Potential of Procedural Knowledge to Enhance Advanced Traveler Information Systems

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The closure of a portion of the Santa Monica Freeway following the 1994 Northridge earthquake afforded the opportunity to study the behavior of motorists as they found their way around the collapsed bridges along alternate and detour routes. In this study, 502 motorists, many of whom were displaced from the damaged Santa Monica Freeway, responded to a mailed questionnaire asking about changes in travel patterns, factors affecting alternate route choice, way-finding strategies used, difficulty in following alternate routes, attitudes toward the neighborhoods containing alternate routes, and attitudinal changes regarding the risk of traveling city freeways. A factor analysis of the responses revealed a procedural knowledge factor, indicating that motorists found landmarks, street signs, and written directions to be helpful aids in following alternate and detour routes. Procedural knowledge, the stored sequence of decisions about how to get from one place to another, is part of the spatial knowledge acquisition process. It is suggested that cues supporting a procedural level of knowledge could be used to enhance Advanced Traveler Information Systems (ATIS). Alternate and detour route information could include more emphasis on landmarks and street signs and be conveyed in the form of written or verbal directions.

On January 17, 1994, parts of four major freeways in the Los Angeles area were destroyed by the Northridge earthquake. Among the four was the purported world's busiest, the Santa Monica Freeway (I–10), carrying, approximately 341,000 vehicles per day and linking downtown Los Angeles with Santa Monica and its Pacific Ocean beaches. The Santa Monica Freeway suffered two bridge collapses, one at the La Cienega-Venice undercrossing and the other at the Fairfax-Washington undercrossing (Figure 1). Motorists who used the Freeway or surface streets that became detour and alternate routes to the damaged portion of the Freeway were particularly affected by the damage to the Santa Monica Freeway. Although the daily commuting patterns of these motorists were affected in a variety of ways over the 3-month period while the Freeway underwent repairs, most continued their solo auto-bound commutes using either one of the many designated detour or alternate routes to the damaged portion of the Freeway or they found alternate routes on their own. The alternate and detour routes consisted primarily of the many surface streets that parallel the Santa Monica Freeway and run through areas that are highly variable socioeconomically.

Five hundred and two motorists, many of whom were displaced from the damaged Santa Monica Freeway, responded to a mailed questionnaire. This questionnaire asked about changes in travel patterns, factors affecting alternate route choice, way-finding strategies used, difficulty in following alternate routes, attitudes toward the neighborhoods containing alternate routes, and attitudinal changes regarding the risk of traveling on city freeways. The data were analyzed using a variety of methods in order to explore motorists' impressions and behavior when forced to abandon their customary routes. Although a number of interesting results emerged from the data exploration, the focus here will be on one result that could potentially enhance the utility of Advanced Traveler Information Systems (ATIS).

The factor analysis portion of the data exploration revealed a factor defined as procedural knowledge, the category of spatial knowledge required to move about within an environment. Procedural knowledge consists of a sequence of decisions of how to get from one place to another. It is generally believed to follow the acquisition of declarative knowledge, linking the components of declarative knowledge (landmarks, routes, and areas). Some researchers have suggested that procedural knowledge is then followed by the acquisition of configurational knowledge, with a map-like quality that integrates information about a place into a comprehensive system of spatial knowledge.

The scores for this procedural knowledge factor were used to continue the analysis, searching for relationships between procedural knowledge and sociodemographic and geographic characteristics of the responding motorists. The results of this and the initial factor analysis seem to indicate that procedural knowledge cues—i.e., linked landmark and street name information in the form of written or voice directions, could indeed enhance the utility ATIS.

EXPERIMENTAL DESIGN

In order to explore the impact of the earthquake damage to the Santa Monica Freeway on Los Angeles motorists, a questionnaire was developed to ask motorists about changes in their travel patterns while the Freeway was under repair, the strategies they used to navigate without the Freeway, the factors affecting their alternate route choices, whether their impressions of the neighborhoods changed while traveling on surface streets, and whether they continued to use alternate routes after the Freeway was repaired.

The target population for the survey was those motorists who used the damaged portion of the Freeway regularly before the earthquake, in particular commuters. To sample this population, motorists' license plate numbers were recorded as they entered and exited the Santa Monica Freeway and traveled posted and unposted alternate and detour routes (Figure 2) when the Freeway was closed. License plate numbers were collected between March 11 and March 18, 1994. Both posted and unposted detour and alternate routes were selected in an effort to include motorists who might have ordinarily used the posted alternate routes before the

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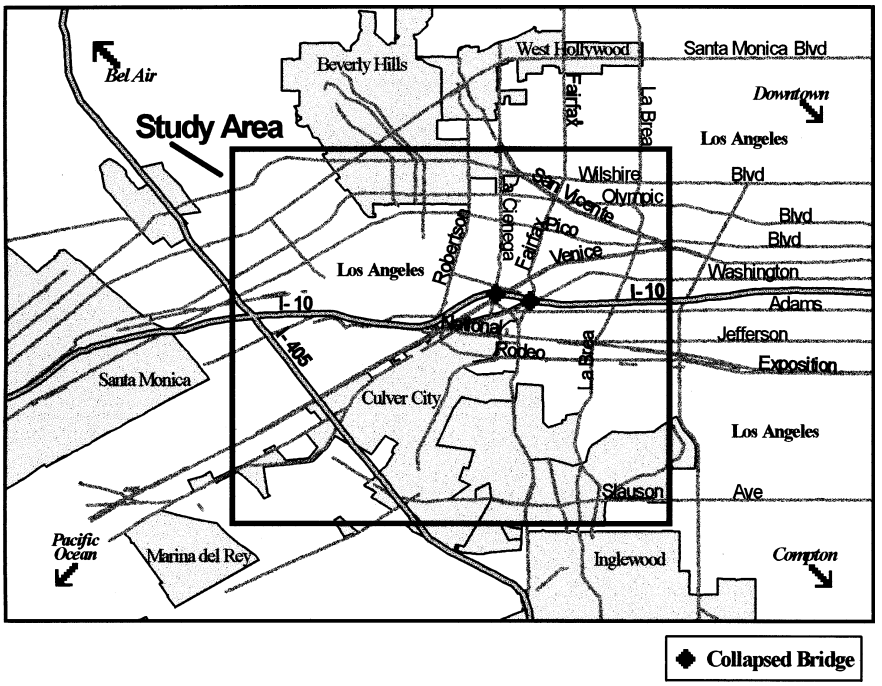

FIGURE 1 Black diamond symbol shows location of collapsed bridges on Santa Monica Freeway (I-10).

earthquake but found new, unposted routes in an effort to escape the increased traffic volume.

Motorists' license plate numbers were recorded at twelve intersections (Figure 2) along the detour and alternate routes for both east- and westbound traffic during the morning (7 to 9 a.m.) and evening (4 to 6 p.m.) rush hours. The rush hours were surveyed to focus on commuters. Commercial vehicles and vehicles with out-of-state license plates were excluded. A total of 3,581 license plate numbers were submitted to the California Department of Motor Vehicles to obtain the corresponding registered owners' names and addresses. Of those, 3,459 addresses received fell within the metropolitan area of Los Angeles. For control, the mailed survey also included a random sample of 100 people listed in the *March 1994–1995 West Los Angeles GTE Telephone Book*.

A variety of sources determined the design of the questionnaire, including Dillman's Total Design Method (TDM) (*1*), Palm and Hodgson's questionnaire surveying homeowners about earthquake insurance (*2*), and input from social scientists from a variety disciplines. The questionnaire was eight pages long and consisted of 52 questions, most of which had predefined responses to eliminate interpretive responses. Many of these questions were subsequently recorded as dummy variables to facilitate the analysis. Given the large Hispanic population in the Los Angeles area, the questionnaire included was also provided in Spanish.

Of the 3,459 questionnaires sent to both the observed motorists and the random sample selected from the telephone book, 502 responded, a response rate of 15 percent. The respondents were, for the most part, clustered around the Santa Monica Freeway (Figure 3). Five percent of the mailed questionnaires were returned as Address Unknown. This response rate compares favorably to that achieved by Ng et al. (*3*) in the private vehicle drivers portion of their nationwide survey designed to obtain user information requirements for an advanced traveler information system. It is, however, considerably lower than the 30 to 40 percent response rates achieved by other related studies (see, for example, *2*, *4* and *5*) which can perhaps be attributed to the method of contact—i.e., license plate survey and no contact prior to mailing the questionnaire.

RESPONSE OVERVIEW

More males, 56 percent, responded to the questionnaire than females, 44 percent. With the exception of Hispanics, the race and ethnicity of the sampled motorists closely resembles that of the population of Los Angeles County. (The disparity in the number of Hispanics would appear to be because of the difference in the way they are documented by the U.S. Census Bureau and the questionnaire used in this study.) Generally, reported annual household income levels of the responding motorists are significantly different than what might be expected in Los Angeles County. The highest income group (over $75,000) is overrepresented, while the lower income groups (less than $24,000) are underrepresented. This is undoubtedly because of the greater tendency for upper income group members to be commuters than lower income group members. Seventy-eight percent of the responding motorists fell into the 25- to 54-year-old age group, also an indication of the commuting population.

The majority (62 percent) of the respondents used the Santa Monica Freeway 4 to 7 days a week before the earthquake. Only 1 percent did not use it at all. Most responding motorists used the Freeway most frequently to go to work or school. The Freeway was also used, with some frequency, to reach social and recreational destinations. The respondents tended to use the Freeway less frequently to reach shopping venues.

Most responding motorists (87 percent) reported that their travel patterns changed during February and March following the earthquake. Those motorists used other routes to avoid the damaged

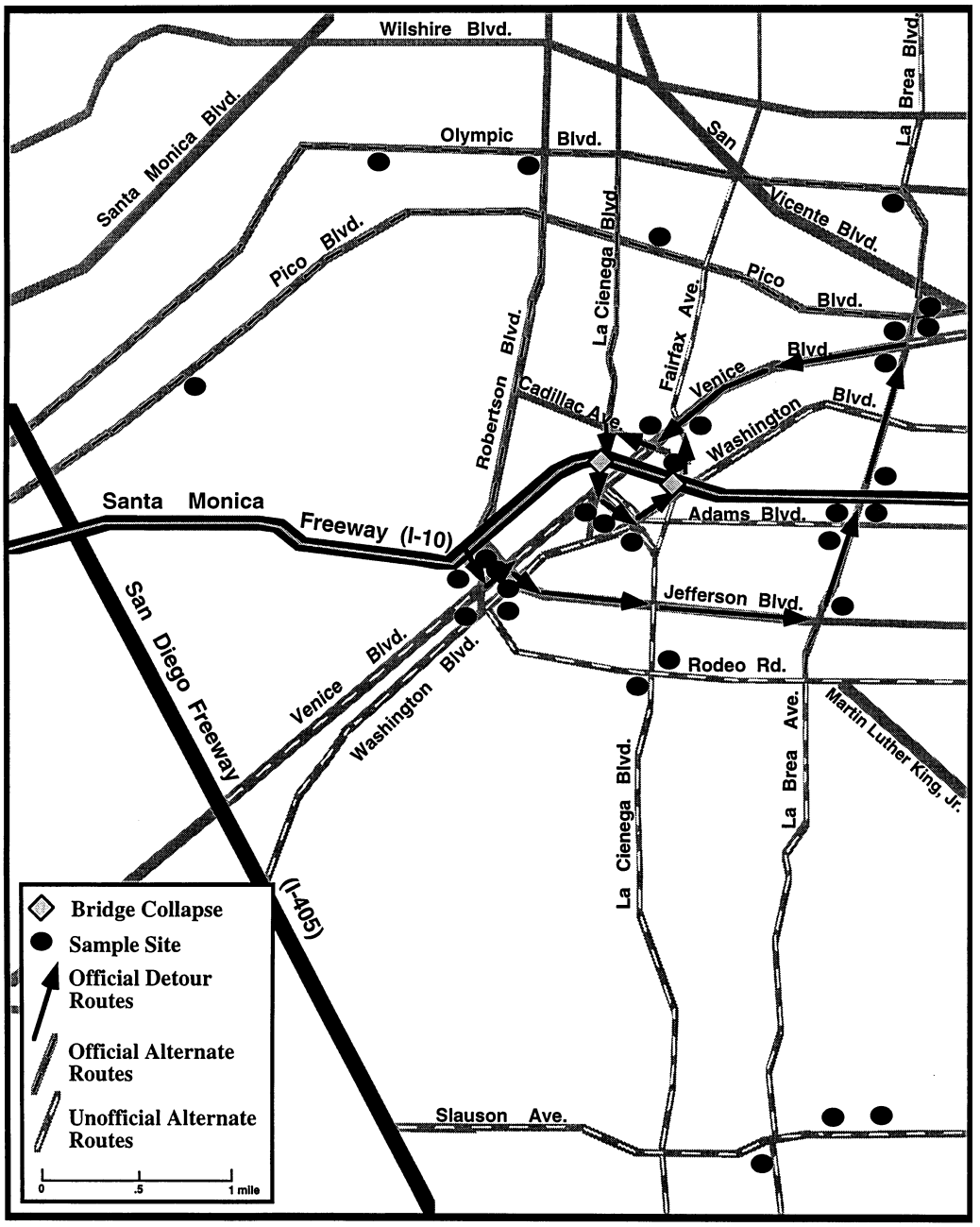

FIGURE 2 Study area, including sample sites and alternate and detour routes. (Source: Automobile Club of Southern California, Travel Publications Department, 1991.)

portion of the Freeway (65 percent), to completely avoid the Freeway (23 percent), and to avoid the increased traffic on other surface streets (53) percent. Most (91 percent), however, did report that they continued to buy gas and groceries at the same places they bought them from before the earthquake. The majority reported seldom stopping to buy anything along the alternate or detour routes. If they did stop, it was usually at a gas station. If they did not stop, it was usually because of unfamiliarity with the neighborhood or too much traffic.

Interestingly, many responding motorists (66 percent) had used routes other than the Santa Monica Freeway to avoid heavy traffic, accidents, or construction prior to the earthquake. Thirty-four percent reported never having used alternate routes. While 34 percent is certainly a substantial number and perhaps more attention should be devoted to preparing them in the event that they must use alternate routes, the fact that 66 percent were already finding alternate routes is encouraging. Perhaps "going surface" is not as eccentric an undertaking as some might have thought (*6*).

When asked how they found out about the alternate and detour routes they used, 73 percent reported that they were already familiar with them. Following the orange detour and alternate route signs was the next most popular method for finding out about the alternate and detour routes (32 percent), followed by maps, atlases, and information from acquaintances or relatives (both at 18 percent), information from television or radio (15 percent), information from newspapers

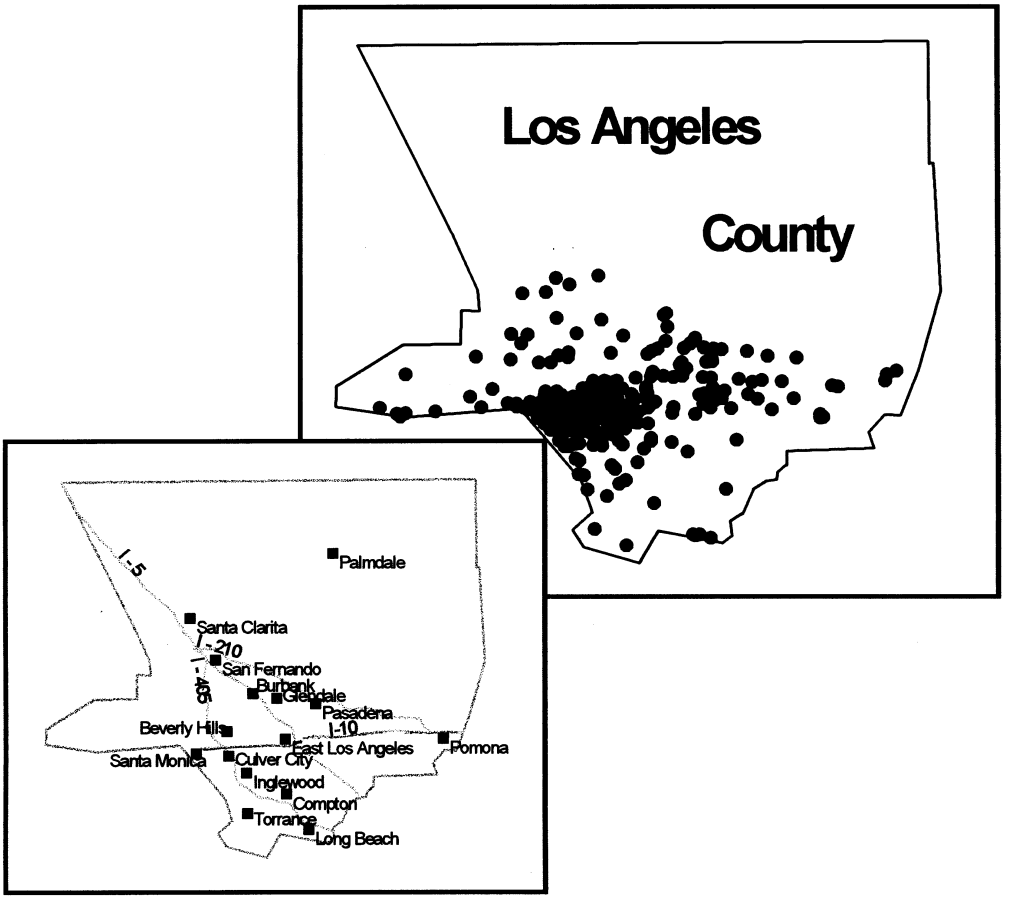

FIGURE 3 Residence locations of Los Angeles County motorists responding to questionnaire.

(13 percent), and following other motorists (11 percent). Maps and atlases also proved to be very helpful to motorists when planning their trips and navigating along the alternate and detour routes.

The majority of the responding motorists (53 percent) reported that they were not uncomfortable trying the alternate and detour routes for the first time. Twenty-two percent gave neutral responses and 24 percent reported that they were uncomfortable. Sixty-one percent of the respondents stated that they made very few or no wrong turns while learning the alternate and detour routes. The remaining 39 percent admitted to making more than a few wrong turns, and 18 percent reported making many wrong turns.

It took an average of 1 to 3 days for the responding motorists to become comfortable with the alternate and detour routes. Nine percent reported that they never became comfortable. Not surprisingly, those motorists for whom it took a long time to become comfortable with the routes also made more wrong turns ($r = 0.48$, $p < 0.001$). Surprisingly, there was only a slight tendency for motorists who used alternate routes before the earthquake to make fewer wrong turns ($r = -0.10$, $p < 0.05$).

FACTOR ANALYSIS

Factor analysis was used in this study to explore the motorists' responses to the questionnaire for a meaningful underlying structure. Although it was possible to specify a domain of variables or questions of interest, it was difficult to know how many variables were necessary to adequately represent the domain of displaced motorists or their nature. The 76 variables (excluding the sociodemographic and geographic variables) captured in the questionnaire were considered overwhelming, so factor analysis provided a practical solution to such a measurement dilemma.

Given that the number of responses (502) was relatively large, the classical eigenvalue-of-1 rule (*7*) provided a good guide to the number of common factors to be extracted from the correlations. There were 27 eigenvalues in excess of unity. The distribution of residuals for a 27-factor solution was respectable at 15 percent. The number of residuals increased dramatically when the number of factors to be extracted was reduced. The eigenvalue-of-1 rule thus summarized the 76 variables to a minimum of 27 common factors.

Principal components factor extraction with the varimax rotation method was used in this study because the resulting factors were more readily interpreted. Although the rationale behind a principal axis or image analysis factor solution seemed more intuitive given the study domain, both produced a number of very weak and uninterpretable factors. The varimax rotation method was used because the domain of motorist responses is not one where a general factor on which all variables have some loading would be expected. Thus a simplified factor structure was sought rather than a simplified variable structure. Varimax enhances the differences between high and low factor loadings; thus, if there are distinct clusters of variables, the varimax rotation tends to find them. The resulting factors were not

substantially correlated so an oblique rotation was not necessary. Table 1 summarizes the extracted factors; those in italics have only one variable that loads more highly on that factor than any other and is, therefore, technically not a factor, but probably the result of sampling fluctuation.

As stated earlier, the factor analysis was used for exploratory purposes, to identify an underlying structure that might warrant further study. One of the factors listed in Table 1, emerging as part of this structure that is particularly suggestive, is factor 11, the procedural knowledge factor. Before developing the analysis of this factor further, procedural knowledge will be defined in the following section.

SPATIAL KNOWLEDGE ACQUISITION

Considerable research and theory have been published by geographers, psychologists, and planners detailing how human beings come to acquire knowledge about their spatial environments (*8*).

TABLE 1 Common Factors Summarized via the Eigenvalue-of-1 Rule

Factor #	Factor Name	Eigenvalue
1	Stopped to Shop	5.74
2	Map Use & Trip Planning	4.41
3	Unfamiliarity	3.43
4	Info from Newspapers	2.62
5	Journey to Work	2.50
6	Changed Travel Patterns	2.24
7	Willingness to Use Alt Rtes	1.99
8	Orange Alt/Det Rte Sign Usage	1.91
9	Fwy Users w/Nonwork Destinations	1.88
10	Info from Broadcast Media	1.72
11	**Procedural Knowledge**	**1.63**
12	Info from Acquaintances/Relatives	1.58
13	Sociodem Characteristics	1.54
14	Mass Transit Usage	1.50
15	Fwy Avoidance	1.43
16	Willingness to Shop Elsewhere	1.42
17	Earthquake-Related Reasons for Not Stopping	1.30
18	*Planned Rte from Info on TV/Radio*	1.22
19	Left Turn Avoidance & Street Vendors	1.20
20	Reasons for Using Different Rtes AM/PM	1.16
21	Commuter Hot-Line Usage	1.15
22	Street Vendors & Unwillingness to Leave Rte	1.13
23	*Motorists w/Few or No Children*	1.11
24	*Used Alt Rtes to Avoid Traffic*	1.08
25	Inc Time to Reach Dest	1.05
26	Male Motorists w/Map/Atlas in Car	1.04
27	Used Different Rtes AM/PM during Feb & Mar	1.01

Although there is some disagreement regarding the actual spatial knowledge acquisition process (what its basic building blocks are and how to facilitate it), researchers agree that there are two distinguishable components to the acquisition of spatial knowledge: declarative (landmark) and procedural (route). Some argue for a third component, configurational (survey) knowledge.

Declarative knowledge in the spatial domain consists of features often referred to as landmarks, which may exist in both the natural and built environments. Lynch (*9*) defined landmarks as points of reference external to the observer that may vary widely in scale, such as buildings, mountains, signs, and parks. Procedural knowledge is characterized by the knowledge of sequential locations without the knowledge of general interrelationships. In other words, it links the declarative knowledge features together but the relationships between features are purely topological. Configurational knowledge is characterized by the ability to generalize beyond learned routes and locate features within a general frame of reference. It is considered to be more holistic than procedural knowledge and incorporates Euclidean, rather than solely topological, relationships.

Some research suggests that the acquisition of spatial knowledge is strictly ordered, beginning with declarative knowledge, followed by procedural knowledge, and culminating with the acquisition of configurational knowledge (*10*). It has also been suggested, however, that configurational and procedural knowledge are acquired together under some circumstances (*11*). Furthermore, there is evidence that either procedural or configurational knowledge could be acquired first, depending on how the environment was learned (*12–14*). Thorndyke and Hayes-Roth (*13*) have, for example, shown that people acquire configurational knowledge from a map and procedural knowledge from navigation. Learning an environment by studying a map has been shown to be more effective than directly experiencing the environment via navigation when judging relative locations and straight-line distances among features; learning it from navigation is superior for orienting oneself with respect to unseen objects and estimating route distances. Thorndyke and Hayes-Roth (*13*) found, however, that any advantage maps may have over navigation disappears as the subject is exposed extensively to the environment via navigation. In other words, accurate configurational knowledge could be achieved through navigation, without map study. Lloyd's (*15*) results run somewhat counter to those findings. He found that extensive navigational experience in a particular area did not result in accurate configurational knowledge. Subjects who had an average of 11 years of navigation experience in Columbia, South Carolina, had achieved only a procedural knowledge of their city. Freundschuh (*16*) has suggested that the differences between the results of these two studies may result from the different geometries or patterns of the test environments or different scales.

In terms of improving navigational success, then, it is unclear whether the acquisition of configurational knowledge, particularly through map learning, prior to procedural knowledge is preferable. As May et al. (*17*) observed, configurational knowledge must be transformed before it can be used for navigation. The main problem with learning from maps, according to their research, is that the information must necessarily be presented in an orientation-specific manner, requiring a transformation between two different spatial frames of reference—i.e., the map and the real-world scene as perceived from where one is actually located during navigation. From navigation, whether direct or indirect via slides (*14*) or simulations (*18*), people acquire procedural knowledge and are quite successful at orienting themselves during navigation. So, while configurational knowledge is certainly very useful when navigating in an area one

has already experienced, if it precedes a procedural level of knowledge, it is perhaps not as useful when navigating in an area in which someone is not very experienced.

In summary, there appears to be evidence for three levels of spatial knowledge acquisition: declarative, procedural, and configurational. It is, however, not clear how crucial each level is to the task of successful navigation nor is it clear how crucial the order of acquisition is to that task. In spite of the theoretical disagreements and disparity in findings, procedural knowledge, whether acquired before or after the other levels, does seem to be sufficient for successful navigation. Certainly configurational knowledge would enhance navigation in terms of improving the accuracy of distance estimations and judgments for relative locations, but it would not seem to be necessary for successful navigation.

PROCEDURAL KNOWLEDGE FACTOR

The variables in the procedural knowledge factor, as identified during the factor analysis, include "Used landmarks to follow the alternate/detour routes," "Used written directions to follow the alternate/detour routes," and "Used street signs to follow the alternate/detour routes." The factor loadings of these variables are 0.71, 0.69, and 0.56, respectively. These are the way-finding strategies typically used by people with at least a procedural knowledge of the area containing the alternate and detour routes. The domain of motorists' responses would, therefore, appear to be characterized by a knowledge of the landmarks and the routes that connect them so that they found landmarks, street signs, and written directions "helpful" to "very helpful" as they followed the alternate and detour routes.

The procedural knowledge factor scores were used to determine whether there is a relationship between procedural knowledge and sociodemographic or geographic variables. The results of this correlation analysis indicate that there is, to some extent, a relationship between procedural knowledge and geography, but not sociodemographic characteristics. As shown in Table 2, procedural knowledge is significantly correlated with such geographically based variables as area of residence, reported route choice, and the sample sites where the motorists were observed. Motorists' addresses were geocoded using Thomas Brothers GeoFinder® software. Arc/INFO's point-in-polygon operation was then used to determine in which census tract each geocoded address was located. Since there were seldom instances of census tracts with more than one geocoded address, census tracts were aggregated by municipal boundaries or similar sociodemographic statistics for a more meaningful analysis.

Where motorists live, in some cases, seems to be related to their spatial knowledge of the areas containing the alternate and detour routes. Motorists living in the immediate vicinity of these routes (Mid-City Los Angeles) appear to have a procedural level of knowledge of this area, while Santa Monica motorists do not (Figure 4). If living in the area, as the Mid-City motorists do, means motorists have navigational experience of it and therefore acquisition of procedural knowledge, then the significant positive correlation between Mid-City addresses and procedural knowledge would seem to support the results from both the Thorndyke and Hayes-Roth (*13*) and Lloyd (*15*) studies. The significant negative correlation between Santa Monica addresses and procedural knowledge could perhaps be explained by their having achieved either a configurational level or declarative level of knowledge of this area instead. If spatial proximity is an indicator of spatial knowledge acquisition, then it might be reasonable to speculate that Santa Monica motorists, living further away from the alternate and detour routes than the Mid-City motorists, have only a declarative level of knowledge of the area. According to Thorndyke and Hayes-Roth (*13*), it may, on the other hand, be that the Santa Monica residents have bypassed the procedural knowledge level and have a configurational level of knowledge instead because they know the area only through map study, rarely experiencing it directly.

Thus, although interesting and suggestive, the relationship between procedural knowledge and spatial proximity must be examined further before any definitive generalizations can be made. It is unclear from these results whether spatial proximity is just another way of expressing navigational experience. Although difficult to separate, spatial proximity, exclusive of navigational experience, should be studied to see if it is indeed a contributor to the process of acquiring spatial knowledge. There may also be other variables, yet to be identified, that may be manifesting themselves as a spatial proximity variable. For example, Freundschuh (*16*) has suggested that the geometry of the area in question—the layout of the city streets (e.g., grid street-block pattern, organic)—may also affect the acquisition of spatial knowledge.

The procedural knowledge factor was also correlated with two reported route choices during February and March, National Boulevard and Jefferson Boulevard. Although offered as separate route choices on the questionnaire, National Boulevard actually merges with and becomes Jefferson Boulevard as it crosses the eastern city

TABLE 2 Significant Correlations Between Procedural Knowledge and Geographic Variables

Geographic Variables	Pearson Correlation Coefficient	p
Area of Residence		
(Aggregated Census Tracts)		
Mid - City Los Angeles (218100-220000)	.14	.05
Santa Monica (701201-702300)	-.15	.03
Route Choice during Feb & Mar		
National Boulevard	.14	.03
Jefferson Boulevard	.12	.09
Sample Site		
Adams & La Brea • Westbound AM	.16	.02
Robertson & I-10 • Westbound AM	.13	.06
Slauson & Angeles Vista • Eastbound AM	-.13	.07
Washington & Higuera & Robertson • Westbound PM	-.14	.05

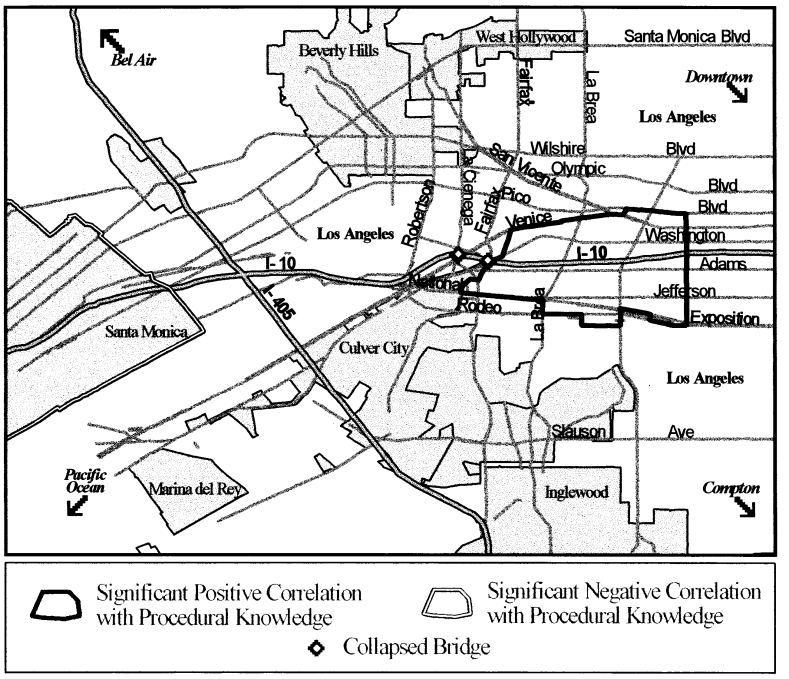

FIGURE 4 Areas significantly correlated with procedural knowledge.

limit of Culver City. This route was posted as a detour route and runs parallel to and south of the Freeway (Figure 1). It is possible that motorists with a procedural level of knowledge were not comfortable deviating from the posted detour route, at least in the eastbound direction. (It is interesting to note that there is no significant correlation between motorists living in the Mid-City Los Angeles census tracts and National/Jefferson Boulevards, given that this route runs through this area.)

National/Jefferson may also be characterized by other attributes that might inform the relationship between route choice and procedural knowledge. National/Jefferson is (*a*) close to the Freeway, (*b*) designated the eastbound detour route, (*c*) south of the Freeway, (*d*) straight-line, east-west path rather than a diagonal (e.g., Venice Boulevard), and (*e*) bounded by land that is used for light industry and parking. The other routes are either solely neighborhood commerce and parking or medium density housing or some combination of all three. By themselves, these characteristics are, with the exception of the eastbound detour designation and land use, unremarkable, as several other routes also possess them. Thus as route choice relates to procedural knowledge, it is difficult to make any sort of generalization based on these results. The aforementioned route characteristics, on further study, may help determine whether they do indeed have an affect on procedural knowledge or whether procedural knowledge of an area predisposes motorists to use particular routes.

Some of the sites where motorists were observed are significantly correlated with procedural knowledge (Table 2). All four sites are south of the Freeway (Figure 5). The two sites that are positively correlated with procedural knowledge are quite close to the Freeway and both are part of the eastbound detour. Of the two that are negatively correlated, one is quite far away from the Freeway (Slauson at Angeles Vista) and the other closer (Washington, Higuera, and Robertson), but off the beaten path relative to the posted alternate and detour routes. Like the relationship between route choice and procedural knowledge described above, it is difficult to generalize the relationship between sample site and procedural knowledge. It might be that, at least south of the Freeway, motorists' procedural knowledge decays as they move away from the detour route. Whether that means they have a declarative or configurational level of knowledge of the areas containing these two sample sites is unclear.

SUMMARY AND IMPLICATIONS FOR ADVANCED TRAVELER INFORMATION SYSTEMS

In this study, procedural knowledge appears to be a component of the motorists' responses following the 1994 Northridge earthquake.

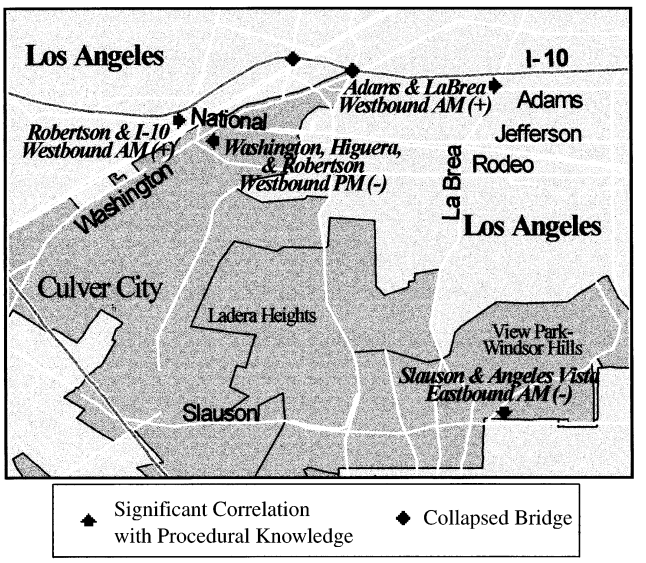

FIGURE 5 Sample sites significantly correlated with procedural knowledge.

The responding motorists seem to have acquired a spatial knowledge of the alternate and detour routes that consist of a sequence of features and actions that describe parts or all of those routes. The variables included in the procedural knowledge factor are those way-finding strategies typically used by people with at least a procedural knowledge of their environment. They have some knowledge of the landmarks and the routes that connect them so that they found landmarks, street signs, and written directions "helpful" to "very helpful" as they navigated along the alternate and detour routes.

Sociodemographic variables do not seem to be related to procedural knowledge, but some geographic variables are. Some route choices and sample sites are significantly correlated with procedural knowledge, but these results are difficult to generalize from, suggesting even more questions. Several areas of residence, Mid-City Los Angeles and Santa Monica, are also significantly correlated with procedural knowledge. It is, however, difficult to tell whether this evidence of spatial proximity as a contributor to spatial knowledge acquisition is perhaps confounded by motorists' navigational experience or lack thereof.

These suggestive yet inconclusive results, to some degree, may be because of the limitations of the research presented here. First, the questionnaire was constructed somewhat hastily, without any pilot testing, in order to reach motorists as soon after the earthquake as possible. Second, the resulting factor structure should be assessed by conducting factor analyses of similar or related domains. This is a domain characterized by a structure that may, in fact, depend on the personal characteristics of the respondents and the trauma surrounding the earthquake experience. Even if this factor structure were duplicated, the loadings of the individual variables may switch from positive to negative and vice versa. Although these are limitations of the research, in the sense that it is difficult to make more than some suggestive generalizations, the size of the data set is a strength, and it offers many directions for future research and potential implementation in the context of ATIS.

An awareness of the level of spatial knowledge acquired by motorists displaced from the Santa Monica Freeway following the 1994 Northridge earthquake could inform the content and format of the information provided by ATIS. The procedural knowledge factor identified in this study suggests that alternate and detour route information should perhaps include more references to landmarks and street signs in the form of written or voice directions. Although maps and atlases were quite popular with the responding motorists, written directions emerged as supporting motorists' procedural knowledge of the alternate and detour routes. Written or voice directions can list the landmarks, paths, and the connections between them without the superfluous and potentially distracting information maps include when one is merely trying to journey successfully from one place to another.

As Streeter et al. (*19*) showed, voice directions can be far superior to maps when motorists attempted to follow routes in unfamiliar environments. Subjects listening to voice directions made approximately 70 percent fewer errors than subjects using maps. As their subjects were completely unfamiliar with the environment to be navigated, the voice directions gave preference to landmarks over street names, facilitating the acquisition of declarative knowledge. Motorists responding to the questionnaire in the study presented here, on the other hand, are apparently somewhat familiar with the environment to be navigated and require a combination of both and the links between them.

The significant correlation between procedural knowledge and some areas of residence, however, points to the need for some customization of the information. Although motorists living in Mid-City Los Angeles may benefit from alternate and detour route information based on their procedural knowledge of the area, Santa Monica motorists may not. Motorists' levels of spatial knowledge acquisition essentially adds another dimension to the results of other studies looking at the kinds of information that must be included in ATIS. Khattak et al. (*5*), for example, found that for ATIS to be useful to all motorists, the provided information must be customized, including the ability for users to have control over route planning, diversion preferences, and the display of the information. Such customization could permit users to select the content and type of display based on their level of spatial knowledge of the given area.

As Golledge (*20*) observed, most way-finding and navigational devices do not incorporate the same way-finding and navigational procedures that humans do. Although they think they do, humans do not always seek the shortest path with the least effort (*21*). It is, therefore, important to incorporate traveler information that contains the cues that motorists will use. The more that is understood about the spatial knowledge motorists have acquired, the better those cues can be identified, thereby minimizing the uncertainty experienced by motorists when they are forced to abandon their customary routes.

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REFERENCES

1. Dillman, D. A. *Mail and Telephone Surveys: The Total Design Method*. Wiley and Sons, New York, 1978.
2. Palm, R., and M. E. Hodgson. *After a California Earthquake: Attitude and Behavior Change*. University of Chicago Press, Chicago, 1992.
3. Ng, L., W. Barfield, and F. Mannering. A Survey-Based Methodology to Determine Information Requirements for Advanced Traveler Information Systems. *Transportation Research Part C: Emerging Technologies*, Vol. 3, No. 2, 1995, pp. 113–127.
4. Barfield, W., M. Haselkorn, J. Spyridakis, and L. Conquest. Integrating Commuter Information Needs in the Design of a Motorist Information System. *Transportation Research Part A: Policy and Practice*, Vol. 25A, No. 2/3, 1990, pp. 71–78.
5. Khattak, A. J., J. L. Schofer, and F. S. Koppelman. Commuters' En Route Diversion and Return Decisions: Analysis and Implications for Advanced Traveler Information Systems. *Transportation Research Part A: Policy and Practice*, Vol. 27A, No. 2, 1993, pp. 101–111.
6. Hall, P. *Cities of Tomorrow*. Blackwell Publishers, Oxford, U.K. 1988, p. 282.
7. Kaiser, H. F. The varimax criterion for analytic rotation in factor analysis. *Psychometrika*, 1958, pp. 187–200.
8. Golledge, R. G., T. R. Smith, J. W. Pellegrino, S. Doherty and S. P. Marshall. A Conceptual Model and Empirical Analysis of Childrens' Acquisition of Spatial Knowledge. *Journal of Environmental Psychology*, Vol. 9, 1985, pp. 309–331.
9. Lynch, K. *The Image of the City*. MIT Press, Cambridge, Mass., 1960.
10. Siegel, A. W., and S. H. White. The Development of Spatial Representations of Large-Scale Environments. In *Advances in Child Development and Behavior*. H. W. Resse (ed.). Academic Press, New York, 1975, pp. 10–55.

11. Moar, I., and L. R. Carleton. Memory for Routes. *Quarterly Journal of Experimental Psychology*, Vol. 34A, 1982, pp. 381–394.
12. Evans, G. W., and K. Pezdek. Cognitive Mapping: Knowledge of Real-World Distance and Location Information. *Journal of Experimental Psychology: Human Learning and Memory*, Vol. 6, No. 1, 1980, pp. 13–24.
13. Thorndyke, P. W., and B. Hayes-Roth. Differences in Spatial Knowledge Acquired from Maps and Navigation. *Cognitive Psychology*, Vol. 14, 1982, pp. 560–589.
14. Hirtle, S. C., and J. Hudson. Acquisition of Spatial Knowledge for Routes. *Journal of Environmental Psychology*, Vol. 11, 1991, p. 335–345.
15. Lloyd, R. Cognitive Maps: Encoding and Decoding Information. *Annals of the Association of American Geographers*, Vol. 79, No. 1, 1989, pp. 101–124.
16. Freundschuh, S. M. *Spatial Knowledge Acquisition of Urban Environments from Maps and Navigation Experience.* University Microfilms, Ann Arbor, Mich. 1991.
17. May, M., P. Péruch, and A. Savoyant. Navigating in a Virtual Environment with Map-Acquired Knowledge: Encoding and Alignment Effects. *Ecological Psychology*, Vol. 7, No. 1, 1995, pp. 21–36.
18. Péruch, P., J. Vercher, and G. M. Gauthier. Acquisition of Spatial Knowledge through Visual Exploration of Simulated Environments. *Ecological Psychology*, Vol. 7, No. 1, 1995, pp. 1–20.
19. Streeter, L. A., D. Vitello, and S. A. Wonsiewicz. How to Tell People Where to Go: Comparing Navigational Aids. *International Journal of Man-Machine Studies*, Vol. 22, 1985, pp. 549–562.
20. Golledge, R. G. Place Recognition and Wayfinding: Making Sense of Space. *Geoforum*, Vol. 23, No. 2, 1992, pp. 199–214.
21. Gärling, T.; E. Lindberg, M. Carreiras, and A. Böök. Reference Systems in Cognitive Maps. *Journal of Environmental Psychology*, Vol. 6, 1986, pp. 1–18.

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