Spatial Dimensions of Commuting and Transportation Demand Management: An Analysis of Eastern Pima County, Arizona

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With the increasing number of regions adopting or revising travel reduction ordinances (TROs), the performance evaluations of these TROs should be standardized. The author of this paper argues that the effects of TROs should be considered at different geographic scales and that attention should be given to the socioeconomic characteristics of commuters. The methodologies used highlight the importance of socioeconomic and urban employment structures and the spatial variations of transportation infrastructures and services in determining the transportation behavior of employees. This paper suggests that the success of a transportation demand management program is as much a function of the type of activities it adopts as the type of neighborhoods from which the employees commute. The overall spatial distribution of socioeconomic characteristics, as determined by factor analysis and the commuter matrix, closely predict the predominance of transportation modes and their changes in Eastern Pima County, Arizona.

In early 1988, the jurisdictions of Pima County, City of Tucson, City of South Tucson, Town of Oro Valley, and Town of Marana passed a travel reduction ordinance (TRO) in an attempt to improve the regional air quality in Eastern Pima County, Arizona. As in other parts of the nation, the Pima County TRO emphasizes programs that improve air quality and decrease traffic congestion through transportation demand management (TDM). With an overall goal of increasing the efficiency of the existing urban transportation infrastructure, TDM programs may be operated in two ways. The first way is implementation of strategies that manage and accommodate traffic, such as removal of street parking and flextime, which shifts peak-hour traffic. The second way is adoption of measures that reduce travel demand mainly by reducing solo driving and increasing the use of alternative modes (e.g., carpools, vanpools, bicycles, and walking). Measures in this category include parking management techniques such as increased parking costs and preferential parking for alternative mode users, marketing alternative modes through incentives, and telecommuting. Bhatt and Higgins (*1*) provide a complete discussion of available transportation control measures.

The recent growth of TDM programs in the United States, especially in areas such as Southern California, has created an environment in which program and policy evaluation has become problematic because there is no standardized performance evaluation for TDMs, especially for cost-benefit analyses. This problem is aggravated further by the different requirements and language of each TRO. Even in Arizona, Pima and Maricopa Counties have some differences, making cross-comparisons difficult.

The Pima County TRO was adopted in 1988 with the goals of reducing the number of vehicle miles traveled (VMT) of major employers (those with 100 employees or more at a work site), increasing their alternative mode usage (AMU), or both. Each work site under the TRO was to conduct a survey in 1989 and, using that as a baseline, achieve 15, 20, and 25 percent reductions in their VMT (or demonstrate a 15, 20, and 25 percent AMU) during the next 3 years.

Pima County's TRO began like many other TROs throughout the country, with the aim of addressing the commuting behavior of employees at large work sites, and hence targeting a major portion of the working population. However, a number of jurisdictions (e.g., the South Coast Air Quality Management District) are considering including smaller work sites (25 employees or more) in their TRO program. Before such an attempt is made, the potential administrative problems and the methodology that will be used to measure the performance of different TDM programs at these work sites must be considered. Since agencies responsible for the implementation of TROs evaluate TDM programs mainly for individual work sites or at a cumulative regional level, the spatial variations in the effectiveness of TDM programs are rarely addressed. The recent requirements of the 1990 Clean Air Act Amendments, reflected in the Environmental Protection Agency's Employee Commute Options Guidance (*2*) highlight this shortcoming and attempt to mitigate it. Requiring regions to adopt average vehicle occupancy (AVO) zones is a step toward creating subregional performance requirements that are more responsive to the urban and social structure of the region. The problem, however, remains that in determining the AVO zones, politics of development and economic growth and the prospect of administrative demands for implementation are apt to play a much stronger role than transportation and air quality considerations.

Unfortunately, TDM research has not provided much in the way of profound methodologies for spatial analysis or an understanding of the relationship between transportation behavior modification and the urban structure. The general urban theory is most likely the best explanation available for commuting patterns and their changes in most American cities. Even though the importance of geography is incorporated in some of the recent literature (*1*,*3*,*4*), these researchers focus only on specific sections of cities (e.g., suburban work centers)

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and rarely attempt to explain the urban system as a whole. Among geographers, there has been a more direct attempt to explain the social theory behind transportation behavior, and the urban structure has been examined more closely (*5–9*). The concern among these authors appears to be focused on two aspects of urban transportation that are highly relevant to TDM programs. First, they examine the dynamic nature of urban places, especially the restructuring of work places and home. Second, they examine socioeconomic, ethnic, and gender differences and how these variables affect transportation behavior patterns.

The author will attempt to integrate some of these theories in order to understand the commuting characteristics of Eastern Pima County, Arizona.

SOURCE OF DATA

Since 1989, the Pima Association of Governments' Travel Reduction Program (PAGTRP) has been collecting data on the commuting behavior of Eastern Pima County's work force at work sites with 100 or more employees. The TRO Task

TABLE 1 Work Force Under Pima County TRO

	1989	1990
Number of Companies	153	134
Number of Work Sites	148	120
Number of Employees	77,230	77,118
Surveys Returned	52,892	57,559
Response Rate	68.5%	74.6%

TABLE 2 Changes in Weekly Mode Split by Employee Trips

Mode	1989 (%)	1990 (%)	Change (%)
Drive alone[a]	77.2	76.5	−0.9
Carpool and vanpool	13.5	14.2	5.2
Transit	3.9	4.7	20.5
Walk	2.9	2.0	−31.0
Bicycle	2.5	2.6	4.0
Total trips	249,848	267,903	

NOTE: Respondents who indicated commuting more than 7 days per week were excluded from this calculation.
[a]Includes motorcycle trips.

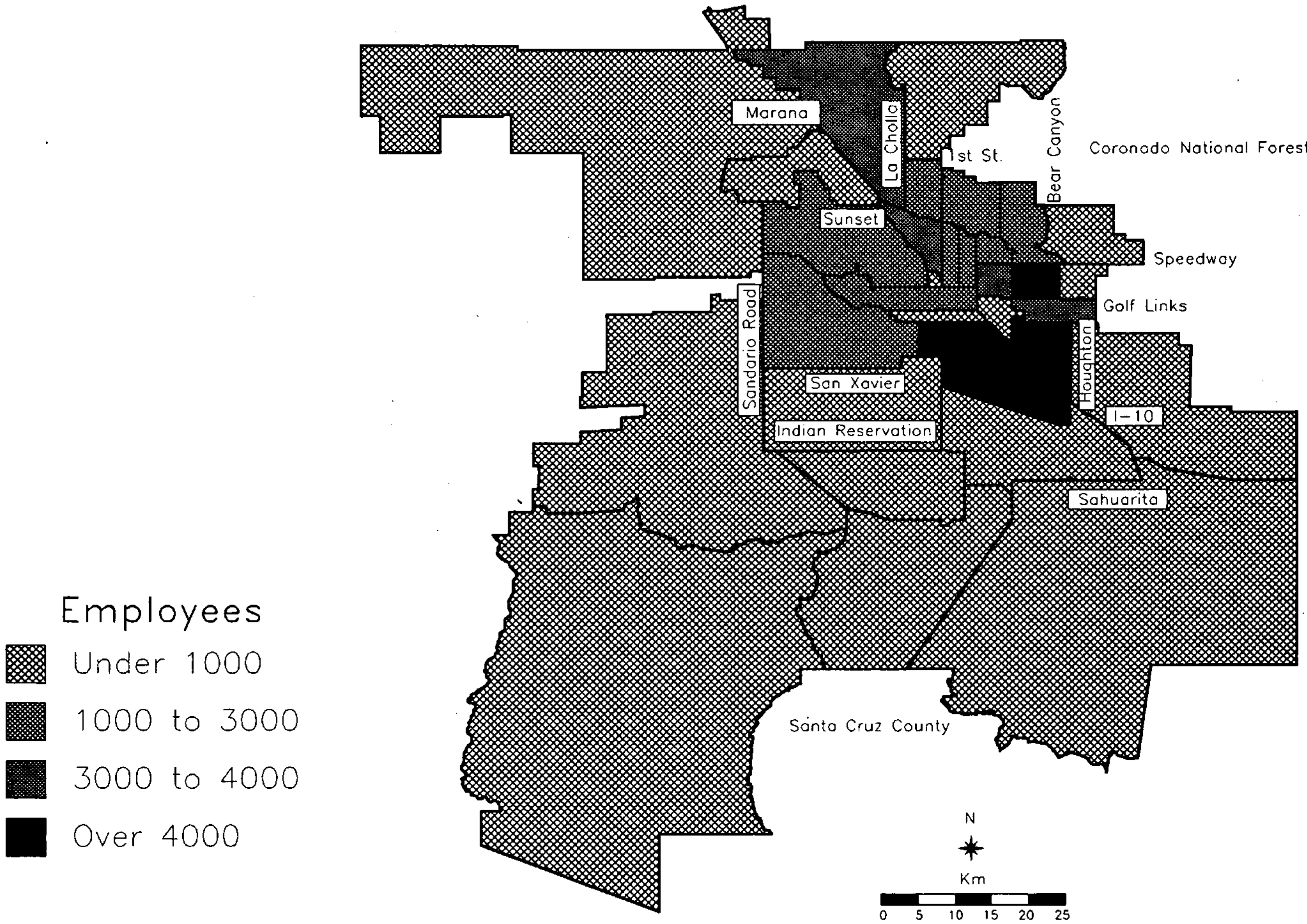

FIGURE 1 Employee residential distribution, 1989 (source: PAGTRP).

Force Committee mandated that these work sites were to achieve a minimum response rate of 50 percent on their annual survey, the only instrument used to measure each work site's compliance with the ordinance. Because nonrespondents are automatically counted as solo drivers, most work sites have attempted to achieve the highest response rate possible. These efforts yielded a regional response rate of 68.5 percent in 1989, which increased to 74.6 percent in 1990. This translates to 52,892 surveys in 1989 and 57,559 in 1990 (see Table 1).

Because employees at major work sites constitute about one-third of the total labor force in eastern Pima County, the travel reduction program (TRP) data base is extremely valuable for transportation research. In this paper, the 1989 data, considered the baseline data, are compared with the results from 1990 to illustrate the significant spatial variations in the level of success and failure of TDM programs. The selection of the 1989 data base is to ensure that the spatial characteristics of commuters are evaluated using data collected before the implementation of any TDM activities resulting from the TRO.

It should be noted that the TRP data base is made available to the public with one modification. Any variable that could identify a specific work site is removed from the data base to ensure complete anonymity.

To assist in this research, PAGTRP provided the author with information on the spatial distribution of work sites (i.e., number of sites per ZIP code). These data supplemented the employee transportation information for a general evaluation of the relationship between residential and employment concentrations in Eastern Pima County.

DATA ANALYSIS

General Characteristics

With respect to commute distance, time, and speed, employees at major work sites in Eastern Pima County appear to be similar to those at U.S. suburban employment centers (SECs). In 1989, the base year, the average one-way commute was 17.2 km (10.7 mi), well within the national range of 15.4 to 19.1 km (9.55 to 11.9 mi) for SECs, and the average travel time was 21.4 min, which is slightly less than the national range of 21.6 to 25.9 min (*3*). The average commuting speed was 47.1 km/hr (29.25 mph), which is again within the national range of 46.7 to 51.5 km/hr (29 to 32 mph) for SECs. In 1990, the average one-way commute distance, time, and speed were 17.2 km (10.7 mi), 21 min, and 47.6 km/hr (29.6 mph), respectively. Therefore, regionally, these commuting characteristics have not changed significantly since 1989.

Table 2 presents the 1989 and 1990 mode split for the employees. These percentages reflect the number of trips by each mode and do not incorporate ridership.

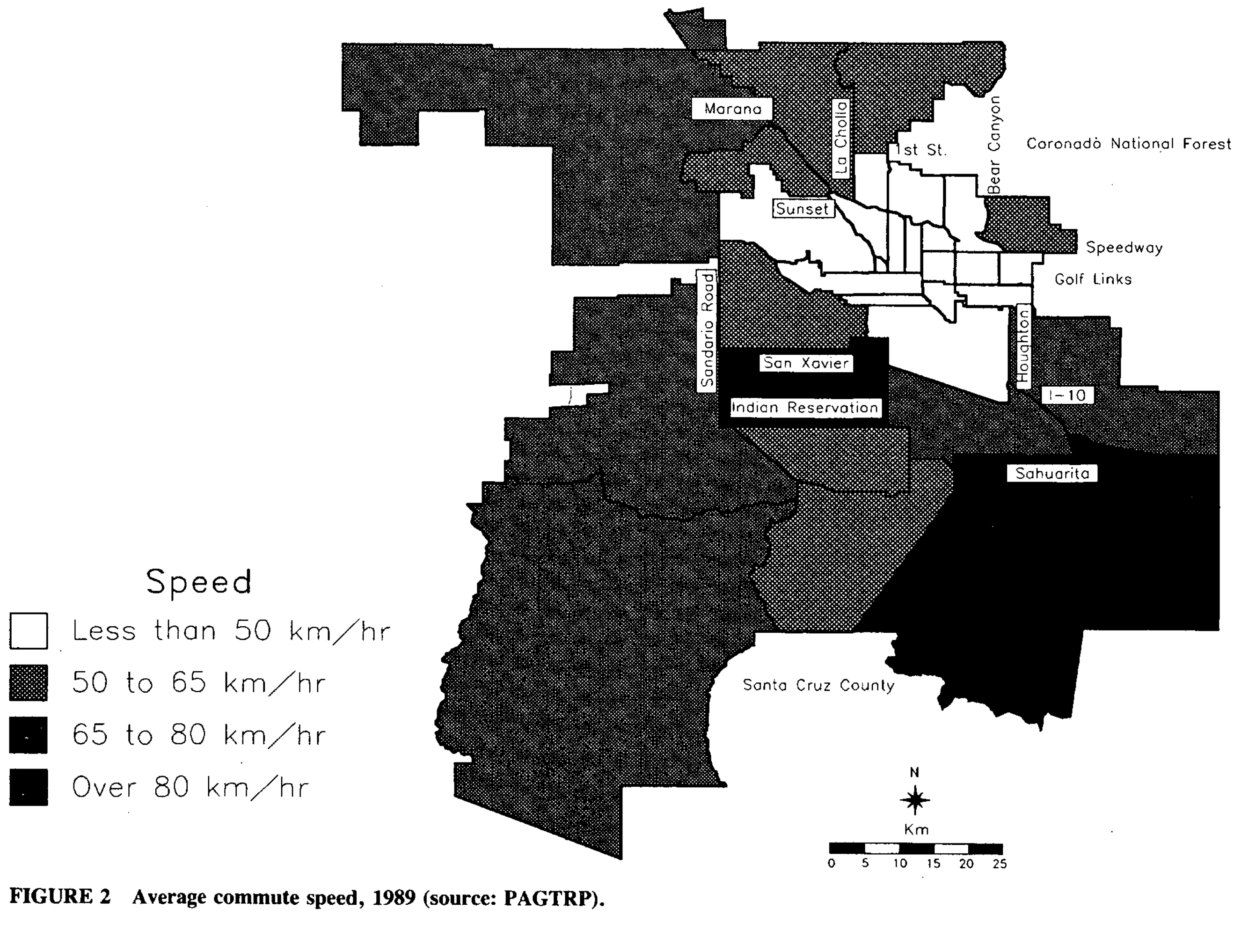

FIGURE 2 Average commute speed, 1989 (source: PAGTRP).

The 1989 mode split is similar to other regions of the country, with driving alone and carpooling being the primary means of getting to work. The low percentage of riding public transit, walking, and bicycling indicates that Tucson is generally a low-density community with characteristics not unlike other southwestern cities. The low density is partially caused by a land annexation policy that has occurred at a much faster rate than population growth. Between 1980 and 1985, Tucson annexed 69.4 km^2 (26.8 mi^2), a growth of 25 percent, while its population grew by only about 7 percent (*10*).

From 1989 to 1990, employee trips appear to shift from driving alone to alternative modes of transportation, with carpooling and transit accounting for most of these trips. Interestingly, not unlike other regions, walking appears to have declined regionally after the implementation of TDM programs. See work by Wachs and Giuliano (*11*) for the case of Southern California.

Despite the seemingly small changes in the mode split, the regional level of AMU increased from 17.59 in 1989 to 20.2 in 1990, reflecting a nearly 15 percent improvement. However, in the case of VMT, which reflects the changes in mode split more closely, the regional reduction was at a modest level of 2.9 percent, from an average of 76.1 weekly one-way km (47.3 mi) in 1989 to 73.85 km (45.9 mi) in 1990.

Although the overall regional changes in Eastern Pima County appear to provide an overview of the TROs effectiveness in the area, a spatially smaller scale of analysis is necessary to determine the relationship between the urban and social structure of the major work sites' employees and their commuting characteristics.

Spatial Examination of Commuters

To allow determination of a work site's compliance with the TRO, respondents have to provide answers about mode choices and number of days per week in each mode. Because a person may use several modes to get to work, the spatial association with each mode requires a set of parameters to define a person specifically as a solo driver, carpooler, bus rider, walker, or bicyclist. To remove personal biases from such a definition and to incorporate the varying nature of mode use from one city to another, the best method is to use the frequency distribution. The mode value for the number of days in each transportation alternative is considered the defining index for that category. For an individual to be associated with a single form of transportation, he or she must use that form as many days or more than the mode value.

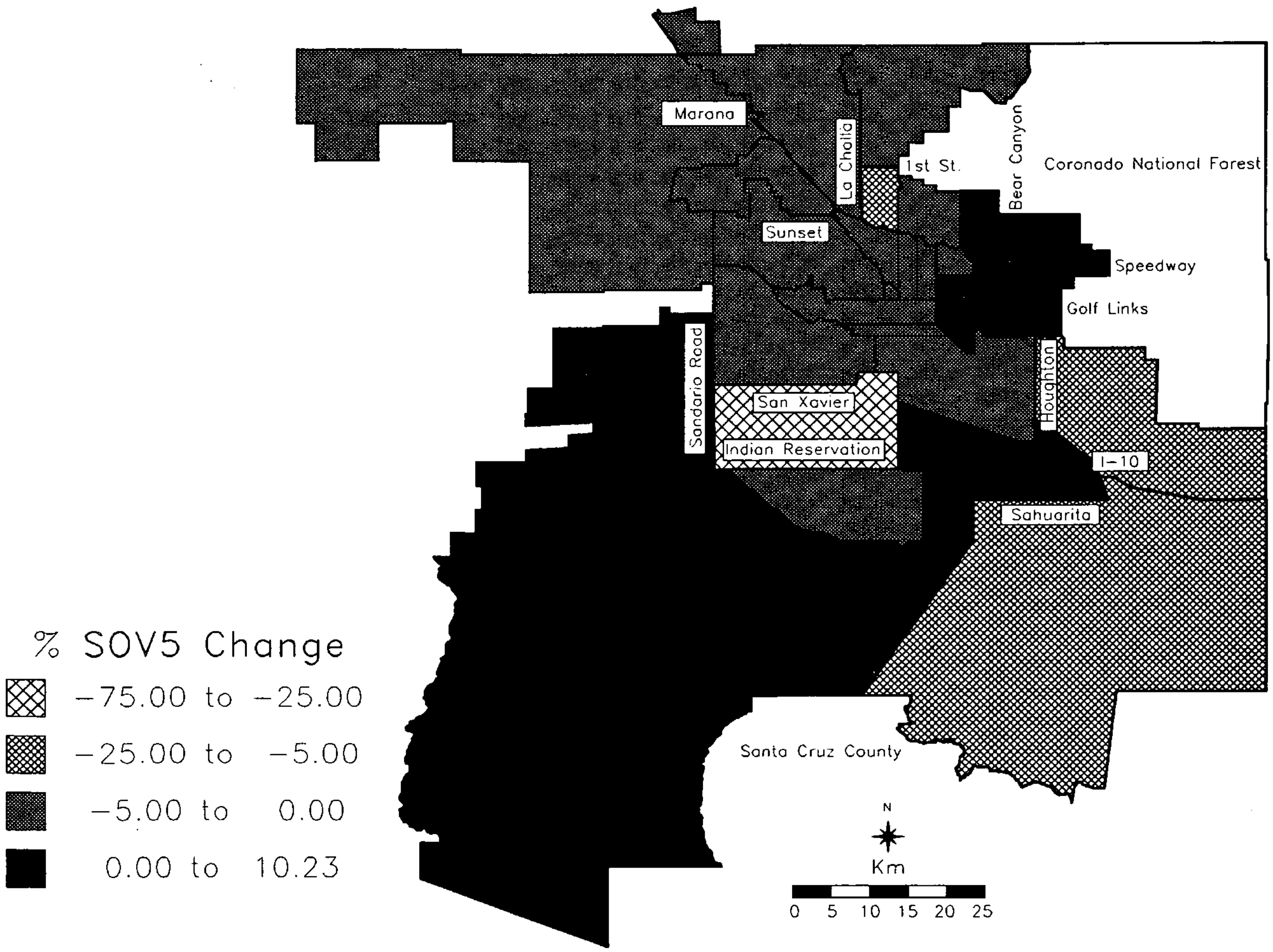

FIGURE 3 Percent change in 5 days per week SOV (source: PAGTRP).

A frequency distribution of the 1989 and 1990 data indicated that 5 days is the mode value for all transportation alternatives. A subset of the 1989 and 1990 data was created by aggregating the home ZIP code of commuters to provide a spatial data base for an analysis of the commuting characteristics of employees at major work sites and their changes over time. The final data base contained ZIP codes for 47,874 employees in Eastern Pima County for 1989 and 51,188 employees for 1990. This is nearly 91 percent of the entire data base for 1989 and 90 percent for 1990.

Figure 1 shows that the highest level of residential concentration of employees occurred in the southern and northwestern portions of the metropolitan area. This pattern remained unchanged in 1990. Considering that the majority of work sites are located in the south-central portion of the region, it is clear why average commuting speed is similar to that found in SECs throughout the nation. There is clearly a separation between major residential concentration of employees and work sites, which leads to major commute-related congestion problems within the core of the region (see Figure 2). It is interesting that the northwestern portion, the least favorable area for ridesharing, has an overall faster commute, compared even with the Foothills area. This is primarily because the northwest is one of the few places with access to I-10, making it easier to reach a variety of jobs downtown and in other areas of the city. Interestingly, the greatest number of single-occupant vehicle (SOV) trips originate in the northwest, which is caused not only by easier access to the freeway, but also by inadequate public transit service. From 1989 to 1990, TDM activities resulted in a 5 percent reduction in the number of employees who drive alone 5 days a week in this area (see Figure 3). Actually, with the exception of the northeastern area, which has witnessed a high level of growth in recent years, Eastern Pima County has experienced some level of SOV trip reduction throughout the region. The causes of these changes will be discussed later.

Carpooling appears to be lowest in the core, increasing with distance toward the periphery. This low rate is to be expected because ridesharing is considered inconvenient and less beneficial for short commuting distances. The highest spatial concentration of carpoolers occurs in the south. This pattern is significant because this area is also associated with a higher representation of low-income population (more than 20 percent of the residents have incomes below $15,000).

By 1990, the carpooling rate for 5 days per week had increased further in the periphery areas (with the exception of the northeast), whereas locations closer to the center of the urban area witnessed a small level of decline (see Figure 4).

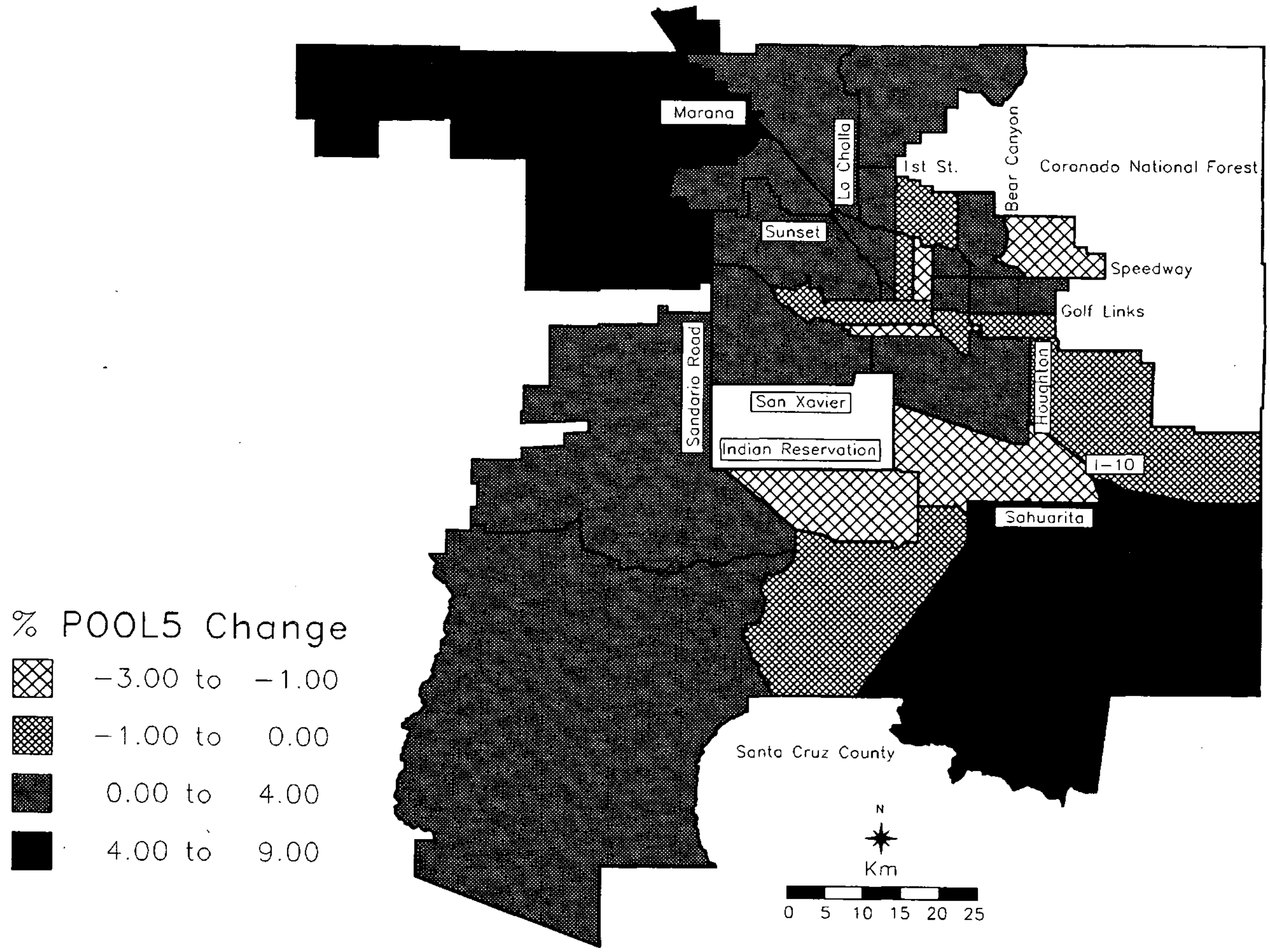

FIGURE 4 Percent change in 5 days per week carpool (source: PAGTRP).

TABLE 3 Commute Distance, Time, and Speed by Mode

Mode	Average Distance (km)	Average Time (min)	Average Speed (km/hr)
Drive alone	16.9	20.4	49.7
Bus	17.4	34.7	30.1
Carpool	22.5	24.9	54.2

NOTE: Based on 1989 data.

ZIP codes with 1 percent or more decline are those with the highest level of growth. The neighborhood east of Bear Canyon and north of Speedway is a good example of such an area. This is mainly a middle to upper middle class region with inadequate access to public transportation services.

The use of public transit as a mode of traveling to work is generally low in Tucson. This low rate is due to two factors: (a) the bus service is spatially limited, and (b) in areas where buses are available, mainly the core of the city, commuting distances are short. Therefore, without offering substantial incentives, it would be difficult to encourage employees to take buses to work. Tucson could not really market public transit from the standpoint of commute time because carpooling appears to be the best option among all the ridesharing modes (Table 3).

Although the variables discussed demonstrate some of the unique characteristics of employees' commuting patterns and highlight possible problem areas, the resulting spatial structure is not fully explained. In order to provide such an insight, the urban and social structure of Eastern Pima County has to be examined. In this paper, two methodologies will be used to illustrate the different possible approaches to this problem.

The first technique is factor analysis, which is used by many researchers in urban geography and related fields. For the purpose of this paper, the available socioeconomic and trans-

TABLE 4 Factor Matrix

	Factor I	Factor II	Factor III	Factor IV	Factor V	Factor VI	Factor VII	Factor VIII
Variables	Low Income Commuting	Job/ Housing	Socio-economic Status	Drive-Alone	Carpool	Industrial Area	Older Neighborhood	Public Transit
Commute Speed		-0.36		0.56	0.36	0.3		
Number of Work Sites		0.77						
Number of Male		0.95						
Number of Female		0.97						
Percent 5+ days SOV				0.8				
Percent 5+ days Carpool					0.66			
Percent 5+ days Bus								0.84
Percent 5+ days Walk	0.68							
Percent 5+ days bike	0.72			-0.3				
Percent Young[1]	0.83							
Percent Middle Age[2]	-0.83							
Percent Old[3]							0.76	
Percent Low Income[4]	0.77					0.38		
Percent Middle Income[5]	-0.38		-0.79					
Percent High Income[6]	-0.3		0.84					
Percent Clerk							0.74	
Percent Managerial			0.74			-0.3		
Percent Manufacturing						0.86		
Percent Professional					0.87			
Percent Service				-0.76				
Percent Skilled			-0.47	0.55	-0.48			
Percent Technical			0.47					0.55
Eigenvalue	3.8	3.5	2.5	2	1.6	1.6	1.2	1
Percent of Variation	17.3	16	11.4	9.1	7.4	7.2	5.5	4.6

1 Percent of employees 18 to 25 years old
2 Percent of employees 26 to 65 years old
3 Percent of employees 66 years or older
4 Percent of employees with less than $15,000 yearly income
5 Percent of employees with $15,000 to $40,000 yearly income
6 Percent of employees with over $40,000 yearly Income

portation variables were combined to perform this analysis. The selected variables were aggregated values of each ZIP Code for commuting speed, number of major work sites, percent male, percent female, percent employees in each commuting mode, percent employees in each income category, and percent employees in each job category (see Table 4 for a list of these variables).

The results of the factor analysis are presented in Table 4. Each factor is labeled according to the pattern of variables it loads. For brevity, a full discussion of the results will not be presented here; however, because the purpose of this analysis is to seek an explanation for the spatial distribution of commuting patterns, the significance of Factors I and III will be briefly discussed.

The resulting scores from Factor I are illustrated in Figure 5. This map identifies those ZIP codes with the highest rates of bicycle and walking (i.e., areas with high positive scores). The majority of these ZIP codes occur in areas where young and low-income employees reside. This includes both the central part of the urban area and the San Xavier Indian Reservation.

Scores from Factor III illustrate the socioeconomic structure of the area, as defined by the employee characteristics (see Figure 6). The data identify the Tucson Foothills as the area with the highest socioeconomic score value. This is the area north of River Road and east of First Avenue. Comparing this map with Figure 3 reveals an interesting spatial covariation. Areas with the highest socioeconomic scores are least amenable to reduction in the number of SOV commuters. This problem appears more aggravated in areas where a fast rate of growth is experienced. This finding supports previous work by researchers (*9,12*) emphasizing the importance of income level in determining how people get to work or how far they travel.

In order to investigate the role of socioeconomic status, a second methodology is adopted from Rutherford and Wekerle (*8*). While discussing women's employment characteristics, these researchers suggest that urban commuting patterns may be understood through a two-by-two matrix, which categorizes commuters into four groups on the basis of their income and distance traveled to work. This matrix is presented in Table 5.

Using the 1989 data, the median values for percent low income (i.e., percent employees with yearly incomes of $15,000 or less), percent high income (i.e., percent employees with yearly incomes above $40,000), and distance to work were calculated and used to create the matrix in Table 5. Each ZIP code is then defined in terms of the four possibilities. Fig-

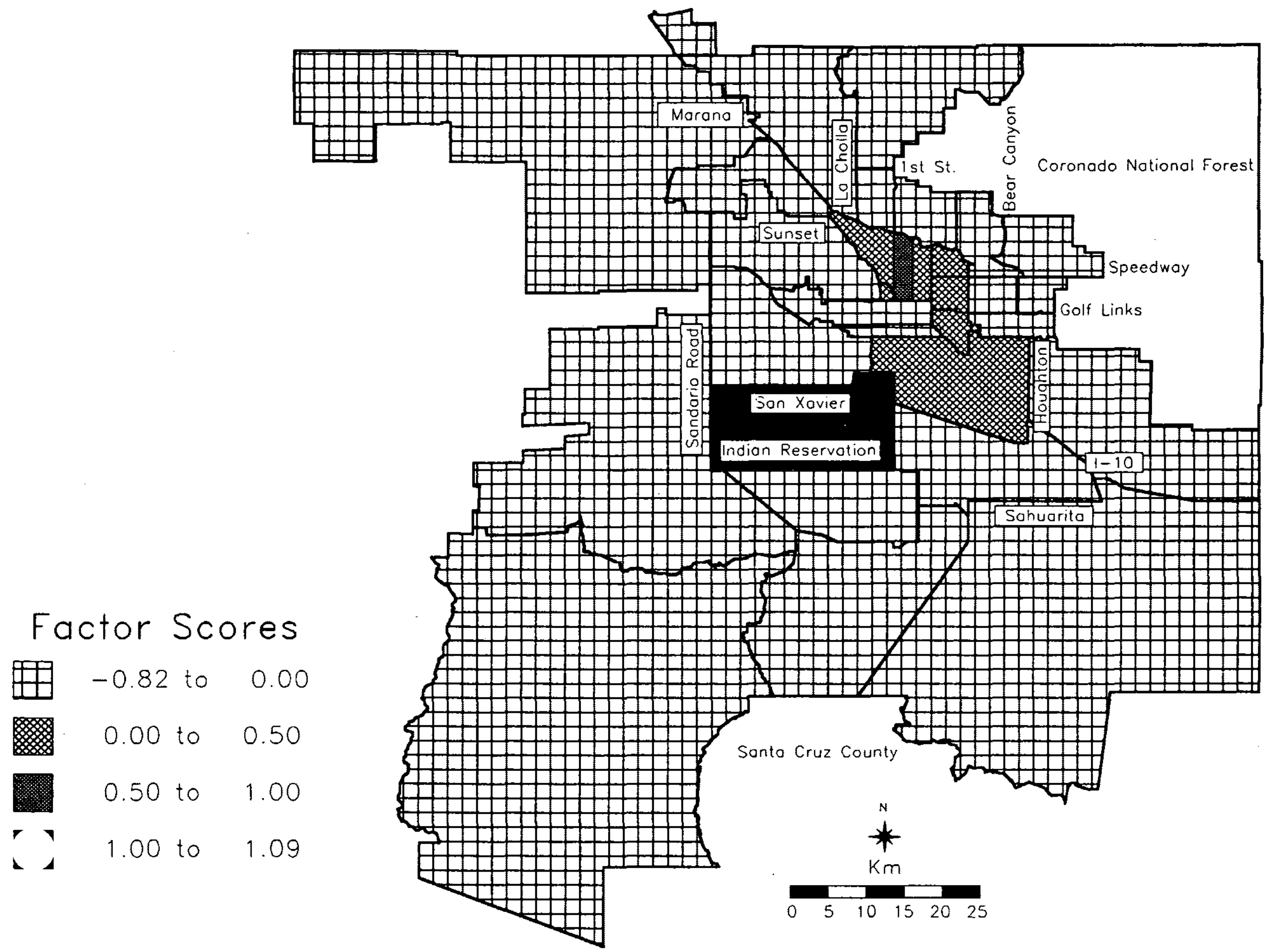

FIGURE 5 Low-income commuting patterns (source: PAGTRP).

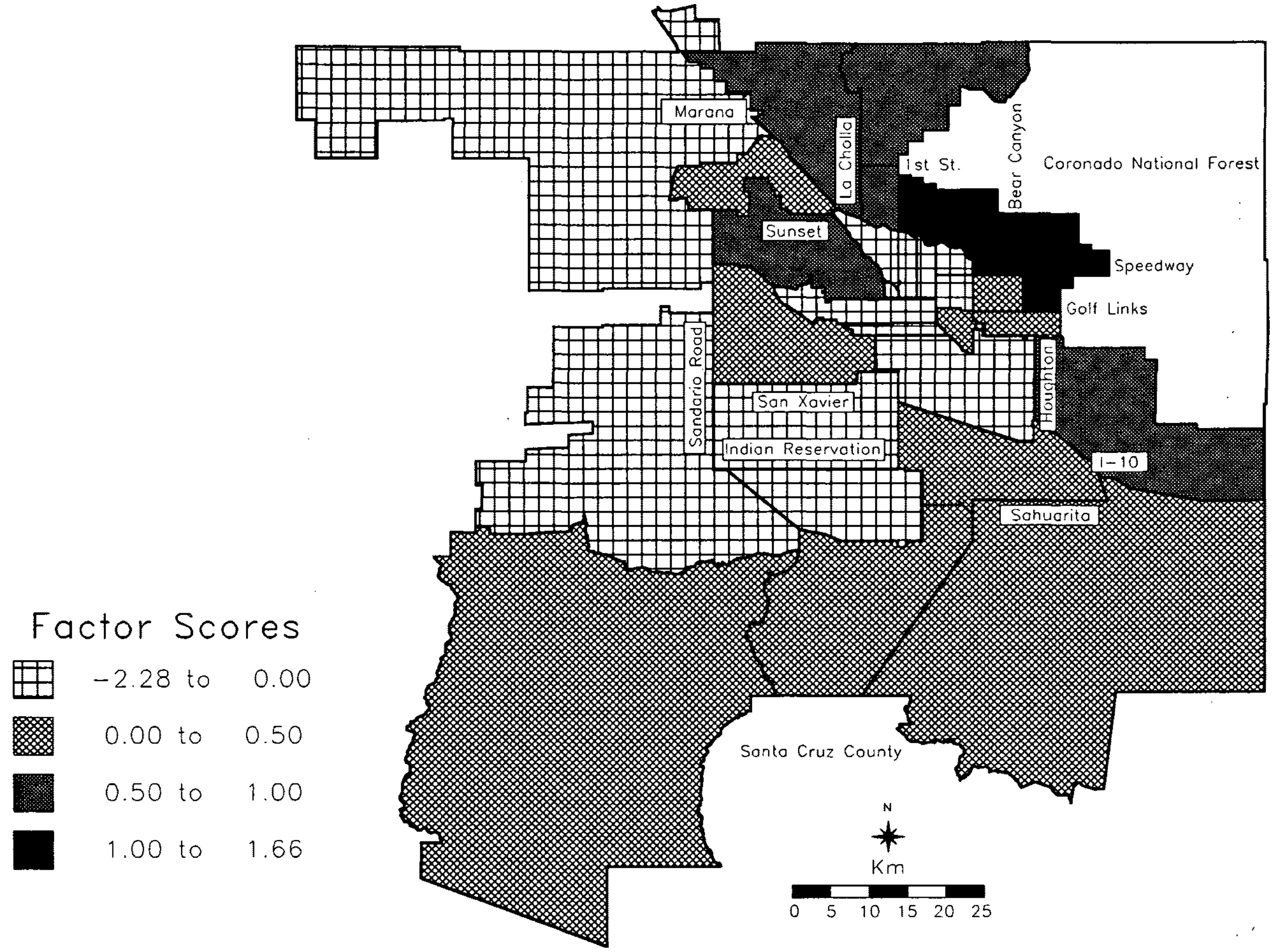

FIGURE 6 Socioeconomic status (source: PAGTRP).

ure 7 shows the spatial distribution of these commuting zones. As can be observed, the "worst zone" occurs west of I-10 from Marana to south of the San Xavier Indian Reservation. The growth of medium-low- to low-income neighborhoods west of Tucson Mountain and along Ajo Highway to Three Points could be responsible for this. Despite an increased residential concentration in this area, Ajo Highway to the south and I-10 to the north appear to be the only major access routes to the area (two other roads are Gates Pass and Picture Rock). This problem leaves local residents who have long-distance commutes to work with only one option: the automobile. Fortunately, as indicated by the 1990 data, the rate of carpooling has increased in this area (see Figure 4). In the absence of adequate public transportation, carpooling appears to be the only solution possible.

As expected, the "captive zone" occurs within the core of Tucson. This area contains low-income individuals who commute short distances to work, and it also accounts for most of the bus riders, walkers, and bicyclists. The pattern of the "captive zone" is much like Factor I of the previous analysis. The "captive zone" should demonstrate the highest level of TDM success rate, because if the low income and high transportation options of this zone are mixed with appropriate incentives, a higher participation rate in ridesharing and a lower drive-alone rate would result. Indeed, the usage of public transit increased significantly from 1989 to 1990.

The "ideal zone," which contains the high-income population with a short commuting distance, is concentrated in two parts of the metropolitan area. One is the Foothills neighborhood north of River Road from Bear Canyon to First Avenue, and the other is the area west of I-10 between 22nd Street and Ina Road. The "ideal zone" describes parts of the city where carpooling promotion could be successful and where the short commute distances allow for the serious consideration of some nonmotorized commuting modes. The high income, however, will be detrimental to the success of any alternative mode of transportation. Data from 1990 suggest that despite their ideal situation, employees in these areas still rely on driving alone to work as a major form of transportation (see Figure 3). However, carpooling has increased in the areas west of Interstate 10 and the areas west of Bear Canyon (see Figure 4).

TABLE 5 Commuter Matrix

	Low Distance	High Distance
Low Income	Captive	Worst
High Income	Ideal	Enterprising

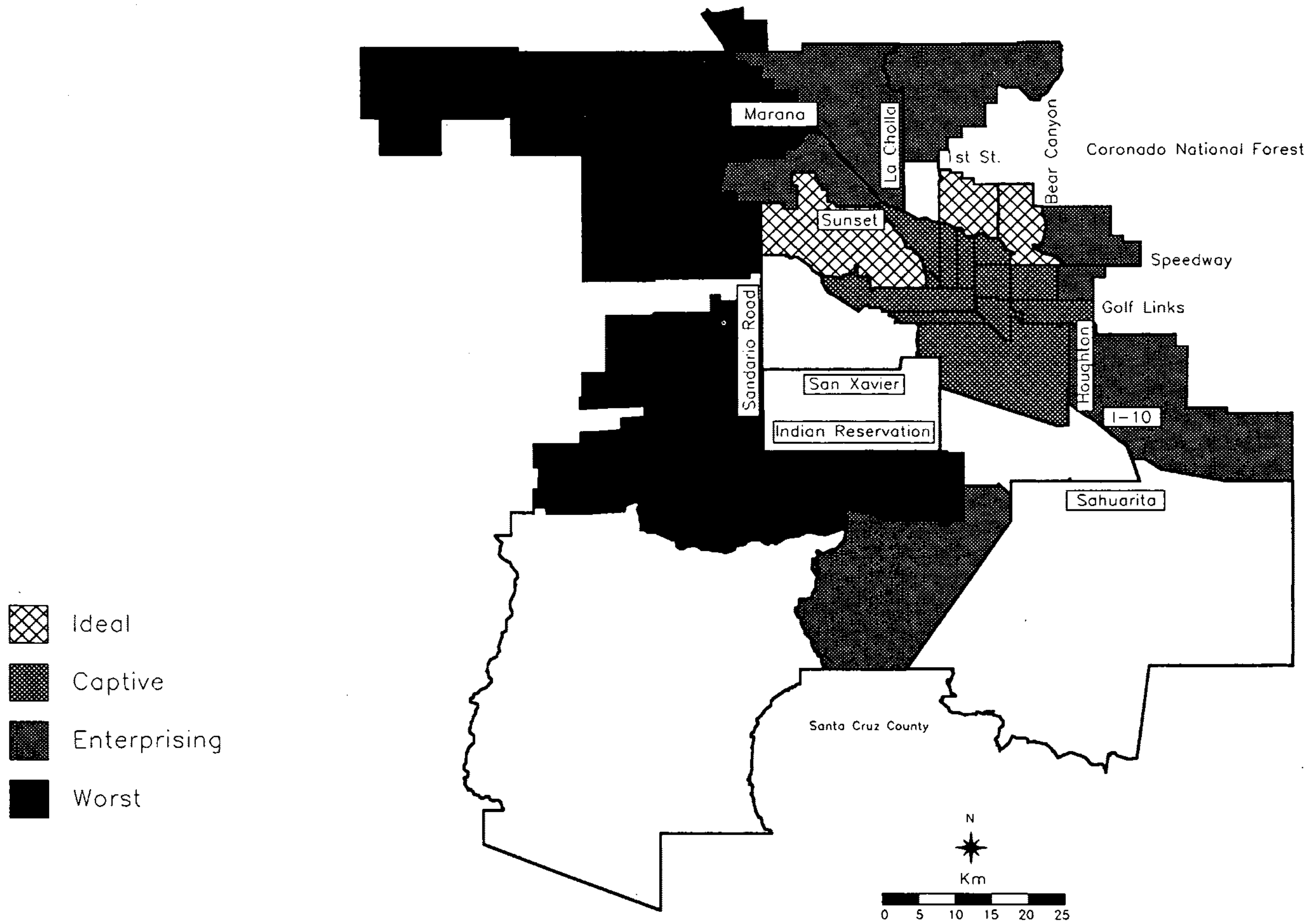

FIGURE 7 Eastern Pima County transportation zones (source: PAGTRP).

"Enterprising zones" are typically on the periphery of the metropolitan area. They occur in regions where the high cost of housing, combined with an unfavorable residential/bedroom community characteristic, creates an environment in which the number of VMT is high and alternative modes of transportation are rarely used. A combination of high income and inadequate transportation services leaves only one option available, and that is the automobile. This situation, however, can be remedied by carpooling and vanpooling. In Tucson, the preferred commuting mode within the "enterprising zone" is driving alone. This zone covers the following areas: (a) east of Bear Canyon and Harrison Road, north of Golf Links Road; (b) west of Houghton Road, south of Irvington Road, and north of I-10; and (c) the northwestern portion, mainly north of Hardy Road and east of I-10.

The 1990 data suggest that the third neighborhood has witnessed an increased level of carpooling, and the drive-alone rate has dropped in the second neighborhood. Due to their unique characteristics, "enterprising zones" should be the primary target of TDM programs with an emphasis on carpooling and vanpooling.

Because of general accuracy with which transportation zones can predict possible commuting patterns and their changes over time, this methodology may prove useful for specific targeting in any TDM program. However, care has to be taken in determining the zones and their exact configuration.

CONCLUDING REMARKS

The spatial characteristics of commuting (both of commuters and their means of transportation) are as dependent on individual behavior and characteristics as they are on the urban spatial structure and its transportation environment. This paper provided a case study of Eastern Pima County, Arizona, in which individual commuters and their collective behavior were analyzed. It was demonstrated that the home-to-work commute is not independent of the spatial distribution of commuter characteristics. Furthermore, as one attempts to understand and analyze commuting patterns, it becomes clear that the spatial vantage point not only provides a clearer picture of this complex phenomenon, but also enhances the programming and detailed population targeting for different marketing strategies.

Eastern Pima County, like other regions of the country, is attempting to implement a TRO to alleviate congestion and improve air quality. The effectiveness of these programs is generally viewed from a regional perspective, whereas program implementation is at the work-site level. The author's findings suggest that a spatial evaluation makes it possible to examine the success and failure of TROs in smaller spatial units than an entire metropolitan area. If this analysis is conducted annually, program implementation could be better planned, and eventually, it will be possible to recommend modifications to existing TROs.

The policy implications of applying spatial analysis to commuting do not end here; it can provide additional programming options for major mitigation processes. For example, in the case of congestion management, where an entire traffic network system is concerned, a full understanding of the spatial aspects of commuting characteristics will allow for either (a) varied TRO requirements by zones, instead of one standard for the entire city or (b) different TDM activities tailored to each zone for the maximum possible return in the form of lower VMT and higher AMU. In this case, solutions for specific areas, such as major cross-sections with severe congestion problems, could be more readily addressed.

These few points illustrate the importance of applying spatial approaches to the study of commuting characteristics of specific urban areas.

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