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Authors
Kwan, Mei-Po
Golledge, Reginald

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Mei-Po Kwan
Reginald Golledge

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University of California Transportation Center

108 Naval Architecture Building
Berkeley, California 94720
Tel: 510/643-7378
FAX: 510/643-5456

Integration of GIS with Activity-Based Model in ATIS

Mei-Po Kwan

Department of Geography
The Ohio State University
Columbus, OH 43210

Reginald Golledge

Department of Geography
University of California at Santa Barbara
Santa Barbara, CA 93106

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Please address all correspondence to the first author.

1. Introduction

Intelligent Vehicle Highway Systems (IVHS), which aim at the utilization of advanced information processing and communication technologies for improving travel efficiency and safety, have become an important policy measure in recent years. One of their major components, Advanced Traveler Information Systems (ATIS), has been developed specifically to assist drivers in trip planning and decision making on destination selection, departure time, route choices and congestion avoidance.

Conventional transportation models such as the Urban Transportation Planning Systems (UTPS) often assume the individual has perfect information on the costs of travel and all activity locations in the environment. ATIS challenges these assumptions and emphasizes the provision of information to travelers, recognizing that they have imperfect and incomplete information about the environment. As a result of this new focus, it becomes imperative to understand and model how an individual interacts with the environment and makes travel choices in the presence of real-time information. In order to meet these requirements of ATIS, alternate models that are capable of handling the traveler's decision-making process and interaction with the environment need to be developed. In this paper, it is argued that the activity-based approach, which treats travel as a set of deliberate decisions made by people in order to perform certain activities, provides a useful framework for such alternative models. The view that future transportation planning based on IVHS will largely draw from alternate frameworks such as the activity-based modeling approach is also supported by some recent studies (Stopher et al. 1993, Axhausen et al. 1991; Jones et al. 1986).

Despite efforts and insights in modeling driver's response to real time information, the fact that travel is a derived demand and generated by the decision of individuals to participate in various activities is still largely absent in existing literature (Bonsall et al., 1991; Allen et al. 1991, Adler et al. 1991 and 1992; Chen and Mahmassani 1993; and Kaysi et al., 1993). When the activity-based approach is ignored in the context of ATIS, the traveler's choices in response to unexpected traffic delays are largely confined to alternative routes. Because of the lack of consideration of the activity schedule which gives rise to the trip patterns of the traveler, other alternatives such as rescheduling of activities and changing the intended destinations are not provided in these models. This paper argues that a broader perspective built upon the activity-based approach and the activity scheduling framework would allow alternatives other than re-routing to be incorporated. For instance, in response to severe congestion, the traveler has the choices of re-routing, rescheduling or changing the destination, resulting in a different travel pattern. Considering just the option of re-routing captures only part of the picture. In view of this, activity scheduling is an important component missing in current ATIS literature. This study attempts to address this issue based on the activity-based approach and through the use of GIS.

2. Activity-based Travel Models

The activity-based approach to transportation modeling has gained considerable interest since the 1970's. It recognizes the importance of studying travel behavior as a result of decisions made by an individual or household member. Dissatisfied with the trip-based transportation model which relies on zonal analysis of matrix flow, the activity-based approach views travel as a derived demand. The approach emphasizes the participation in activity that leads to travel by the individual. Travel is constrained in time and space and the decision to participate in activities is often interdependent within a particular household. Furthermore, not only interactions within a household change over time, activity and travel behavior also change over time. Both household and individual can adapt to changes in the environment.

Some researchers have attempted to operationalize the activity-based approach using computational-process models (CPMs). CPMs are simulation models that can be used to handle the behavioral dimensions of information acquisition, information representation, information processing, and decision making (Smith et al., 1982). Various attempts have been made to implement a conceptualization of travel choices in a computer program aiming at emulating how people make such choices (see Garling, Kwan and Golledge 1994 for a more extensive review). They included the NAVIGATOR (Gopal et al. 1989; Gopal and Smith 1990), CARLA (Jones et al. 1983), Hayes-Roth and Hayes-Roth's model (Hayes-Roth and Hayes-Roth, 1979), STARCHILD (Recker et al. 1986a, 1986b) and the SCHEDULER (Garling et al., 1989). As information provision in both the pre-trip and enroute stages has become an important consideration in the context of IVHS, the motivation to use CPMs is ever increasing. Although these models address behavioral questions of travel at a disaggregate level, they still face a number of limitations. The major limitation is that they are highly complex and are difficult to be implemented in the real world context. The specific and person-specific details used by the models have deterred the development of general and transferable results. The approach has also been criticized for its lack of predictive power. In addition, it is very difficult to collect the detailed data needed for evaluating these operationalized models.

To tackle some of these problems, this paper proposes an operational model for implementing activity scheduling in the context of ATIS using Geographic Information Systems (GIS) and real world data. Extending the work of Golledge et al. (1994), it examines the issues associated with using a CPM called the Scheduler 2 for supplying real-time information in ATIS. It also investigates how GIS can be integrated with this CPM and together allow for its operationization for ATIS applications. Golledge et al. (1994) and Miller (1991) have discussed the opportunity of using GIS to define spatial alternatives available for the traveler. This paper further uses different landuse criteria to represent the feasible opportunity set for a particular traveler. It develops a set of GIS procedures for taking into account the effect of distance in terms of either the Euclidean distance or network distance in a transport network.

3. Interfacing a GIS with a CPM for Activity Scheduling

Although most trips in the daily life of a person are routines, an individual occasionally makes deliberate travel choices. Discrete choice models are often applied in transportation research (see Timmermans and Golledge 1990 for a review) based on a utility-maximizing framework. As the models are largely confined to specifying what factors affect the final choice, the *process* resulting in this choice is largely left unspecified. However, how people actually make decisions is frequently questioned by researchers (Edwards, 1954; Kahneman & Tversky, 1979; Simon, 1990). It may be argued that process is unimportant if the goal is to forecast choices. But it is important to know how people make decisions so that useful and relevant information can be supplied to them especially in the context of ATIS. In the research on human decision-making, process description has been a focus of interest for a long time (Garling et al. 1994). In order to develop testable hypotheses and compare the results of alternative assumptions (e.g. sensitivity analysis for different policy measures), it is important to develop an operationalized CPM. It can be used as an alternative, or necessary complement, to discrete choice models (see Ettema et al. 1993).

The proposed CPM to be integrated with GIS in this paper is called the SCHEDULER 2 (Garling et al., 1994; Smith et al. 1982). It conceptualizes how an individual interacts with the environment and adapts to changes in the environment. It operationalizes the relationship between activity scheduling and destination choice using a person's cognitive representation of the environment. Taking a person's preference and priority into account, the model describes explicitly the process of decision-making in a dynamic environment in the form of a computer program.

As mentioned in the previous section, one salient problem of CPMs is their requirement of detailed data about the environment. Usually travel diary surveys are carried out to record individual travel patterns regarding route, mode and destination choices. However, modeling human movement in space and time at such a detailed level has been difficult, and thus is regarded as less practical for planning purposes. In this paper, a GIS is used to overcome these problems. GIS provides the geographic information about the environment needed by the model, including various network elements and locations of activities. GIS also has the functionality to handle refined and personal travel diary data. GIS operations can be used to transform the objective environment to a cognitive environment, if the rules are clear to the researcher. Since human beings are not capable of developing and comparing all the alternatives, a feasible opportunity set reflecting a person's spatial and temporal constraints can be defined. Similarly, feasible route sets can be defined in relation to activity participation. Since in the Scheduler 2 there is no capability of handling network distance, a GIS is used in this study to deal with network information.

4. Methodology

The revised SCHEDULER 2 (Garling et al. 1993) is used as the simulation model for activity scheduling in this paper. It is based on a conceptual framework of the cognitive processes involved in activity scheduling developed by Garling et al. (1989). Below I discuss the elements of Garling's framework and how GIS can be used to represent elements in the model and provide data handling capability for the SCHEDULER 2. Representation of the cognitive map and activity space of the traveler are also discussed. Problems and issues associated with this application will be examined in the conclusion.

Cognitive map

People make travel decisions based on how they remember and retrieve the information about the environment (Simon 1955, 1990). Information about the environment stored in long-term memory is called a cognitive map (Garling et al, 1984, Garling 1993). The cognitive map is acquired, maintained, and updated according to certain principles (Garling and Golledge 1989). It also contains approximate information about opening hours and aversion for location.

Location information can be stored in the GIS as the environmental information in the cognitive map. TIGER files were used as an approximation of the street network on which individuals travel. The street network is geo-referenced in latitude and longitude and therefore also give a base on which to locate trip origins and destinations when locations are known. Other information, such as land use and sociodemographic characteristics (which often come in areal units such as land use, traffic zones or census tracts) can be superimposed on the network. Business hours, attributes of origins and destinations, availability and travel speed associated with specific origins and destinations can also be stored in the GIS in the form of attribute tables associated with specific origins and destinations, or more generally for selected traffic zones or census tracts.

Long-term calendar

The long-term calendar is another long-term memory structure. It contains information of activities such as their duration and utility. Information about the utility level for different time of the day is represented in the long-term calendar. A zero utility for a particular activity at a certain hour means the performance of the activity is not allowed in that particular time.

In the conceptual framework, the model schedules a set of activities selected from the Long-term calendar. In the absence of an accurate memory representation of the environment, the network elements and attributes about the environment represented in a GIS provides as factual a physical environment as possible to work with. Buffering, allocation according to maximum distance, and overlaying operations, are then used to select environmental information to be included in the SCHEDULER's representation of the environment.

How the SCHEDULER 2 processes this information is described as follows. A set of activities with the highest priority is selected from the long-term calendar. For these activities, the information of when and where they can be performed is then retrieved from the representation of the environment. The duration is retrieved from the long-term calendar. The activities are first sequenced on the basis of the priority and temporal constraints.

ARC/INFO was selected as the GIS to operationalize the conceptual framework. As Miller (1991) points out, the data handling and network operations required are normally present in the generic procedures of ARC/INFO. For the purpose of this paper, ARC/INFO is sufficiently versatile. It has the basic set of functions required in the analysis (e.g. shortest path selection, location allocation, buffering, overlaying, estimation of centroids, etc.). An IBM RS6000 was used to perform the experiments described in this paper. However, it is recognized that implementation of the framework in the context of ATIS has to be done in a distributed and parallel computer which can process information much faster.

5. An Empirical Example

The problem posed in this section is how to define feasible opportunity sets for different activities, and how to select environmental information based on behavioral principles to be input into the SCHEDULER 2 in real cases. In particular, experiments on different methods to define feasible opportunity sets for each individual for performing various activities are made. In this study, we attempt to define the feasible opportunity using different criteria of landuse data. By defining such sets we can effectively search for nearby opportunities when the individual decides to reschedule his/her activities in space and time. In addition, defining feasible opportunities also gives us environmental information about activity locations needed to define the values of certain parameters in the model (such as location aversion and travel time).

In order to illustrate how the GIS-interfaced Scheduler works, travel diary data from a telecommuting pilot project were used. These data were collected from households before and after they volunteered to participate in a telecommuting program organized among state employees in Sacramento County, California (Kitamura et al. 1990). Data presented below are of one household selected from those participating in the telecommuting study.

6. Case Study

One driving-age household's travel diary

Before Telecommuting

The telecommuter before telecommuting performed a series of activities such as personal business, eating meal and recreation. Trip length was usually short, ranging from 1 to 2 miles besides work trips. Trip length for work is about 8 miles (Table 1).

After telecommuting

After telecommuting the telecommuter eliminated the trip for eating meal after work in the evenings. The number of trips dropped. Also, he only made a trip to pick up a passenger and a trip home on the telecommuting day. Trip lengths are reduced also, ranging from 0.5 to 1 miles besides work trips. Trip length for work is about 8 miles (Table 2).

Applying the GIS-interfaced CPM

To apply the SCHEDULER 2 interfaced with a GIS to schedule activities, either for pre-trip planning or enroute rescheduling, the following steps are developed.

1. Representation of the Cognitive Map

A realistic environment consisting of possible origins, destinations, routes and census tracts were constructed from the TIGER file of Sacramento County. For the individual household, home and work places between which the travel took place were geo-coded. The link between the two locations was defined in the network using the shortest path algorithm in ARC/INFO.

2. Formation of Activity space

In order to define a set of feasible locations provided for the individuals to choose from (i.e., for pre-trip planner and enroute traveler who is faced with severe congestion) a feasible opportunity set is developed using GIS operations.

We needed to define the activity space, i.e. where the movement space of an individual was. The feasible opportunities are assumed to locate within this space. The BUFFER operation in GIS is particularly useful because it represents the space the individual can reach within a certain distance (or travel time). We used travel distance in this study. Three different experiments were used for the definition of feasible opportunity set. The first experiment was to buffer by the Euclidean distance from a home and work location. The second one was to buffer by the network distance from a home and work location. The third one was to buffer both from home and work location and overlay with the buffer for the home to work link.

In ARC/INFO GIS, we use travel distance contained in the travel diary, both via Euclidean and network distance. For the first experiment, as suggested in Golledge et al. (1994), BUFFER operations are used to find zones that are within a certain distance from home and work locations. For the second experiment, the ALLOCATE operation in ARC/INFO is used to branch out and find all the routes that are allocated out from both home and work locations by a certain network distance. The third experiment is by buffering the home, and work location, and by buffering the home-work link. These buffers should be overlaid together to form an activity space for the individual.

In order to find out the appropriate distance for defining the activity space, the mean distance for each trip purpose is then used. For this particular case, trips with purpose of meal, recreation, and personal business need to be modeled. Due to the high standard deviation associated with their means, trip length over the mean plus one standard deviation are excluded. The resulting mean values are used for estimating the travel distance for home and work location (able 3). The buffer for the home and work link is 1/3 of the mean since people do not divert their route from home to work link the same distance as from home and work. In this case, we buffer 8 miles from both home and work location using Euclidean and network distance for recreation landuse (see Figure 1) and 6 miles for commercial landuse (see Figure 2). In this case, the buffer resulted from the third method is included in the one resulted from method 1 since the former lies within the latter buffer.

3. Formation of Choice Set

Define feasible destinations for different types of activities. This was done in ARC/INFO by matching and aggregating land use zones into census tracts. Land use attribute tables for each census tracts were developed and matched for each census tract in the TIGER file. Since the data consist of the percentage of each type of landuse in each tract, there is a need to select the level of percentage to be deemed as a feasible location. Usually a landuse component larger than 10% is used. However, in the case of a more dense pattern, higher percentage should be used. For a more dispersed pattern, a lower percentage should be used. Commercial landuse is more densely distributed, and both a 5% and a 10% were used as criteria for the experiments. For recreation landuse, a 1% and 5% landuse criteria were selected for the experiments due to the scatter distribution. Example of commercial landuse over 10% is shown in Figure 3.

4. Formation of feasible opportunity set

Select feasible locations to be included in the opportunity set for each activities. This is done by overlaying the defined activity space with each census tract that contained the landuse up to the criterion level. In this case, four different combinations are used, i.e. 1% recreation, 5% commercial, 1% recreation 10% commercial, 5% recreation and 5% commercial, and 5% recreation and 10% commercial. Since we cannot define the exact location of each type of activity in the census tract, the centroid of the census tract (calculated by using the LABEL and TRANSFORM functions of ARC/INFO) was used to indicate possible destinations. Each destination is differentiated by the centroid of a census tract. After being overlaid by the activity space, the centroids that locate within the space will be selected as feasible locations.

5. Transforming the GIS environment to individual's activity space

Transform the feasible locations and the home and work locations into the X, Y coordinates in the SCHEDULER 2. This is done by imposing a grid on the points and matching points to the nearest node. A 3 by 4 grid is created using the boundary file of the activity space since the program will take up to 15 locations, which is realistic for what travelers would consider. It is essential to maintain the same length for each unit in the X, Y coordinates because they are used to calculate the travel speed.

6. Parameters estimation

Estimate the parameters for the SCHEDULER 2. First of all, *travel time* is estimated by the following:

$$\Sigma di/\Sigma t$$

where di is the distance in miles traveled as reported by the travel diary
t is the travel time in hours reported by the travel diary

Second, *location aversion* is the factor about which we have little information. Each location is represented as a node in the study area. It is assumed that the more feasible locations that matched on a node, the less aversive the node is. Aversion is ranked as from 1 to 9, 9 being the most aversive value. Since the commercial locations are for evaluating both personal business and meal trips, they are counted twice. The nodes with the largest number of locations are ranked in ascending order. The node with no location matched is ranked as the lowest value, i.e. 9. Below are the tables for the locations using varying landuse percentage criteria for both network and Euclidean distance.

7. Formation of the Long-term Calendar

There are two elements in the long-term calendar, namely, activity duration and utility associated with each activity. The actual activity duration obtained from the travel diary is used in the absence of a decision rule to obtain the data. Utility for each activity at each hour is inferred from the travel diary based on whether they are discretionary or obligatory activities. The former will be given a lower priority than the latter. The long-term calendars before and after telecommuting are listed as follows.

Having prepared the input for the cognitive map, the long-term calendar and the parameters, the activity scheduling took place using the SCHEDULER 2. Tables 10 and

11 show the different outcomes on various simulations. As compared to the travel diary presented in Table 1, there are the following similarities and differences.

Results of the simulation

Criterion 1

Before telecommuting (1% recreation, 5% commercial landuse criteria). Varying the weight for parameters such as location aversion and travel time results in the same schedule as presented in Table 10. The model schedules the same sequence of the activities. The destination for meal and recreation coincided with the actual location. However, the estimated destination for personal business is the same as the home location, instead of the actual location. It is because the SCHEDULER 2 attempts to minimize location aversion and/or travel time. The home location is the closest to the previous and next activities. The location aversion is also the lowest.

There is no difference between the results from buffering using the network distance and buffering using Euclidean distance. The main reason is that the activity space of the individual is located in a very dense network with a lot of feasible opportunities. Thus, the cognitive maps created by the two methods only have marginal difference, i.e. only adding a few more feasible opportunities in remote locations. The total predicted travel time is 54 minutes, as compared to 55 minutes reported in the travel diary. It should be noted that the SCHEDULER 2 underestimated travel time because it does not consider travel time within zones.

Criterion 2

Before telecommuting (1% recreation, 10% commercial landuse criteria).
Using the 1% recreation, 10% commercial landuse criteria results in the same schedule as in the 1% recreation, 5% commercial criteria. This is because there is no major difference in the feasible opportunities by changing from a 5% to a 10% commercial landuse criterion. As shown in Table 5, the effect on the change of this criterion has been a change on a few feasible opportunities on commercial locations, resulting in only one minor change in aversion for two locations.

Criterion 3

Before telecommuting (5% recreation, 5% commercial landuse criteria).

As shown in Table 11, the SCHEDULER 2 still schedules the same order of activities for the same day. The location for personal business is still the same as the home location. However, the location for recreation is not the same as in the 1% recreation criterion and the actual location, requiring 13 minutes of travel time. It is due to the fact that the actual location is not in the feasible opportunity set as in the case of the 1% criterion. It indicates that the 5% recreation landuse criterion is not adequate for prediction for recreation destinations. Again, there is no difference between using network distance and Euclidean distance using this criterion.

Criterion 4

Before telecommuting (5% recreation, 10% commercial landuse criteria).

This criteria results in the exact same schedules as the 5% recreation, 5% commercial landuse criteria (Table 11). As shown in Table 6 and Table 7, there is no major difference between the 5% and 10% commercial landuse criteria for this case.

After telecommuting

In this case the telecommuter started telecommuting. On the telecommuting day, his activity schedule is the same as in the travel diary (Table 2). Since there is no prediction for the destinations, no feasible opportunity set is created for this case.

7. Conclusion

Current ATIS research does not recognize activity scheduling as an important element for pre-trip planning and enroute information supply strategy to cope with changes in the environment. In this paper, we have shown how a GIS can be used to calibrate a computational-process model for activity scheduling. The model was formulated upon the theoretical foundations of the activity-based approach to transport modeling and insights from recent studies on ATIS. It incorporates, to a certain extent, a person's preference and cognitive structure in a simulated process of travel decision making for destination selection. It has significant implication for expanding ATIS to include destination substitution as an information supply strategy in addition to rerouting.

Several difficulties made the integration of the CPM with GIS necessary. First, to date no CPM has been constructed on the basis of a realistic geographic environment. Second, despite the requirement to deal with person-specific data, no existing CPM has the capability to deal with a vast number of actual geographic locations and elements in a transportation system, especially for calculating the network distance and travel time. Third, none of them can perform spatial operations through the complex topology of a transportation network. In order to remedy these problems, ARC/INFO GIS was interfaced with the SCHEDULER 2 in this study in an attempt to provide environmental information such as the representation of the network and to provide locations for the definition of choice sets and feasible opportunity sets. It was also used to calibrate parameters such as location aversion for the model. Sensitivity analyses were performed by varying different landuse criteria and the weighting on travel time and location aversion. Results of the activity schedule with destination selection are particularly important during the enroute stage of travel when the immediate environment is not familiar to the traveler. In the future, the use of GIS on handling dynamic real-time data should be explored in more details.

TABLES AND FIGURES

TABLE 1: Travel Diaries for the Telecommuter Before Telecommuting

Condition	Activity	Start	Stop	Activity Duration (Mins.)	Travel Time (Mins.)	Travel Distance (Miles)
	Home-based	0:00	7:30	7:30	N/A	0
	Other	7:35	7:36	0:01	5	2
	Work	7:55	12:10	4:15	19	8
	Home-based	12:21	12:30	0:09	11	7
Telecommuter	Personal business	12:35	12:52	0:17	5	2
non-telecommuting	Home-based	13:00	13:20	0:20	8	2
day	Work	13:30	18:00	4:30	10	7
	Home-based	18:16	19:22	1:06	16	7
	Meal	19:40	21:00	1:20	18	3
	Home-based	21:10	24:00	2:50	10	3
	Home-based	0:00	7:30	7:30	N/A	0
	Other	7:35	7:36	0:01	5	2
	Work	7:55	12:20	4:25	19	8
Telecommuter	Personal business	12:22	12:55	0:33	2	1
non-telecommuting	Work	12:58	17:30	4:32	3	1
day	Home-based	17:40	18:30	0:50	10	7
	Meal	18:32	19:45	1:13	2	1
	Home-based	19:47	24:00	4:13	2	1
	Home-based	0:00	7:30	7:30	N/A	0
	Other	7:33	7:34	0:01	3	2
	Personal business	7:45	8:00	0:15	11	7
Telecommuter	Home-based	8:15	8:55	0:40	15	2
non-telecommuting	Work	9:05	17:30	9:25	10	7
day	Meal	17:40	19:35	1:50	12	7
	Recreation	19.39	22.12	2:33	2	1
	Home-based	22.14	24:00	1.46	2	1

TABLE 2: Travel Diaries for Telecommuter after Telecommuting

Condition	Activity	Start	Stop	Activity Duration (Mins.)	Travel Time (Mins.)	Travel Distance (Miles)
Telecommuter telecommuting day	Home-based	0:00	7:25	7:25	N/A	0
	Pick-up passengers	7:30	7:31	0:01	5	1
	Home-based	7:36	24:00	16:24	5	1
Telecommuter non-telecommuting day	Home-based	0:00	7:35	7:35	N/A	0
	Pick-up passengers	7:36	7:37	0:01	1	1
	Work	7:55	13:00	5:05	18	7
	Personal business	13:05	13:15	0:10	5	1
	Work	13:20	17:20	4:00	5	1
	Home-based	17:35	24:00	6:25	15	7
Telecommuter non-telecommuting day	Home-based	0:00	7:37	7:37	N/A	0
	Pick-up passengers	7:42	7:45	0:03	5	1
	Work	8:00	18:05	10:05	15	8
	Home-based	18:20	18:30	0:10	15	6
	Recreation	18:34	19:33	0:59	4	1
	Home-based	19:40	24:00	4:20	7	1

TABLE 3: Mean Trip Values for Different Trip Purposes

Trip purposes	Mean trip length +1 S.D. Before Telecommuting	Mean trip length+1 S.D. After Telecommuting
Recreation	8	6
Meal	6	5
Personal business	6	6

TABLE 4: Feasible Locations and Location Aversion Using 1% Recreation and 5% Commercial Criteria

			Case 1					
Location	X	Y	Frequency			Frequency		
number			1% rec	5% com	Location	1% rec	5% com	Location
			Network distance		aversion	Euclidean distance		aversion
1	1	4	0	2	7	0	3	7
2	2	4	1	0	8	1	0	8
3	0	3	0	0	9	1	0	8
4	1	3	9	19	1	9	19	1
5	2	3	7	10	3	7	10	3
6	3	3	2	0	8	3	0	8
7	0	2	3	0	8	3	0	8
8	1	2	6	16	2	6	16	2
9	2	2	4	12	4	4	12	4
10	3	2	0	0	9	0	1	8
11	0	1	2	0	8	2	1	8
12	1	1	1	3	6	1	3	6
13	2	1	0	5	5	0	5	5
14	3	1	0	0	9	0	0	9
15	1	0	0	0	9	0	0	9
16	2	0	0	0	9	0	0	9
Total			35	67		37	70	

TABLE 5: Feasible Locations and Location Aversion Using 1% Recreation 10% and Commercial Criteria

			Case 1					
Location number	X	Y	Frequency			Frequency		
			1% rec	10% com	Location	1% rec	10% com	Location
			Network	distance	aversion	Euclidean	distance	aversion
1	1	4	0	2	7	0	3	7
2	2	4	1	0	8	1	0	8
3	0	3	0	0	9	1	0	8
4	1	3	9	17	1	9	17	1
5	2	3	7	7	4	7	7	4
6	3	3	2	0	8	3	0	8
7	0	2	3	0	8	3	0	8
8	1	2	6	15	2	6	15	2
9	2	2	4	10	3	4	10	3
10	3	2	0	0	9	0	1	8
11	0	1	2	0	8	2	0	8
12	1	1	1	3	6	1	3	6
13	2	1	0	5	5	0	5	5
14	3	1	0	0	9	0	0	9
15	1	0	0	0	9	0	0	9
16	2	0	0	0	9	0	0	9
Total			35	59		37	61	

Table 6: Feasible Locations and Location Aversion Using 5% Recreation and 5% Commercial Criteria

			Case 1					
Location number	X	Y	Frequency 5% rec Network	5% com distance	Location aversion	Frequency 5% rec Euclidean	5% com distance	Location aversion
1	1	4	0	2	7	0	3	7
2	2	4	1	0	8	1	0	8
3	0	3	0	0	9	0	0	9
4	1	3	0	19	1	0	19	1
5	2	3	1	10	4	1	10	4
6	3	3	0	0	9	1	0	9
7	0	2	0	0	9	0	0	9
8	1	2	3	16	2	3	16	2
9	2	2	2	12	3	2	12	3
10	3	2	0	0	9	0	1	9
11	0	1	0	0	9	0	1	9
12	1	1	0	3	6	0	3	6
13	2	1	0	5	5	0	5	5
14	3	1	0	0	9	0	0	9
15	1	0	0	0	9	0	0	9
16	2	0	0	0	9	0	0	9
Total			7	67		8	70	

TABLE 7: Feasible Locations and Location Aversion Using 5% Recreation and 10% Commercial Criteria

			Case 1					
Location number	X	Y	Frequency 5% rec Network	10% com distance	Location aversion	Frequency 5% rec Euclidean	10% com distance	Location aversion
1	1	4	0	2	7	0	3	7
2	2	4	1	0	8	1	0	8
3	0	3	0	0	9	0	0	9
4	1	3	0	17	1	0	17	1
5	2	3	1	7	4	1	7	4
6	3	3	0	0	9	1	0	9
7	0	2	0	0	9	0	0	9
8	1	2	3	15	2	3	15	2
9	2	2	2	10	3	2	10	3
10	3	2	0	0	9	0	1	8
11	0	1	0	0	9	0	0	9
12	1	1	0	3	6	0	3	6
13	2	1	0	5	5	0	5	5
14	3	1	0	0	9	0	0	9
15	1	0	0	0	9	0	0	9
16	2	0	0	0	9	0	0	9
Total			7	59		8	61	

TABLE 8: Long-term Calendar Before Telecommuting

Activity

Type	Duration	Utility																							
1	0.01	0	0	0	0	9	9	9	9	9	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2	0.15	0	0	0	0	9	9	9	9	9	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
3	0.4	0	0	0	0	0	0	0	9	9	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
4	8.25	0	0	0	0	0	0	0	0	9	9	9	9	9	9	9	9	9	9	0	0	0	0	0	0
5	1.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	5	5	5	5	5	5	5	5	0	0
6	2.33	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3	3	3	3	3	3	0
7	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
9	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
10	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
11	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
12	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
13	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
14	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
15	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

TABLE 9: Long-term Calendar after Telecommuting

Activity Type	Duration	Utility																							
1	0.01	0	0	0	0	9	9	9	9	9	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2	16.00	0	0	0	0	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9
3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
6	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
7	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
9	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
10	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
11	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
12	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
13	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
14	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
15	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

TABLE 10: Activity Schedule Before Telecommuting for Using Criteria 1 and 2

Activity Type	LocX	LocY	Start Time	Stop Time	Travel Time	Wait Time
Start	1	3	7.30		0.00	0.00
Pickup	1	3	7.30	7.31	0.00	0.00
Personal-Business	1	3	7.31	7.46	0.00	0.00
HomeAct	1	3	7.46	8.26	0.26	0.00
Work	1	1	8.52	17.17	0.26	0.00
Meal	1	3	17.42	19.32	0.00	0.00
Recreation	1	3	19.32	22.05	0.00	0.00
Ready	1	3	22.05			0.00

TABLE 11: Activity Schedule Before Telecommuting for Using Criteria 3 and 4

Activity Type	LocX	LocY	Start Time	Stop Time	Travel Time	Wait Time
Start	1	3	7.30			
PICK-UP	1	3	7.30	7.31	0.00	0.00
PERSONAL	1	3	7.31	7.46	0.00	0.00
HOMEACT	1	3	7.46	8.26	0.00	0.00
WORK	1	1	8.52	17.17	0.26	0.00
RECREATION	1	2	17.29	20.02	0.13	0.00
MEAL	1	3	20.15	22.05	0.13	0.00
Ready	1	3	22.05			

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