b) Princeton employees and comparably salaried employees of other institutions and corporations in the area. Evaluation of these distributions allows a preliminary assessment of the effects of the Princeton plan. More rigorous evaluation of the impact of the Princeton plan in reducing VMT will be based on the results of the detailed survey currently being conducted.

Rutgers University, the Squibb Corporation, and the Educational Testing Service (ETS) were selected to provide comparisons of work-trip length distributions with Princeton University. Both Squibb and ETS are located close to Princeton and employ workers whose socioeconomic characteristics are similar to those of Princeton employees. Rutgers was selected for comparison because it is the closest major university to Princeton. Rutgers is located in New Brunswick, New Jersey, approximately 20 miles from Princeton.

It was necessary to generate dichotomous employee groups at Rutgers, ETS, and Squibb comparable to the eligible and ineligible dichotomy at Princeton. Consequently, a salary level of $25 000 was chosen as an approximate dividing line between those employees eligible for Princeton's loan program and those not eligible. Thus, an employee whose salary is more than $25 000 at Rutgers or ETS corresponds to an employee at Princeton eligible for the mortgage program. Due to data restrictions, the employee sample from Squibb is divided at $20 000 rather than $25 000.

Length of the work trip was calculated on a straight-line basis rather than on a road-mileage basis. Employees were aggregated by zip code area and were assumed to live at the centroid of the zip code area. Although these simplifications reduce the precision of the model, this level of detail was considered sufficient for preliminary comparisons of distributions of work trip length.

Figures 1-3 present cumulative work-trip length distributions for groupings of Rutgers, Squibb, and ETS employees comparable to the eligible and ineligible groups of Princeton employees. Figure 4 presents cumulative distributions of work trip length for eligible and ineligible Princeton employees. If, for example, there is a cumulative percentage of 40 at 10 miles, this indicates that 40 percent of the employees in that salary range live within 10 miles of work.

Inspection of these plots supports the hypothesis that Princeton's mortgage loan program is successful

Figure 1. Cumulative work trip length distributions for Rutgers University employees.

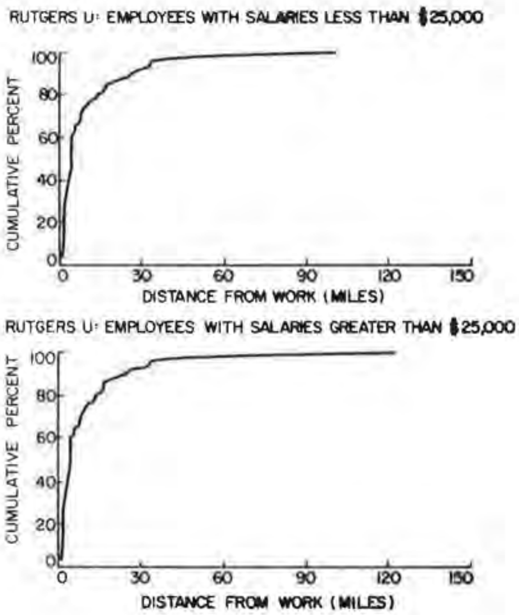

Figure 2. Cumulative work trip length distributions for Squibb employees.

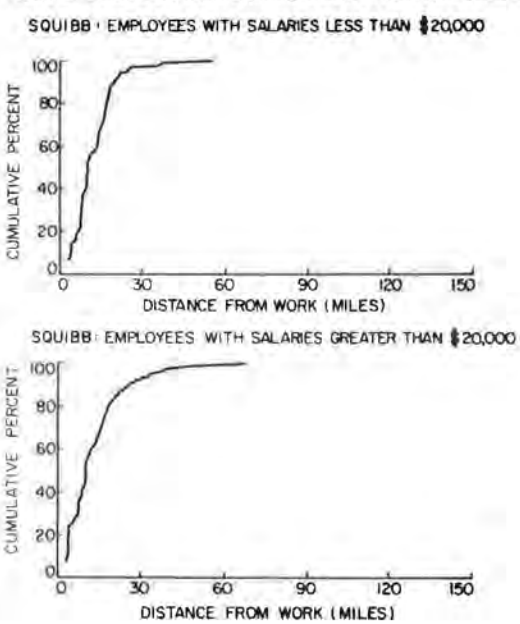

Figure 3. Cumulative work trip length distributions for ETS employees.

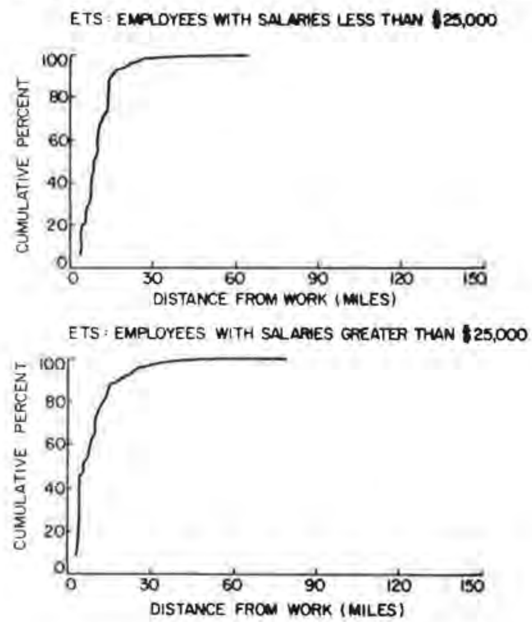

Figure 4. Cumulative work trip length distributions for Princeton University employees.

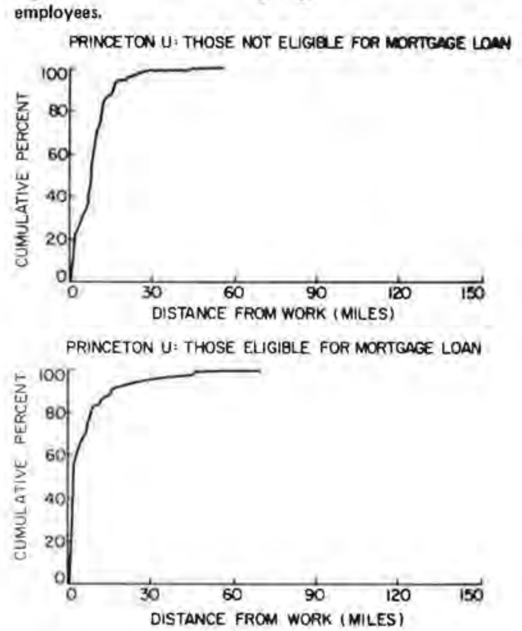

Table 1. Work trip length means and standard deviations.

Employer	Employee Salary Category	No. of Employees	Mean	SD
Rutgers	<$25 000	1953	9.4	12.6
Rutgers	>$25 000	3817	9.3	12.8
Squibb	<$20 000	357	12.4	7.5
Squibb	>$20 000	546	13.3	10.2
ETS	<$25 000	1791	10.1	6.2
ETS	>$25 000	405	9.3	8.6
Princeton	Not eligible for loan	2174	8.9	6.6
Princeton	Eligible for loan	2138	6.8	9.6

in inducing employees to live closer to the work place. Rutgers' distributions for low and high-salaried employees appear almost identical to each other. The Squibb and ETS distributions appear less alike, but only Princeton's work-trip length distributions appear greatly different. This indicates that there is little difference in the distributions of work-trip length of highand low-salaried employees, except at Princeton, which has a mortgage-loan program for its high-salary personnel.

Table 1 presents sample sizes, mean work-trip lengths, and standard deviations for employee group pairs at Rutgers, Squibb, ETS, and Princeton. Within groups, both the high-salary (eligible) groupings and the low-salary groupings (ineligible) are significantly different at the 95 percent confidence level. The ETS groups are significantly different at the 95 percent level but not at the 99 percent level. The Princeton distributions, however, are significantly different at all confidence levels up to 99.9 percent. The distributions of work trip length for the employees eligible for the program and those who are ineligible can, therefore, be declared significantly different. Comparably salaried groups at Rutgers and Squibb showed no significant difference in trip length; comparable groups at ETS showed only marginal differences. These results indicate that the mortgage-loan program at Princeton does entice eligible employees to live closer to work.

Weighted averages were used to compare the distribution of work trips of Princeton employees who participate in the mortgage program with the distributions of comparably salaried employees at Rutgers and ETS. This revealed that the Princeton employees live approximately 2.5 miles closer to their work place than do their counterparts. In this initial analysis, the difference in commuting distances is attributed to the mortgage subsidy. Consequently, the Princeton plan is responsible for reducing annual VMT for the 2138 participants by approximately 3.2 million miles. (This figure is based on assumptions of a 300-workday year and twice daily commuting trips.)

This reduction in work trip VMT results in a conservation of energy and reduction of air pollution. Approximately 200 000 gal of gasoline are conserved annually as a result of the subsidy-induced VMT reduction. This estimate is based on a fleet fuel-economy average of 14.2 miles/gal, extrapolated from the Transportation Energy Conservation Data Book (23). In addition, the reduced VMT that accrues from the Princeton plan results in annual reductions of emissions of approximately 150 tons CO, 19 tons HC, and 10 tons NO_x. [These figures are derived from the Mobile Source Emission Factor Tables (24) for 21 percent cold starts, 53°F, and 25 mph.]

Although the objective of the Princeton plan is to encourage a residential university community, these figures demonstrate that the plan also induces significant savings in both energy consumption and vehicular emissions. In order to assess the feasibility of implementing this type of program on a more widespread level, the issue of costs must be addressed. As a starting point, the costs of the Princeton plan were estimated.

The Princeton mortgage program is financed through the university endowment. As of 1979, $26 837 000 was held in outstanding loans to faculty and staff, almost all of which was in the form of mortgage loans. In 1979 alone, the university invested $3 322 000 in the mortgage program. The plan has a default rate of virtually zero, and administrative costs are low. Thus, the cost of the program to Princeton University is essentially just the opportunity cost of directing funds to the mortgage-loan program rather than to some alternative investment opportunity.

We assume that, in the absence of the mortgage program, the university would diversify its portfolio in much the same manner. That is, the university would invest a comparable amount in long-term, low-risk investments through a commercial institution. Thus, the opportunity cost to the university of providing the mortgage subsidy is estimated as the amount of the mortgage investments multiplied by the differential interest rate.

Although the Princeton mortgage rate has since been capped at 10.5 percent, at the time the data were collected the interest rate was set at 1.5 percentage points below the prevailing local commercial interest rate. Since approximately $27 million was invested in the program in 1979, the opportunity cost to the university for that year was approximately $400 000. The inclusion of $25 000 annual administrative costs for the program brings the total cost of the mortgage-subsidy program in 1979 to approximately $425 000.

IMPLEMENTATION OF MORTGAGE SUBSIDIES

Although the Princeton plan induces a significant reduction in employee work trip VMT and associated fuel consumption, these benefits are achieved at a significant cost. Consequently, in this time of fiscal austerity and deregulation, implementation of such a mortgage policy through the public sector is probably infeasible. In addition, Princeton's rather unique motivation for implementing a geographically restricted mortgage-subsidy program would not be widely shared throughout the private sector.

We propose, however, that an important financial incentive for implementation by the private sector of geographically restricted mortgage-subsidy programs does exist. This incentive has been provided by the EPA's emissions offset policy.

Emissions Offsets

By using this policy, industries can trade-off part of their mandated emissions reductions at the plant for emissions reductions that accrue from subsidy-induced VMT reductions. Thus, industry can use this type of subsidy program to increase flexibility in finding the most cost-effective means of pollution control. In the process, significant energy savings can be realized.

The failure of the Clean Air Act to provide for new sources of industrial pollution in areas that had not attained the national ambient air quality standards (NAAQS) effectively put a stranglehold on major industrial development in many urban areas. As a result, a 1976 interpretive ruling on section 110 of the Act provided for economic development in nonattainment areas under certain stringent conditions. The ruling allowed a new source of pollutants to locate in a nonattainment area if its emissions would be more than offset by concurrent reductions of emissions from existing sources in the area. This became the heart of the emissions-offset policy, or simply the offset policy.

The same ruling also addressed the problem of new sources that cause a previously clean area to violate federal air quality standards. Under these conditions, a potential source of pollutants was required to obtain offsets in an amount sufficient to prevent violation of the NAAQS.

The offset policy can only be applied to the same types of air pollutants, and, in addition, the limitations on the geographic source of offsets depend on the type of pollutant involved. For example, hydrocarbon or nitrogen oxide emissions offsets could be obtained from anywhere in the broad vicinity of the new source, but other pollutant offsets would have to be obtained from a more limited area because they are more site dependent.

The 1977 Clean Air Act Amendments expressly approved the emissions-offset interpretive ruling, and on December 29, 1978, EPA announced a revised emissions-offset policy. The most important feature of the revised policy was EPA's provision for the banking of emissions offsets.

The approval of offset emissions banking provided the key to the organizational problem of coordinating pollution offsets. An offset banking system can facilitate the trading of offsets by certifying that the promised pollution reductions have been made and by keeping track of available offsets within the region. Banking enables the pollution offsets to be traded, sold, or saved.

The emissions offset and banking policies provide industry with an important financial incentive to implement geographically restricted mortgage-subsidy programs. By using these policies, industries may offset increased pollution at the plant with decreased emissions from shorter employee work trips. Thus, industries are provided with a larger spectrum of feasible solutions to pollution abatement from which they can find the most cost-effective means of control. In particular, an industry does not have to shorten its own employees' trips; the banking policy allows the same benefit in reduced pollution controls to be obtained by purchasing reduced employee emissions from other firms in the area.

In comparing the costs of pollution control via mortgage subsidies with the cost of industrial pollution abatement measures, it is important to use the marginal cost of control in the evaluation. The marginal cost of industrial pollution abatement typically increases with increasing levels of control. Consequently, if pollution offsets obtained through mortgage subsidies are to be traded with the last X percent of regulated industrial control, the cost of the subsidy program should be compared with the cost of that last increment of abatement.

Mortgage-Subsidy Programs

Many mortgage-subsidy programs currently exist in the private sector. The two most common are direct mortgage financing and mortgage interest-rate-differential programs (MID programs). Although only a small percentage of these is geographically restricted, the existence of these programs suggests their potential feasibility on a more widespread level. In particular, it suggests that it would not be a radical step to modify these programs to be geographically restricted, such as by offering an increased subsidy that is restricted to a specified geographic area.

The first type of mortgage subsidy is the direct mortgage financing program. Through this program, eligible employees can obtain mortgages, often at an interest rate below the prevailing commercial rate. Financial benefits accrue to the participating employee through both the lower interest rate and actual availability of a loan in a tight money market.

Direct mortgage programs are offered primarily through academic institutions, but several businesses also provide such programs. A sample of those that offer direct subsidy programs includes the University of Michigan, Columbia, Harvard, the University of California, Carnegie-Mellon, Yale, and the Gulf Oil Corporation. According to a 1980 Merrill Lynch survey of major corporations, 7 percent of the respondents (40 firms) indicated that they provide mortgages directly to their employees, and 22 percent (18 firms) of the banking, financial, and insurance corporations interviewed provide such programs. Another trend revealed by the survey is that the percentage of companies that have mortgage-financing programs increases with their propensity to transfer employees (25).

Several of the academic mortgage programs restrict participation to homeowners who live within a specified geographic area. This has generally been done to further such objectives as offering a recruitment aid and establishing a proximate residential community, but the success of these programs suggests that geographically restricted mortgage-subsidy programs could be used to achieve other objectives as well.

The second common type of mortgage-subsidy program is the MID program. Under this policy, reimbursement is made to eligible employees according to a formula based on the interest rates of the new and old mortgages. The same Merrill Lynch study found that 27 percent of the interviewed firms (164 firms) have MID programs. Companies that provide MID programs include Digital Equipment, B.F. Goodrich, Anheuser Busch, Anchor Hocking, Eli Lilly, and Celanese Corporation.

Although none of these programs is restricted geographically, implementation of such a policy would be feasible. Future research will examine the impact geographically restricted MID programs can have on influencing residential location.

CONCLUSIONS

The intention of this paper has been to report research in progress on the feasibility of geographically restricted mortgage-subsidy programs to reduce employee work trip VMT, energy consumption, and vehicle emissions. Future research is planned to analyze in more detail several aspects of the mortgage subsidy. A questionnaire is being distributed to provide much needed disaggregate data. These data will aid measurement of the sensitivity of residential location decisions to MID programs and direct mortgage subsidies. These data will also help determine the effect of geographically restricted mortgage subsidies on total household VMT and travel patterns.

This paper reported only general conclusions on the cost to industry of a mortgage-subsidy program. In order to determine more fully the financial incentive to private industry of implementing such a program, the costs of both mortgage-subsidy programs and industrial pollution abatement will be documented more completely.

The results of research to date, however, indicate that geographically restricted mortgage-subsidy programs can be feasibly implemented in the private sector as a means of reducing VMT, and, consequently, of reducing excessive energy consumption and vehicular emissions. Linkage of mortgage subsidies to EPA's emissions offset policy can provide industry with a financial incentive to provide such programs. This linkage forms a policy that provides industry with the means of achieving more cost-effective pollution control while realizing significant savings in energy consumption.

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Transportation-Related Impacts of Compressed Workweek: The Denver Experiment

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This paper summarizes results of an evaluation of the federal employee compressed workweek experiment in the Denver area. In this experiment, more than 7000 federal employees changed from standard work schedules to either a four-day workweek or nine workdays in a two-week period. Emphasis is placed on transportation impacts related to air quality and energy issues, with particular attention given to quantifying the more-indirect impacts of compressed work schedules on overall weekly household travel patterns. The analysis approach developed to evaluate these issues essentially involves the measurement of a number of travel-related impacts prior to implementation of the compressed workweek and again one year later. Also involved is the use of experimental and control groups to isolate those impacts attributable to the compressed workweek from other impacts from factors exogenous to the experiment, such as changes in the price and availability of gasoline. The findings indicate that compressed work schedules lead to a reduction in weekly household vehicular travel. Further, reductions are observed not only for work travel but for nonwork travel as well. Results also suggest that the compressed workweek can be compatible with other regional transportation actions such as ridesharing and transit. Although not demonstrated conclusively in the Denver experiment, the compressed workweek also appears to have the potential for improving traffic flow conditions by reducing peak-hour traffic volumes.

The compressed workweek, a form of alternative work schedules in which employees work a full 40-h week in less than the standard five days, became popular in the early 1970s, particularly among small manufacturing and local government employers. From a relatively small number of employees in 1971, nationwide participation increased to more than 1 million workers by 1975 (1). Subsequent data, though, indicate that participation levels have stabilized or possibly decreased somewhat. By 1976, for example, national participation had dropped to 1.27 million workers.

Renewed interest in the compressed workweek has been expressed on the part of the federal government as evidenced by the Federal Employees Flexible and Compressed Work Schedules Act of 1978, which authorized federal employees to participate in alternative work schedules, either flexible hours or compressed workweeks, on an experimental basis for a three-year period (Public law 95-390, section 2). One of the most intensive efforts directed toward implementing this Act occurred in the Denver region, which has 93 federal agencies that employ nearly 30 000 employees in the metropolitan area and is second only to Washington, D.C., as a center of federal employment. Unlike most earlier applications in which compressed work schedules were viewed for the most part as a means of improving productivity or as an employee benefit, implementation of the compressed workweek in Denver was motivated primarily by its potential transportation-related energy and air quality impacts.

Initiative for the Denver compressed workweek experiment originated with the Denver federal executive board (DFEB), an organization of regional administrators of all federal agencies in the Denver region. The DFEB, after considering the air quality problem in Denver and feeling obligated to respond to the federal legislation that authorized variable work-hours experiments, conceived of a compressed workweek experiment to be conducted among all federal agencies within the Denver region. This organization provided both a forum for discussion of the concept itself and the mechanism needed for obtaining commitments from a number of federal agencies to participate in the experiment. Of critical importance in allowing the experiment to proceed was agreement by the affected labor unions to allow their employees to participate in the program. The unified commitment by the DFEB was also, no doubt, instrumental in securing this agreement.

Implementation of compressed work schedules among Denver's federal employees was quite extensive. A poll of Denver area federal agencies taken in December 1979 revealed that 35 agencies were participating in the compressed workweek experiment and that well over 7000 employees were actually on compressed work schedules of one sort or another. One year later, participation had increased to include more than 9000 federal employees in 42 agencies.

Participation within individual agencies ranged from about 50 percent to more than 95 percent; average participation was approximately 65 percent. In terms of specific form of compressed work schedule, participation appeared to be split almost evenly between the four-day workweek and the five/four-nine plan. With the former, employees work four 10-h days each week; with the latter, employees work 80 h in nine workdays and take an extra day off every other week. Not surprising, the most popular days off were Mondays and Fridays (chosen, respectively, by 36 and 60 percent of those employees on compressed work schedules) since this afforded the opportunity for three-day weekends.

SCOPE OF EVALUATION

The Denver Regional Council of Governments (DRCOG), as the designated transportation and air quality planning agency in the Denver region, viewed the participation of Denver's federal community in this experiment as an excellent opportunity to demonstrate the potential effectiveness of the compressed workweek, as one form of alternative work schedule, in improving air quality and reducing fuel consumption. Therefore, unlike the evaluation of this experiment at the national level conducted by the Office of Personnel Management (OPM), which addressed a number of impacts that ranged from the efficiency of government operations to the quality of life for individuals and families, objectives of the Denver study were more narrowly defined and focused primarily on the transportation-related air quality and energy issues associated with the compressed workweek that may be unique to the Denver area (2,3,). Specifically, in sponsoring the evaluation, DRCOG sought to address the following issues:

1. The effectiveness of the compressed workweek in reducing automobile emissions and fuel consumption and
2. The compatibility of the compressed workweek with other regionally accepted transportation measures such as ridesharing and transit.

A secondary area of investigation, not discussed in this paper, was the identification of factors important in determining employee acceptability of compressed work schedules.

POTENTIAL TRAVEL IMPACTS

Weekly Household Travel

In the context of transportation-related impacts, the basic motivation for promoting the compressed workweek is that, by revising work schedules so that employees work four 10-h days rather than five 8-h days, work travel and associated fuel consumption and vehicle emissions are reduced by 20 percent. To consider this 20 percent (or, with the five/four-nine plan, 10 percent) reduction in work travel as the bottom line in terms of vehicle emissions and fuel consumption, though, is somewhat naive; a number of potential changes in nonwork travel could occur as a result of compressed work schedules as well.

For example, many employees on compressed work schedules could use their extra day off to engage in activities that would result in an increase in nonwork travel that could partly offset or perhaps even exceed any savings in work travel. This was of particular concern in the Denver experiment in view of that area's abundance of nearby recreational facilities. However, although increased travel on the extra day off is certainly one possible response to compressed work schedules, a number of other more subtle impacts on household vehicular travel can be identified that could lead to an overall reduction in nonwork vehicle miles of travel (VMT).

For example, during the course of the normal five-day workweek, many employees on standard work schedules (i.e., eight-hour workdays) would probably make a number of trips for non-work-related purposes (e.g., shopping, recreation, doctor, or dental appointments) either as part of their normal trip to and from work or as separate trips in the mornings or evenings. One would expect that, for those employees who switch to compressed work schedules, the extent to which these additional trips are made would drop off markedly.

After 10 h of work, for example, it is not likely that many people would be particularly anxious to delay their trip home in order to run an errand or, once home, to set out again later in the evening.

Instead, the options of rescheduling the trip to the extra day off during the week, having another household member make the trip, or perhaps even eliminating the trip entirely may be much more appealing.

Another potential impact of the compressed workweek would be a shift in travel for non-work-related purposes from Saturday or Sunday to the weekday that the employee has off. For day trips to recreational areas, for example, this would be particularly attractive from the standpoint of avoiding crowds. Similarly, shopping trips and other household errands normally made on weekends might be shifted to the weekday off in order to take advantage of less-crowded conditions.

Because of the wide range of potential changes in household travel patterns that could occur in response to the compressed workweek, a focus only on changes in work travel and travel on the employee's extra day off would not provide a complete assessment of the VMT-related impacts of compressed work schedules. Instead, all household travel should be considered over a seven-day period.

Ridesharing

In addition to impacts related to the number of work trips and changes in nonwork travel patterns, other potential impacts associated with compressed work schedules can be identified that could adversely affect ridesharing. For example, because ridesharing arrangements among employees on compressed work schedules and those on standard work schedules would be quite difficult (if not impossible) to coordinate, the implementation of compressed work schedules on a limited basis could disrupt existing carpools and vanpools.

Transit

The compressed workweek could also have an adverse impact on transit ridership. For example, because of their longer workday, employees on compressed work schedules travel to and from work outside the peak hour. If the level of transit service outside the peak hour is considerably lower than that during the peak hour, transit would become less attractive relative to automobile. As a result, some of those employees that switch to compressed work schedules may also switch from transit to automobile.

However, even if those employees on compressed work schedules continue to ride transit, there still exist potentially negative impacts on transit fare revenues. For example, the 20 percent reduction in work trips associated with the four-day workweek could translate into a corresponding 20 percent reduction in fare revenues.

Reduced Peaking

The longer workdays associated with compressed work schedules could lead to potentially beneficial travel-related impacts as well. In terms of automobile travel, for example, those employees who arrive at work earlier and leave later in the day would be traveling outside the period of peak travel volumes. Depending on the severity of peak traffic congestion, then, substantial travel time savings could be realized. Further, if participation in the compressed workweek is high enough in areas of concentrated federal employment, improvements in traffic flow conditions throughout the peak period could result not only in travel time savings for other commuters but also in reductions in automobile emissions and fuel consumption. In the case of transit, longer workdays could serve to flatten peak-hour transit demands, which in turn could be viewed as either an increase in effective peak-hour capacity or a reduction in peak-hour transit supply requirements.

The potential travel impacts associated with the compressed workweek examined in the course of this study are summarized in the table below.

Item	Potential Impact: Positive	Potential Impact: Negative
Weekly household travel		
Reduced work travel	X	
Induced nonwork travel on day off		X
Consolidation of nonwork travel	X	
Commuting		
Disruption of existing carpools		X
Reduced transit use		X
Reduced transit fare revenues		X
Reduced peaking		
Flattened peak transit demands	X	
Improved traffic flow conditions	X	

Evaluation Approach

The basic approach used in evaluating the transportation-related impacts of the compressed workweek involved comparing measurements of selected impacts obtained prior to the implementation of compressed work schedules in June 1979 with those taken one year later in June 1980. These measurements involved surveys of more than 2100 federal employees in 29 agencies located throughout the Denver area supplemented by traffic counts and bus ridership data.

Ideally, the impacts of the compressed workweek would be represented by observed differences before and after implementation of the compressed workweek for just those employees who actually switch to compressed work schedules. However, during the one-year period between surveys, a number of other events occurred that also had an effect on travel. In particular, there were some rather dramatic changes in both the price, and more importantly, the availability, of gasoline. June 1979 was the height of an energy crisis, during which time there were some relatively severe constraints on the availability of gasoline in the Denver area. One year later, though, although the price of gasoline had increased by about 25 percent, the supply situation had eased considerably.

In order to control for these and other factors, it was necessary to obtain measurements for those employees who remained on standard work schedules as well as those who switched to compressed work schedules. In an experimental design sense, then, employees in those agencies that participated in the compressed workweek experiment (i.e., agencies in which employees had the option of choosing compressed work schedules) served as the test group, and those in nonparticipating agencies (i.e., agencies in which compressed work schedules were not an option) served as the control group.

Data-Collection Considerations

The employee surveys, which served as the primary source of data used in developing the measures necessary to analyze potential impacts of the compressed workweek, involved two types of questionnaires. First, a relatively short questionnaire was used to obtain data on the employee's work trip, socioeconomic characteristics, and household composition. Second, included with each questionnaire was a set of three vehicle logs that were designed to measure changes in household vehicular travel that resulted from the compressed workweek. Employees were asked to keep one log in each household vehicle (up to a maximum of three) and record odometer readings, time of day, and trip purpose for travel over a seven-day period (or in some cases a three-day period).

The sample design that was developed for the employee survey, which was essentially a stratified cluster sampling approach, reflected the need to achieve a reasonable level of accuracy while at the same time minimizing both sample size and administrative requirements associated with the survey. Two stages of cluster sampling were involved. First, a sample of 29 of the 93 federal agencies in the Denver area was selected. Then, work units within each selected agency were sampled and all employees within each of the sampled work units were surveyed. The advantage of employing such a technique is clear. Rather than contacting and organizing separate survey efforts in each of Denver's 93 federal agencies, only a subset of these agencies had to be included in the sample.

This technique lowers the costs associated with survey administration; however, the possibility exists of a trade-off in terms of reduced sampling efficiency relative to a straightforward random sample. The extent to which sampling efficiency could be reduced is dependent on, among other factors, the degree to which variability among federal employees in Denver occurs between agencies versus within agencies. If most of this variability exists within agencies, for example, reduced sampling efficiency would be minimized. If most of this variability exists between agencies, though, sampling efficiency could be reduced considerably, since employees from only 29 of Denver's 93 federal agencies were surveyed.

To ensure that any interagency variability was captured, agencies were organized into groups or strata with the intent of minimizing the variation between agencies in any single stratum (i.e., ideally all interagency variation would be captured by interstratum variation). Three levels of stratification were used. First, agencies were grouped together based on their intent to allow their employees to participate in the compressed workweek experiment. Each of these groups then was stratified by location (CBD versus non-CBD). These four groups were further stratified by agency size (small, medium, and large), which resulted in a total of 12 strata from which agencies were selected in the first sampling stage.

The sample sizes used for the before-and-after employee surveys and the response rates for both the employee questionnaire and vehicle logs are presented in the table below.

Employee Survey	No. of Employees Surveyed	No. of Employees Returning Questionnaire or Vehicle Log	Response Rate (%)
Before			
Questionnaire	2309	2149	93
Vehicle log	2309	1504	65
After			
Questionnaire	2464	2150	87
Vehicle log	2464	1283	52

For the most part, the after survey was administered to employees in the same agencies and work units used in the before survey. As a result, it was possible to match the response of more than 800 employees in the after survey to their corresponding responses in the before survey.

TRAVEL-RELATED IMPACTS

Results from the seven-day vehicle logs for those employees in agencies located outside the CBD are presented in Table 1 and Figure 1. Unfortunately, it was not possible to evaluate the impacts of the compressed workweek on household VMT for those employees in CBD-located agencies due to an insufficient number of observations for this group. However, fewer than 600 of the 7000 or more employees who were actually on compressed work schedules were in CBD agencies; therefore, this does not significantly affect any of the key findings related to household travel patterns.

As shown, results are presented in Table 1 in terms of four categories of VMT:

1. Total VMT for the seven-day period,
2. Weekend VMT (two-day total),
3. Weekday VMT (five-day total), and
4. Weekday work VMT (five-day total).

Note that weekday work VMT includes the total VMT associated with any trip or tour for which work was indicated as one out of possibly several trip purposes. In the seven-day logs, entries were made only at those times that the vehicle was actually being driven from home. As a result, weekday work VMT would also include any VMT associated with additional nonwork travel made on the way to or from work as well as any trips made while at work during the day.

As shown, different sample sizes are used for certain VMT categories. This is due to a greater nonresponse rate for more-detailed information related to individual trips. For example, although total VMT is based on odometer readings recorded at the beginning and end of the seven-day period, weekend and weekday VMT are calculated by summing the appropriate entries in the vehicle log. In those instances where day-of-week information was missing for one or more trips, that log could not be used for estimating weekend versus weekday VMT. As a result, these VMT values are based on a subset of those seven-day logs used to calculate the mean value of total VMT, and their sum does not necessarily equal that indicated for total VMT.

In each case, estimates of total VMT are based on a larger sample of logs than the corresponding estimates for weekday and weekend VMT. Where differences exist, total VMT is always greater than the sum of weekday and weekend VMT, which would indicate that those logs that contain incomplete day-of-week information have, on average, a higher total VMT than those that have complete information. This is not totally unexpected, though, since when the amount of travel is greater there is also a greater chance that some information would be omitted in recording this travel.

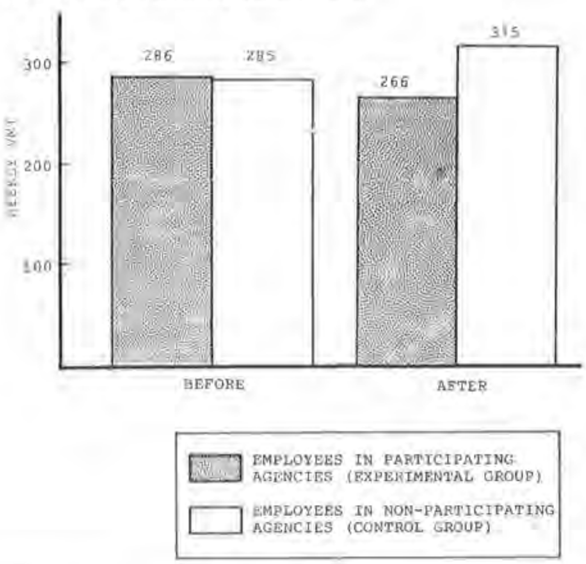
In assessing the impact of compressed work schedules on total household vehicular travel, employees in those agencies that participate in the experiment serve as the test group, and those in nonparticipating agencies serve as the control group. Based on the differences in VMT between the test and control groups for non-CBD agencies presented in Table 1 and Figure 1, a number of inferences can be made. First and foremost, the compressed workweek resulted in a significant decrease in average seven-day household VMT. Prior to compressed work schedules, total weekly VMT for employees in participating and nonparticipating agencies was, for all practical purposes, identical. One year later, though, average

Table 1. Changes in weekly household VMT: participating versus nonparticipating agencies.

	Employees in Nonparticipating Agencies			Employees in Participating Agencies			Difference[a]	
Item	VMT	No. of Observations	SE	VMT	No. of Observations	SE	VMT	SE
Before Compressed Work Schedules								
Total	285	154	15.8	286	594	8.3	+1	17.8
Weekend	75	129	6.6	79	490	3.6	+4	7.5
Weekday	210	129	13.4	202	490	6.5	−8	14.9
Weekday work[b]	133	111	9.7	145	432	6.2	+12	11.5
After Compressed Work Schedules								
Total	315	138	27.6	266	395	10.9	−49[c]	29.7
Weekend	86	110	13.2	75	320	5.9	−11	19.5
Weekday	204	110	15.1	185	320	8.6	−19	17.4
Weekday work[b]	156	91	14.4	124	286	7.2	−32[d]	16.1

[a]Difference is VMT for employees of participating agencies minus VMT for employees of nonparticipating agencies.
[b]Weekday work VMT as used here includes total VMT of any home-based tour that has work as one of several possible trip purposes.
[c]Significantly different from zero at the 90 percent level of confidence (two-tailed t-test). VMT of participating employees significantly less than that of nonparticipating employees at the 95 percent level of confidence (one-tailed t-test).
[d]Significantly different from zero at the 95 percent level of confidence.

Figure 1. Changes in weekly household VMT.



weekly household VMT for the test group was 49 miles less than that for the control group. This would imply that the compressed workweek resulted in a 15.6 percent reduction in total weekly household VMT among all employees in participating agencies.

Second, contrary to concerns that savings in work trip VMT would be offset to some extent by induced travel for nonwork purposes on the extra day off, nonwork travel also appears to have decreased somewhat. Although a difference in total VMT of 49 vehicle miles was observed between test and control groups, only about 65 percent of this difference can be attributed to a decrease in work-related travel. The implication, then, is that a number of shifts in the patterns of nonwork tripmaking occurred, with some trips either being rescheduled and combined more effectively or eliminated entirely.

The differences in VMT noted earlier in Table 1 are the net result of decreases in VMT on the part of employees in participating agencies and increases in VMT by employees in nonparticipating agencies.

Changes in Household Travel Patterns: Participating Employees

From the standpoint of obtaining an estimate of the aggregate change in household VMT attributable to compressed work schedules, the use of all employees in participating agencies (i.e., those employees that remained on standard work schedules as well as those that switched to compressed work schedules) as the experimental group is certainly appropriate. In order to gain some insight into the specific changes in travel behavior that have brought about this decrease in VMT, though, it is essential that not only the change in total seven-day VMT be isolated but also the relative contributions of changes in weekday, weekend, and work VMT as well. In this instance, the use of observed changes in VMT for all employees in participating agencies is not entirely satisfactory since any shifts on the part of those employees actually on compressed work schedules would be masked somewhat by the actions of those employees who remain on standard work schedules.

As mentioned earlier, more than one-third of the responses by employees in the after survey could be related to their corresponding responses in the before survey. For analyzing changes in household travel patterns, these paired observations are particularly useful in that responses prior to the experiment of those employees in participating agencies who eventually switched to compressed work schedules can be distinguished from those who remained on standard work schedules. The primary drawback to using this subsample is its decreased representativeness. Nonetheless, despite this potential difficulty, analysis of these matched responses is instructive. Although the specific magnitudes of observed shifts to VMT may be unique to this particular subset of employees, the general nature of these shifts is likely to be indicative of those that occurred in the sample as a whole.

Results from the seven-day vehicle logs for those responses that could be matched are presented in Table 2 and Figure 2 for those employees who actually switched to compressed work schedules. As shown, decreases are observed for each of the five VMT categories presented. Further, with the exception of average Monday and Friday VMT (defined as the sum of Monday and Friday VMT divided by two), these decreases are all quite significant.

A closer look at the specific changes shown in Table 2 shows a number of interesting points concerning some of the shifts in VMT that appear to have taken place.

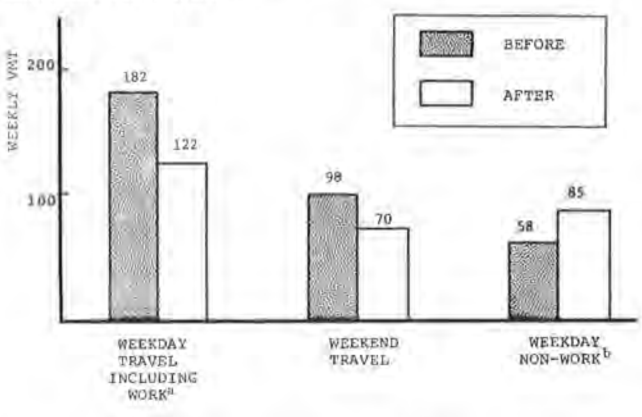
1. The change in total weekday work VMT (−60 vehicle miles) represents about one-third of its

Table 2. Changes in household VMT for employees who choose compressed work schedules.

VMT	Base VMT[a]	Change in VMT One Year Later	SE of Change	No. of Observations
Total for seven days	336	-59[b]	23.5	140
Weekend	98	-28[b]	10.9	72
Weekday	240	-33[c]	14.9	87
Weekday work[d]	182	-60[b]	15.9	65
Avg Monday and Friday	52	-6	5.1	85

[a]Prior to compressed work schedules.
[b]Significantly different from zero at 99 percent confidence interval.
[c]Significantly different from zero at 97.5 percent confidence interval.
[d]Note that weekday work VMT as used here includes the total VMT of any home-based tour that has work as one of several possible trip purposes.

Figure 2. Before and after household VMT for employees who choose compressed work schedules.



[a] Weekday Work VMT includes the total VMT of any home-based tour which as work has one out of possibly several trip purposes.

[b] Weekday Non-Work VMT includes the total VMT of any home-based tour for which work was not listed as one of the trip purposes.

base value (182 vehicle miles). Since at most only a 20 percent reduction can be attributed to the compressed workweek, this would indicate that, in addition to the elimination of one trip directly to and from work, at least some of the nonwork trips previously made in conjunction with work travel were either eliminated or rescheduled.

2. Although a reduction in weekday work VMT of 60 vehicle miles was observed, total weekday VMT decreased by only 33 vehicle miles, which suggests that some of the nonwork trips previously made in conjunction with work travel were in fact rescheduled to another weekday.

3. These differences between the reductions in weekday work VMT and total weekday VMT together with the reduction in weekend VMT of 28 vehicle miles suggest that there was also a shift in nonwork travel from the weekend to a weekday.

4. Although weekend VMT, weekday VMT, and weekday work VMT all exhibit relatively large decreases in VMT, the average decrease for Mondays and Fridays (the days that more than 95 percent of those employees on compressed work schedules take off) is only 6 vehicle miles, which suggests rather strongly that trips formerly made on the weekend and other weekdays were rescheduled to the employee's day off.

5. Given that average weekday work VMT was 182 vehicle miles for the standard five-day workweek, a maximum estimate of the VMT saved just by eliminating one work trip would be 20 percent of 182, or about 36 vehicle miles. Since the total reduction in weekly VMT was 59 vehicle miles, in addition to rescheduling nonwork travel to the extra day off, an overall reduction in nonwork travel also occurred as a result of the compressed workweek. This could be accounted for by more-efficient chaining of trips on the extra day off or by the elimination of some of the more discretionary trips previously made in conjunction with the trip to or from work.

Changes in Weekly Household VMT: Nonparticipating Employees

The differences in household VMT observed between test and control groups were due in part to an increase in VMT among nonparticipating employees as well as a decrease in VMT among participating employees. It is useful, then, to examine briefly those factors other than the compressed workweek that could have had a significant impact on travel. Since the two surveys were administered one year apart and with the same relation in time to school closings and holidays, seasonal effects can probably be ruled out. Weather, too, was quite similar during the periods covered by the vehicle logs. The most influential factors remaining, then, are the price and availability of gasoline.

Between June 1979 and June 1980, the average statewide price of unleaded fuel as reported by the American Automobile Association (AAA) increased from $0.91 to $1.29/gal. Adjusting for the increase in the cost of living during that period (up by 10.6 percent) and the increase in average fuel economy of vehicles used by federal employees (up by 3 percent), this would translate into a 25 percent increase in the per mile cost of gasoline. All else being equal, this should have resulted in a decrease in VMT.

Since VMT was observed to increase, though, all else was not equal. In particular, the availability of gasoline changed markedly between the two survey periods. June 1979 was near the height of the second energy crisis, and considerable publicity was given at that time to the severe shortfalls in California. In the Denver area, AAA was issuing weekly reports concerning station closings in the evenings and on weekends. During this period approximately 95 percent of those stations surveyed by AAA were closed on weekends and in the evenings on weekdays. One year later, though, the supply situation changed dramatically. The AAA was then issuing reports only once a month, and no mention was made of station closings at all. The widespread availability of gasoline at that time is probably best reflected in the stabilization (and subsequent drop) in gasoline prices that occurred. Based on the increase in weekly VMT observed for the control group (i.e., employees in nonparticipating agencies) presented in Table 1, it would appear that the effects of increased supply far outweighed those of increased price.

Ridesharing

The table below presents shared-ride mode shares for work travel prior to the implementation of compressed work schedules and again one year later for employees in participating agencies and those in nonparticipating agencies.

	Ridesharing			
	Before		After	
Employees	No.	Percent	No.	Percent
In participating agencies	1483	31	1432	29
In nonparticipating agencies	608	32	643	30

As shown, prior to the compressed workweek mode shares were similar between these two groups, although the changes after one year were identical. On the surface, then, compressed work schedules appeared to have no impact on ridesharing.

A closer look at just those employees in participating agencies, though, reveals that some rather dramatic changes in ridesharing did in fact occur. The table below presents shared ride mode shares for that subset of employees in participating agencies whose responses in the before and after surveys could be matched.

	Ridesharing			
	Before		After	
Employees	No.	Percent	No.	Percent
Who choose compressed work schedules	405	29	405	32
Who remain on standard work schedules	181	36	181	24

As shown, the aggregate decrease in shared ride for all employees in participating agencies, noted earlier in the preceding table, was the result of a moderate increase among those employees who switched to compressed work schedules (from 29.4 to 32.0 percent), which was more than offset by a very large decrease among those employees remaining on standard work schedules (from 35.5 to 24.4 percent).

These results would tend to indicate that compressed work schedules do indeed disrupt existing ridesharing arrangements involving employees who choose different work schedules. However, because such a large proportion of employees in participating agencies had chosen compressed work schedules (i.e., 65 percent), this group apparently was able to form new carpools. Those employees who remained on standard schedules, though, had more difficulty in forming new carpools since the number of employees with compatible work schedules was reduced considerably. Therefore, although the aggregate level of ridesharing was not adversely affected by compressed work schedules in the Denver experiment, the transferability of this finding to other applications would be contingent on similar levels of participation in compressed work schedules.

Impacts on Transit

Table 3 presents the transit mode shares for employees in participating and nonparticipating agencies. In addition, because the level of transit service available to those employees who work in the CBD was quite different from that available to employees whose work locations are outside the CBD, separate mode shares are presented for CBD and non-CBD employment locations. As shown, the transit mode shares remained essentially unchanged for non-CBD work locations. For CBD work locations, the transit mode share among employees in nonparticipating agencies rose from 0.32 to 0.37, a 16 percent increase. A somewhat smaller increase, from 0.28 to 0.31 (an increase of 11 percent), was observed among employees in participating agencies. Overall, though, the compressed workweek appears to have little impact on transit ridership among employees on compressed work schedules.

Impacts of the compressed workweek on transit fare revenues can be estimated based on the number of employees actually on compressed work schedules, the fraction that have a day off during a given week, and their current transit mode share. In the Denver experiment, the decrease in weekly transit ridership that resulted directly from the reduction

Table 3. Impacts on transit.

	Transit Mode Share			
	Before		After	
Agency	No.	Percent	No.	Percent
Non-CBD				
Participating	1175	2	1058	3
Nonparticipating	424	4	409	4
CBD				
Participating	308	28	374	31
Nonparticipating	184	32	234	37

in work travel was estimated to be 309 round trips. Assuming that this represents 618 revenue trips at an average fare of $0.56/trip (25 percent pay $0.75 express fare, 75 percent pay $0.50 local fare), this translates into an average fare revenue loss of about $348/week.

Note, however, that the compressed workweek also has the potential for flattening peak transit demand, since, because of longer work days, employees would be traveling outside the peak hour. Since transit service was not reduced at all during the experiment, the result of those employees on compressed work schedules shifting from the peak hour essentially would be to make additional bus capacity available for other employees who still travel in the peak hour. If a sufficient portion of this available capacity is used, the decrease in fare revenues that results from fewer work trips by those employees on compressed work schedules could be more than offset by an increase in ridership by other employees, both federal and nonfederal. For example, to the extent that transit service is characterized by crush load conditions during the peak hours, one could argue that the demand for transit service is sufficiently great that any increase in peak-hour capacity would be used immediately.

Clearly, such a situation would not be representative of all routes during the peak hour. However, if only one new, regular rider is attracted to transit for every five employees on compressed work schedules who shift their peak-hour transit trip, fare revenues would not change.

Potential Improvements in Traffic Flow

Figure 3 characterizes the midweek (i.e., Tuesday-Thursday) time-of-day distributions for arrivals and departures prior to and again after implementation of the compressed workweek for the 775 employees in participating agencies located in the CBD. As shown, the implementation of compressed work schedules flattened somewhat the peak in arrival times. The maximum percentage of total arrivals in a 0.5-h period, for example, was reduced from 56 to 42 percent. In addition to being flattened, the peak in arrivals was also shifted earlier by one hour from 8:00 to 7:00 a.m. Similarly, the peak in departure times was also flattened, and the maximum one-half-hour percentage of total departures was reduced from 47 to 34 percent. In this case, though, the peak in departure times was shifted one hour later.

With respect to all CBD traffic, peak 1-h volumes occurred between 7:30 and 8:30 a.m. and between 4:30 and 5:30 p.m., with excess capacity available during 6:00-7:00 a.m. in the morning peak and 5:30-6:00 p.m. in the afternoon peak. Thus, the shifts in arrival and departure times that resulted from the compressed workweek among employees in CBD agencies, which tended to reduce peak volumes and take advan-

Figure 3. Distribution of arrival and departure times for participating CBD agencies.

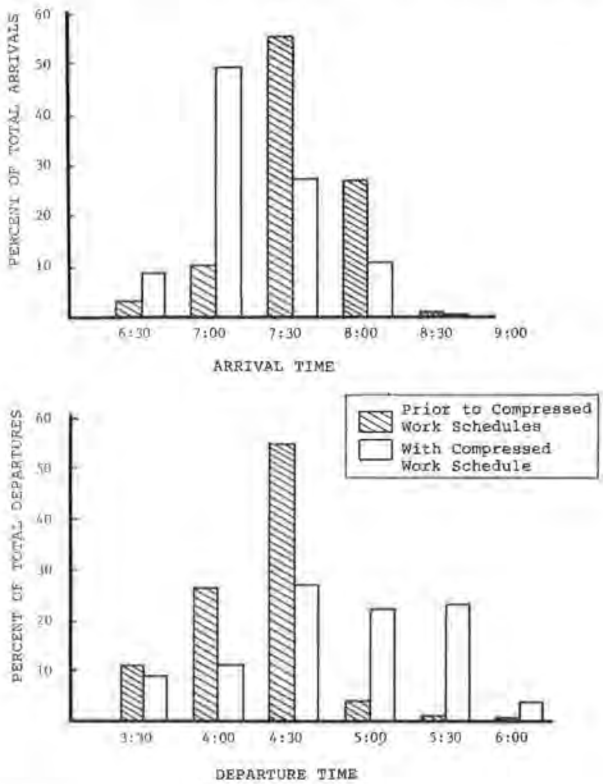


Table 4. Air quality impacts of compressed workweek: total seven-day impacts.

Affected Group	VMT[a] (%)	Emissions Reduction (%)			Fuel Consumption[e] (%)
		CO[b]	HC[c]	NO_x[d]	
Employees in participating agencies	15.6	15.7	15.8	15.4	15.6
All federal employees	5.6	5.7	5.7	5.5	5.6
Total regionwide travel	0.3	0.3	0.3	0.3	0.3

[a]Total reduction = 494 000 miles/week.
[b]Total reduction = 67 960 kg/week.
[c]Total reduction = 4970 kg/week.
[d]Total reduction = 1590 kg/week.
[e]Total reduction = 26 130 gal/week.

tage of this excess capacity, had the potential for improving traffic flow conditions in the CBD. However, because of lower participation levels among CBD agencies, extension of the compressed workweek concept to a larger number of CBD employees would have been necessary in order to realize this potential.

Air Quality and Energy Impacts

Table 4 presents the reductions in VMT and associated emissions and fuel consumption attributable to the compressed workweek experiment over a seven-day period. These results are also presented in percentage terms relative to the total weekly household VMT of

1. Just those federal employees in participating agencies,
2. All Denver area federal employees, and
3. All Denver metropolitan area residents.

As shown, the 15.6 percent reduction in total weekly VMT for employees in participating agencies translated into similar reductions in emissions and fuel consumption. Relative to all federal employees, these reductions represent about a 5.6 percent reduction in total weekly travel and related emissions and fuel consumption; on an areawide basis, this represents a 0.3 percent decrease.

CONCLUSIONS

As a transportation measure designed to reduce vehicle emissions and fuel consumption, the compressed workweek is attractive from several aspects:

1. It is an effective action for reducing total weekly household VMT. Results from the Denver experiment indicate that reductions occur not only in work travel but in nonwork travel as well.
2. Although not conclusively demonstrated in the Denver experiment, in addition to reducing VMT, the longer workdays associated with compressed work schedules could improve traffic flow by flattening the distribution of traffic volumes during peak periods.
3. Results in Denver indicate that the compressed workweek can be compatible with other, ongoing transportation measures oriented toward ridesharing, at least for participation levels similar to those achieved in federal agencies.
4. The widespread use of compressed work schedules among federal agencies that range in size from fewer than a dozen employees to several thousand and with very diverse operations goes a long way toward removing any uncertainty that surrounds its popularity among employees and at least the feasibility of its implementation, if not specific employer-related operational impacts.

Transferability of Results

Transferability of the results observed among Denver area federal employees to public and private sector employers in other urban areas raises several questions. First, if given the opportunity, to what extent would employee participation in other urban areas match that observed among Denver's federal employees? Second, for those employees who would participate, to what extent would shifts in travel patterns be similar to those observed for participating federal employees in Denver? Third, what characteristics are unique to the Denver experiment that would affect the transferability of its findings?

To answer the first question, an analysis of those factors important in determining employee acceptability of compressed work schedules indicates that participation rates among employees that have different socioeconomic characteristics can vary considerably. To a large extent, then, whether or not the overall participation rate observed for federal employees in Denver would be directly transferable to other urban areas would depend on similarities (or differences) in socioeconomic characteristics between federal employees in the Denver area and employment in other urban areas. Employer acceptability of compressed work schedules, particularly in the private sector, would also be a crucial factor in determining the level of participation in other urban areas.

Results of the Denver study indicate that similar shifts in travel patterns occurred among various groups of participating federal employees who represented a broad range of socioeconomic characteristics. With respect to the second question, then, it would seem reasonable to expect that similar shifts in travel patterns would also occur in other urban areas among employees who switch to compressed work schedules.

A number of characteristics of the Denver experiment and the Denver area in general could also affect the transferability of the results reported in this paper. Denver is somewhat unique in its abundance of nearby recreational facilities. The finding that nonwork travel decreased as a result of compressed work schedules despite the availability of numerous recreational opportunities would suggest that similar or perhaps even greater reductions in nonwork travel could be expected from applications in other urban areas.

Although the shifts in arrival and departure times that result from the compressed workweek had the potential for improving traffic-flow conditions in Denver's CBD, this potential was not realized because of lower participation among federal agencies located in the CBD. In other urban areas, if higher participation levels were to be experienced in areas of severe traffic congestion, more significant improvements of traffic-flow conditions could result.

With respect to ridesharing, the findings of the Denver experiment appear to be sensitive to the level of participation in compressed work schedules. If levels of participation in other urban areas were lower than those among Denver area federal agencies, ridesharing could be adversely affected. In terms of impacts on transit, the transferability of findings from the Denver experiment would be contingent on similar service levels outside the peak hour.

Implications for Future Transportation Decisionmaking

In Denver, the compressed workweek was promoted primarily on the basis of its potential air quality and energy impacts. Experience has shown that, in implementing any form of alternative work schedule, particularly in the private sector, such measures are seldom sold on their transportation benefits alone. Instead, employers are much more concerned with the impacts of such measures on the effectiveness of their particular operation. A key element in promoting these measures, then, is convincing upper management of the benefits associated with alternative work schedules in terms of increased employee morale, productivity, and reduced absenteeism.

The employer-related impacts of other forms of alternative work schedules (e.g., flex-time or staggered work hours) have been fairly well documented and are reasonably well understood. Experience with compressed work schedules, though, is not nearly as extensive. Further, based on what experience is available, results are somewhat mixed, which indicates generally that the compressed workweek is successful for certain work environments but not for others.

Given this relatively high level of uncertainty surrounding the potential employer-related impacts of compressed work schedules, many employers will be reluctant to implement such an action, particularly since the compressed workweek represents a more radical departure from standard work schedules than other forms of alternative work schedules. The experiences of the 42 federal agencies in the Denver area that participated in the compressed workweek experiment will be valuable in reducing some of this uncertainty. This information currently is being developed by the U.S. Office of Personnel Management as part of their nationwide evaluation of alternative work schedules among federal employees.

ACKNOWLEDGMENT

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Development of Computerized Analysis of Alternative Parking Management Policies

A.G.R. BULLEN

This paper describes the development and application of a computer model for the analysis of policies for the supply and management of parking facilities. The model, developed to analyze parking problems in the Oakland area of Pittsburgh, is a micromodel that allocates vehicles to parking spaces at the block level within a defined study area. The parking model is based on the origin-constrained entropy-maximizing gravity model. The destinations are the spaces in which drivers park their cars in the study area. Since all spaces need not be used, the destinations are unconstrained. The locations, to which the drivers then walk, represent the origins. As these are fixed and known, the model's origins are constrained. The study area is divided into two-zone systems that overlay each other. Land use zones represent the origins, and parking zones contain the destinations. The attraction of a parking zone is a function of the number and general cost of each type of parking space in that zone. The parking problems in the Oakland area of Pittsburgh arose from the conflicting needs of two universities, five hospitals, several cultural institutions, and residential and commercial areas. The alternative policies examined include residential sticker parking, parking pricing and time limit changes, and the location and size of new parking buildings. The results from the model indicate that the parking problems for the area could be overcome by a coordinated program of management changes and construction of parking buildings. Several predictions of the model have been confirmed by subsequent detailed feasibility studies. The model developed should be generally transferable with some recalibration of cost and walking distance trade-off parameters. The current application dealt with a situation of inelastic demand. If the demand were elastic, then the model would have to be used in combination with a travel-demand package.

This paper presents a model for the analysis of the supply and management of parking facilities. The model was developed to analyze the parking problems of the Oakland area of Pittsburgh, which is the second largest traffic generator in the metropolitan area, second only to the downtown. The Oakland area contains a mix of residential, commercial, and cultural activities along with the University of Pittsburgh and the University Health Center, which includes five major hospitals. These activities provide a varied range of conflicting parking requirements that are met by on-street parking and publicly available, private off-street parking facilities. For this varied range of parking problems and possible solutions, a streamlined analysis capability was essential, and thus the computerized model was developed.

Existing computerized parking models consist of two main types. The first is the optimization approach, where a variable such as total walking distance is minimized. Typical of this class of models are those of Ellis and others (1) and Whillock (2). The other type of model is the gravity-distribution type, where parking location is allocated relative to the destination of the driver according to some distance-deterrence function. These models include those by Bates (3) and Austin (4).

For this particular study, the gravity-distribution model was chosen. The reasons for this choice over the optimization approach were as follows:

1. A large number of the parkers to the area are relative strangers (visitors to the hospitals) and it is doubtful that they, in fact, minimize their walking distance;
2. A considerable amount of parking in the area is illegal, which the gravity model was modified to accommodate;
3. Many parkers use legal spaces illegally; for example, long-term parkers feed short- and medium-term parking meters; the gravity model accommodates this activity; and
4. The characteristics of the parkers and the spaces available vary widely.

With the development of the gravity parking model, the following specific issues were to be studied:

1. Changes in the pricing of the existing parking facilities,
2. Changes in the time limits for existing parking,
3. The introduction of residential sticker parking programs,
4. The needs for employee parking by large employers, and
5. Various proposals for new off-street parking lots and buildings at several locations in the study area.

MODEL THEORY

To carry out the analysis of parking for an area, the area is first divided into land use zones and parking zones. The land use zones represent the ultimate destinations of persons who park their cars, and in the Oakland study these were defined by census blocks. The parking zones contain the locations where the cars are parked. The land use zones and the parking zones overlay each other but are completely separate. These distinct zone structures were created for two main reasons.

1. A land use zone should contain complete city blocks and the streets form natural boundaries, whereas a parking zone should contain complete street blocks and off-street parking facilities accessible from that street block. The natural boundaries for parking zones are the midpoints of city blocks. Thus, the two-zone systems logically divide into distinct entities.
2. A key function in the model is the distance-deterrence function for which the main parameter is the distance between zone centroids. Because the origin zones are distinct from the destination zones, this measure is always finite and never approaches zero.

The theoretical model used is the origin-constrained entropy-maximizing gravity model as defined by Wilson (5). In its application as a parking model, the origins are the land use zones in which the vehicle is parked. Thus, the trip in the model is the walking trip of the car driver. Since the exact number of drivers destined for each land use zone is known, the model is origin constrained. On the other hand, the model is unconstrained for destinations because there is no requirement that all parking spaces in a parking zone be used.

In its Oakland application, the model deals with three classes of parker, short term (less than 2 h), medium term (2-4 h), and long term (greater than 4 h). It models the peak-parking load (at 2 p.m.) for a normal weekday. This was sufficient for the policies studied in the Oakland case. The model, however, could be adapted for dynamic analysis throughout the day.

Three classes of parker were determined by the characteristics of the parking demand and supply. The short and medium definitions coincided with on-street parking time limits, which were mostly of 2- or 4-h duration. These definitions also clearly differentiate the distinct duration groupings of hospital visitors and university students.

The model equations are

$$T(i,j,k) = O(i,k) \cdot A(j,k) \cdot X(j) \cdot B(i,j,k) \cdot D(i,j)^{-r(k)} \quad (1)$$

where

- i = land-use zone of origin (i = 1, ..., m),
- j = parking zone of destination (j = 1, ..., n),
- k = type of parker (short, medium, long),
- T(i,j,k) = persons from zone i who park in zone j for type k,
- O(i,k) = total persons from zone i who are parkers of type k,
- A(j,k) = attractiveness of zone j as a parking location for type k parkers,
- X(j) = capacity calibration factor for parking zone j,
- D(i,j) = distance between centroids of zones i and j,
- r(k) = distance-deterrence parameter that is a function of parker type k, and
- B(i,j,k) = the balancing coefficient given by

$$B(i,j,k) = \left\{ \sum_j [A(j,k)\, X(j)\, D(i,j)^{-r(k)}] \right\}^{-1} \quad (2)$$

The O(i,k) for all i and k are inputs to the model. They are the basic parking demands and are obtained from survey data and growth forecasts if appropriate. The A(j,k) is the attractiveness of a parking zone as a parking location. It is based on two assumptions related to the number and type of parking spaces available. The first is that the attractiveness of parking will be proportional to the size of the parking facility or the number of spaces available. This is similar to the attraction basis of most gravity model applications. It appears to be a reasonable assumption in that the larger the parking facility, the better known it will be.

The second assumption derives from a basic characteristic of this parking model. Although demand and supply are divided into three classes, parking allocations are not exclusive to class. If the demand is great enough, for example, long-term parkers may be allocated to short-term spaces. In practice, this would be done by feeding parking meters or by paying high charges in a building that favors short-term users. In the model, the relative attractions of the different types of parking spaces are handled by weighting factors that could be considered as general cost coefficients.

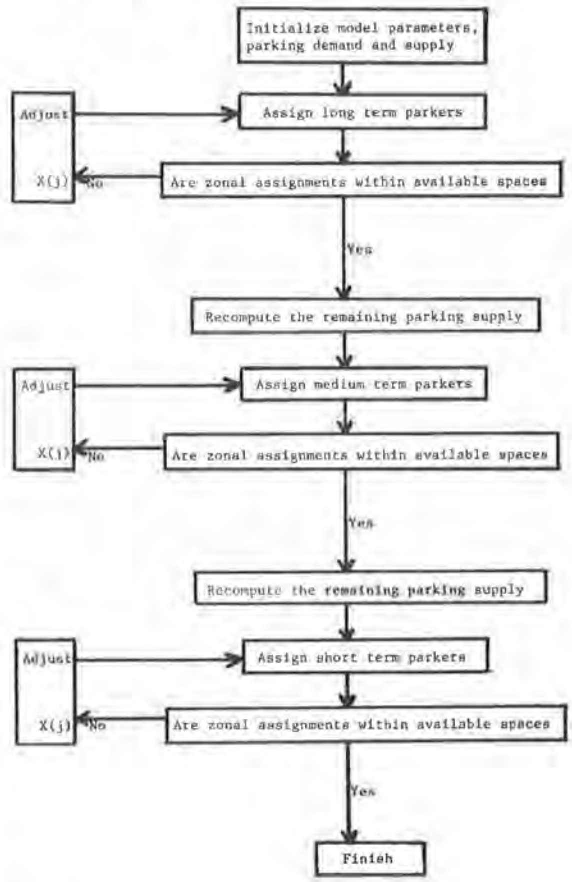
The attraction of a parking zone is given by

$$A(j,k) = \sum_{s=1}^{6} [a(k,s) \cdot n(j,s)] \quad (3)$$

where

- a(k,s) = inverse of the cost coefficient of type s parking spaces for type k parkers;
- n(j,s) = number of type s parking spaces in parking zone j;
- k = long, medium, or short; and
- s = long, medium, or short for off-street or on-street parking.

Figure 1. Operation of parking model.



X(j) is an adjustment factor that modifies the zonal attractions for each model iteration until the parking in all zones is within the capacity of those zones. X(j) is explained further under the model's operation. The term D(i,j) is the walking distance from the centroid of land-use zone i to the centroid of parking zone j.

Model Operation

The operation of the parking model is illustrated in Figure 1. Parkers are allocated sequentially in the order long, medium, and short, which is the order in which they would acquire the spaces. After each type of parker has been allocated, the spaces that they have used are withdrawn and only the remaining empty spaces are used for recalculating the new zonal attractions for the next type of parker.

The allocations for each type of parker are performed iteratively. The initial allocation, with X(j) = 1.0 for all j, gives the unconstrained allocation for each parking zone. For any zones where the number of available spaces has been exceeded, X(j) is reduced in proportion to the excess and another iteration is made. The iterations continue until the capacity overloads are insignificant. Usually three iterations are sufficient.

For the allocation of short-term parkers, the experiences with the model in Pittsburgh led to one particular modification. In parking zones where demand far exceeds the supply, the available spaces will be completely used by long- and medium-term parkers, and nothing is left for short-term parkers, who thus will not be allocated to those zones. In practice, when this situation arises, a great deal of short-term illegal parking takes place both on street and in restricted off-street areas. To replicate this behavior, all parking zones in the model always have a minimum number of short-term spaces available. If an insufficient supply of legal short-term spaces is available, then the balance is made up by hypothetical illegal spaces, which are never available for long- or medium-term parkers. The number of illegal spaces provided will depend on the application.

In Pittsburgh, the figure of 10 spaces/zone was derived from a survey of illegal parking. These hypothetical illegal spaces were never made available to medium- or long-term parkers because local enforcement prevents any measurable illegal parking by these classes. As described earlier, however, the model does allow these latter classes to illegally use legal parking spaces.

The outputs of the model are provided for each iteration of each type of parker allocation. The first iteration is the unconstrained allocation and thus gives the fundamental supply-demand balance for each parking zone, for each type of parker. In the final iteration, the value of the adjustment $X(j)$ gives a measure of the actual supply-demand balance. If $X(j) = 1$, then supply is adequate for the existing demand patterns. If $X(j) < 1$, then it is a measure of the parking deficiency in the zone. In the case of short-term parking, the degree of use of the illegal spaces in the final allocation gives a measure of the short-term problems in each parking zone.

For the comparison of alternative parking policy scenarios, therefore, an assessment can be made by first looking at the unconstrained assignments, then checking the final values of the $X(j)$'s, and finally reviewing the allocations of illegal parking.

In the Pittsburgh application, parking demand was inelastic with respect to the parking characteristics so the constant demand could be maintained over all scenarios. If demand were elastic, then it would have to be adjusted by iterating the output values for parameters such as cost and walking distance from the microparking model, back through the overall travel demand model for the area, until equilibrium was obtained.

Model Application

The parking analysis model was developed for application to the Oakland area of Pittsburgh. The study area contains a mixture of residential, commercial, institutional, and cultural activity. The major generators are five hospitals and two universities. The residential population of the Oakland area is 22 600 persons, and total employment is 25 000 in the district. On a normal weekday, between 6:30 a.m. and 6:30 p.m., about 75 000 persons come to Oakland in all forms of transportation, including 42 000 automobiles. There are 18 000 public and private parking spaces available for these visiting cars and those of the area residents who do not park on their own property.

The maximum vehicle accumulation in these spaces is about 14 000 vehicles at 2 p.m. Thus, there is a net surplus of parking supply in the area. This situation, together with the very low level of choice transit ridership into the study area, led to the assumption of an inelastic parking demand.

The parking component of the Oakland transportation study was concerned with the following problems:

1. Shortages of employee parking especially for the large employers,
2. Shortages of suitable parking for hospital visitors and university students,
3. Lack of convenient short-term parking space for commercial patrons,
4. Saturation of on-street residential areas by commuter parking, and
5. Aggravation of all of the above by continued growth in the area.

The particular parking policies that needed examination were as follows:

1. Proposals for residential sticker programs for five districts within the study area,
2. Provision of more short-term parking in existing facilities through changes in their pricing structures,
3. Impact of moving a major hospital to a new site,
4. Location and size of several proposed parking buildings throughout the area, and
5. Additional restrictions on streets and parking lots owned by the University of Pittsburgh to reduce their availability to the general public.

INVENTORIES AND DATA COLLECTION

The study area was divided into 90 land use zones, as shown in Figure 2, and 62 parking zones, as shown in Figure 3. These zone delineations were digitized and the centroids calculated.

Travel interviews, carried out as part of the overall transportation study, provided the data for trip generation for each land use zone. This included mode of travel and length of stay. For the hospitals, universities, and large office buildings, the surveys also provided the parking location of car drivers.

A detailed inventory of each parking zone included the amount, type, and charge for the on-street and off-street parking spaces. The current use of the parking zones was provided by conventional parking surveys. The final data files for the parking model included the number of car drivers present in each land use zone at 2 p.m. on a normal weekday and the length of their stay.

Calibration and Validation

Several parameters in the parking model needed calibration. Generally, these calibrations were done by running the model with current data and comparing its output with the known parking distribution and also by comparing model outputs with values given in the literature.

The interzonal distance $[D(i,j)]$ was taken to be the direct distance between centroids. No attempt was made to correct this for any network factor since the streets in Oakland form a fine grid and many of the blocks that have heavy pedestrian traffic have short cuts through buildings and alleys.

The distance-deterrence parameter $[r(k)]$ was calculated by testing the model outputs for various values of r against distributions of walking distance given by the literature (6,7). The values used were $r = 1.5$ for short-term, $r = 2.5$ for medium-term, and $r = 4.0$ for long-term parkers.

The cost coefficient matrix $\{a(k,s)\}$ for the development of the parking zone attractions $[A(j,k)]$ were arbitrarily chosen initially and were later refined in the validation process. The final matrix was

$$a(k,s) = \begin{matrix} 10 & 4 & 1 & 6 & 3 & 1 \\ 9 & 5 & 2 & 5 & 4 & 2 \\ 8 & 6 & 6 & 4 & 4 & 4 \end{matrix} \quad (4)$$

The validation of the model involved the valida-

Figure 2. Land use zones.

Figure 3. Parking zones.

tion of individual parameter values and the validation of the model as a whole. These validations were carried out by running the model with existing data and comparing the outputs with the observed patterns of parking. Close agreement was obtained for the following known characteristics:

1. The limits of the penetration of commuter long-term parking into residential areas,
2. The saturation of two medium-price parking buildings by long-term hospital parkers,
3. The use of two fringe-parking lots owned by the University of Pittsburgh, and
4. The use by short- and medium-term parkers of a large off-street lot near the university and the museums controlled by parking meters.

In addition to these overall validations, some specific checks were made on the distribution of walking distance for some large land use trip generators. A good comparison is shown in Figure 4, which shows a close agreement for medium-term parkers destined for the main university travel zone. The trip interchanges for this application of the gravity model need not have an exact statistical fit, since it is the destination zone totals that must be forecast accurately.

Policy Alternatives

Several parking problems were examined in the Pittsburgh application of the model.

Deficiencies in the Parking Supply

The model was run by using existing data and the deficiencies in parking supply in the Oakland area were highlighted. These are shown in Figure 5. The major deficiencies occurred in the areas of the major hospital systems. Here parking demand was overwhelming. Of particular concern was the acute shortage of short-term parking for hospital patients and visitors. This problem had already been suggested by the great amount of illegal parking noted in the parking surveys.

A surprise in these first runs was that supply deficiencies around the University of Pittsburgh were only minor. Although parking spaces in this area are always filled and employees and students claim great parking difficulties, the actual deficiencies are not large and not concentrated in any particular zone. Only where the campus area and the hospital area adjoin are the shortages significant. Elsewhere in Oakland, the supply deficiencies were localized.

Parking Management Programs

The model was run with residential sticker programs and pricing changes in parking buildings to increase short-term availability. The results indicate that the programs would achieve their goal of reducing commuter parking in residential areas and ease slightly the short-term deficiencies around the hospitals, as shown in Figure 6.

The impact on the hospital employees and university students by the residential sticker program was not as great as had been feared. The actual number involved turned out to be quite a small proportion and their redistribution throughout the area produced only marginal impacts.

New Hospital Parking Facilities

The proposal for a 1200-space parking building on a hillside behind the hospital area in parking zone 10 was tested. The analysis indicated that the facility would not attract patronage sufficient to fill it and, accordingly, it would have to be used primarily for employee permit parking. The impact of the building is shown in Figure 7. It does ease parking deficiencies in the hospital area and substantially reduces the deficiencies around the University of Pittsburgh. The new facility would have no direct impact in the latter case, but the changes are caused by a ripple effect through the whole area as parking migrates toward the new supply point.

Figure 8 shows the great improvement that would occur if the 1200 new spaces were put into the center of the hospital area with buildings in zones 19 and 21. Both buildings would fill up easily and parking throughout Oakland would be reasonably freely available. In the most deficient areas,

Figure 4. Distribution of walking distances for medium-term parkers from land use zone 46.

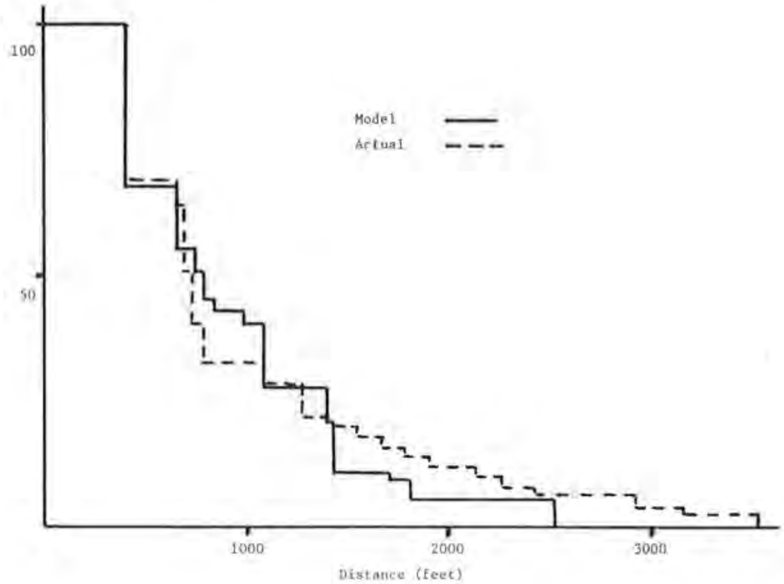


Figure 5. The current situation.

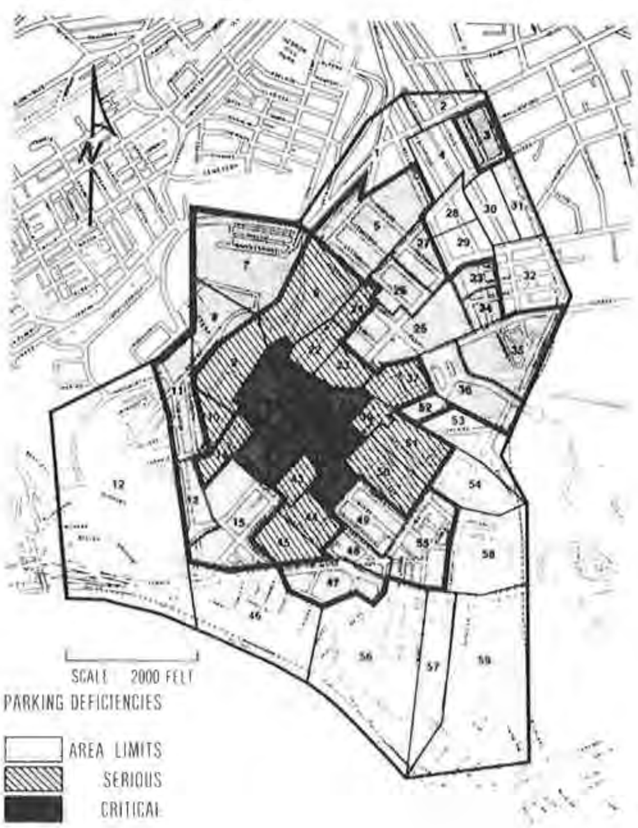
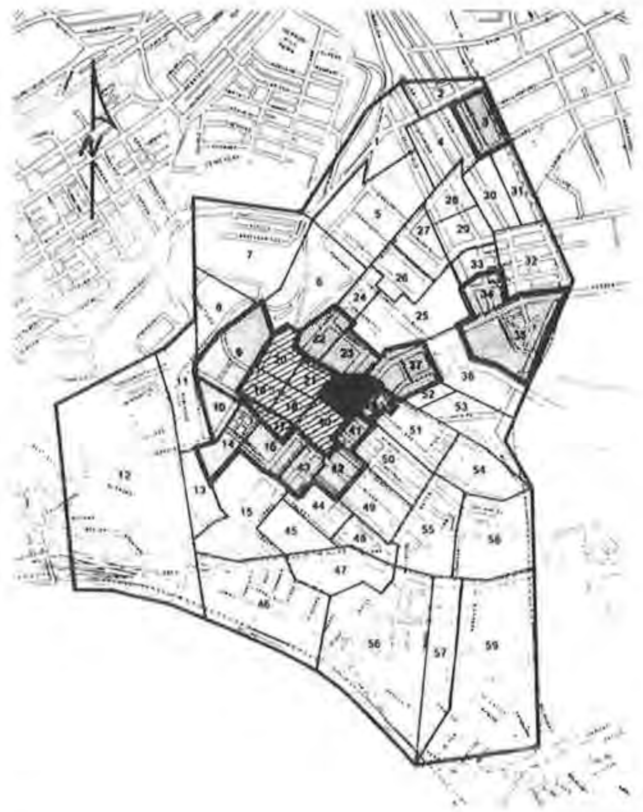


Figure 6. Parking management policies only.

Figure 7. One 1200-space building in zone 10.

Figure 8. Two 600-space buildings in zones 19 and 21.



short-term parking will still be available within a walking distance of 0.25 mile.

University of Pittsburgh Parking Needs

As previously indicated, the model initially failed to confirm that any substantial deficiency in parking supply existed in the university area, a result that did not sit well with the university community. To test the situation further, a hypothetical parking building of 400 spaces was tested at all feasible construction sites in the area. In most locations, this building never reached capacity. In parking zone 53, long considered a prime candidate for new parking, the building reached only 30 percent of capacity.

The university parking problem illustrates the conflict between desire and reality. There is a great desire for parking at $0.25/h. There is little demand, however, for parking at $1.00/h, which is closer to the actual cost of new supply. Further analysis indicated that the university could meet its needs by greater use of its existing facilities.

Other Analyses

The model was run for many other scenarios, particularly for several development proposals that included new hospitals, a new hotel and conference center, and shopping developments. For all of these proposals, parking needs and impacts were estimated.

CONCLUSION

The parking model described proved to be successful in meeting its objectives. It appeared to be accurate in modeling the parking behavior in the Oakland area of Pittsburgh and provided a mechanism for quick analysis of a large number of alternatives that cover a wide variety of parking policies. In application, the model provided many insights into the local parking problems and contributed to a wide range of solutions that were recommended in the final report (8).

Three independent detailed feasibility studies for new parking buildings in the area have subsequently been made. They confirmed the results of the model. The hospitals have now commenced construction of the first new parking building in zone 18 and Pittsburgh is actively pursuing the residential sticker parking proposals.

The model described is a micromodel for parking allocations at the block level within a defined area. As such, it should be readily transferable. The major recalibrations required would be in determining the cost and walking distance trade-offs. If the parking demand were elastic with respect to walking distance, cost, and availability, then the parking model would have to be coordinated with travel-demand models for the area.

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Abridgment

Opportunities for Small-Car Parking

J.G. PIGMAN AND J.D. CRABTREE

The reduction in automobile size provides an important opportunity for more-efficient use of parking space through a corresponding reduction in the dimensions of parking facilities. Many types of classifications have been offered for the classification of vehicles by size; however, guidelines suggested by the National Parking Association appear to be the most reasonable for a two- or three-group classification. There is still considerable room for additional effort in this area. Due to the wide range of existing parking-area dimensions and layouts, it is very difficult to recommend criteria for redesign without analysis of the specific parking facility in question. The problem is further complicated by the uncertainty in trends in vehicle preference. However, by using a two-group classification of vehicles, a recommendation is made for small-car stalls to be 16.5 ft long x 8.0 ft wide for 90-degree parking. A layout for parking at angles other than 90 degrees can be determined by simply rotating the basic stall for 90-degree parking to the desired angle and using geometry to determine the associated dimensions. Two alternatives discussed for the design of new parking facilities are to accommodate the present population of cars or to give more consideration to inevitable increases in the percentage of small cars. Of the several types of parking facilities evaluated, those that have the greatest potential for redesign to accommodate small cars have rigid control over the users. Included are employee parking areas provided by employers and a variety of special-use parking areas. Many college and university campuses have particularly high potential for implementation of small-car parking.

The reduction in the size of automobiles provides an important opportunity for more-efficient use of parking space through a corresponding reduction in the dimensions of parking facilities. The shift toward smaller cars has been brought about by several factors, most related to a diminishing supply of oil. Dramatic increases in the price of gasoline and a sudden shift in driver preferences have increased the number of small cars significantly. Statistics reported by the National Parking Association show that the percentage of small cars in the traffic stream has increased from 25 percent in 1975 to 45 percent in 1980 (1). This trend is expected to continue, and the percentage of small cars will increase to 75 percent by 1985 (1). Another factor that enters into the projected increased use of small cars is the mandate by the federal government that requires automobile manufacturers to produce a fleet that can achieve an average of 27.5 miles/gal by 1985. This probably cannot be achieved without additional reduction in vehicle size and weight.

Obviously, the opportunity and need exist to reduce the sizes of parking stalls, which will result in more-efficient use of available space. Escalating costs of land and construction have increased the expense of providing adequate parking, especially in urban areas. The cost per parking space frequently ranges up to $5000 for some parking structures; therefore, the potential for savings brought about by reduced stall and aisle dimensions is considerable. Unfortunately, substantial reductions in the sizes of all parking spaces would not be practical. Large cars currently comprise about one-half of the average traffic stream, and provisions must be made to ensure adequate stall dimensions for these vehicles. A solution to this problem is to reduce the size of some spaces but allow others to remain full-size. This approach allows the creation of additional spaces through stall size reduction while larger cars are still accommodated.

WHAT IS A SMALL CAR?

Before we can attempt to make special provisions for small cars, we must determine just what is a small car. First, consideration is usually given to some dimension of the vehicle. Overall length, overall width, wheelbase, and height are often included. Some classifications of automobiles are based on the overall weight. The U.S. Environmental Protection Agency's Gas Mileage Guide is based on the interior capacity of the vehicle (2). The Motor Vehicle Manufacturers Association annually produces a list of domestic vehicles and their respective dimensions (3). Another compilation of vehicle statistics is published by Road and Track Magazine for each model year (4). Road and Track presents a more-comprehensive list, which also includes most of the foreign-made automobiles. Still, these lists classify vehicles as minicompact, subcompact, compact, intermediate, medium, standard, full-width, and luxury, and it becomes difficult to decide what is small and what is large. The National Parking Association has provided guidelines to classify automobiles into either two or three groups, based on overall length and overall width (5). By multiplying the overall length times the overall width and converting to square meters, a number is obtained that can be used to easily classify a vehicle based on either the two- or three-group classification. The accepted procedure is to drop the decimal part of the measurement and use only the integer portion for classification. In the two-group classification, any car that covers an area less than 9.0 m^2 is considered small, and anything greater than or equal to 9.0 m^2 is large (6).

Table 1. Summary of small-car categories for 1976-1981 model years.

Manufacturer	Model
Alfa Romeo	All models
American Motors Corporation	Concord, Eagle, Gremlin, Hornet, Kammback, Pacer, Spirit, and SX4
Aston Martin	All models
Audi	All models
Avanti II	All models
BMW[a]	All models except 1979 and 1980 733I
Bricklin	All models
Buick	Skyhawk and 1980 and 1981 Skylark[a]
Capri	All models
Chevrolet	1978 and 1979 two- and four-door and all 1980 and 1981 Chevelle[a] and Malibu[a], Chevette, Citation, Corvette, Monza, and Vega
Datsun	All models
DeLorean	All models
Dodge	Aries, Challenger, Colt, and Omni
Ferrari	All models
Fiat	All models
Ford	Escort, Fairmont, Fiesta, 1981 Granada[a], Maverick, Mustang, and Pinto
Honda	All models
Jaguar[a]	All models except 1977-1979 XJ6L and XJ12L
Jensen	All models
Jensen-Healey	All models
Lamborghini	All models
Lancia	All models
Lincoln Mercury	Bobcat, Capri, two-door Comet[a], Lynx, and 1979-1981 Zephyr[a]
Lotus	All models
Maserati[a]	All models except 1980 and 1981 Quattroporte II
Mazda	All models
Mercedes Benz	All models except four-door 280S, 280SE, 300SD, 380SEL, 450SEL, and 6.9
MG	All models
Oldsmobile	1980 Omega[a] and Starfire
Opel	All models
Peugeot	All models
Plymouth	Arrow, Champ, Horizon, Reliant, and Sapporo
Pontiac	Astre, 1980-1981 Phoenix[a], and Sunbird
Porsche	All models
Renault	All models
Rover	All models
Saab	All models
Subaru	All models
Toyota	All models
Triumph	All models
TVR	All models
Volkswagen	All models
Volvo	All models

[a]Appears in both small- and large-car categories.

In an effort to provide a comprehensive source of car dimensions, a list of American and foreign-made automobiles manufactured as 1976 through 1981 models was produced (for the 1981 model year, some large cars were omitted). This list includes the make, model, body style, engine size, weight, wheelbase, overall length, overall width, and area occupied for 1339 different automobile types. In the two-group system of classification, 856 cars were classified as small, and 483 were classified as large. The list is too long to include in its entirety. A more concise summary of automobiles categorized as small in presented in Table 1. To attempt to classify vehicles into more than two groups for the purpose of parking segregation would be impractical.

LAYOUT OF PARKING AREA

Existing parking facilities have a wide range of designs, which range from the typical rectangular-shaped module with 90-degree parking to a variety of shapes with angle parking. In the modification of an existing facility to one with reduced stall dimensions, three factors must be considered: the dimensions of the reduced stalls, the number of stalls to be reduced, and the location of the reduced stalls. For 90-degree parking, a typical parking area has stall widths of 8.5-9.5 ft, depending on the type of parking facility in question and the availability of land. Based on a minimum door opening width, 10 in is needed between each side of the vehicle and the respective stall edgelines. Therefore, an additional 20 in should be added to the vehicle width in order to determine the minimum stall width. By using the comprehensive list of vehicle types and dimensions, the National Parking Association's method of classification has been used to divide the vehicle types into categories of large and small cars. If a stall width of 8.0 ft is used, only 9 models of cars classified as small would exceed the allowable width (all 9 are models of the American Motors' Pacer). This is also the case for a stall width of 7.75 ft. If the stall width is decreased to 7.5 ft, 134 vehicle models classified as small exceed the allowable width, although all but 9 of these models exceed the allowable width by 3.0 in or less. A stall width of 8.0 ft should be used, then, if we are to accommodate the classification of small cars that meet the requirements of having an area less than 9.0 m^2. However, this can be reduced to 7.75 ft without seriously hampering performance, and even 7.5 ft could be accepted if space was sufficiently critical. In addition, a stall width less than 8.0 ft could be used comfortably if coupled with a more-stringent definition of a small car. A recent study reported that the incidence of large cars in violation of small-car stalls was substantially lower for 7.5-ft stalls than for 8.0-ft stalls (1). This suggests that 7.5-ft stalls may be advantageous in at least some applications. Whichever stall width is selected for a particular application, a small car can then be defined so that it will fit comfortably into the design stall.

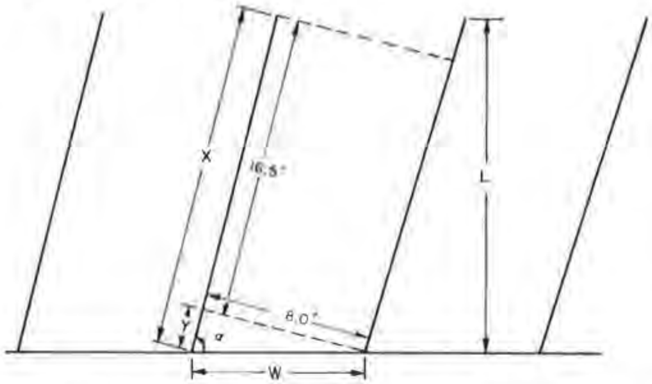
The minimum stall length is another factor that must be taken into consideration when attempting to downsize 90-degree parking. Again, from the comprehensive list of vehicle dimensions grouped by small and large cars, the longest vehicle in the small category was 197 in long. If the stall length was selected to be 16 ft, 79 small vehicles would exceed this length. In order to accommodate all vehicles classified as small, the stall length would have to be at least 16.5 ft. Therefore, if we use the two-group classification of vehicles, parking stalls to accommodate small vehicles for 90-degree parking should be 16.5 ft long x 8.0 ft wide.

Small-car parking may also be provided at angles other than 90 degrees. In general, a layout for parking of this type can be determined by simply rotating the basic stall for 90-degree parking to the desired angle and using geometry to determine the associated dimensions. Examples of this are shown in Figure 1. Parallel parking is not discussed in this paper, but additional research is needed in this area. Existing facilities that have stall angles different from 90 degrees and one-way circulation aisles can often achieve a higher proportion of gain by converting to a two-way circulation pattern and 90-degree parking. Some limitations regarding minimum module width are involved and the overall savings are related to the type of parkers to be accommodated.

If an entire lot or an entire section of a lot is to be restricted to small cars, then aisle widths and other dimensions in addition to stall sizes may be reduced. However, a thorough discussion of this would require an analysis of turning capabilities, which is beyond the scope of this paper. Further research is needed into the turning capabilities and door-opening characteristics of large versus small cars.

Along with the decision on the size of the reduced spaces, a decision is required regarding the

Figure 1. Angle parking calculations.



$\sin \alpha = \frac{8.0'}{W}$ $\quad W = \frac{8.0'}{\sin \alpha}$

$\cos \alpha = \frac{Y}{W}$ $\quad Y = W \cos \alpha$

$X = 16.5' + Y$

$\sin \alpha = \frac{L}{X}$ $\quad L = X \sin \alpha$

1 foot = 0.3048 meters

α →	90°	75°	60°	45°
W	8.0'	8.28'	9.24'	11.31'
Y	0.0'	2.14'	4.62'	8.0'
X	16.5'	18.64'	21.12'	24.5'
L	16.5'	18.01'	18.29'	17.32'

number of spaces to be reduced and the number to be left full size. Since small cars can use full-size spaces but large cars cannot use reduced spaces, a safe excess of full-size spaces should be provided. To decide how many spaces to reduce, the characteristics of the users of a parking area must be considered. Drivers in some sections of the United States have traditionally bought more small and foreign-made cars than in other areas. Therefore, for any proposed redesign, counts should be conducted to determine the mix of vehicles that use the lot.

In the design or redesign of any parking facility, the question is raised as to whether to design for the present population of cars or give more consideration to inevitable increases in the percentage of small cars. There seem to be two practical alternatives to this possible dilemma. The facility could be designed with 60-degree parking to accommodate only large cars at present but with the option to change some or all of the facility to 75- or 90-degree parking for small cars. This change, when made, could result in a 20-25 percent increase in the capacity of the parking area. The other alternative is to design the facility to accommodate an appropriate percentage of both large and small cars now and an option to alter some of the larger spaces at a later date. The exact details of any design should be worked out individually so as to gain optimum use of available space.

The location of the reduced stalls is also of primary importance. They must be placed in a prime location in order to encourage their use. If small cars park in the full-size spaces first and leave only reduced spaces vacant, then late-coming drivers of large cars will have no place to park except in reduced spaces. To avoid this situation, the reduced spaces must be placed in an attractive location. However, this should not be carried to such an extreme that the drivers of large cars are punished by being forced to park in undesirable locations.

CONTROLLING THE USE OF DOWNSIZED SPACES

One of the difficulties with having both reduced and full-size parking stalls is preventing the use of reduced stalls by large cars. If large cars are allowed to park in reduced stalls, the adjacent stalls may become unusable. Even if the adjacent stalls can still be used, dents, nicks, and angry drivers may result. Therefore, the use of reduced spaces must be restricted to small cars. For this to be accomplished, the driver must know where the reduced spaces are located and whether he or she is permitted to park in them. The placement of signs in the area designated for small-car parking should be one of the first steps in communicating the location of the reduced spaces to the driver. Special pavement markings can also be used for this purpose. It is more difficult to inform the driver whether his or her car is a small car or not. One technique that is often used is to merely post a message to the effect "small cars only" and depend on driver judgment and honor. Under this system, the parker should be given considerable room for judgment, and enforcement should take place in only the most blatant cases of misuse.

For any of the above methods, enforcement would be difficult to provide. If enforcement officers were required to carry a list of qualifying vehicle types and check parked cars against it or to carry a tape measure and measure the cars, this would be very time-consuming and tedious. In any case, strict enforcement of parking regulations would be very difficult as long as drivers have no easy way of knowing whether or not their vehicles qualify as small.

Locations that require a sticker for parking have a built-in solution to the communication and enforcement problems. Rigidly controlled parking areas such as employee parking provided by employers and college or university parking are examples of this type of location. In these cases, an application for a parking permit should include a description of the vehicle on which the permit is to be placed. The agency or employer that issues the sticker could use a list of automobiles categorized as small or large. A list of small cars similar to that presented in Table 1 would be ideal for this purpose.

APPLICATION ON A COLLEGE CAMPUS

The types of parking that have the most potential for redesign to small cars are those with rigid control over the users. These types would include employee parking provided by employers and a variety of special-use parking areas, such as hospitals, airports, and colleges or universities. College and university campuses have some of the more heavily used parking areas, and the potential for improvement is significant. Increased use of small cars in general, and particularly on college campuses, has prompted some parking authorities to consider drastic redesign seriously. At the University of Kentucky, which has approximately 24 000 students and 8000 parking spaces, a survey of users of parking areas was made. The percentage of small cars was sought in order to determine the potential for increasing the number of parking spaces. The percentage of small cars on campus was found to be considerably higher than on one of the primary routes in a rural section of Fayette County, where the university is located. In the university parking areas, 59 percent were small cars as compared with 38 percent at the rural location. The University of Kentucky is a prime example of a location where redesign of the parking area could have significant benefits. The high percentage of small cars, the intense demand for parking, and the strict control by permit over parking in university lots make the idea of reducing stall sizes very attractive.

SUMMARY AND CONCLUSIONS

The opportunities for improved efficiency in the design and redesign of parking facilities appear certain to increase as the percentage of small cars increases. Our abilities to take advantage of these opportunities will vary by section of the country and type of parking facility in question. There is still considerable room for additional thought and effort in the classification of vehicles by size. The list referred to in this discussion of parking opportunities includes 1339 vehicles manufactured as 1976-1981 models, but it may not be comprehensive enough for many purposes.

With the wide range of existing dimensions and layouts of parking areas, criteria for redesign are difficult to recommend without detailed analysis of the special parking facility in question. However, by using a two-group classification of vehicles, a recommendation was made for small-car stall dimensions to be 16.5 ft long x 8.0 ft wide for 90-degree parking. Alternatives for the design of a new facility are to accommodate the present population of cars or to give more consideration to the inevitable increases in the number of small cars. A safe excess of large stalls is required because some small cars can be expected to park in large stalls, but large cars cannot park in reduced stalls. In addition, it is crucial that reduced stalls be located in a prime spot so that they will never be the last spaces to be filled.

Of the several types of parking facilities, those that have the greatest potential for redesign to accommodate small cars have rigid control over users. Included in this group are employee parking areas provided by employers and a variety of special-use parking areas. Many college and university campuses are particularly well-suited to small-car parking because of their high percentages of small cars, intense parking demand, and strict control over users.

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New Directions in Central Business District Parking Policies

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Several North American cities have recently adopted innovative approaches to central business district (CBD) parking requirements to manage the supply and location of downtown parking. Traditional zoning ordinances require sufficient parking in downtown developments to accommodate automobile access by building tenants and visitors. Some new approaches to parking involve the provision of an enhanced parking supply as an incentive to the economic development or redevelopment of an urban area; these approaches are generally being pursued in areas whose goals and objectives relate to economic development and new employment opportunities. Other new approaches to parking are directed at reducing the supply of downtown parking or redirecting new parking supply to the CBD periphery; these techniques generally are being pursued in areas where alternatives to automobile commuting exist or can be created. This paper reviews innovative parking policies in selected cities and describes and assesses the range of tactics for off-street parking supply that can be used in activity centers.

Policies to manage the supply and location of downtown parking are receiving renewed attention from many older cities that seek to revitalize their central business districts (CBDs) as well as from developing cities that are actively shaping their urban development. The traditional approach to CBD parking is a zoning requirement on developers to provide a minimum number of spaces, depending on the size of the building. However, limitations on the number of automobiles that can be accommodated in a CBD without serious congestion and pollution problems have prompted many cities to manage automobile use by controlling parking opportunities.

This paper examines the policies adopted by several North American cities to regulate the supply of CBD parking and, in some instances, to direct the construction of new spaces to areas on the CBD periphery. Most of the policies reviewed are directed at reducing the total available supply of CBD parking, although several cities are also pursuing programs to increase short-term parking opportunities and reduce long-term parking in the CBD. Efforts to reduce total available parking are most evident in cities where feasible alternatives to automobile commuting exist.

DOWNTOWN PARKING POLICIES IN SELECTED NORTH AMERICAN CITIES

Several cities in both Canada and the United States have implemented parking management policies to manage automobile access to their downtowns. These communities have adopted various zoning and related parking control measures that address their individual circumstances. The survey of downtown parking policies conducted in this study showed that no one approach to downtown parking will be universally successful (1). Parking is only one aspect of larger transportation management activities, and we must consider the other actions that the cities described below have taken to understand the framework for their parking policies.

In general, the surveyed communities have parking requirements in their zoning ordinances that range from 1 space/1000 gross ft^2 of development to 1 space/2500 gross ft^2. (Note: 1 net ft^2 is roughly equivalent to 0.85 gross ft^2.) Although zoning ordinances have traditionally specified the minimum amount of parking required, more and more communities are using the zoning requirement as a maximum limit as well as a means to control the growth in supply of downtown parking. Transit's role for downtown access is stressed in communities that seek to limit parking supply, and several cities reported that developers voluntarily built significantly fewer parking spaces than the maximum allowable in well-recognized transit corridors. Some communities interpreted this as the building industry's willingness to place the transportation burden on the public sector and there improve its return on investment. A developer's willingness to provide less than the allowable amount of parking space was dependent on the characteristics of the individual site; the survey of communities did not produce any conclusive generalizations about how much parking should be provided throughout a downtown area.

This paper reviews the parking policies in the following North American communities:

1. Calgary;
2. Chicago;
3. Denver;
4. Edmonton;
5. Los Angeles;
6. Montgomery County, Maryland;
7. Ottawa;
8. Portland, Oregon;
9. San Francisco;
10. Seattle;
11. St. Paul;
12. Toronto; and
13. Vancouver.

Table 1 summarizes the demographic, transportation, economic, and downtown parking characteristics of most of these cities.

Chicago

Chicago responded to its air quality problems by banning new parking structures in 1975 and by creating zoning incentives to reduce parking provided in new buildings. Ten percent reductions in the required parking are permitted for each of the following:

1. If parking is underground,
2. If the building has a good transit connection,
3. If the building has a pedestrianway connection, or
4. If the building is located in the CBD.

If fewer than a total of 50 spaces are required, the developer need not provide any parking. Experience suggests that developers will provide the least amount of parking possible. Fifty-story buildings typically have as few as 100 spaces, and some CBD office towers of more than 500 000 ft^2 are being built with as few as 80-100 stalls. Since the CBD work trip transit mode split is 80 percent, developers apparently are more concerned about avoiding costs than in providing parking.

Denver

Denver does not require any parking in its downtown buildings, except in an urban renewal area where there is a requirement of 1 space/100 ft^2 (gross). The requirement in the urban renewal area was established in the 1960s, when a larger freeway system was envisioned. What is noteworthy about Denver is the actual rate at which parking is provided in the absence of any requirements. Denver city planning staff cited the following examples to support their belief that developers will try to avoid building parking to the maximum extent possible:

Parking Spaces	Building Size (gross ft^2)	Parking Spaces
175	800 000	1 space/4571 gross ft^2
400	630 000	1 space/1575 gross ft^2
600	820 000	1 space/1367 gross ft^2
325	421 000	1 space/1295 gross ft^2
80	205 000	1 space/2563 gross ft^2
100	157 000	1 space/1570 gross ft^2
134	650 000	1 space/4851 gross ft^2

Denver CBD office space increased by 40 percent between 1970 and 1980 to a total of 33 million ft^2 and is expected to further increase to 44 million ft^2 by 1985. Regional office and retail space has been growing at a slightly faster pace than the Denver CBD. A city official stated that recent CBD construction shows that parking in or next to buildings is not necessary to encourage development. Of the 60 000 parking spaces in the greater CBD area, 24 000 spaces are in fringe lots that serve long-term parkers. There are 1.5 parking stalls per employee in the greater CBD area.

Edmonton

The City of Edmonton has linked transportation access to its parking policies. The city's objective is to reduce the rate of growth of parking stalls in the CBD and to encourage alternative access modes. Edmonton has enacted an ordinance in its CBD that requires developers to provide 1 stall/1000 gross ft^2 either in the building or within 400 ft of the entrance. However, if the building has direct access to a pedestrianway, the requirement is to provide 1 stall/2000 gross ft^2. If there is direct access to the light rail transit (LRT), the requirement is reduced to 1 stall/25 000 gross ft^2.

Edmonton estimates its 1980 downtown employment at 54 000 and its total CBD parking inventory at 20 136, or an average of 1 stall/2.68 employees. The city thinks that it has maintained good rapport with the developers and there is not a widespread apprehension that these policies will create a parking shortage in the future. The Edmonton metropolitan population grew 12.2 percent from 1976 to 1980, and the city anticipates 80 000 CBD employees by 1986.

Los Angeles

Los Angeles is currently developing a parking management plan that will allow developers to provide transportation alternatives in lieu of providing parking. The municipal zoning ordinance currently requires 1 space/1000 ft^2 of development in the CBD and 1 space/500 ft^2 of development in other parts of the city. Under the proposed parking management plan, developers can reduce their parking construction if they are able to implement an effective transportation alternative to driving alone.

Three elements of the proposed parking management plan allow reductions in parking requirements:

1. Developer may provide alternatives to single-occupant automobile commuting (e.g., ridesharing promotion),
2. Park-and-ride program can be implemented to substitute off-site spaces for on-site requirements, and
3. Preferential parking can be designated on-site for high-occupancy vehicles (HOVs).

Table 1. Comparison of downtown parking in selected North American cities.

City	Regional Population	Employment		CBD Office Space (ft^2)		Downtown Parking Supply					CBD Work Trip Mode Split (% transit)	Zoning Bylaw
		Regional	CBD	Total	Growth	Total	Surface On-Street and Off-Street	Structure	Long Term	Short Term		
Calgary	583 100	231 920	72 675	14 200 000	16 400 000 additional by 1982	41 212	24 419	16 793	15 295	21 175	45	Minimum of 1 stall/1500 gross ft^2. If in the office core, 20 percent of requirement (or 50 stalls, whichever is greater) can be provided on site; balance will be provided by the city outside the office core by using developers' cash-in-lieu payments that are based on the minimum parking requirement
Denver	1 400 000	NA	93 000	33 000 000	11 000 000 additional by 1985	34 000 in CBD core; 60 000 in CBD core and fringe	36 000 in core and fringe	24 000 in core and fringe	NA	NA	24	No zoning bylaws govern parking except in an urban renewal area where 1 stall/1000 gross ft^2 is required
Edmonton	621 600	NA	54 000	NA	NA	20 100	NA	NA	6400	13 700	NA	Minimum of 1 stall/1000 gross ft^2. If direct access to pedway, 1 stall/2000 gross ft^2; if direct access in light rail transit, 1 stall/2500 gross ft^2. Parking must be provided within 400 ft
Ottawa	739 400	285 000	65 000	NA	None in the past 4 years	13 600 total off-street only; 7700 of this figure available to the public	1500 off-street only	12 100	NA	NA	66	No zoning bylaws govern parking for office development
Portland	1 200 000	575 000	80 000	13 500 000	1 000 000/year	33 000	NA	NA	23 000	15 000	35-40	Maximum of 1 stall/1000 gross ft^2 to 1 stall/1429 gross ft^2, depending on proximity to transit spine
Seattle	2 400 000	400 000	115 000	19 000 000	4 500 000 additional by 1982	43 700	NA	NA	NA	NA	45	Maximum of 1 space/1500 gross ft^2 for buildings in which at least 80 percent of gross floor area is office space; 1 space/1200 gross ft^2 for buildings in which less than 80 percent of gross floor area is office space; principal-use parking structures and surface lots are prohibited
St. Paul	2 500 000	1 500 000	62 000	8 000 000	150 000/year	30 000	10 000	20 000	NA	NA	35	No zoning bylaws govern parking for office development
Toronto	2 900 000	NA	185 600	NA	NA	35 800	18 000	17 800	NA	NA	80	Minimum of 1 stall/1668 net ft^2; maximum of 1 stall/1453 net ft^2
Vancouver	1 200 000	NA	125 000	NA	NA	41 600	20 000	21 600	NA	NA	50	Maximum may not be required; if required, 1 stall/1000 gross ft^2
Winnipeg	585 900	280 000	55 000	3 000 000	400 000/year	27 200	18 100	9 100	17 200	10 000	55	No zoning bylaws govern parking for office development in CBD

Note: NA = not readily available.

The developer is responsible for developing the transportation alternatives. Performance standards that are included in contractual agreements between developers and the city are an important part of the proposed plan. These performance requirements are intended to ensure adherence to the agreed on contractual agreement and may include on-site monitoring to ascertain whether solo driving has been reduced.

The city hopes that reducing the costs of providing parking facilities will act as the major incentive to encourage ridesharing programs that are operated by developers and employers. To date, this parking management plan has not been adopted by the city council.

Montgomery County, Maryland

Montgomery County, Maryland, is a suburban county located north of Washington, D.C.; its population is approximately 600 000. In response to a deficiency of shopper and employee parking, four parking lot districts were established that correspond to the county's business areas. The parking lot districts are economically self-sufficient units designed to meet the parking needs of the business areas.

Funding for the districts is provided by an ad valorem parking lot district tax on office developments that do not provide the 2 spaces/1000 ft^2 required by the zoning ordinance. The ad valorem tax is levied only against the value of the proportion of the building that is not used for parking. The county thinks that the ad valorem ordinance enhances development because it is cheaper for the developer to pay the tax than to build parking. Additional funding for the parking districts is obtained from parking fees, enforcement fines, and income from investments and bond issues.

Currently, a total of 2000 on-street and 1000 offstreet publicly owned spaces are provided. Most of the long-term parking is provided in off-street facilities; the short-term parker is served by on-street and off-street facilities. Each parking lot district is designed to be financially self-sufficient. Surplus funds are used for new programs and capital projects.

Ottawa

Four years ago the City of Ottawa commissioned a major parking study to develop parking control strategies to encourage transit use. As a result of the study, the city rescinded its zoning bylaw, which required office developers to provide 1 space/1000 ft^2 of office space, and currently there are no parking requirements. In an effort to discourage long-term parking and to ensure an adequate supply of short-term parking, the city also changed its pricing policy at municipal lots from day rates to higher hourly rates and built several short-term lots. In conjunction with these efforts, the city expanded and improved transit service. As a result, transit buses now serve 66 percent of the downtown work trips.

The development impacts of Ottawa's change in zoning requirements for parking cannot be determined yet as there has been little new office construction since the relocation of 15 000 federal employees from downtown Ottawa to Hull. The city currently expects several major office developments and anticipates that developers will provide parking to prevent a parking shortage. The amount of parking in buildings may be limited, however, by the expense of building on the bedrock that underlies the city. The amount of surface parking will be limited by the expense of providing lots, since the city assesses vacant lots at market rates that reflect their development potential. The anticipated completion of a transit mall by 1984 is another factor that may influence developers' decisions to provide parking.

Portland, Oregon

In response to federally mandated clean air requirements, Portland implemented coordinated transit and parking policies designed to discourage downtown automobile traffic and to promote transit use. The city is directing high-density development to its main transit corridor and freezing the number of parking spaces allowed downtown at the 1973 level of 38 870 (includes on-street and off-street parking).

Portland currently has 13.5 million ft^2 of downtown office space and the supply of office space is increasing at a rate of about 2 million ft^2/year. Downtown employment is about 80 000; therefore, Portland has 2.06 employees for each downtown parking space. Approximately 15 000 of the total of 38 870 spaces are short-term parking spaces (the city controls about 10 000 spaces), which reflects the city's policy of promoting short-term parking opportunities.

Portland's zoning ordinance sets a maximum limit on allowable parking that ranges from 1 space/1000 gross ft^2 to 1 space/1429 gross ft^2, depending on the proposed building's proximity to transit. The City Planning Department also reviews each application for its impacts on the parking freeze policy and the preservation of the ceiling. To date, the city believes that downtown development has not been deterred by these restrictions. CBD employment has increased by 10 000 since the program was adopted in 1975, and there has been a greater increase, proportionally, in CBD development than in suburban development. The lack of concern about the policy is apparently due to a doubling of transit ridership and the net contribution of usable spaces to the total number allowable. Parking that was previously in surface lots that no longer exist and on-street parking lost as a result of traffic improvements are both credited to the total allowable supply.

Initially, the parking management program encountered substantial resistance from developers. In a recent review of its policies, the city concluded that this resistance has largely dissipated as developers realized that they were being treated equitably and that the reduced parking requirements were saving them money. Developers are apprehensive about Portland's actions once the ceiling is reached, but they also recognize that the LRT scheduled to open in 1985 could be an important factor in reducing parking demand. A representative of the Portland Building Owners and Managers Association indicated that Portland's policies are successful so far, but the representative thought that a mechanism for change should be available if these policies create serious problems and dislocations in the future.

Portland's experience since it adopted a maximum zoning ordinance indicates that most developers provide less than the allowable amount of parking. Outside the transit corridor, the maximum limit is 1 space/1000 ft^2; however, several buildings have provided 1 space/1200 ft^2, and one site provided 1 space/2000 ft^2. On the transit corridor, examples were cited of 1 space/2000 ft^2, another that has 1 space/2400 ft^2, and a third that has no parking at all. Exceptions to this trend are smaller projects farther away from transit where developers provide the maximum allowable parking.

San Francisco

San Francisco adopted a maximum allowable parking bylaw in 1968 in its core area to address air quality issues. The bylaw permits a maximum of 7 percent of a building's gross floor area to be used for parking without special approval. Assuming 300 ft^2 (gross) per stall (and ramps), this requirement equates to 1 stall/4285 ft^2 of office space. Parking has been growing at a rate of 1500 spaces/year outside of the core (mainly in parking structures) and office space has increased by approximately 2.0 million ft^2 to yield an estimated downtown incremental parking supply rate of 1 stall/1333 ft^2. San Francisco is concerned that its current policy is not achieving the objective of decreased automobile use and is now considering a cap on the total supply.

St. Paul

In an effort to promote downtown retail and commercial activity, St. Paul operates a program that allocates more than half of center-city parking to short-term use and provides fringe parking for long-term parkers. To achieve these objectives, the city uses pricing, a fringe-parking shuttle bus, and a skywalk system to create an integrated set of parking incentives and disincentives. St. Paul has no parking requirements in its zoning law nor does it limit the amount that a developer may provide.

To encourage short-term parking in the CBD, the city set the following rate structure at city-owned facilities and at private lots that participate in the city's program:

1. \$0.25/0.5 h for the first 3 h,
2. Rate increases (increment depends on location) for parking after the first 3 h and the total daily rate may be as high as \$8.00/day, and
3. Free parking during evening shopping hours.

Private operators participate on a voluntary basis, and the city reimburses them for their foregone parking fees. Under the program, private parking providers who participate in the program are still allowed to set special long-term rates; only the short-term fees are fixed. Several of the short-term structures are also connected to the skywalk system (which is the largest in the United States), and St. Paul thinks that the system has been well received and is well used.

Long-term parking is encouraged in the fringe lots through attractive long-term rates of \$1/day or \$20/month and by providing free shuttle-bus service during peak hours to the CBD at 5-min headways east-west and 10-min headways north-south. Most of the fringe lots are located on the vacant city-owned land. Two private lots are also used as fringe lots, and the city receives \$0.25 from each \$1.00 collected to help pay for the shuttle-bus service. The operations and capital expenses of the entire shuttle-bus and parking program is self-sufficient and is financed through the parking revenues and half of the meter receipts.

Developers initially opposed these policies but opposition has decreased over time as buildings have been successfully leased (the overall occupancy rate is 93 percent). The CBD has 62 000 employees and 30 000 total parking spaces, for an average rate of 2.06 employees/stall. Parking supply consists of 20 000 long-term parking spaces and 10 000 short-term spaces. Industry and warehousing are important functions in this city, and office space occupies only 8 million ft^2 in the downtown.

Seattle

Like Portland, Seattle adopted parking restrictions in response to federal clean air requirements. Seattle's zoning ordinance prohibits principal-use parking garages (i.e., a building dedicated to parking only) and parking lots in the downtown core. It also sets a maximum allowable rate of 1 space/1500 gross ft^2 for CBD developments when at least 80 percent of the gross floor area is office space. The maximum limit for CBD developments when less than 80 percent office space is 1 space/1200 gross ft^2. The city requires 30-40 percent of the allowable parking to be reserved for carpools and vanpools.

Allowable limits for the area that surrounds the office core are 1 space/1500 gross ft^2 if 80 percent of the gross floor area is office space, and 1 space /2000 gross ft^2 if less than 80 percent of the gross floor area is for office use. Principal-use parking garages and parking lots in the CBD periphery are allowed if the city determines that the additional automobiles attracted to these facilities will not adversely affect nearby traffic flow or exceed street capacity. The parking supply in recent developments indicates that parking is actually provided at a rate that is substantially lower than the amount allowed. Seattle estimates that 1 space/2500 gross ft^2 is actually being provided and developers are not anxious to provide more due to the economics of building parking. Developers have voiced strenuous objections to the 30-40 percent set aside for carpoolers; however, and argue that this does not reflect actual travel behavior and hurts their competitive position with older buildings that do not have similar restrictions.

The total CBD parking inventory in Seattle declined from 44 642 spaces in 1976 to 43 264 spaces in 1978, largely due to redevelopment activities and the ban on principal-use parking. Since CBD employment is approximately 114 200, this provides an average of 1 space/2.64 employees. Seattle expects an additional 4.5 million ft^2 of office development by 1982, for a total of 23.6 million ft^2.

Toronto

Within the past few years, Toronto has set minimum and maximum requirements on parking that enables them to better control the amount of parking constructed. The minimum amount of parking required is 1 space/1668 net ft^2, and the maximum is 1 space/1453 net ft^2. Previously there were no parking requirements.

CBD employment is 185 000 individuals and the downtown parking inventory is 35 800 spaces, so there are 5.2 employees/parking stall. However, 80 percent of Toronto's downtown work trips are made by transit. There has been an increase in the supply of downtown parking since the requirements took effect, but it is unclear whether new developments are providing more or less parking than older ones. Developers were surprised by the bylaws since previously there were none, but the city staff believes that these bylaws have not discouraged developers from investing in the downtown.

Vancouver

Vancouver, like Toronto, recently instituted a new parking bylaw. The new restriction allows a maximum of 1 space/1000 gross ft^2. This bylaw replaced a minimum of 1 space/4800 gross ft^2.

Vancouver's downtown employment is 125 000, and there are 41 600 parking spaces. Of the total number of parking spaces, 20 000 are curb or surface-lot spaces and the remainder are in parking structures. Even though the total parking supply in Vancouver's CBD has been growing slowly in the past few years, the number of surface spaces is decreasing. There are 3 workers/parking stall.

The new bylaw has not altered radically the number of spaces that developers provide. In 1973, before the current bylaw was instituted, developers provided between 1 space/1000 ft^2 and 1 space/5000 ft^2. Currently, two new developments provide 1 space/1500 ft^2 and 1 space/4500 ft^2. A third major development is providing 1 space/1250 ft^2 and the developer said he would like to provide more. Developers generally have accepted Vancouver's new zoning restrictions.

PLANNING AND IMPLEMENTING OFF-STREET SUPPLY TACTICS

The types of tactics of particular interest to cities are as follows:

1. Changes in zoning requirements for parking (e.g., minimum space requirements, maximum space requirements, joint use of parking, and reduced requirements for developments near transit facilities);
2. Constraints on the growth in parking supply (e.g., ceilings on supply, reductions in parking requirements through HOV and transit incentives, and restrictions on principal-use parking facilities);
3. Preferential parking for HOVs, handicapped, and small vehicles in off-street parking facilities; and
4. Construction and management of peripheral parking to reduce long-term parking demand in the CBD.

The private sector typically builds, owns, and operates most of the off-street parking facilities in activity centers (e.g., CBDs and office parks), although some jurisdictions are notable exceptions to this. Consequently, the role of government agencies in providing such parking is predominantly one of developing and applying rules and standards to regulate the amount, location, and type (e.g., lot or garage) of parking and amenities and facilities to be provided to protect public health and welfare (e.g., lighting, ventilation, and fire protection).

Assessment of Existing Parking System

Some of the off-street supply tactics, particularly those that involve parking ceilings or freezes or major changes in zoning requirements, may generate considerable controversy. Experience with such tactics is limited, and it is difficult to accurately predict their economic, development, environmental, and transportation impacts.

Most communities are concerned as to how changes in parking policies will affect the economic feasibility and the development potential of activity centers such as the CBD or major office and retail areas outside the CBD. The feasibility of such centers is important to the tax base of a community and, therefore, proposed government policies that will affect such activity centers should be analyzed carefully and objectively. Consequently, it is important to comprehensively, even if qualitatively, analyze and evaluate such tactics and to address important issues raised by affected interests.

In many jurisdictions in which zoning and supply constraint tactics have been implemented, broad-based community sentiment favored reduced traffic congestion, improved transit ridership, reduced air pollution and other undesirable environmental impacts, and promotion of an economically and culturally strong downtown.

A basic step that should be taken in evaluating changes in off-street parking policies (e.g., zoning changes and freezes) is determination of the characteristics and adequacy of the existing parking system and the likely characteristics and adequacy of the future system under current parking policies. This should include compilation of accurate information on the existing supply, location, type (e.g., ownership), use, and prices of parking within activity centers. Specific types of data of interest and sources of such information are shown in Table 2 (2-4). These data should be used to identify existing parking problems such as inadequate short- or long-term parking supply or an oversupply of parking. Such information is necessary (a) to demonstrate an understanding of the parking system and (b) to provide a basis for assessing the impacts of changes in off-street parking policies on the activity center.

Existing parking policies should also be reviewed in terms of their long-range implications. For example, future parking demand should be estimated based on land use and employment projections, planned highway and transit improvements, and other factors (e.g., price of gasoline and transit fares). This information is available from the urban transportation planning agency in each urban area. Parking demand forecasts should be compared with existing and future parking supply to identify potential parking problems and requirements. In some jurisdictions this information is available from activity center parking studies.

Selection of Tactics

Based on the results of the problem assessment described above, planners should be able to identify changes to existing off-street parking supply programs or new tactics to promote activity center development and economic objectives. Table 3 shows the applicability of selected off-street parking supply tactics to alleviate activity center problems. The advantages and disadvantages of selected off-street parking supply tactics are described below and summarized in Table 4.

Minimum and Maximum Parking Requirements

Most communities have zoning codes that specify the number of parking spaces to be provided per unit (e.g., 1000 ft^2 of development, dwelling unit) and type (e.g., office, retail, hotel, or industrial) of development. Some communities specify the minimum number of spaces required, and others specify the maximum number per unit of development. The use of minimums or maximums is important from the perspective of controlling the off-street supply of parking. If a community wishes to constrain supply, it can set maximum (i.e., build no more than) parking requirements at a low level that achieves this objective. Alternatively, if inadequate parking supply is available for certain uses (e.g., retail), minimum (i.e., build at least) parking space requirements can be set at a high level to promote additional supply.

Aside from specifying parking requirements in terms of minimums and maximums, many jurisdictions should review their zoning requirements for parking space in light of public transit, carpool or vanpool, and other transportation programs designed to increase modal split and vehicle occupancies, particularly for work trips. Zoning requirements can be set to restrict parking supply, which will likely increase the price of parking. Both of these ef-

Table 2. Potential sources of data for planning off-street parking management tactics.

Item	Applicable Data for Problem Assessment	Potential Sources of Data
Parking inventory	Number of spaces by type, location of spaces, applicable parking rates, restrictions and use of facility, hours of operation, and ownership	Parking inventory; records of local transportation, parking authority, or planning department
Parking use data	Maximum parking accumulation, number of parkers by parking duration, parking turnover, and trip purpose, residence, number of occupants, and destination of parker	Use survey, records of local transportation department or parking authority, and parker survey
Existing and projected land use, employment, and economic data		Local and regional planning agencies, chambers of commerce, and universities
Existing and projected travel by mode and purpose		Local, regional, and state transportation planning agencies and transit operators
Existing and projected transportation system characteristics		Local, regional, and state transportation planning agencies; transit operators; and parking authority

Table 3. Applicability of off-street supply tactics to selected problems in major activity centers.

		Selected Problems					
Objective	Tactics for Off-Street Parking Supply in Activity Centers	Provide Adequate Supply of Short-Term Parking	Provide Adequate Supply of Long-Term Parking	Encourage Efficient Use of Existing Supply	Reduce Highway Congestion in Peak Periods	Promote Economic Development	Conserve Energy and Reduce Air Pollution
Expand or restrict off-street supply in CBD and activity centers	Zoning requirements						
	Minimum requirements				X	X	X
	Maximum requirements				X	X	X
	Joint use			X		X	
Constrain normal growth in supply	Maximum ceiling (i.e., freeze) on CBD spaces				X		X
	Reduced minimum parking requirements through HOV and transit incentives				X	X	X
	Restricted principal-use parking facilities				X		X
Construct new lots and garages		X					
Change mix of short- and long-term parking		X	X	X	X	X	X
Restrict parking before or during selected hours of the day		X			X		X
Preferential parking	Carpool and vanpool parking, handicapped parking, spaces for small vehicles			X	X		X

Table 4. Characteristics of selected off-street parking management tactics.

Tactic	Jurisdiction	Agency	Area	Operating Characteristics	Compliance	Impacts
Expand or restrict supply in CBD and activity centers						
Zoning requirements						
Maximum and no minimum parking requirements	Portland, OR	Planning commission	CBD	No minimum required parking, maximum allowed parking for retail or office development is 1 space/1000 ft^2	Development review process	This action in conjunction with other tactics has resulted in 1 space/1350 ft^2 being provided for new developments
	San Francisco	City planning commission	CBD	No minimum required parking, limits parking to 7 percent of the gross floor area	Development review process	Moderate growth in private off-street parking has occurred in contrast to high growth in downtown office and retail space
	Seattle	Department of buildings	CBD	No minimum required parking, depending on the zone and use; maximum allowed parking ranges from 1 space/1000 ft^2 to 1 space/2000 ft^2	Environmental impact statement review	Parking supply is growing in areas farther from the retail core and decreasing closer in
Joint use	Los Angeles	Planning commission	Entire city	Would allow developments within 1500 ft to share parking if demand patterns do not conflict	Land convenant and performance bond	Proposed action
	Montgomery County, MD	Division of parking	Suburban CBD	Spaces rented by local college for use by students	Parking patrol checks for valid stickers	Student parking impacts have been reduced
	Portland, OR	Planning commission	CBD	City has agreed to increase number of short-term spaces in city garage if developer reduces number of off-street spaces provided; code allows developers to share parking	Development review process	Development under construction
Constrain normal growth in supply	Palo Alto, CA	Department of planning and community environment	Entire city	Allows reductions of up to 20 percent for developers without conflicting demand patterns	Development review process	
Maximum ceiling (i.e., freeze) on CBD supply	Boston	Boston air pollution control commission	CBD	Limit on total number of allowable commercial spaces; freeze does not apply to free employee and customer parking	Development review process	Development has not been hindered
	Portland, OR	Planning commission	CBD	Limit on total number of allowable parking spaces by sector	Development review process	Ceiling has not been reached; tactic has encouraged parking in desired sectors; development has not been hindered
Reduced minimum parking requirements through HOV and transit incentives	Arlington, VA	Zoning administration	Entire county	Developers located near rail rapid transit station may provide approximately 70 percent of required parking	Development review process	Should reduce commuter parking impacts
	Chicago	Zoning administration	CBD	Required parking reduced if developer meets certain conditions concerning transit stations	Development review process	There are 1000 fewer spaces in CBD since 1975; a 110-story building (Sears Tower) constructed with only 150 spaces
	Los Angeles	Planning commission	Entire city	Parking requirements would be reduced if developer provides HOV and transit incentives; developer would be allowed to substitute on-site spaces for off-site park-and-ride spaces; developer would be able to reduce required parking by 1.5 space for each space reserved for HOVs	Land covenant, development review process, developer would contribute money for park-and-ride facility development and transit shuttle services	Proposed actions

Table 4 (Continued).

Tactic	Jurisdiction	Agency	Area	Operating Characteristics	Compliance	Impacts
Reduced minimum parking requirements through HOV and transit incentives	Palo Alto, CA	Department of planning and community environment	Entire city	Allows up to 20 percent reduction in required parking if transit and HOV incentives are employed	Development review process, legal agreements	Several new developments have agreed to institute HOV incentives
Restrict principal-use parking facilities	Chicago	Zoning administration	CBD	Prohibits construction of principal-use parking facilities	Development review process	Number of parking spaces has decreased by 1000 since 1975; number of long-term parkers has increased
	San Francisco	Planning commission	CBD	New principal-use parking facilities require conditional use review	Development review process	
	Seattle	Department of buildings	CBD	New parking lots prohibited; new parking structures prohibited in most of CBD	Development review process	No new principal-use facilities have been built since 1976, economics is major factor
Construct new municipally owned parking facilities						
CBD	Baltimore, MD	Baltimore City	CBD	New facilities for tourists and shoppers in capital improvement plan	NA	Facilities planned and under construction
	Montgomery County, MD	Division of parking	Suburban CBDs	New parking structures have been constructed to meet long-term and short-term demand	NA	Employers and shoppers are encouraged to work and shop in these suburban CBDs
	Portland, OR	Downtown development commission	Retail core of CBD	Recently completed 492-space garage with a 752-space garage under construction; designated for short-term use only; $0.60/h, merchant stamp program	NA	Merchants pleased by increased supply of short-term parking
Neighborhood shopping districts	Los Angeles	City transportation department	Various neighborhoods	More than 7000 spaces in more than 100 facilities have been provided	NA	Program has increased attractiveness of shopping districts
	San Francisco	Parking authority	Various neighborhoods	Began program to increase number of available short-term spaces	NA	Merchants are supportive; made less impact on surrounding neighborhoods
Carpool and vanpool preferential parking	Alexandria, VA	Alexandria	CBD	Reserved spaces for city employee carpools of three or more persons; city vehicles are also available to carpools	Applications are cross checked	15 pools in program
	Los Angeles	City of Los Angeles	City facilities	Free reserved spaces are proposed for city employees		Proposed action
	Montgomery County, MD	Division of parking	Suburban CBDs	55 spaces reserved for carpooling of three or more; cost is $16/month versus normal fee of $24/month	Vehicles must arrive with three or more occupants	48 pools in program
	San Francisco	California Department of Transportation	Fringe of CBD	40 percent of under freeway lots reserved for vanpools; fee is $10/month versus normal fee of $60/month	Vanpools are certified	Program just beginning
	Seattle	Commuter pool	CBD and fringe of CBD	219 spaces under freeway reserved for 3 + carpools at $5/month; 1000 spaces in stadium lot available to poolers of 3+ for free	Carpools must be certified and are audited	Freeway lot is full; stadium lot has low utilization; 40 percent of carpoolers formerly used transit

Note: NA = not applicable.

fects may encourage transit ridership, carpooling, and vanpooling. Gasoline price increases and possibly its availability also may cause reductions in parking demand over time. Changing parking requirements in a zoning code are likely to have long-range rather than short-range impacts on supply. Such impacts would occur as new developments or redevelopment occurs over time.

Joint Use of Parking Facilities

This tactic is intended to lessen the duplication and improve the use of existing and new parking facilities. Two or more nearby developments would be able to meet local zoning requirements by constructing fewer total parking spaces (probably in a single facility) than would normally be required if each development were treated separately. Several conditions typically must be met for this tactic to be feasible:

1. The proposed joint parking facility should be in close proximity (e.g., within 1500 ft) of each participating development,
2. The time periods during which each development would use the parking facility should not overlap or be in conflict, and
3. There should be a legally enforceable agreement between each participating developer to ensure that the parking facility is built and operated in accordance with local zoning requirements.

For example, a joint-use parking facility may be feasible in settings where theaters or sports arenas, which attract evening and weekend travel, are built near an office development that experiences its peak parking demands on weekdays between 8:00 a.m. and 6:00 p.m. The key element of this example is that the temporal distribution of parking demand for these developments would not overlap, and consequently, the parking supply in the joint-use facility could serve both developments. This would eliminate the need for duplicating parking supply.

This tactic provides an incentive to developers to reduce their costs associated with meeting municipal parking requirements and allows the development of more revenue-producing space in their projects. Duplicative parking can eliminate spaces that serve travelers who have different temporal parking patterns (e.g., daily work-trip parkers versus evening theater or sports parking). The land freed by such a tactic can be developed for employment and revenue-producing purposes that benefit citizens and municipalities. Further, the tactic might encourage multipurpose projects and increase activities during the evening hours in downtown areas that are oriented to office buildings.

This tactic has limitations. In relatively few instances do no conflicts exist in the hours of parking for two or more developments. The developments must be in close proximity; otherwise, the long walking distance to one or both developments may inconvenience parkers. The enforcement of the joint-use agreement through a land convenant or a performance bond may discourage the execution of such an agreement. This tactic can be implemented through a revision of the zoning code. However, in order for it to be effective, considerable care must be exercised in defining the criteria where joint use will be permitted and in specifying the legal and financial mechanisms to be followed by developers to enforce the agreement over time. If either or both of these items are perceived by developers and others as being too rigid, use of this tactic may be undermined.

Ceiling and Freeze on Parking Supply

Ceilings and freezes are major actions taken to control parking supply. A ceiling sets an upper limit on the parking supply within a geographic area. The supply ceiling could be equal to or larger than the existing parking supply. Conversely, a parking freeze would limit future parking supply in a geographic area to the number of spaces available for use at the time the freeze is put into effect.

Several significant factors must be considered in planning and implementing a ceiling or a freeze on parking:

1. Types of parking to be covered,
2. Geographic area to be affected,
3. Provisions for review and approval of proposed parking facilities, and
4. Provisions for banking parking that is converted to other uses.

Reduce Parking Requirements Through HOV and Transit Incentives

This tactic is intended to reduce vehicular travel to and congestion in major activity centers by encouraging travelers to park at remote locations and use carpools, vanpools, and transit to reach their place of employment. This tactic differs from conventional park-and-ride tactics in several important respects. The affected municipality would construct park-and-ride facilities in suburban parts of the municipality. The municipality would then encourage developers and employers to purchase such spaces as an alternative to building spaces within major activity centers. The developers and employers would be charged the unit development cost per space to acquire the remote parking supply. Regulations that govern this tactic should be documented in a municipality's zoning code.

Developers and employers who participate in this proposal would be required to support transportation services (e.g., carpools, vanpools, and public transit) to link the lots with the places of employment. To ensure that all elements of this agreement are adhered to, performance bonds may be required or covenants may be executed on the property in question.

The provision of remote parking for transit, carpools, and vanpools would promote HOV travel, particularly among single-occupant automobile drivers, and may reduce congestion. The developer can use more of the project for office, retail, or other purposes that could increase the profitability of the project. Developers will also save capital costs of constructing parking facilities.

Selection of sites for such park-and-ride lots, operation of the lots, and support for transit services must be done with extreme care. Lots must be located to serve commuting patterns of employees for specific firms that have purchased spaces in a park-and-ride lot. Clearly, commuting patterns may change over time for a given employer. Facility locations must be selected in locations where a stable market of employees is likely to be found.

Keys to developer and employer participation in this type of effort are likely to include (a) the role and cost to the developer or employer in promoting and supporting carpool, vanpool, and transit service programs; (b) the type of legal agreements (e.g., performance bonds or land convenants) required by the municipality; (c) the savings in parking facility capital costs to the developer; and (d) the ease of leasing space under the provisions of the parking substitution program. These questions are difficult to answer; however, they are critical to the overall success of the project.

A particularly important municipal responsibility in this tactic is the timely and cost-effective development of park-and-ride facilities that can be acquired by the private sector. If the planning and construction of such spaces are not in phase with private sector schedules, the results of this tactic may be jeopardized. Municipal staff and capital and operating budgets will have to be structured to meet this need.

Restrict Principal-Use Parking Facilities

A number of cities such as Chicago, San Francisco, and Seattle have implemented restrictions on the development of principal-use (i.e., stand alone) parking facilities. Both Chicago and Seattle have prohibited the development of principal-use parking facilities in all or most of their CBDs. In San Francisco, proposed new principal-use parking facilities must undergo a conditional use review.

These restrictions generally have been implemented to restrict the growth in parking supply, especially that which is not a part of a development project within these cities.

Note that this tactic may not be applicable in many jurisdictions that have inadequate parking or that must rely heavily on the private parking industry to build and operate such facilities.

Preferential Parking

Considerable interest has been generated in providing preferential parking in off-street parking facilities to promote certain social, energy conservation, and other objectives. A growing practice in many parts of the country is to reserve convenient parking spaces for the handicapped.

Increasingly, government and private employers are providing preferential parking for carpools and vanpools. This traffic compliments carpool and vanpool programs that are sponsored by such employers.

There is little evidence that the private parking industry has implemented preferential parking tactics for carpools and vanpools. Several factors may contribute to this. Reservation of spaces for carpools and vanpools may cause a loss in revenues if the spaces are not fully used, and such spaces may require additional supervision and rules to identify carpools. These types of problems are likely to be overcome through proper coordination between the public sector and the private parking industry.

CONSIDERATIONS IN APPLYING OFF-STREET SUPPLY TACTICS

Several factors should be considered in using off-street parking as a tactic in managing the supply of parking. First, parking management tactics can be effective in alleviating certain types of transportation problems within individual municipalities and an overall urban area. Such tactics frequently should be planned and implemented in conjunction with other transportation system management tactics to help achieve local, regional, and national transportation, energy, economic, environmental, and related objectives. Note that parking management tactics are not limited to actions that restrict the use of passenger vehicles. Rather, they include many actions that are intended to use roadway capacity more effectively, to manage parking supply, and to encourage the economic growth of activity centers while promoting transportation, environmental, energy conservation and other community objectives.

Parking management tactics frequently can be implemented quickly and inexpensively, which is an important concern to local governments. Many of the on-street, off-street, pricing, marketing, and enforcement tactics involve development of new ordinances (e.g., zoning and enforcement) or modification of existing ordinances to implement tactics and do not entail large increases in staffing or costs.

Frequently, parking management tactics are planned, implemented, and operated by local governments or transit authorities and state departments of transportation. In many situations, local governments are the lead agencies because of the highly localized and frequently politically sensitive impacts of such tactics. Nevertheless, such planning needs to be supportive of adopted regional transportation plans and policies and the transportation improvement program of the affected metropolitan planning organization (MPO). MPOs play an important role in the identification and promotion of the use of parking management tactics and programs to encourage the urban area's goals and objectives.

The highly localized and potentially significant nature of the impacts associated with many tactics makes it extremely important (a) to encourage residential, business, governmental, and other interests to participate in the planning of such tactics and (b) to use accurate, current data on parking demand and supply for the study area in question. If either of these items is lacking, the credibility of the recommended parking management program can be jeopardized. Another potentially serious constraint in the planning and implementation of parking management tactics is institutional conflict between various local, regional, and state agencies. These conflicts are common and should be accounted for in the planning, implementation, and operation of such tactics.

An often overlooked, but critical, element that affects the successful operation of parking management tactics is an effective parking enforcement program. On-street parking tactics require strict enforcement if they are to be successful.

Although this paper has endeavored to present best current practice, it does have several important limitations. Most importantly, the suggested procedures and practices should be tailored to the needs of each urban area, municipality, and problem. Unless this is done, strict adherence to procedures described may undermine the success of the parking management program.

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