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Computational-Process Modelling of Travel Decisions: Empirical Tests

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Abstract

Travel behavior entails several interrelated decisions made by people, as well as the execution of routines not preceded by deliberate decisions. Furthermore, travel decisions are dependent on choices to participate in activities. A conceptual framework is proposed as the basis of a computational-process model (CPM). Because of the complexity of the decision-making process in which individuals are engaged, CPMs are promising alternatives to disaggregate discrete choice modelling with its limited ability to account for interrelated decisions and its reliance on an unrealistic utility-maximizing framework. Empirical support for the proposed conceptual framework is presented in the paper from case studies of telecommuting households in Sacramento, CA. The value of geographical information systems (GIS) in these empirical tests is demonstrated.

Introduction

The choice of travel destinations is considered an outcome of a process of choosing from among feasible alternatives. People learn about these alternatives through different processes of information acquisition from mass media, advertisements, interactions with other people, and direct experience. (Table 1) They represent the alternatives' locations and attributes in their long-term memory, access that information when making choices of destinations in connection with planning and scheduling trips, and update it on the basis of the outcome of those choices when executing their activity schedules. In the context of developing an activity-based conceptualization and model of trip scheduling over time, this paper will discuss both real world examples of activity scheduling and possible inaccuracies and distortions of people's cognitive representations of destinations and routes, how they might affect choices of routes and destinations, and, in turn, influence activity patterns.

Travel behavior entails several interrelated decisions made by people, as well as the execution of routines not preceded by deliberate decisions (Burnett & Hanson, 1982).

Furthermore, it has become increasingly evident that travel decisions are not only interdependent but also dependent on choices to participate in activities (Jones, Koppelman & Orfeuil, 1990). Thus, an activity analysis may often be essential for the successful modelling of travel decisions.

Disaggregate discrete choice modelling has frequently been applied in the past (Timmermans & Golledge, 1990), in particular with the focus on modelling single travel decisions as a function of properties of the possible alternatives (Pas, 1990). In addition, successful attempts have been made at discrete choice modelling in interrelated travel decisions using the nested logit (McFadden, 1979) or structural equations approach (Golob & Meurs, 1988). As reviewed in Axhausen & Gärling (1991), in several of these attempts the dependency of travel decisions have also been modelled. However, Timmermans (1991) recently questioned the adequacy of these modelling techniques. Besides, they invariably draw upon a utility-maximizing framework despite frequent questioning of its appropriateness for describing how people actually make decisions (Edwards, 1954; Kahneman & Tversky, 1979; Simon, 1990).

Interrelated decisions may be modelled by discrete-choice models, although, as has been noted, there appear to be several limitations. In attempts to replace the utility-maximizing framework with cognitive principles of information acquisition, information representation, and decision making, computational-process models (CPMs) have been developed. Such models offer much greater flexibility. Furthermore, even though deterministic, interdependencies are not easily modelled by other means. CPMs are, however, not without problems. A most salient problem is how to calibrate such models (Smith et al., 1982). Appropriate statistical estimation techniques are yet to be defined.

Several CPMs were reviewed in Gärling, et al. (1991). None of them was comprehensive enough to match the conceptual framework proposed by Gärling, et al.

(1989). A priority in the present paper is to validate the Gärling, et al. conceptual framework. After a condensed presentation of this framework, we report on empirical data related to specific components of the model - particularly scheduling activities and defining feasible alternatives. Finally, possible directions for future research are discussed.

Other CPMs and their Limitations

Most CPMs seem to do a good job in modelling different aspects of individuals' interrelated travel decisions. As illustrated in Table 2, these aspects differ between the different models. Whereas those models which target navigation and route choice also tend to model acquisition and representation of information about the environment, the other models, focusing on planning, do not seem to do that in as much detail. These models are, on the other hand, much more complete in modelling interrelated activity/travel decisions. A few models in each category appear more realistic descriptions of how people process information and make decisions, whereas the remaining models make at least some assumptions which are clearly unrealistic. There is, however, a need for more extensive, comparative empirical tests.

A review of existing CPMs (Gärling, et al., 1991) points to the possibility of developing a model that integrates parts of other models. The model proposed by Hayes-Roth & Hayes-Roth (1979) is perhaps the most promising to use as a point of departure. It may be possible to augment this model with a model of the acquisition and representation of information about the environment as well as of how route choices are made.

There are a few things that none of the existing models accomplish. The models of interrelated activity/travel decisions fail to explicitly represent the fact that such decisions may in varying degree be interwoven with their execution. In this way they do not adequately take into account that individuals' time horizons may differ at different points in time (Axhausen & Gärling 1991). Furthermore, revisions of plans are not modelled.

Another shortcoming of the current models is that they fail to model changes over time as a function of repeated experience of the environment and changes in saliency of goals. Such changes may be observed both in terms of which decisions are made and how they are made. The representation of the decision alternatives may also change. The current models thus need to be turned into dynamic models, as suggested by Goodwin, Kitamura & Meurs (1990).

A final shortcoming is that the models reviewed only consider one decision maker. Even though most decisions are made individually, it may still be necessary to simultaneously model other decision makers (e.g., other household members) to be able to validly represent constraints. Furthermore, an important future task should be to model how social interaction with others affects the information acquired about opportunities and constraints.

Conceptual Framework

In our conceptual framework (Gärling et al. 1984; Gärling et al. 1989) the environment offers individuals opportunities to perform various activities, such as work, shopping, and relaxation, by means of which their obligatory and discretionary needs are satisfied. The individual informs himself or herself about these opportunities, identifies spatiotemporal constraints, forms shorter-term as well as longer-term travel plans taking these constraints into account, executes the formed plans, and evaluates the resulting outcomes. According to this view, travel decisions constitute an integral part of travel plan formation.

Fig. 1 depicts an individual's cognitive processes responsible for plan formation. The individual has a memory representation of the objective environment which has been acquired by different means. Another memory representation (termed the Long-Term Calendar) contains information about an agenda of activities with different priorities. The activities with highest priorities are planned (by the Scheduler) taking opportunities and constraints into account. The resulting plan is stored in memory (as the Short-Term Calendar) before being executed (by the Executor).

The set of feasible opportunities at which an activity can take place are perceived by individuals on the basis of their memory representations (cognitive maps) of the environment. For instance, only destinations that are remembered will enter into the feasible opportunity set. Furthermore, their properties may be incomplete or distorted depending on imperfect memory or source of information. This is also true of other components of the environment, such as paths and travel modes. Identified constraints delimit the set of opportunities. Some constraints include physical or cognized distance, cost, and time. As suggested in Fig. 1, others concern the frequent need to coordinate the plan with other people, such as additional household members. Whatever the constraints are, it is important to note that they result from a process of identification and judgment. Thus, it is possible that some apparent objective constraints are never identified, or that constraints are subjectively identified although they do not exist objectively.

Forming Travel Plans

Plan formation is highly dynamic and flexible. Plan formation is supposed to start with a set of prioritized activities. However, if it is perceived that there are no feasible opportunities to perform the initially selected activities, less prioritized activities may be chosen. Activities with higher priority may have to await identification of feasible opportunities on subsequent occasions. This is also possible when the priorities assigned to activities change over time, both over a day or over a longer time span.

How planning is accomplished differs depending on tactical decisions. One important decision is the trade-off between planning in detail and starting to execute a plan. In general, planning may proceed in a top-down fashion. A schematic plan entailing choice of the sequence in which to perform the set of activities in different places is first formed, then through a process of mental execution, a more detailed plan is formed entailing choice of travel modes and departure times. Conflicts encountered in this detailed planning stage are solved by changing the sequence, compressing and/or deleting activities, or postponing departure times. At any point in time the individual may decide to postpone the detailed planning stage. He or she may also need to do that because information is not available. Plan execution thus starts before a complete plan is formed. As execution proceeds, the plan is made complete in subsequent stages of planning. Not only additions to but also revisions of the plan depending on changes in the environment may then be accomplished. An example would be that the activities to be performed during a day are first prioritized and sequenced, then a detailed plan is made for the morning. However, because of unforeseen delays or other constraints, the plan may have to be changed during its execution in the morning. This, in turn, may affect the agenda of activities to be performed in the afternoon, thus making necessary another sequencing of activities, and so forth.

Constraints may arise because the plan needs to be coordinated with other people's plans. This will occur for activities that can only be performed mutually, or for activities which can be performed optionally by any of the involved people. Such interdependencies arise perhaps most frequently within a household, although it is certainly not confined to household members (e.g., carpools). Even though decisions are made singly, they are influenced by other people's agendas as communicated to the individual forming his or her plan. The communication may be untimed, incomplete, or distorted, thus giving rise to another source of suboptimality of plans. Furthermore, in general one individual often dominates the other(s), that is, one household member is more unwilling to change his or her plan, on the basis of temporal precedence, the relative priorities of activities, or perhaps personal characteristics.

Over time planning becomes less deliberate. Although incomplete and distorted, an individual has a memory representation of his or her evaluations of the outcome of the execution of previous plans. This record has the potential of affecting subsequent planning. When repeatedly facing the same or similar situations, some decisions entailed by planning are never deliberated or, if deliberated, another decision rule entailing less information search is employed. The number of repetitions is, however, only one factor causing planning to become less deliberate and more habitual or automatic. Some assessment of how important the plan is for the attainment of salient, current goals is another factor. Thus, even plans executed every day may become deliberate if their execution is currently important for the attainment of salient goals.

A GIS-Based Computational-Process Model of Activity/Travel Decisions

Geographical information systems (GIS) have many uses in a transportation context. For example, in vehicle routing and scheduling tasks, a GIS can provide both the environmental map and the path selection algorithm. A salient problem in our conceptualization is to determine the relationship between the CPM, the GIS, and traditional network-based routing and allocation processes. Ideally, a successful resolution would deal with both aggregated and disaggregated data. Most GIS are used in anaggregate context. Activity-based discrete-choice or computational-process modelling often works with disaggregated or incomplete data, in small traffic zones or unique origin/destination location sets. This disaggregate approach makes it feasible to examine in real time the temporal impact of changing household decisions on the household's patterns of flow and the selection of route segments in specific networks. Without disaggregation the evaluation and application dimensions of these models would be seriously impaired. Fig. 2 illustrates how SCHEDULER can be interfaced with a GIS to model disaggregate travel behavior in real time..

GIS can provide a host for a comprehensive database and analytical procedures to operationalize segments of the conceptual framework presented in the preceding section. For example, an approximation of the street network on which individuals travel in US cities may be provided through available TIGER files. These also provide a base on which to locate household origins when exact addresses are available. Specific destinations can also be tied into these databases. Other information such as landuse and sociodemographic characteristics, may be superimposed on this network. For example, at this time we have landuses by census tract which can be overlain on the street network to help select feasible destinations for many trip purposes (e.g., education, recreation). Business hours, attributes of origins/destinations, and availability and speed of different transport modes are still other information that can be stored in the GIS in the form of attribute tables associated with specific origins and destinations, network links or more generally for selected polygons (e.g., traffic zones or census tracts).

Providing as factual a physical environment as possible in which to simulate travel allows us to provide a realistic initial input to a model concentrating on household travel decisions. A second advantage is that it allows us to emulate the actual trips associated with specific activities (or trip purposes), this should help refine the reasons for selecting criteria on which decisions are made, and help with the purpose of modelling how decisions may be revised during the course of a specified time cycle (planning horizon). If data are also available on how households travel (i.e., mode choice), then calibrating the mode choice component of the model will be more feasible, as will estimating that proportion of a trip made by freeway (etc.).

Still another use of GIS is in the modelling of the decisions. Transformations of the objective information may first be accomplished according to principles of how people distort such information in perception and memory, i.e., base maps can be distorted using appropriate map transformation procedures. In addition, a GIS data model could be selected to represent the process by which plans are formed.

Finally, to be useful in a policy context, some possibility of aggregating data is needed. Again, GIS offer this by overlay or other combinatorial procedures. GIS are thus not only useful for the development of realistic models but also for rendering such models directly relevant for traffic planning. Examples include (a) allocating trips between origin and destinations to most probable network segments; (b) estimating the proportion of trips made on a freeway vs. proportion made on highways, arterials or other (local) streets; (c) estimating congestion; (d) choosing locations for carpooling or park and ride origins; (e) simulating trips with mode changes. [Note, other papers in this session will address several of these questions.]

An Empirical Example: Activity Scheduling and Telecommuting

A preliminary analysis of some data provided by Kitamura for Sacramento, California, shows that telecommuting reduces a household's propensity to use specified network segments by as much as 50% on telecommuting days. Total trips undertaken in the city by telecommuters are also reduced (see Tables 3, 4, and 5). The total patterns of movement in the system is also reduced and altered (see non-work trips of pre and post telecommuting - Figs. 3 and 4); the total time spent travelling changes for both household members (e.g., for the telecommuter travel time drops from 337 to 308 minutes total over the 3 sample days, and for the other household member it increases from 153 to 206 minutes).

It is possible to examine the individual movement patterns and trip purposes in relation to the urban environment by relating these flows to an underlying landuse and population attribute surface. We are attempting to do this using the ARC/INFO GIS system.

Using our conceptual model we now turn to an explanation of how some components of activity patterns (drawn from the Sacramento data) can be modelled. A limited number of business places and home locations are first defined, together with duration of business hours during which each activity could take place. Locations are defined by x-y or other types of coordinates. They can then be projected into a geo-referencing system using the built-in projection function of a GIS.

Each activity defined for a household can be described as a set of productions. But these productions need to be implemented in a network context reflecting the idiosyncrasies of a real environment. GIS can facilitate the construction of such an environment for activity scheduling by providing an approximation of the street network on which the individuals travel either through digitizing or by importing existing digital networks. The ability to modify (either add or delete) arcs to the network enables us to input finite network elements essential for disaggregate modelling. If the location of an activity is given in address form, the location can be placed in the network using the address matching capability available in a GIS (e.g., ARC/INFO).

Location of activities represented as points, street network specified as a list of nodes and a list of arcs between pairs of nodes, and census tracts represented as polygons are the geographical component of the GIS. Non-spatial data such as the business hours of an activity, availability of transport modes on a network segment, speed over specific distances by mode of travel, purpose of the trips, etc., can be stored as attributes and linked to the environment through a relational join in a GIS. For example, it should be possible to select a trip purpose and identify the set of locations at which that purpose can be satisfied. A set of numerical and statistical operations can also be performed on these points, arcs and polygons and their attributes (for example, distances between pairs of locations can be calculated either using a Euclidean distance or network distance).

Using the buffer operation in a GIS we can define the feasible opportunity set within a user-defined interval (e.g., distance or time from a point, an arc or a polygon). For example, a circle defined by a certain radius (representing time, distance, or cost of travel) can be generated around home. Relevant locations at which a specific activity can be undertaken within that circle can be selected as possible destinations for a given trip purpose. Or a road can be "buffered" (i.e., reconstructed as a corridor or sector of a defined width) to represent a region which is accessible from the road within a certain time or distance. Again sets of feasible activity locations can be defined within this buffer.

GIS and Household Scheduling

The selected case focuses on a 2-adult household, one of whom telecommutes. A three day trip profile for both of them is listed in Tables 6 and 7. To illustrate how SCHEDULER works with the GIS, the following procedures are involved.

Task 1. A realistic environment which contains the origins, choice of destinations and possible routes is represented in a GIS. Environmental components include:
Street network (TIGER file) (Fig. 5)
point coverage showing locations of origin and activities (Fig. 6a, b)
Polygon coverage of landuse zones
The Environment: attribute tables of business hours and characteristics (Table 8a, b, c, d)

Task 2. Select the feasible opportunity set by using GIS operations like buffer and shortest path algorithm.

Prior to beginning telecommuting on a regular basis, the telecommuter commuted from home to a work location on day 5. Using the shortest path algorithm, we compute the possible route between his home and work (see Fig. 7). Buffer zones of 1 to 5 miles are generated from the route between home and work. Most of his/her trips made on that day are within the 7 mile buffer zone (including eating a meal on the way to and from work, see Fig. 8). The only exception is a recreation trip after work.

After telecommuting started, however, all his/her trips can be included in a 5 mile buffer generated from home (Fig. 9). Notice also there was a shift in activities. When the individual commutes to work, he/she made all the trips on the way to work, like eating a meal and recreation. On a telecommuting day he/she picked up domestic activities near home like "transport child", probably to and from school.

Task 3. Set up long term calendar. Select activities and their location from a feasible opportunity set, calculate distance and travel time, directed as input to the SCHEDULER's environment (see Table 9a, b, c, d).
The environment represents a constraint on the activity scheduling. It is used together with the long-term calendar in the SCHEDULER (which specifies priority, appointment and duration for each activity) to perform the activity scheduling.

Task 4. For the telecommuter before telecommuting starts, the SCHEDULER checks the environment and schedules according to the first available activity in the calendar. It checks the priority, whether the activity has a (regular) appointment and evaluates the distance between the origin and the destination. Then it goes to the second activity, and so on. Initially, for the telecommuter, the SCHEDULER schedules going to a meal in the morning, then work, then a meal at lunch time, and recreation after lunch. However, when it tries to schedule work in the afternoon, it cannot do so due to the conflict with the business hours during which work can take place (i.e., if the commuter went to work after recreating, there would not be enough time to satisfy work-hour requirements) (Table 10).

Task 5. Activate the Conflict Resolver. Given a list of prioritized spatial activities with different interval durations, the SCHEDULER selects the first activity and reads the distance between the origin and destination. After the first activity is scheduled, if there are conflicts between scheduling the second activity in the remaining time slot and the constraints in the environment, the SCHEDULER will try to change the sequence, or delete the activity. To ensure the scheduling of the second activity in that particular day wold require changing the priority. Extension of the SCHEDULER to schedule for a few days would enable the postponed activity to be scheduled in a second day or third day. The priority will change as the activity is delayed. The plan formation will then change dynamically as the conflicts are being resolved. The Conflict Resolver in the SCHEDULER then changes the order of the activity. By putting work after lunch it enables the scheduling of work; in this way work did not conflict with the recreation time because recreation is open after work but not vice versa). The result of scheduling is represented in Table 11a, b, c, d).

Task 6. The SCHEDULER is thus able to model the change in activities resulting from a life style change (like telecommuting in this particular case). Changes in the environment, or priority, duration, etc. can also be incorporated. For example, if the household member after telecommuting starts, allocates a higher priority to recreation and a lower one to work, the initial scheduling attempt (with recreation after lunch) may become feasible. If alternative destinations for specific activities develop, they can be added to the environment.

Summary and Future Tasks

GIS are able to display the individual or aggregate data of the environment in tables, graphs, or over a map. A combination of the various presentation media is also feasible. For example, color or bar charts can be used to show the individual's schedule of activities and the respective locations at which they take place. In terms of aggregate levels, the traffic flow of each link, the flow to each region by a trip purpose, etc., can be shown by using a map with different network elements.

As a result of changes in episodic movement, one can develop projections of traffic density and volumes on particular road segments in both the main traffic corridors and in local areas. This information should also prove useful for local government decision makers and landuse planners who may be required to estimate changing needs for different types of urban functions in local communities as a result of these changed behavior patterns.

a) System Tasks

In order to overlay an activity scheduling module (e.g., SCHEDULER) on a GIS of a particular environment, the first task is to create point coverage for all possible origins and destinations. This involves geocoding specific landuse systems as well as ensuring they are compatible with the geocoding system used in, say, the TIGER files for the underlying network structure. Once this point coverage is obtained, it may be possible to analyze destination choice by a single household on either single purpose or multiple purpose trips or single stop or multiple stop trips. Comparisons could then be made with a simple gravity type model (or discrete choice model). If individual households are aggregated into traffic zones, then it may be feasible to use a standard entropy model (Wilson, 1970) as a comparison.

b) Using Network Models

To date GIS appear to have limited capabilities to support the kind of network analysis and flow intensity analysis required in much transportation planning. One significant problem for further research consists of being able to handle the pseudo nodes for the development of spatial information in three-dimensional space. A second major problem involves developing an ability to handle matrix information and to perform linear algebraic operations. There will be an ongoing need to integrate GIS with other forms of transport modelling activities such as discrete choice modelling or highly disaggregate activity based modelling. This would involve more flexible data models and developing an ability to convert data structures among different forms.

c) Expanding the network properties

Given this broader set of needs, a GIS data base with a wide variety of information and network elements is highly desirable. The question of how much network analysis capability is "fundamental" immediately arises. It also raises the question of what additional needs can be supplied by other programs or algorithms and how easy these will be to interface with the fundamental GIS.

Yet another task for the future is to explore ways to link existing network based software (e.g., TRANSCAD and TRANPLAN) to help solve traffic assignment problems. These software packages contain a variety of path selection algorithms ranging from linear programming and travelling salesman problems to various solution algorithms that optimize connectivity or minimize some travel characteristic. Once such linkage has been developed, it would be possible to collect actual path data from diary or other longitudinal sources, and compare actual movement patterns with routes predicted to be selected between specific origin and destination pairs based on criteria such as shortest path. Actual selection of routes could then be predicted depending again on traveller preference for scheduling activities or constraints imposed on movement by the need to perform necessary or obligatory household functions.

d) Other cognitive components

More work is needed to integrate perception of the environment into GIS structures. Presently the perceived time required to travel can be represented in a cost table in most GIS. The higher the cost associated with an arc, the more friction there is for route designation including that arc. A representation closer to the cognitive map of the environment is needed for constructing the simulated environment.

Apart from transforming physical into cognitive reality for each household, other components such as activity preferences and priorities, criteria for selecting feasible alternatives, and weighing of activities by length of cycle need to be addressed. This latter feature is important to ensure that necessary activities (e.g., biweekly shopping) *are* carried out in a timely manner, by increasing the priority as the temporal window of opportunity contracts. We have not as yet examined this problem.

Little has been done to incorporate the temporal aspects into GIS. How to extend the temporal aspect in a GIS and make the retrieval, analysis, and display of temporal data more effective for the scheduler still remains an important area for future research.

Obviously, this paper is more of a progress report than a finished piece of research. We have tried to illustrate the principles behind our CPM and to illustrate how it works. The process of extending the model to interface with existing activity based travel models (e.g., STARCHILD) remains a major task, for this will address the problem of aggregating households into a predictive, explanatory, and policy device.

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Table 1

Sources of Information about Grocery Stores

(Goleta)

Source	SmithsCR	VonsTP	Safeway	SmithsUV	Smth/MG	VonsLC	Smiths5P	IVMkt
Radio	—	0.5	—	—	—	—	—	—
Rdo,Psby	0.5	1.1	1.1	0.5	0.5	0.5	0.5	—
Rdo,Ns,Psby	—	2.7	1.6	—	—	0.5	—	—
Rdo,Fd,Psby	—	—	—	0.5	—	—	—	—
Rd,Ns,Fd,Pb	—	—	—	0.5	—	0.5	—	—
Newspaper	4.3	6.5	4.8	5.4	3.8	4.8	2.7	1.1
Nwsp/Psby	8.1	8.1	9.1	5.9	7.5	6.5	5.9	2.7
Nwsp/Fr	0.5	2.2	1.1	—	0.5	0.5	0.5	0.5
Nws/Fd/Psby	1.1	0.5	0.5	0.5	—	0.5	—	3.8
Friend	7.5	12.4	9.7	21.0	5.4	4.3	2.2	5.9
Fr/Psby	6.5	7.0	8.1	11.3	2.7	3.8	0.5	8.6
Pass By	59.1	42.5	53.8	40.3	52.2	61.8	59.1	44.1
Don'tKnow	9.1	12.9	8.1	11.8	24.7	15.1	27.4	30.6
Other	3.2	3.2	2.2	2.2	2.2	1.1	1.1	2.7

Table 2

Computational Process Models

Modelling foci	Model
Information acquisition and representation	TOUR (Kuipers 1978) NAVIGATOR (Gopal et al. 1989; Gopal & Smith 1989) TRAVELLER (Leiser & Zilberschatz 1989) ELMER (McCalla et al. 1982)
Interrelated activity/travel decisions	CARLA (Jones et al. 1983) STARCHILD (Recker et al. 1986a, 1986b) Lundberg (1988) Hayes-Roth & Hayes-Roth (1979)
Navigation route choice	TOUR (Kuipers 1978) NAVIGATOR (Gopal et al. 1989; Gopal & Smith 1989) TRAVELLER (Leiser & Zilberschatz) ELMER (McCalla et al. 1982)

Fig. 1

Schema of SHEDULER

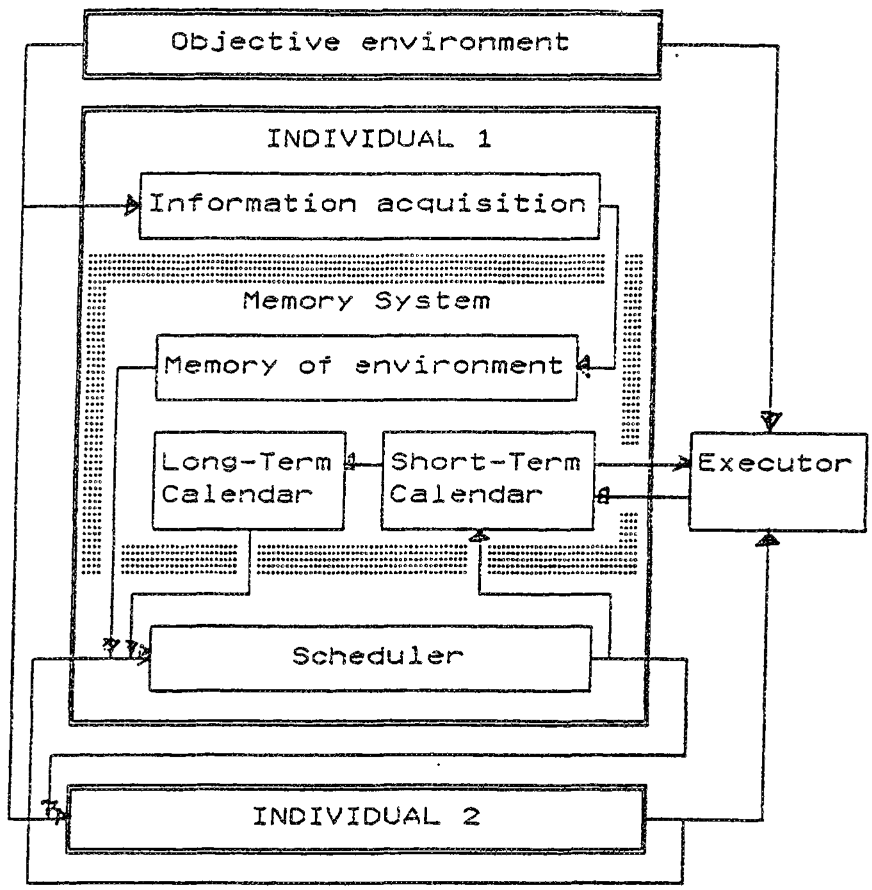

Fig. 2
SCHEDULER and GIS

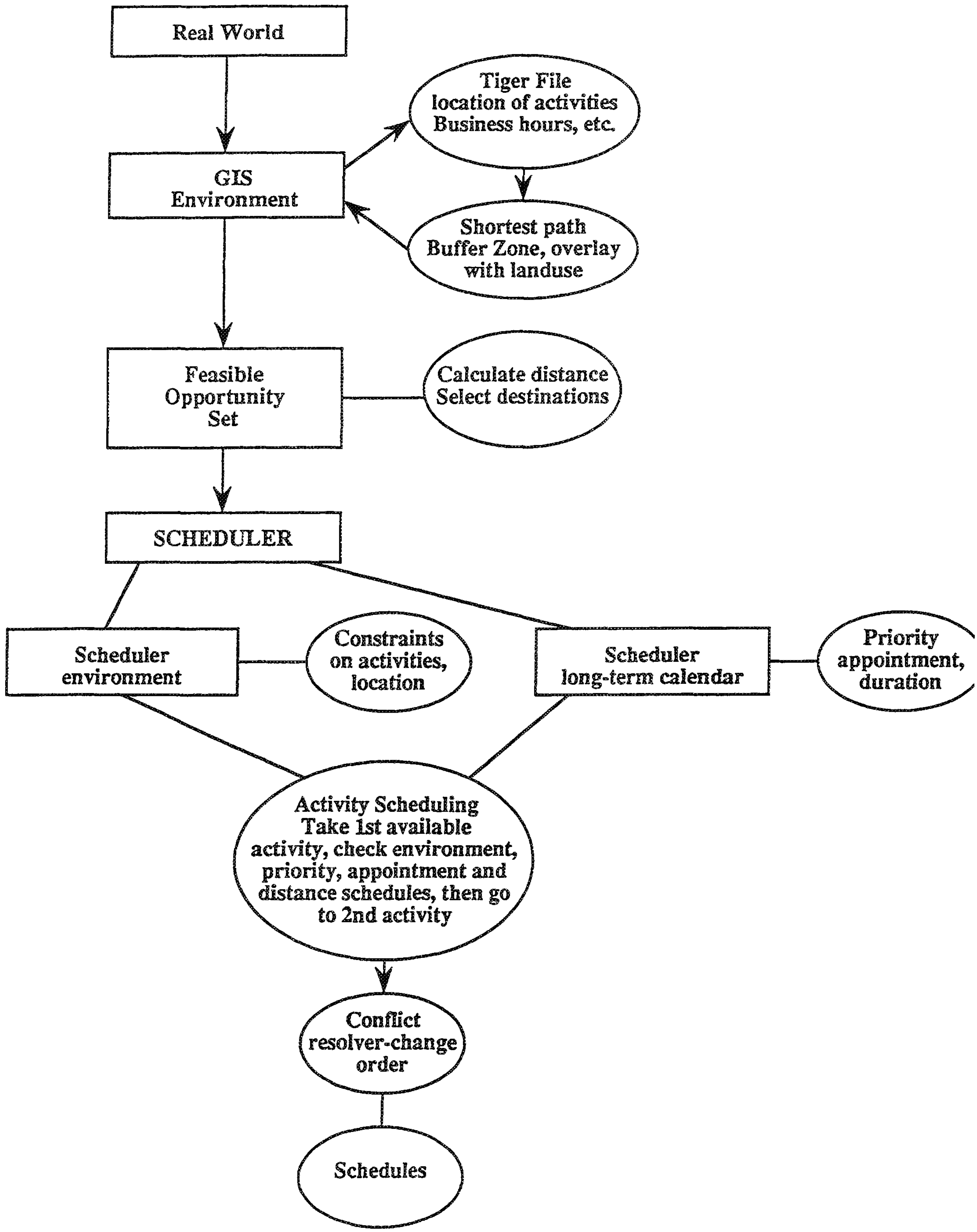

Table 3

Total Trip Making: Telecommuters

	Total trip-making	Work Trip	Non-Work Trip
Wave I	806	254	552
Wave II	543	119	424
Reduction %	-32.6%	-53.1%	-23.2%

Table 4

Trip Making: Control

	Total trip-making	Work Trip	Non-Work Trip
Wave I	541	187	354
Wave II	473	144	329
Reduction %	-12.6%	-22.9%	-0.07%

Table 5

Central City Trips

	Telecommuters (Downtown traffic)	Control Group (Downtown traffic)
Wave I	170	90
Wave II	94	91
Reduction %	-45%	+0.11%

Fig. 3

Non-Work Trips Pre-Telecommuting

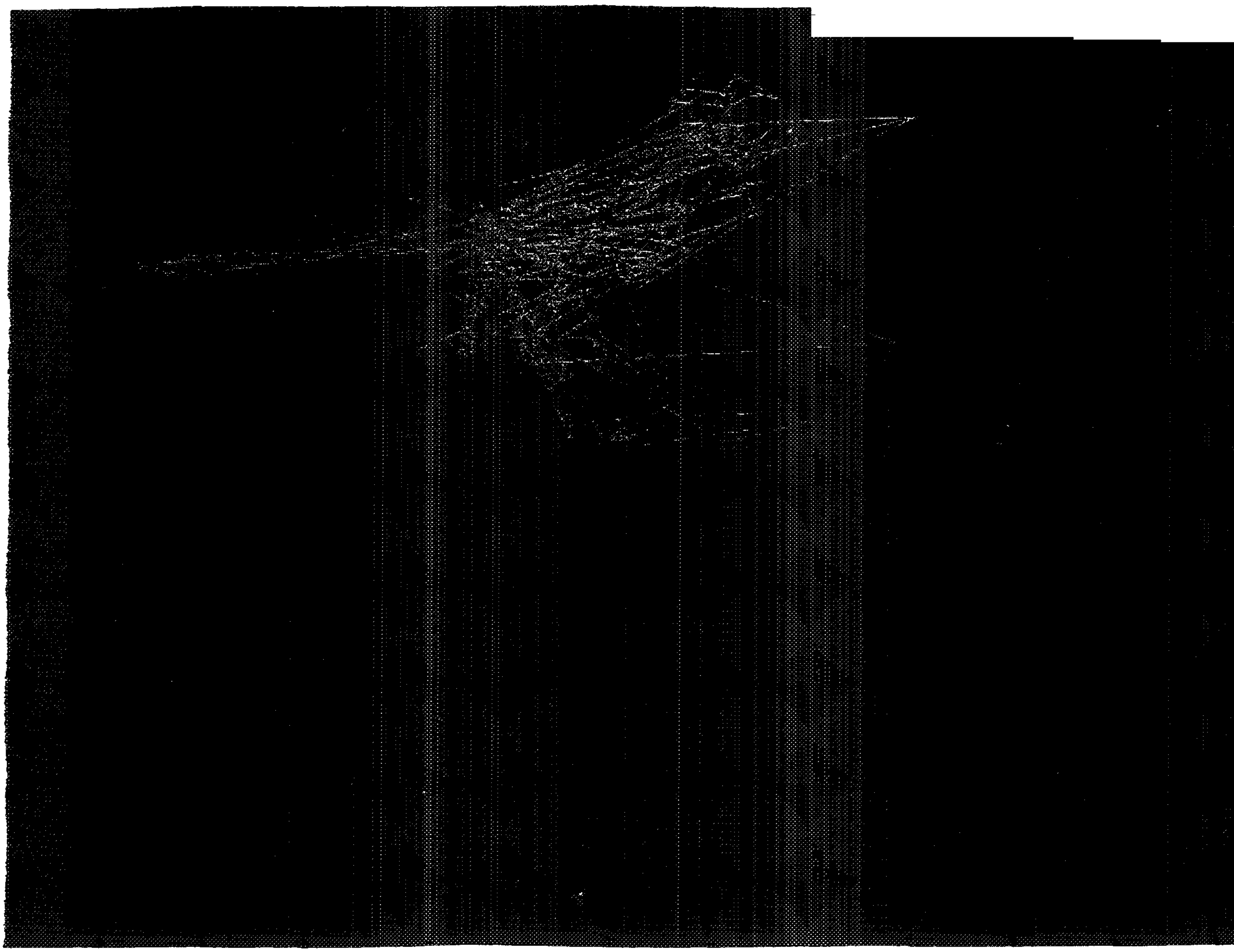

Fig. 4

Non-Work Trips Post-Telecommuting

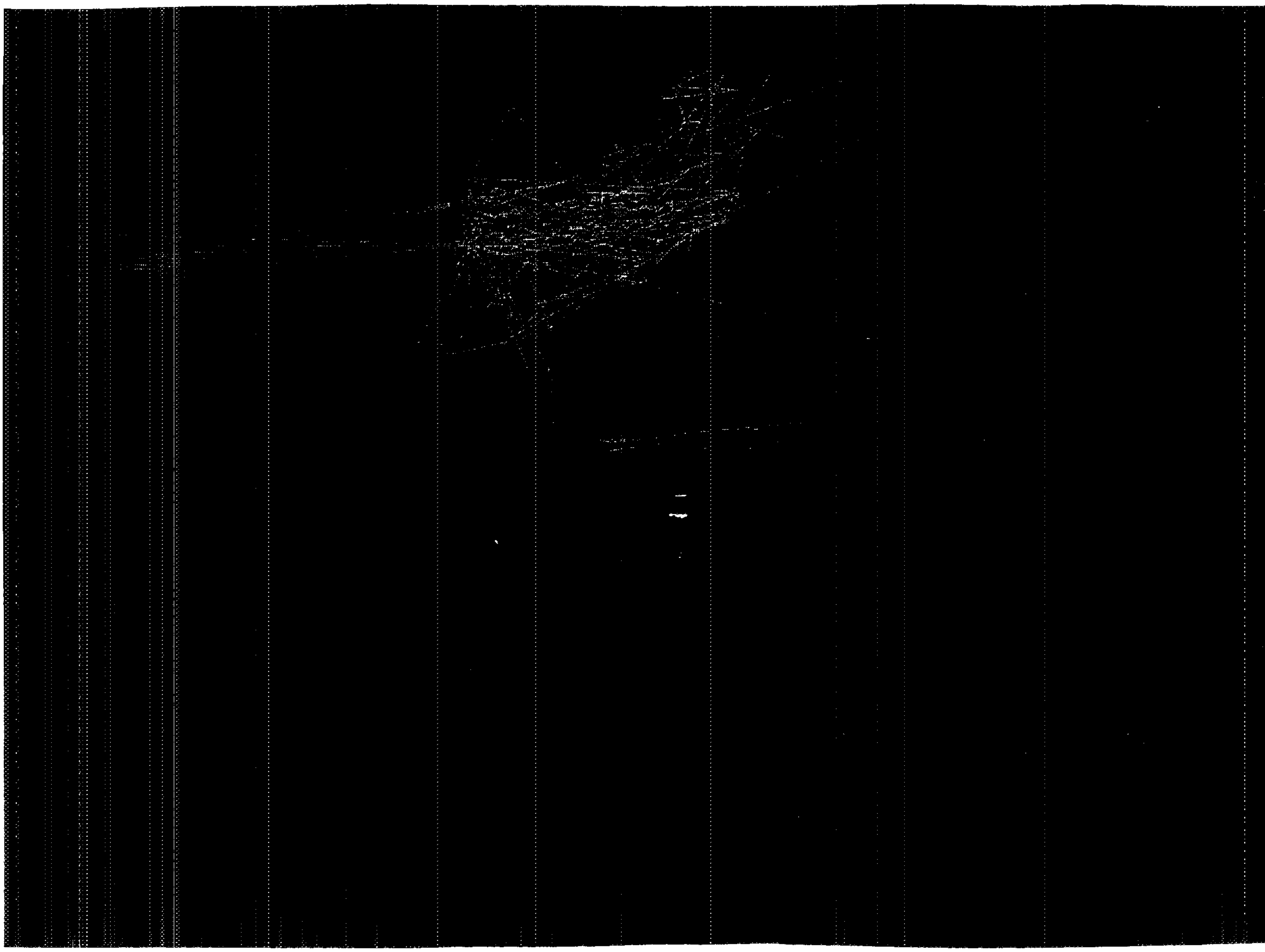

Table 6

Person 1: Trip Profile

	Before Telecommuting			
Date	Time	Purpose	Duration (Mins.)	Fwy % usage
	8:30- 8:30	3	20	0
3	12:45-12:57	11	12	0
	13:22-13:34	3	12	0
	8:13- 8:22	11	9	0
	8:25- 8:36	3	11	0
	11:45-11:53	11	8	0
4	12:28-12:36	3	8	0
	18:26-18:46	2	20	0
	20:10-20:58	10	48	95
	23:15-23:55	2	40	95
	8:10- 8:22	11	12	0
	8:28- 8:37	3	9	0
5	11:50-12:10	11	20	90
	13:12-13:30	3	18	90
	18:30-19:20	10	50	80
	19:45-20:25	2	40	95

Total travel minutes: 337

	After Telecommuting			
Date	Time	Purpose	Duration (Mins.)	Fwy % usage
	8:12- 8:28	8	16	0
	8:31- 9:00	3	29	0
3	15:45-16:05	6	20	0
	16:15-16:45	8	30	0
	18:05-18:33	10	27	0
	21:15-12:35	2	20	0
	7:45- 8:06	3	21	0
4	17:30-17:53	2	23	0
	20:05-20:51	10	46	60
	23:10-23:55	2	45	60
	8:10- 8:24	8	14	0
5	8:25- 8:42	2	17	0

Total travel minutes: 308

8.6% saving on time

Table 7

Person 2: Trip Profile

	BEFORE TELECOMMUTING			
Date	Time	Purpose	Duration (Mins.)	Fwy % usage
3	8:10- 8:20	8	10	0
	8:20- 8:23	5	3	0
	8:23- 8:35	5	12	75
	12:30-12:35	10	5	0
	13:00-13:10	7	10	0
	13:30-13:40	11	10	0
	14:05-14:10	10	5	0
	14:45-14:48	10	3	0
	16:30-16:34	2	4	0
4	8:12- 8:20	8	8	0
	8:23- 8:36	5	13	75
	12:35-12:50	2	15	0
5	8:10- 8:16	8	6	0
	8:17- 8:22	5	3	0
	8:23- 8:35	5	12	75
	12:32-12:48	5	16	80
	12:59-13:03	2	4	0
	19:15-19:22	10	7	0
	23:10-23:17	2	7	0

Total travel minutes: 153

	AFTER TELECOMMUTING			
Date	Time	Purpose	Duration (Mins.)	Fwy % usage
3	8:40- 8:44	9	4	0
	8:46- 9:08	5	22	0
	15:40-16:01	9	21	0
	17:43-17:59	3	16	0
	21:37-21:55	2	18	0
4	8:48- 8:52	9	4	0
	8:53- 9:15	5	22	0
	15:40-15:50	3	10	0
	21:38-21:53	2	15	0
5	8:45- 9:05	5	20	0
	15:38-15:42	11	4	0
	15:47-16:08	2	21	0
	17:42-17:46	3	18	0
	22:16-22:20	10	4	0
	23:10-23:17	2	7	0

Total travel minutes: 206

Fig. 5

TIGER File: Sacramento

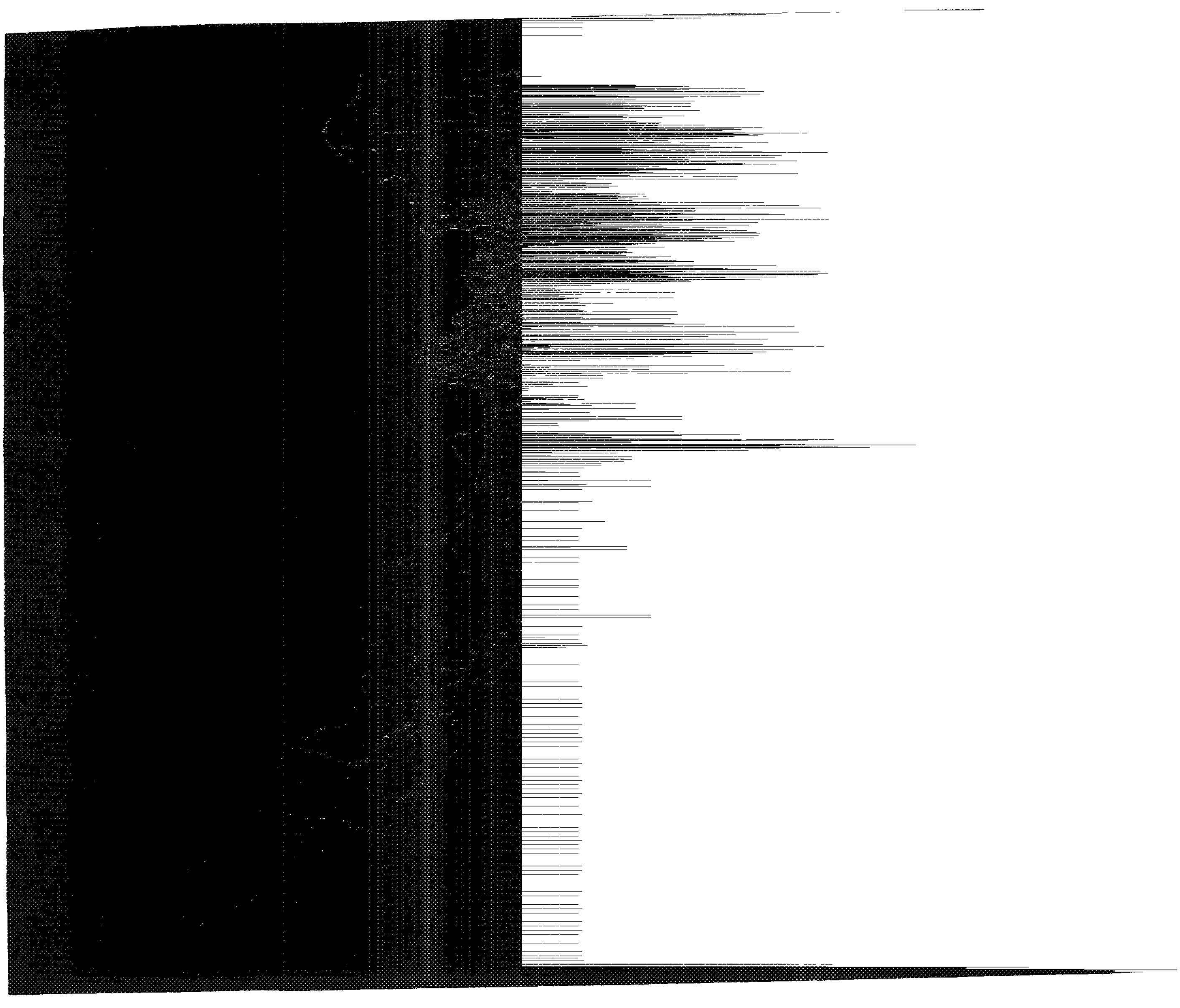

Fig. 6a

Point Coverage of Household Origins and Activity Destinations:

Origins for Telecommuter (Wave 1)

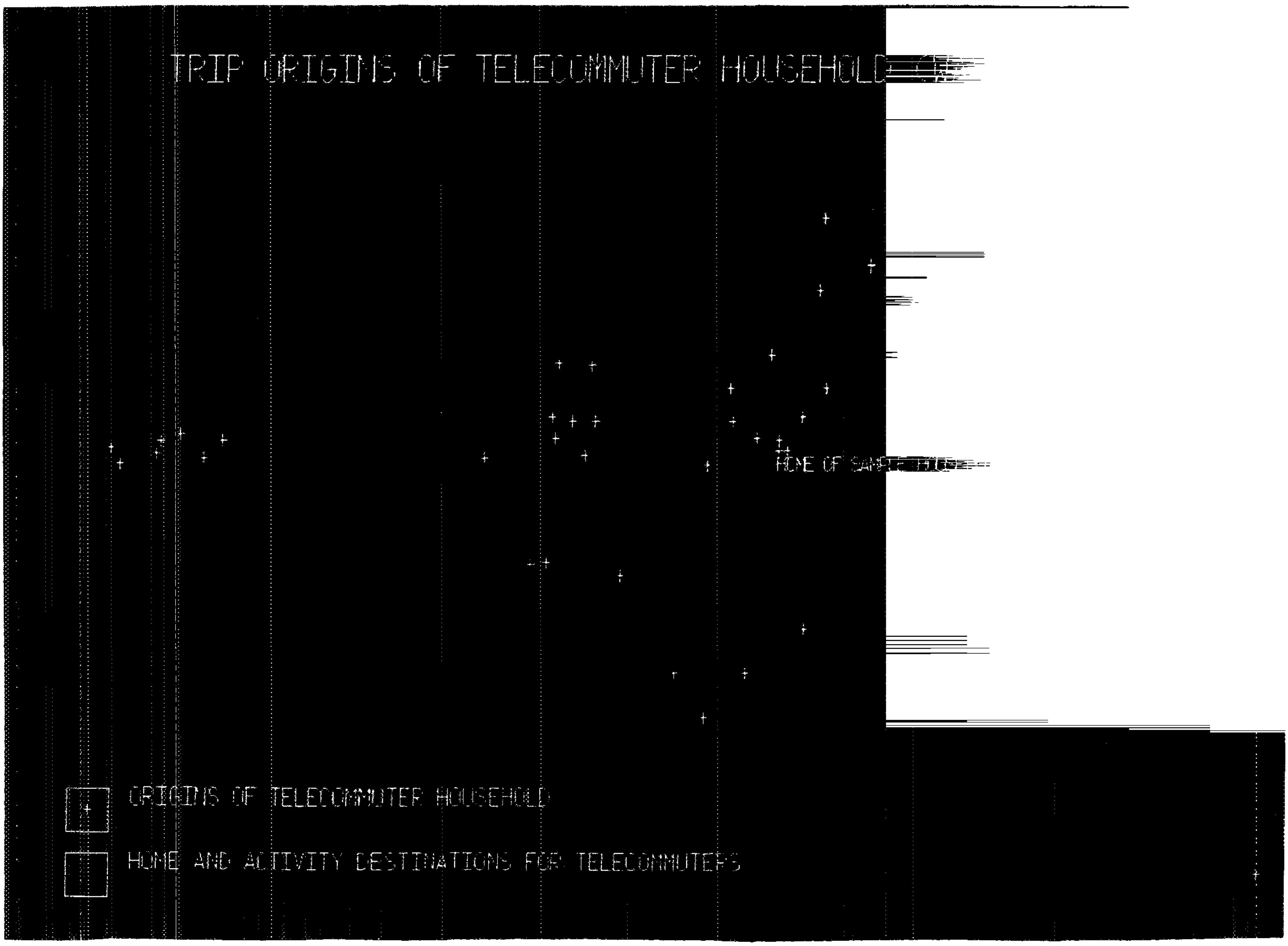

Fig. 6b

Point Coverage of Household Origins and Activity Destinations:

Origins for Telecommuter (Wave 2)

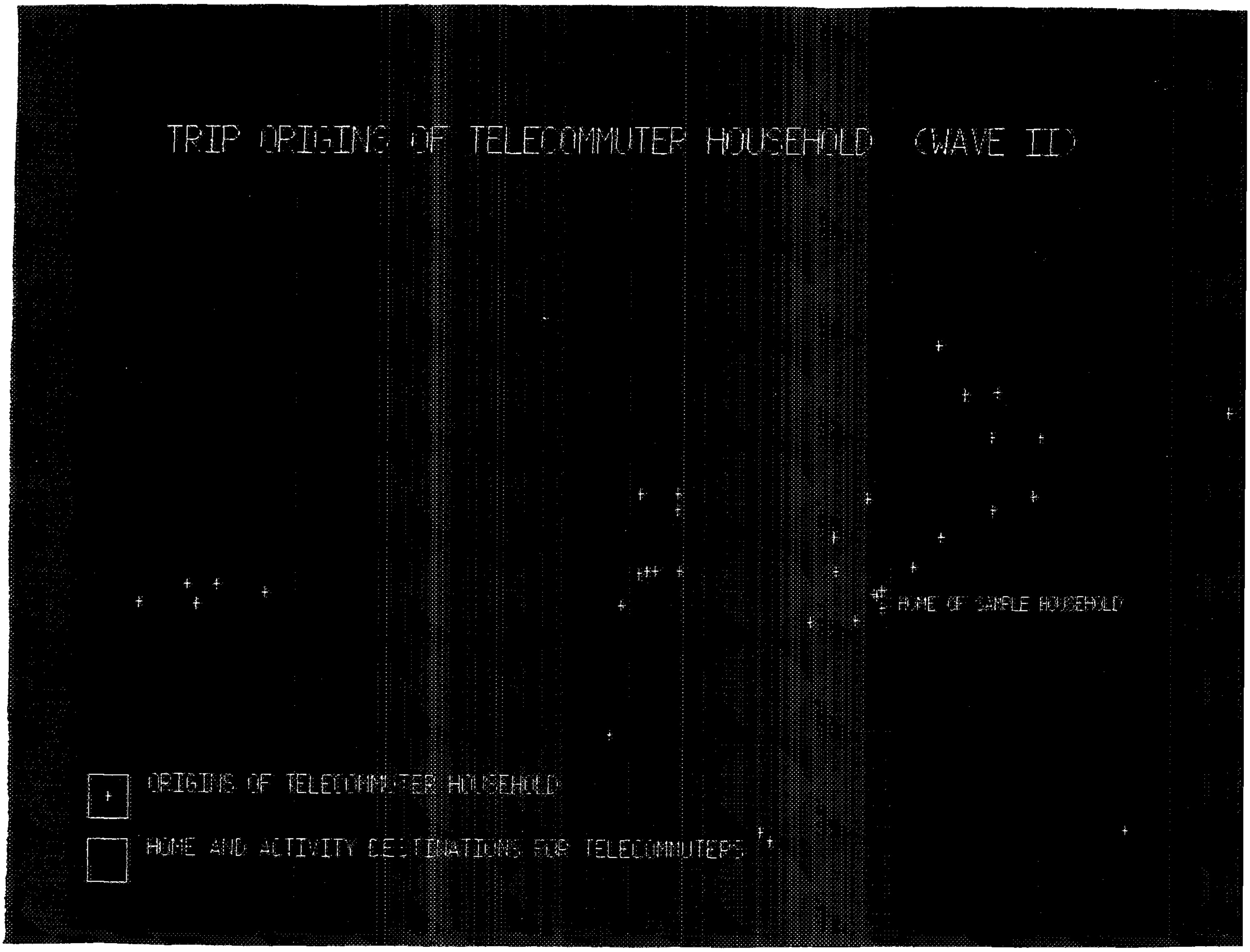

Table 8a

Environment for Telecommuter Before Telecommuting

Activity	x	y	From	To
Recreation	3	3	13.00	24.00
Meal	2	1	8.22	10.00
Work	2	0	8.30	12.00
Meal	1	1	11.00	13.50
Work	2	0	13.00	19.00
Return	0	0	19.00	24.00

Table 8b

Environment for Telecommuter After Telecommuting

Activity	x	y	From	To
Transport child	2	0	8.24	9.00
Return	0	0	8.25	24.00

Table 8c

Environment for Other Member Before Telecommuting

Activity	x	y	From	To
Transport child	1	0	8.15	9.00
School related	1	0	8.16	9.00
School related	1	1	8.20	13.30
School related	1	0	12.00	12.55
Return	0	0	12.00	22.00
Recreation	1	0	19.00	24.00
Return	0	0	23.00	24.00

Table 8d

Environment for Other Member After Telecommuting

Activity	x	y	From	To
Recreation	1	0	18.00	24.00
School related	2	2	9.00	16.00
Meal	2	1	11.00	18.00
Return	0	0	15.00	18.00
Return	0	0	23.00	24.00
Work	1	1	17.30	23.00

Fig. 7

Shortest Path Route

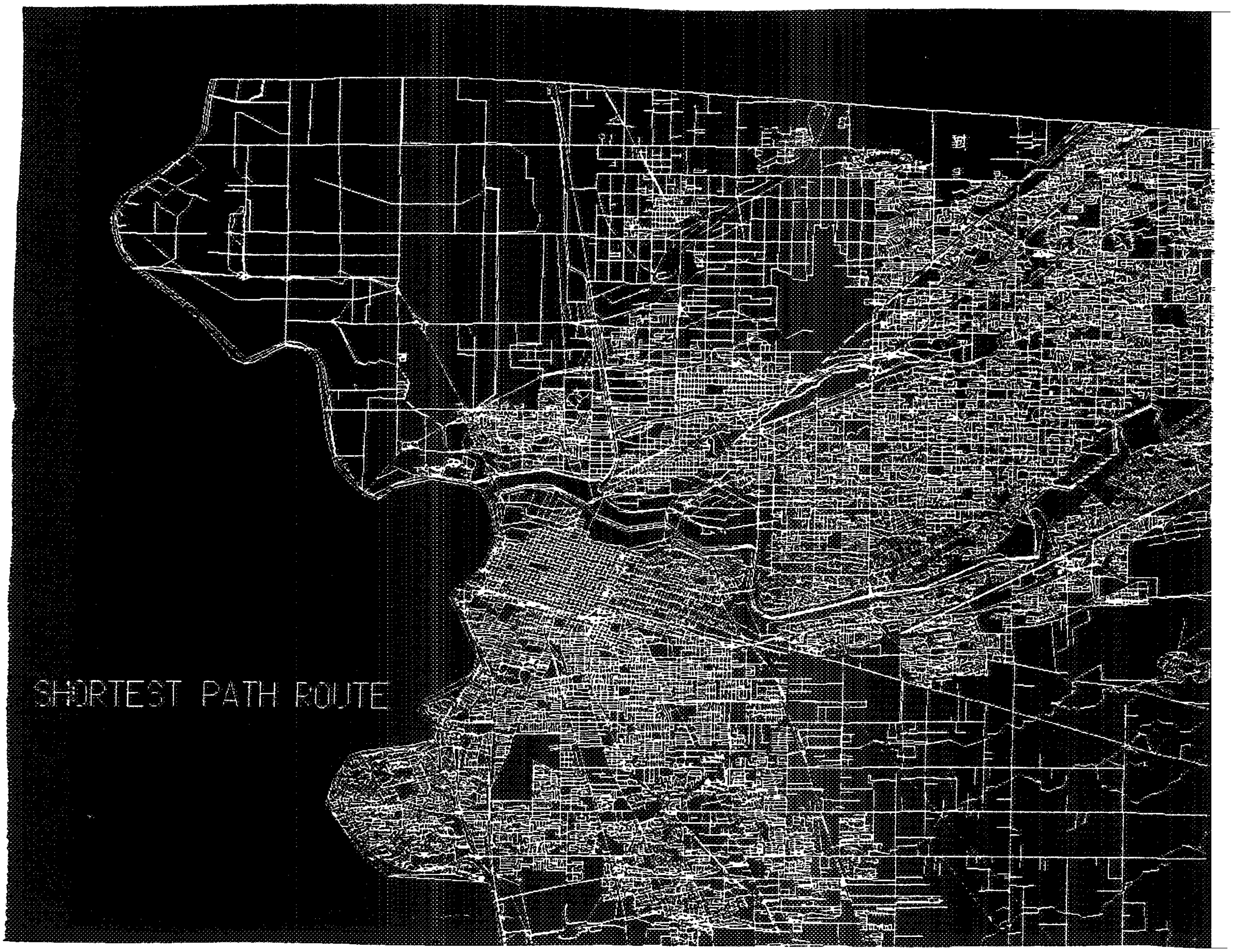

Fig. 8

Buffer Zones Around Shortest Path

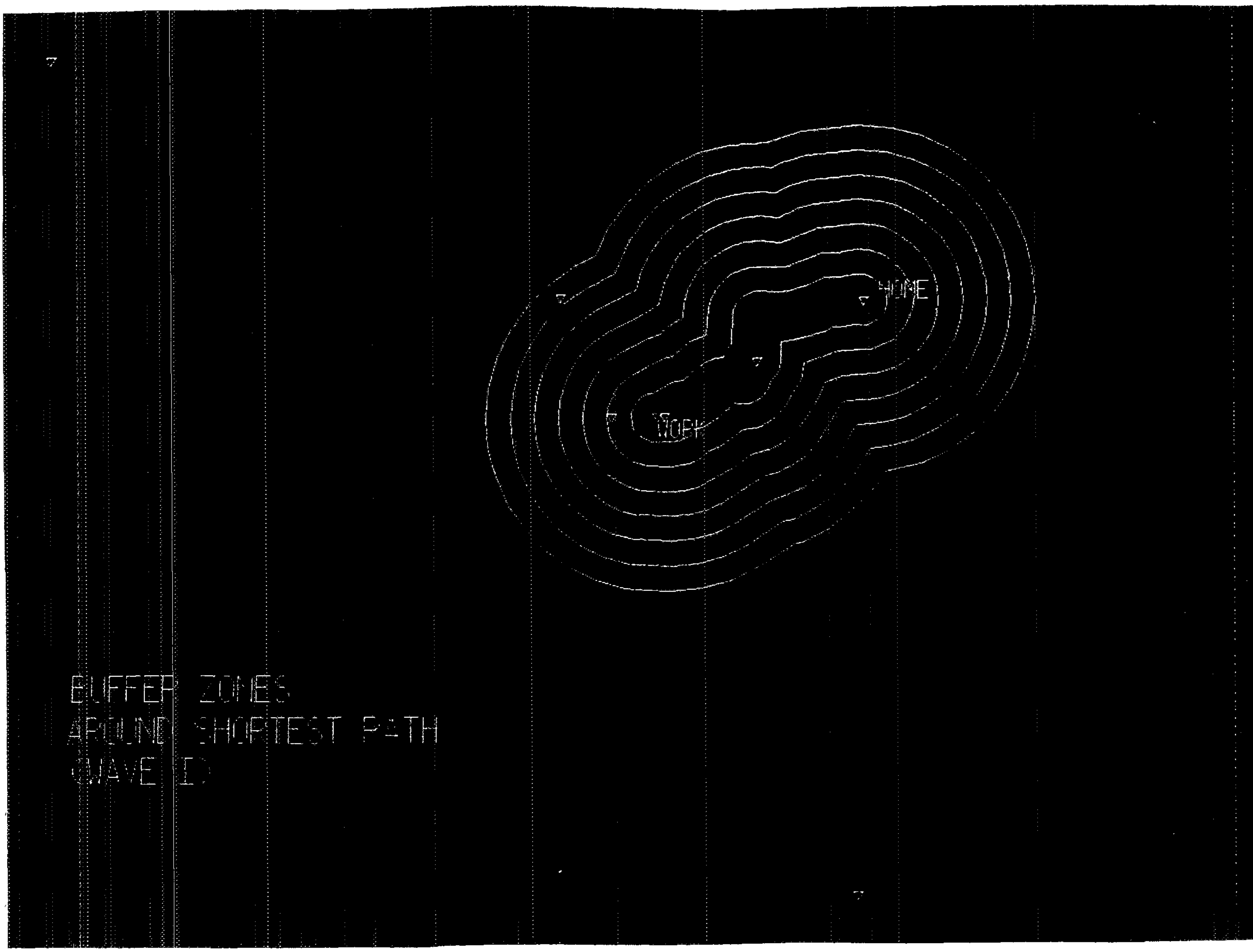

Fig. 9

Five Mile Buffer Zones Around Home

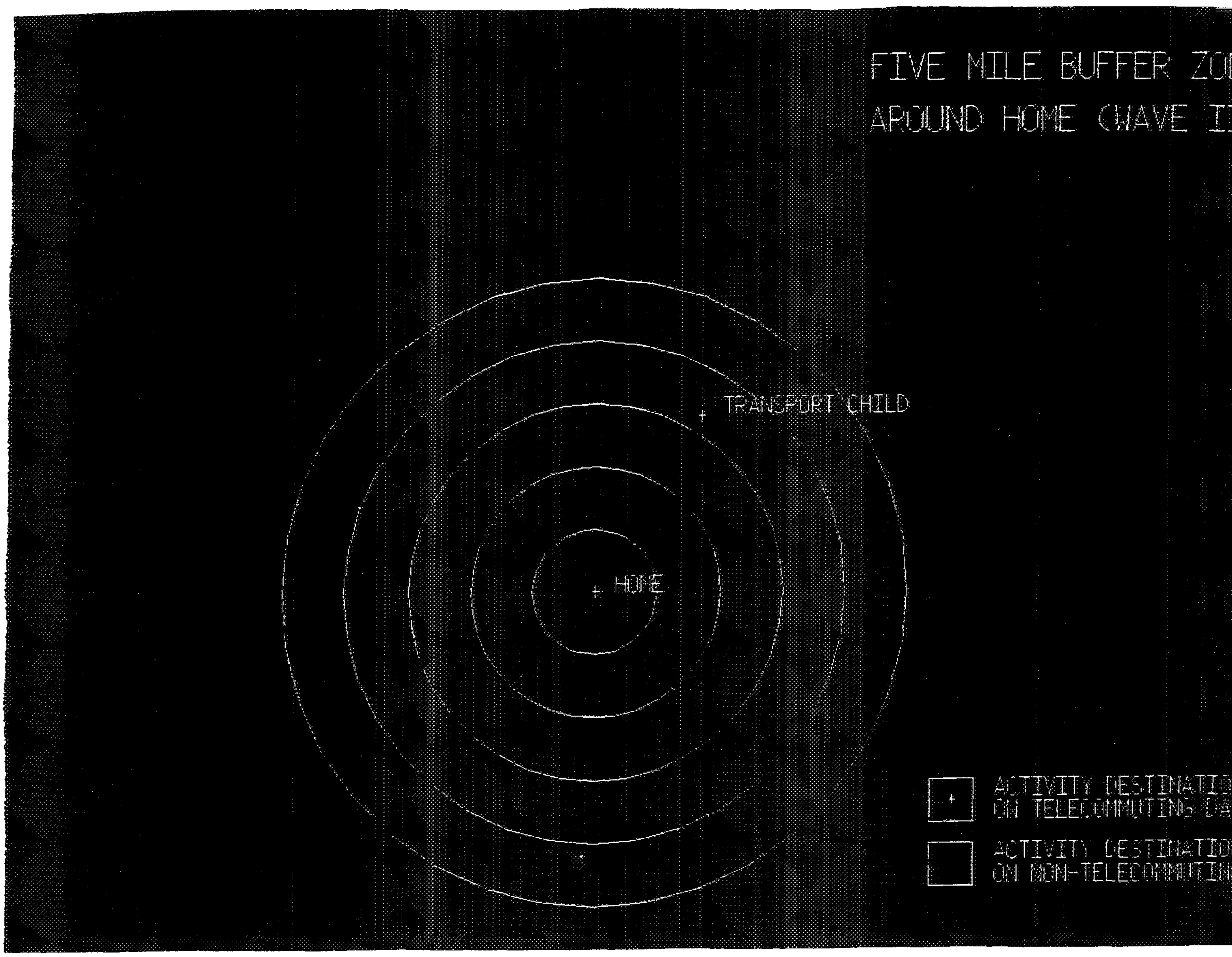

Table 9a

Long Term Calendar - Telecommuter Before Telecommuting

Activity	pr	ap	dur
Meal	2	0	0.10
Work	2	0	3.00
Meal	2	0	1.00
Work	2	0	5.00
Recreation	1	0	0.50
Return	2	0	3.08

Table 9b

Long Term Calendar - Telecommuter After Telecommuting

Activity	pr	ap	dur
Transport child	1	0	0.01
Return	1	0	15.15

Table 9c

Long Term Calendar - Other Member Before Telecommuting

Activity	pr	ap	dur
Transport child	2	0	0.03
School related	2	0	0.01
School related	2	0	4.00
School related	2	0	0.10
Return	2	0	6.00
Recreation	1	0	3.50
Return	2	0	0.51

Table 9d

Long Term Calendar - Other Member After Telecommuting

Activity	pr	ap	dur
School related	2	0	6.00
Meal	1	0	0.05
Return	2	0	1.30
Work	2	0	4.30
Recreation	1	0	0.50
Return	2	0	0.45

Table 10

Initial Results of Scheduling Before Telecommuting

For Telecommuter

Idle	Activity	pr	ap	x	y	WalkT	dur	start	stop
0.52	Meal	2	0	2	1	0.30	0.10	8.22	8.32
0.00	Work	2	0	2	0	0.10	3.00	8.42	11.42
0.00	Meal	2	0	1	1	0.20	1.00	12.02	13.02
0.00	Recreation	1	0	3	3	0.40	0.50	13.42	14.32
3.28	Return	2	0	0	0	1.00	3.08	19.00	22.08

Table 11a

Scheduling After Conflict Resolution Before Telecommuting

For Telecommuter

Idle	Activity	pr	ap	x	y	WalkT	dur	start	stop
0.52	Meal	2	0	2	1	0.30	0.10	8.22	8.32
0.00	Work	2	0	2	0	0.10	3.00	8.42	11.42
0.00	Meal	2	0	1	1	0.20	1.00	12.02	13.02
0.00	Work	2	0	2	0	0.20	5.00	13.22	18.22
0.00	Recreation	1	0	3	3	0.40	0.50	19.02	19.52
0.00	Return	2	0	0	0	1.00	3.08	20.52	24.00

Table 11b

Scheduling After Conflict Resolution After Telecommuting

For Telecommuter

Idle	Activity	pr	ap	x	y	WalkT	dur	start	stop
1.04	Transport	1	0	2	0	0.20	0.01	8.24	8.25
0.00	Return	1	0	0	0	0.20	15.15	8.45	24.00

Table 11c

Scheduling After Conflict Resolution

Other Member Before Telecommuting

Idle	Activity	pr	ap	x	y	WalkT	dur	start	stop
1.05	Transport	2	0	1	0	0.10	0.03	8.15	8.18
0.00	School	2	0	1	0	0.00	0.01	8.18	8.19
0.00	School	2	0	1	1	0.10	4.00	8.29	12.29
0.00	School	2	0	1	0	0.10	0.10	12.39	12.49
0.00	Return	2	0	0	0	0.10	6.00	12.59	18.59
0.00	Recreation	1	0	1	0	0.10	3.50	19.09	22.59
0.00	Return	2	0	0	0	0.10	0.51	23.09	24.00

Table 11d

Scheduling After Conflict Resolution

Other Member After Telecommuting

Idle	Activity	pr	ap	x	y	WalkT	dur	start	stop
1.20	School related	2	0	2	2	0.40	6.00	9.00	15.00
0.00	Meal	1	0	2	1	0.10	0.05	15.10	15.15
0.00	Return	2	0	0	0	0.30	1.30	15.45	17.15
0.00	Work	2	0	1	1	0.20	4.30	17.35	20.05
0.00	Recreation	1	0	1	0	0.10	0.50	22.15	23.05
0.30	Return	2	0	0	0	0.10	0.45	23.15	24.00