SIMULATING EMERGENT BEHAVIOR AND EVOLUTION OF ACTIVITY-TRAVEL PATTERNS: DATA COLLECTION CHALLENGES

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ABSTRACT

The aim of this paper is to focus on different aspects in regard to the collection of data about emergent activity-travel behavior and dynamically evolving activity-travel patterns. Within Flanders, no activity-travel nor panel surveys exist concerning travel behaviour, only a household travel survey is carried out every five years. Therefore, several data collection solutions are proposed and combined into an extensive hybrid, multi-method approach where every component was actually applied and implemented in practice. This paper does not provide detailed results, but rather a brief overview of the different data solutions needed, facing the problem of collecting dynamic activity and (re)scheduling information. The different decisions concerning the survey design are discussed and the major data collection is described. Detailed data on activity-travel patterns are collected using a combination of paper-and-pencil and GPS/PDA devices. In comparison with other activity-based studies, the survey period is particularly long, i.e. 7 days which is required to obtain information about the regular behaviour and two members of the household are questioned as opposed to a single household representative. The survey also includes questions about activity plans and execution and reasons for change/adjustment. Second, a data fusion exercise is undertaken, combining the Flemish travel survey data with the Flemish time use survey data. This results in a larger sample of the population and in more detailed information. Third, data are collected on traveler strategies to cope with unexpected events during execution of an activity agenda by means of stated adaptation experiments. Fourth, data on lifecycle events are collected using an internet-based retrospective survey, asking respondents which lifecycle events they experienced and when they did so. Finally, additional data on regular events are captured using a vehicle embedded data acquisition device, allowing for long-term data collection.

1. INTRODUCTION

In the context of the Feathers project (Janssens and Wets, 2005; Janssens *et al.*, 2007; Arentze et al., 2006), the authors aim at developing a model of dynamic activity-travel patterns. The foundations appear in Timmermans *et al.* (2001) and Joh *et al.* (2003, 2004) focusing on the formulation of a comprehensive theory and model of activity rescheduling and re-programming decisions as a function of time pressure. Several types of dynamics are involved.

First, the model system will address the problem of activity rescheduling behavior, assuming that daily and multi-day activity (re)scheduling processes depend on history, available time, and time pressure. Secondly, it will address the problem of long-term dynamics. Following Waerden, Borgers and Timmermans (2003a, 2003b) and Klökner (2004) it is assumed that critical incidents and key lifecycle events may prompt or force travellers to change their habitual behaviour. Moreover, lifecycle events, such as reaching the age to have a driver's license, leaving home, getting married, first child, retirement, new job, new house, etc. may lead to changes in available resources and choice options. In turn, these may lead to changes in activity-travel patterns. Thirdly, and critical for linking different time horizons, is the notion that travellers learn their environment and cope with an environment which is non-stationary. The non-stationarity can be caused by regularly occurring events such as summer holidays, religious holidays, yearly returning long week-ends or typical days like labour day, etc., but also on changing needs based on their activity patterns and their social network. The basic assumption is that travelers, represented as agents, hold beliefs and have a cognitive representation of their environment during a certain life course, have preferences and basic needs, leading to plans, agendas and schedules. When a deviation exists between an agent's expectation and aspiration an agent may start exploring the environment for new alternatives. Thus, (s)he learns about the environment and the consequences of his/her actions, and is able to adapt to changing circumstances and improve less effective behavior. Based on experiences, an agent forms habits, reinforces memory traces, updates beliefs about attributes of locations and routes, discovers the conditions under which certain states of the environment are more likely than others, and in so doing makes sense of the world around him/her. Moreover, through social contacts agents exchange information and adjust aspirations, which may trigger actions to explore new alternatives. Thus, for an agent, the composition of the location choice-set for a specific activity under certain conditions is dynamic. The alternatives within the choice-set will be expanded with newly discovered alternatives and reduced with old ones that are discarded or are no longer retrievable from memory (see Han *et al.,* 2007a, 2007b for a detailed description of the methodology used).

The results of these behavioural mechanisms are dynamic activity-travel patterns, reflecting emergent behaviour. For example, conditions can be simulated under which learning leads to habitual behavior. Likewise, bifurcation and shock through the system can be simulated. Also, spatial effects of particular land use or transportation measures can be observed. A final example, copying behavior and the effects of social networks on activity-travel patterns and the evolution of choice formation and change can be simulated.

The data requirements of such a model constitute a real challenge. In addition to activity-travel diaries, the model needs data on activity rescheduling decisions of individuals, data on household multi-day activity scheduling, data on life trajectory events and how they impact activity-travel decisions, data on how individuals learn and data on how short-term dynamics are linked to long-term decisions. Such data are available in typical cross-sectional travel surveys, time use surveys and some need to be collected by means of a panel survey. In fact, in Flanders, the intended application area of the model system, neither data on activity-travel schedules, nor on panel surveys are available.

The data collection therefore involves an extensive hybrid, multi-method approach. The approach is situated within a research programme which is funded by IWT, Belgium. In the remainder of this paper, we will discuss this hybrid, multi-method data collection approach. It is not possible within this paper to discuss detailed results which emerged from the different data collections. On the contrary, we will report about detailed data requirements and survey design decisions that have been implemented and about general data collections efforts which have been involved with an emphasis on the collection of dynamic activity and (re)scheduling information.

Data on activity-travel patterns were collected using a combination of paper-and-pencil and GPS/PDA devices. First of all, this data collection differed from the usual activity-travel diaries in that data were collected for a week as opposed to one or two days, for two members of the household, as opposed to a single representative, that it included questions about activity plans and execution and reasons for change/adjustment and that face-to-face contact was established with the participants to question their social network. Second, a data fusion exercise was undertaken, combining the Flemish travel survey data with the Flemish time use survey data, resulting in a dataset which offers a larger sample of the population. The larger sample is valuable in prediction of travel demand and can also be used as a base for simulating travel data. Third, in order to account for travel behaviour dynamics, data on traveler strategies to cope with unexpected events during execution of an activity agenda were collected using a stated adaptation experiments, based on fractional factorial designs to allow an unbiased estimate of effects on the rescheduling of activity-travel patterns. Respondents were asked to imagine hypothetical scenarios in which they experience a delay of a specified magnitude when conducting a specified activity, involving a certain travel time at a specified location using a specified transport mode. Fourth, data on lifecycle events were collected using an internet-based retrospective survey, asking respondents which lifecycle events they experienced and when. As a perfect alternative for this survey, additional data on regular events were captured using a vehicle embedded data acquisition device, allowing for long-term data collection. The latter study allows for deriving the sequence of both lifecycle and regular events and the associated attributes and for capturing long-term travel information.

2. DATA REQUIREMENTS: GENERAL LEVEL

Disregarding the instrument used, the purpose of a full (static or dynamic) activity-based model is to predict which activities will be conducted when, for how long, with whom, where and with which (chain of) transport mode(s). It logically follows that in order to build a model that incorporates all these facets, one requires data on all these facets. Because the interdependencies between these facets are critical, one also needs detailed data about these facets for all activity episodes. That is, for each new activity, the data should reveal where it is conducted, when, for how long, etc. Although this seems evident, the collection of such data requires many operational decisions.

With respect to the classification of activities, we have chosen to implement 14 activity classes which include: in-home activities, sleeping, services, working, eating, daily shopping, non-daily shopping, education, social activities, leisure, bring or get persons or goods, waiting, touring and other activities. In this determination, we conducted a pretest and followed previous activity class recommendations relying upon experiences with the Albatross and Aurora model frameworks. In addition to this, it needs to be said that more detailed information with respect to activity classes is available and can be accessed within Flanders within the context of time use research.

Another facet concerns the timing dimension, which means that data on start and end times, and hence duration of activities and related travel should be collected. We decided to ask respondents to report the exact start and end times of their activities. Obviously, this operational definition also has implications for the measurement of spatial-temporal constraints, which is particularly relevant to fully explore microsimulation and to allow for a full exploration of the advantages of activity-based models.

The next facet concerns the “with whom” dimension. Most existing activity-based models do yet not fully incorporate this choice dimension. It has been decided to use a rather broad categorization of travel party: children and partner information, being household members on the one hand and other members on the other hand. In case the travel party for other members would be more detailed and would concern co-workers, business partners, friends or other people, it is unlikely that activity diaries of these people are available. In that case, although the definition of travel party might include this category, it does not provide any advantages for data cleaning and model building. We also explicitly asked for the number of people that are participating in the travel because this has implications for vehicle occupancy rates and traffic volume.

To model the spatial dimension or location of activities, data on where activities were conducted, are required. Several operational decisions come into play. One needs to decide about the level of spatial resolution. To derive reliable measures of spatial-temporal constraints, a rather high resolution is required, and therefore geo-coded information is preferred. A solution to account for this is implemented and proposed in section 3.2.1. As a second best alternative, one should have data about a spatial system represented by a fine set of zones. Intra-zonal distances or travel times should be such that the measurement of spatial-temporal constraints makes sense. We will further report upon the operational decisions taken regarding this facet in relation to the stratified cluster design which will be discussed in section 3.1.1.

The final facet, deals with the data that is necessary to conduct various activities. Activity-based models do not involve any other requirements than conventional models in terms of transport mode. The usual categorization into car (driver versus passenger), various means of public transport, bicycle, and walking would typically suffice. In the context of modelling multi-modal transportation modes, we have equally collected data about travel chains (journeys). To this end, users have the possibility to enter four different trips and their corresponding transport mode in one journey in our data collection. We equally explicitly asked respondents to report waiting times, for instance in a context of using public transport.

Obviously, the above facets concern the principal choice dimensions with respect to data requirements underlying activity-based models. As mentioned in the introduction, in addition to the facets listed above, we have also conducted additional data collection efforts which are specifically required to account for dynamic activity-travel behaviour and to improve model performance and calibration. The different data collection challenges have been described below.

3. ACTIVITY-TRAVEL DIARIES: (RE)SCHEDULING INFORMATION USING A HYBRID APPROACH

3.1 Survey design decisions

The principal data collection effort that has been developed to capture activity travel and rescheduling information followed after a detailed feasibility study and after several survey design decisions. The goal of the feasibility study is to evaluate how this principal data collection should be effectuated. Several methodological issues have been examined.

3.1.1. Sample size and clustering.

At first the sample unit needs to be determined. Literature on transportation survey research has taught us that the household is often regarded as the sample unit, because of the obvious relationships between the mobility behaviour of persons belonging to the same household. Therefore, the household was opted for as basic sample unit.

The second main decision involves the sample size of the study, which should include at least 2401 households with successful survey results. This sample size figure is based on sample size calculations performed in the feasibility study for “Onderzoek Verplaatsingsgedrag in Vlaanderen” (household trip-based travel survey) (Provinciale Hogeschool Architectuurinstituut, 1993), taking into account specific budget constraints and available logistic means. The minimal sample size depends on different factors such as the accuracy with which one wants to draw conclusions. If one is satisfied with rather general statements on the population, i.e. if one wants to know a certain population parameter only approximately, then a rather small sample size suffices. Based on calculations as proposed by Billiet and Waege (2001), we will now determine the sample size. From classical statistics, we know that the confidence interval for a population proportion is determined by:

$$p - z\sqrt{\frac{p(1-p)}{n}} < \pi < p + z\sqrt{\frac{p(1-p)}{n}},$$

with *p* the survey proportion, *n* the sample size and *z* the z-value of the desired confidence interval. Based on this calculation, one can determine a maximal deviation (*md*), with which the survey proportion *p* can deviate from the population proportion π:

$$md \geq z\sqrt{\frac{p(1-p)}{n}}$$

Isolating *n* leaves us:

$$n \geq \frac{z^2 p(1-p)}{md^2}.$$

Based on this formula, we can observe that the sample size *n* depends on the survey proportion *p*, the accuracy with which we want to draw conclusions via the value of *z* and of the accuracy itself via *md*. Table 1 gives a brief overview of possible sample sizes for some classical values of confidence and maximal deviation for the ‘safest’ case of p equal to 0.5. Based on the feasibility study, a maximal deviation of 2% was chosen and traditionally a 95% confidence level was used, so therefore the questioning of 2 401 sample units seems a minimum.

p=0.5		**Accuracy (*md*)**			
Confidence level	**z-value**	**0.1**	**0.05**	**0.02**	**0.01**
0.90	**1.65**	68	271	1 691	6 764
0.95	**1.96**	96	384	2 401	9 604
0.98	**2.33**	135	541	3 382	13 530
0.99	**2.58**	166	663	4 147	16 587

Table 1. Minimal sample size in function of confidence level and accuracy

The households will be selected using a stratified cluster technique, which ensures a geographical and spatial distribution in the sample which is representative for the study area of Flanders. In this stratified design, the population will first be divided into non-overlapping groups (strata) after which in each group a simple random sample will be drawn. The clustered part of the design means that households will serve as cluster units. The advantage of using a clustered design, is that one does not need to have a full list of individuals at one's disposal. This should be regarded in contrast to doing a simple random sample on individuals (Actually, the design is determined before the sample size, so at this stage in the process it was not sure what the sampling unit would be). In the design of the sampling scheme both the coverage of the people in Flanders and the logistic feasibility of the fieldwork are important concerns. Even when a relatively exhaustive list of units is available (such as the National Register), a direct selection from this list would be too expensive, because the spread would be too wide. Cost savings may allow the investigators to use a larger sample size than they could use for a simple random sample of the same cost (so questioning different individuals within a household will cost less than obtaining survey results for the same number of people from a random sample).

Choosing a stratified sample instead of a simple random sample can be motivated as follows. Sample surveys displaying small variability among the measurements will produce small bounds on the errors of estimation. In other words, stratification may produce a smaller bound on the error of estimation than would be produced by a simple random sample of the same size. This result is enforced if strata are largely homogeneous. In this survey; there are two stratification levels, i.e. at the provincial level and the level of a municipality. Municipalities are established administrative units, they are stable (in general those units do not change during the time the survey is conducted), and they are easy to use in comparison with other specialized sources of data related to the survey. If either one of them had to be chosen, municipalities are preferred to provinces, because the latter are too large and too few, however in this study both per opted for: first a selection of households proportional to the number within a province, and secondly within provinces with respect to the size of the municipality. The great variation in the size of the municipalities is controlled for by systematically sampling within a province with a selection chance proportional to their size. Within each municipality, a random sample of representative households is drawn. Clustering also takes place at the household level since members of the same household are more alike than persons not belonging to the same household. Whereas the stratification effects and the systematic sampling according to municipalities have the effect of increasing the precision, the clustering effect (selecting households instead of individuals) might slightly reduce precision, since units will resemble each other more than in a simple random sample (one may expect larger differences between households and more alikeness within households leading in total to a larger variability between individuals, when compared to individuals taken from a simple random sample, hereby reducing precision). However, since stratification is based on unequal probabilities (to guarantee meaningful sample size per stratum) a slight decrease in overall efficiency is to be expected. The effects due to clustering and stratification observed will however probably not outweigh the advantages.

3.1.2 Form of instrument.

A second decision concerns the question which instrument to use to collect diary data. It has been known from literature that the possibility to enable computer assisted data collection tools with GPS, facilitates the collection of travel and route-information and widens the application area of the data in addition to the traditional travel behaviour model development (Wolf, 2004). This GPS functionality is particularly important in our application case because rescheduling decisions are probably not only undertaken at the level of activity, but are probably also reflected in travel execution (e.g. other routes taken). Furthermore, automated data collection techniques are particularly well suited to obtain data which require a significant effort from the respondent like for instance the rescheduling of activities for the development of dynamic models. Other important advantages are the immediate electronic availability of the data and the semi-automated checks on the data, which have the potential to lead to higher data quality (see Arentze *et al.*, 1999). For these reasons, a considerable portion of our sample (approximately 50%) received a PDA-module (more information about this tool can be found in section 3.2.1). The other part of the sample is being questioned by means of a traditional paper-and-pencil method to account for the sample bias which is introduced when only computer-assisted forms of data collection are used. Furthermore, this choice enables us to carry out comparative studies with respect to the behaviour of both target groups in terms of response rates, experience, etc..

3.1.3. Time horizon.

The concept of time horizon concerns the question whether diary data should be collected for the past or for the future. In principle, respondents may be asked to recall yesterday's trips or activities or activities longer ago, or be asked to fill out the diary for a particular day in the future. Often, the latter option is referred to as 'leave-behind' as it typically involves an interviewer leaving behind the diary for the respondent to fill out after explaining the diary. In contrast, the recall format involves asking respondents, with or without previous notifications, to report their activities performed during a given, previous day. When the interviewer meets the respondent or contacts the respondent by phone, all events of the previous day are systematically reviewed in order to elicit from the respondent's memory the whole sequence of activities and trips, while establishing also the time of the day at which the consecutive events took place, the location of the activities, the persons in whose presence they took place, etc. In our data collection effort, we have collected data for the past, as well as planned activity and travel information for the future since both are important for model calibration of a dynamic activity-based model. The survey therefore asked the members of the selected households to fill out a planned and executed diary (both on paper and PDA) and to report rescheduling decisions and reasons for rescheduling as well.

3.1.4. Frequency.

The principal survey reported in this paper has been carried out during a one-week period. There are several reasons for this choice. First, when one is interested in capturing dynamic travel information, which is reflected in planning of activities, next to the execution of the planning, one should reckon that some activities have a rather fixed time point and hence can be planned a long time ahead. Second, some activities take place only once a week (i.e. non-daily shopping, sport activities) and our goal is to capture them as well. Finally, the choice for increasing the number of days per respondent reduces important dimensions of measurement error and marginal costs (Gershuny, 1992), and increases the usefulness of the data for analysis and model development. In comparison with other activity-based studies, the survey period is particularly long, especially in combination with the high number of households that will participate in the survey.

3.1.5 NKD implementation.

The actions that are taken in our survey approach have been derived from the "New Kontiv Design (NKD)", which is one of the best known approaches for developing a good and reliable survey. The NKD provides a detailed phased survey procedure. The following actions must be performed sequentially according to the NKD: an advance notice (mail), mailing of questionnaires (mail), motivation (telephone), reminder (mail), motivation (telephone), reminder (mail), motivation (telephone), respondent helpdesk (telephone), new mailings of questionnaires on request (mail). The following detailed procedure is followed in our data collection.

The households that are selected for the paper questionnaires, are first sent an introduction letter in which the purpose of the research is explained in general, as well as what is exactly expected from the respondents. Note that advance letters accomplish several useful purposes: they help establish the legitimacy of the survey, inform potential respondents about the study's purposes, allay concerns about confidentiality, and serve as an introduction to the interviewer. In addition to this, studies suggest an advance letter can be quite useful in obtaining cooperation, increasing response rates by an average of about 17 percent (Zimowski *et al.*, 1997, Dillman, 1991). Three working days after sending the introduction letter, a maximum of three attempts is undertaken in order to reach a household: once during the morning, once in the afternoon, and once in the evening. When the household can be reached, they are asked whether they want to participate or not. If they are indeed willing to cooperate, the questionnaires are sent, a starting date is agreed with the household and an appointment is made to call the household on the second day of the research. On that day, the household is contacted again to remind them of filling out the diaries, and to check whether the participants experience any problems filling out the questionnaires. Because of this procedure, any difficulties that the respondents may encounter, will be solved quickly and the households will be motivated to participate. Households who refuse to further participate after the telephone call (second day of the research), are asked to fill out and send back at least the household questionnaire and the questionnaires with personal socio-economic information. After seven days, the household is expected to send back the questionnaires. If the questionnaires have not been received one week after the last day of the research, the household will be called back to remind them of sending back the questionnaires.

The households that receive a PDA go through a similar procedure. They first receive an introduction letter in which the purpose of the research is explained. This letter also includes more information with respect to the PDA-technology and their assignment during this research. Again, three days after sending the introduction letter, the telephonist will again try to reach the household during three calling attempts. When the household can be contacted, they are asked whether they want to take part in this research. If so, an appointment for the delivery of the PDA, the household questionnaire and the socio-economic questionnaire is fixed at the respondents' home location. During this moment the household receives the PDA and the questionnaires. Further explanation is also provided to the participants during the contact moment. Similar to the procedure concerning the paper-and-pencil diary information, each household will also be called on the second day of the survey to ensure that everything goes smoothly, and to motivate the respondents. At this point, a new appointment is fixed to collect the PDA, preferably the day after the last day of the survey. At this appointment, participants are also questioned about their social network. This takes place during a short interview, using Wellmann's instrument (Wellmann, 1979). In the application of this method, one gets information about egocentric social networks, using only one name-generator per group. Questions were asked about people the respondent feels closest to; these could be friends, neighbours or relatives. The named alteri were recorded and described in detail for parents, brothers/sisters, other family members, friends, neighbours, colleagues and (sport)club members. After the appointment, the data on the PDA was processed and the PDA is initialized for use by another household.

In order to limit the costs incurred by delivery and pick-up of the PDA's, a decentralised modus operandi was implemented. Co-workers living scattered over Flanders were recruited such that the travel costs could be minimised by optimising the allocation of tasks to co-workers. The full procedure is administered and guided by means of a computer-assisted application which has been specifically designed for this purpose.

3.2 The instruments used: the parrots and the paper-and-pencil tools

3.2.1 The parrots tool.

The automated activity-travel diary survey tool has been called PARROTS, which stands for (PDA (Personal Digital Assistant) system for Activity Registration and Recording of Travel Scheduling). PARROTS runs on a PDA and uses the Global Positioning System (GPS) to automatically record location data. The PDA was programmed such that besides automatically registering its location, respondents can provide information about their activity-travel behaviour as well. Another part of the collected data consists of data regarding replanning and execution of activities and trips that is manually input by the respondents. Both planned and executed activities and trips are registered with the possibility to alter the attributes of the planned activities. This way, information is collected regarding the decision and scheduling processes, which results in an evolution from an intention to execute some activities and trips to an executed activity-travel diary. A similar philosophy was adopted in Rindsfüser *et al.*, (2003).

If the PDA is switched on, PARROTS starts automatically and the main GUI is shown (Figure 1, Left). Whenever PARROTS is active, the GPS logger is operational logging the GPS location strings at a configurable rate. Hence the respondent can automatically record route and location information using GPS by keeping the PDA switched on. The 'Vergrendelen' button provides a screen lock functionality such that the PDA can safely be stowed during the trip. The PDA is switched off using the 'Afsluiten' button.

The buttons 'Planning' (Planning) and 'Dagboekje' (Diary) are used to launch the graphical user interfaces (GUI) to input planned and executed activities and trips respectively. In the planning GUI, the registered activities and trips are grouped by day and are listed in the same order they were entered (Figure 1, Middle). In the diary GUI, the executed activities and trips are displayed in a layout that resembles an agenda (Figure 1, Right). The difference in both GUI's stems from the fact that providing an agenda layout for planned activities is reported in literature to bias the collected data due to visual feedback of the interface (Zhou and Golledge, 2007).

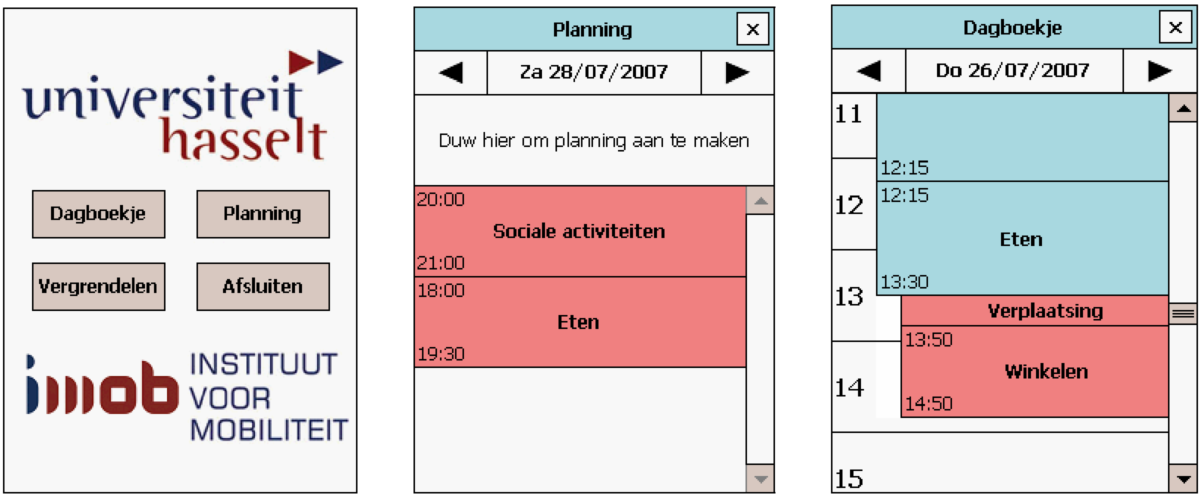

Figure 1. PARROTS main GUI (Left), planning GUI (Middle) and diary GUI (Right). In order to facilitate the distinction between planned and executed activities, planned activities are depicted in red and are wider than executed activities, which are depicted in blue.

Whenever an activity or trip is registered in PARROTS, a number of attributes for this activity or trip are collected using a customized GUI. The most important activity and trip attributes PARROTS collects are: activity type, date, start and end time, location, mode of transportation, travel time and travel party. Note that although PARROTS collects location data using GPS, the location of activities is still queried. The match between location information provided by the respondent and the location logged by GPS can be verified during postprocessing in order to validate the data. Replanning information is collected by allowing the respondent to update all attributes and by querying for the reasons of the registered changes.

PARROTS features several data consistency checks, the most important of which are: checks that all required data are available and feasible, checks on overlaps and/or gaps on the time axis and checks for discontinuities in location. If any of the checks fails, the user is taken to the relevant GUI and an informative error message is shown. These checks are only enforced for activities and trips that are labeled as executed.

Currently, about 900 persons have been questioned by means of the PARROTS tool, which means that this study is probably one of the largest ever using GPS in the field of activity-travel data collection and one of the few that we are aware of that uses GPS-enabled PDA's. More detailed analyses with respect to the collected data, like the analysis of the impact of GPS-enabled PDA technology on the user response rates, the impact of PDA technology on the quality of the collected diary data and PARROTS usage patterns, can be found in Bellemans *et al.* (2008). The functional design of the tool has been discussed in Kochan *et al.* (2006a, 2006b).

3.2.2. The paper-and-pencil tool.

The paper-and-pencil survey is a traditional activity-based travel survey, except for the fact the additional information was collected with respect to travel dynamics and rescheduling information. In the diary, the respondent fills out his personal activity-travel diary which includes all performed activities and journeys during one week. Similar to PARROTS, both the planned and executed activities and trips are registered in a separate booklet. To obtain a link between planned and executed activities, respondents were asked whether the executed activity was planned and if it was, the sequence number of the corresponding activity in the planning booklet was asked.

Obviously, one cannot register detailed information about replanning behaviour of a respondent for every choice facet (transport mode, duration, travel party, location) as this would involve many manual checks on both booklets leading to unacceptable respondent burden. Hence, no detailed replanning information was gathered in the paper-and-pencil survey and only the reason for differences in duration of planned and executed activities was queried.

4. DATA FUSION

Activity-travel surveys like the ones outlined above are notoriously expensive and require an appreciable amount of time to plan and execute. It is likely that while technological survey techniques become increasingly refined, high unit costs and public resistance will continue to plague future survey efforts. Therefore, combining data from different surveys can be a plausible option in an effort to reduce respondent burden and survey costs. A practical solution is to exploit as much as possible all the information already available in different data sources, that is, to carry out a statistical integration of information that has already been collected. To this end, the impact of data combination on some important travel characteristics (number of trips, travel duration, travel goals and modes of travel) has been examined. The study should be seen as a preliminary study to assess the possibility of data fusion and combination, arising from two surveys: the Flemish household travel survey and the Flemish time use survey. While the research area is relatively novel, the adopted methodology can equally be applied for other datasets. However, the research area of rapidly growing interest as well as complexity in response to modern influxes of data.

Homogenization of different data sources is considered as a first labour-intensive step in the methodology. Next, both samples need to be weighted with respect to the Flemish population to ensure representativity. The aim of calibration (Rendtel *et al.*, 2006) is to adjust the weights of sampled persons in order to produce exact estimates for known population totals of some covariate of interest. Typical choices of covariates are socio-demographic key variables such as geographic indicators or age-gender groups. Next, the Iterative Proportional Fitting (IPF) method (Beckman *et al.*, 1996) is used to account for differences that could arise due to the different timeframe that is used in both surveys.

The preliminary results that came out of this exercise are successful in the sense that the integrated dataset is not statistically different for most variables under study. It can therefore be concluded that the combined data resulted into a larger sample that is more representative of the population under study. While these results are of course only preliminary, the technique shows to be promising in response to the problem of large travel data requirements necessary for transportation planning and decision making. Detailed results of the study have been published in Nakamya *et al.* (2007).

5. STATED ADAPTATION EXPERIMENTS: MEASURING SHORT-TERM ADAPTATION BEHAVIOUR

As mentioned in the introduction of this paper, the goal of collecting adaptation data is aimed at developing a dynamic component that more efficiently captures the complex process of activity generation and therefore enhances the behavioural realism of activity-scheduling models.

However, decisions that constitute the short-term adaptation process of people are not trivial to be solely captured by means of activity-travel diaries (e.g. activities that have been undertaken more than a week ago). For this reason, and for benchmarking purposes (with the weekly activity-diary information which has been collected), a specific internet-based stated preference experiment was undertaken to gather additional data. The stated-preference experiment provided each respondent with a number of hypothetical scenarios. 16 such hypothetical scenarios have been designed to collect the data necessary to assess the influence of the different choice facets on the activity utility. An exemplary stated preference question looked as follows:

"Assume it is time of day I and today you have V hours of discretionary time. You have D minutes available at present to conduct activity A, including travel time. What is the probability that you conduct the activity immediately (instead of performing it later (later today, tomorrow,…)) on location L1, if it is … days ago since you last performed activity A?

a) *it is T1 days ago*
b) *it is T2 days ago*
c) *it is T3 days ago*
d) *it is T4 days ago*
e) *it is T5 days ago"*

The experiment's goal in this case was to assess the impact of location availability. Respondents were asked to fill out information on the two locations they most frequently used to perform each of the activity types. Each hypothetical situation was therefore presented twice to the respondents: for the same attribute levels the respondents had to indicate the probability that they would perform the activity immediately on the first location and then they had to evaluate the same situation for the second location that they filled out for that particular activity.

In order to make the scenarios as realistic as possible, the answers the respondents filled out, were used to design personalized scenarios. According to the activity-specific average duration of the activity that the respondents indicated, they were assigned to a duration group and each duration group was granted specific duration values in the hypothetical situations. A similar approach was used to provide the respondents with realistic frequency levels. Respondents were asked to indicate a probability instead of a yes/no answer so that they could take other explanatory variables into account that were not included in the current experiment. By means of a binary logit model, the effect of the attributes (in this case duration, history, location, time of day, accompanying persons and gender) on the probability and thus on the activity utility was estimated, using the technique of fraction-utilities described in Nijland *et al.* (2006) and van Bladel *et al*. (2006).

While this technique can be used for different activities, it is particularly relevant for flexible non-routine activities that are frequently scheduled. Two specific activity types, namely Daily Shopping and Social Visit, were therefore chosen for this experiment, because both of them are generally flexible and a large number of individuals conduct these activities on a frequent and regular basis. Furthermore, the activity types Daily Shopping and Social Visit are supposed to be wide enough to provide useful information and yet limited enough to be homogeneous.

Not surprisingly, stated adaptation choices were considered to be the most difficult questions to answer. The subjects not only had to think consciously about decisions usually taken subconsciously, but they also had to imagine themselves repeatedly in situations that were not always completely familiar to the respondent. This lack of familiarity likely increased respondent burden and for future stated adaptation experiments in this research context, the application of the stated preference off revealed preference technique described by Train and Wilson (2008) could enhance the realism of the hypothetical situations. Therefore, the most important lessons learnt from these experiments is the significance of the hypothetical situations' design: it is fundamental that the hypothetical situations are designed to be as realistic as possible for the respondents, because unfamiliar situations can cause respondent burden and unreliable survey results. More detailed information about the analysis results of the collected data, can be found in van Bladel et al. (2006) and in van Bladel et al. (2008).

6. EVENT-BASED (LONG-TERM) DATA COLLECTION

In the development of a static or dynamic activity-based model, researchers in general assume that the household (and modeling) context is stationary.

However, in reality the household context changes continuously over time as a function of life trajectory events, such as birth of a child, changing jobs, changing residential location, etc. In order to take the increased complexity of a changing environment into account in future model development, data about these events also needs to be collected. Second, in a dynamic modeling environment, researchers are also interested in changing behaviour in the case of regularly occurring events (e.g. public holidays, anniversaries). Indeed, when people undertake Christmas shopping activities in the week(s) before Christmas, then there is more traffic towards large shopping centrums. A detailed study was conducted in the project and has been reported in Cools *et al.* (2007). But not only calendar events have an impact on travel demand, also the environment. It seems only logical that e.g. the choice of a transport mode can rely heavily on the weather or other seasonal components.

The latter problem can be tackled quite efficiently by using traffic intensity data, where traffic intensity is measured at a traffic control centre every minute of every day at the main roads. So, when one can relate this information to seasonal or weather data, one can establish the impact of both events. An application of such an exercise was conducted in the project and can be found in Cools *et al.* (2008).

Unfortunately, one cannot make the connection with important characteristics of a household/individual in this application, while it might be the case that certain types of households (e.g. with versus without children) react differently to different types of holidays (e.g. school holidays versus other) or seasonal effects. To achieve this goal, one should set up a continuous panel (on a smaller amount of households) and ask the individuals in each household to report their travel behaviour (in relation to the other household members) for some time after which the sample was refreshed. An “ideal” scenario, of course, would be to keep the sample for a whole year and refresh it thereafter, hereby measuring people’s activity and travel behaviour at each of the regular events (summer holidays, religious holidays, yearly returning long week-ends or typical days like mother’s day, father’s day, labour day, etc.). This would make it possible to observe the rhythm of the activity patterns and to get a clear image of the locations where the activities take place. However, it is unrealistic to keep people motivated to write down everything they have done - and more - for over a whole year. Indeed, taking the recommendations which have been given in Axhausen *et al.* (2007) into account, six weeks can be considered as a break-point for fatigue in activity-travel surveys.

Ideally, the impact of these key and regular events consists of three waves. The first wave ideally takes place before the occurrence of the key event, the second wave right after the occurrence of the key event, and the last wave some time after the occurrence of the key event. First of all, one can think of a web-based internet survey approach to collect these kind of data. An example of such a data collection have been given in Verhoeven *et al.* (2006). A similar approach was adopted, taking the in-car availability as a case study of a key event. This change compromises of an increase or a decrease in the number of cars in a household or an increase or a decrease in the number of owners of a driving licence who use the available cars in a household. Eligible respondents can be contacted through driving schools. Small incentives were also given. Despite this, our experience was that capturing this behaviour is quite burdensome and response rates remain relatively low.

Taking the arguments given above into account, another solution was implemented to capture travel information in relation to regular and key events. To this end, another data collection tool has been developed with the aim of creating a survey that is able to capture long term travel behaviour of a small sample of persons. The long term survey has been carried out by means of a VEDETT-device, which has been specifically developed for this purpose.

VEDETT stands for a Vehicle Embedded Data acquisition Enabling Tracking & Tracing device. It consists of a basic structure, which can be equipped with several other functionalities. The main functionality of the apparatus is data logging, mostly vehicle parameters but these can optionally be extended with location data. The built in memory used to store the data, can vary in capacity depending on the requirements. The VEDETT is installed parallel to the Controller Area Network (CAN) of the vehicle. This configuration allows to monitor and log virtually every electrical signal that passes through the CANBUS. These include parameters as travelled distance and vehicle speed, but also other parameters as fuel consumption, chosen gear, engine revolutions per minute, engine temperature and others. This offers, among others, the possibility to determine the driving behaviour of the driver. For the purpose of this study, the VEDETT tool is also equipped with a GPS-based element. The VEDETT is equipped with GSM based communication technology (GPRS) and can be optionally be equipped with wireless local area network modem (Wi-Fi). The logged data can this way be transmitted to a central data collection point. This transmission can be performed on a real time basis or in blocks, for example during the night when mobile communication activity and costs are low. The integrated GSM technology also offers the opportunity to update the software of the VEDETT from a distance. Software updates can involve a extension of the logged data, the log frequency can be augmented, etc. There is no need to take the vehicle out of circulation to carry out these adaptations.

The system is installed and running on 14 vehicles. After the registration of the trips by means of the VEDETT-tool, the set of data is transmitted to a central data collection point. Every record which is transmitted stands for one trip. For every trip a new set of data is then being generated by processing the logged data: (i) total distance is calculated from the mileage logged at the arrival and departure point of the trip; (ii) average vehicle speed is calculated from the logged speed data and (iii) the co-ordinates of the departure and arrival point of the trip are translated into addresses. The translation of the GPS co-ordinates into addresses is done by reverse geocoding. The accuracy of these addresses depends on the precision of the GPS network. This is currently performed by a trial version of Microsoft Mappoint, but this can be tuned and changed in the future.

The information with respect to the trips are duration of the trip distance of the trip, average speed of the trip, address of the departure point and address of the arrival point. A website application has been developed for the survey participants in order to communicate with the VEDETT device. On the website, the motivations or reasons behind all the trips made by car, can be indicated. In order to make this data collection suitable for use in an activity-based model, additional information is needed from the driver with respect to his/her motivation or reason behind the trip, and the number of passengers in the car. This has to be added manually by the driver. All the other information which is typically needed in an activity-based is accounted for by means of the VEDETT device. A colour code has been administered in order to guide this process (see Figure 2).

The respondent can add the additional information for the trip, or change it if the trip has already been accounted for. First of all he/she has to specify the driver of the vehicle during that trip by choosing from a scroll list containing the names of all possible drivers. Possible drivers are all persons with logins belonging to that car. A separate sheet lists the possible number of passengers. Finally, check boxes indicate the possible motivations or reasons behind the trip.

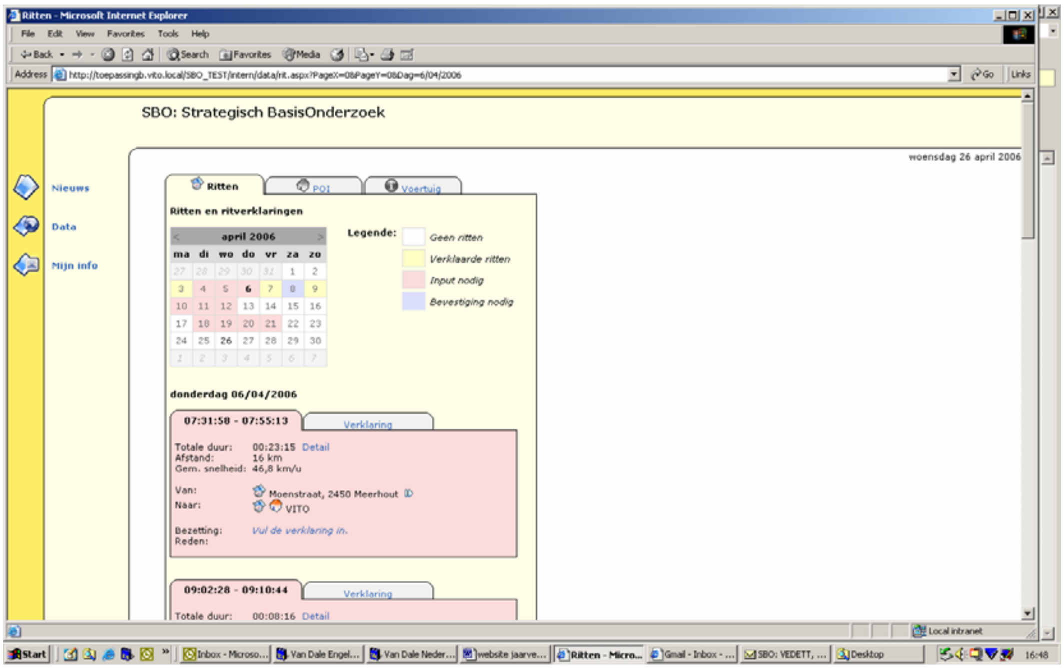

Figure 2. Website calendar and trip information automatically extracted from the VEDETT device

The respondents can choose from the list of activities that was determined during the survey design stage (see section 2).

To minimize the burden for the participators in the long term field trial, the website has some additional functionalities. First of all, addresses which are frequently visited, can be designated as point of interests (POI's). A specific location can be assigned to the addresses: e.g. 'home', 'work', 'grandparents', etc. Every time this specific address is visited, the information on the trip will no longer display the address, but instead call for the POI. The POI's are designated to every set of GPS coordinates which lie within a circle around the coordinates to which the POI was originally designated. Second, it is possible that some trips from two POI's are frequently made, and that the motivation and amount of passengers are always the same. If this kind of trip is made, after a while, the system will fill in the motivation and amount of passengers by itself. A confirmation from the driver will be asked. The self-learning capacity of the system greatly reduces respondent burden. Third, it is obvious that the visualisation tool only captures trips where the car is used as transport mode. For this reason, extra tools like GPS-based personal tracking devices are integrated in the design of the visualisation tool, such that this travel information can be equally incorporated along with the automatic extraction of vehicle trips belonging to the VEDETT tool. More detailed information about this application can be found in Broekx *et al.* (2006).

7. Conclusion

This paper focused on several solutions with respect to the collection of data about emergent activity-travel behavior and dynamically evolving activity-travel patterns. Given the fact that only household travel surveys and thus no activity-travel or panel surveys are available in Flanders, the data collection solutions described in this paper, involve an extensive hybrid, multi-method approach where every component was actually applied and implemented in practice. No detailed results were given in the paper, but a brief overview of the different data solutions needed, facing the problem of collecting dynamic activity and (re)scheduling information, has been provided.

After a discussion of the different survey design decisions, the major data collection of the project was described, where detailed data on activity-travel patterns were collected using a combination of paper-and-pencil and GPS/PDA devices. In comparison with other activity-based studies, the survey period is particularly long, especially in combination with the high number of households participate in the survey. The survey also included questions about activity plans and execution and reasons for change/adjustment and accounted for two members of the household, as opposed to a single representative. Second, a data fusion exercise was undertaken, combining the Flemish travel survey data with the Flemish time use survey data, resulting in a dataset which offers a larger sample of the population. Third, data on traveler strategies to cope with unexpected events during execution of an activity agenda were collected using stated adaptation experiments. Fourth, data on lifecycle events were collected using an internet-based retrospective survey, asking respondents which lifecycle events they experienced and when. Finally, additional data on regular events were captured using a vehicle embedded data acquisition device, allowing for long-term data collection.

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