The reliability and validity of interactive virtual reality computer experiments

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THE RELIABILITY AND VALIDITY OF INTERACTIVE VIRTUAL REALITY COMPUTER EXPERIMENTS

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Amy Ah Wan Tan

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Preface

There is agreement among scholars and practitioners that undertaking the task to understand travel behaviour requires them to understand a complex range of questions about daily life in an urban environment. Urban planners for example would be motivated to study the relation between shifts in peoples' behaviour especially when the travel environment changes. The local context of one's environment and one's behaviour in it forms interactions that give rise to activity patterns that informs about one's activity-related decision choices in that particular space – time settings. Considerable research has been done on human choice behaviour and to relate that to the travel choices people make. Activity patterns reflect the individual's response to everyday needs within the context of existing opportunities for activity participation which in turn are influenced and limited by the social, institutional, and environmental constraints within which behaviour can take place.

Describing people's daily activity patterns may seem straightforward, even trivial. But how we choose to describe and explain the activity patterns depends on what we see as important. In other words, measurement depends on theory. One has to consider whether to attempt to measure and account for all (or at least many of these) elements of activity patterns as a whole, or individually, or both. The former approach presents great difficulty in being operational due to the immense complexity of the multi-dimensionality of activity patterns while the latter approach is an understandably limited analysis. In any case, the basic questions that underscore the design of an activity pattern study concerns whether the information collected is what it sets out to measure and if it is measured precisely.

As fundamentally, what is to be measured is the human being, a singular kind of communication is called for because we are attempting to persuade people to provide information about themselves willingly and these responses must be maximally valid and reliable. Thus, the methods and procedures must incorporate concepts and methodologies of social science. Existing techniques of measurement do not support adequately the socio-psychological theories of the individual environment interaction and the potential causal relationships. New technologies, in particular virtual reality technologies may permit the operationalization of such a notion. This due in part to the potential of being able to "live" inside a virtual environment and experience the participation of activities as one would do in reality. However, the value of such a technique that uses this technology depends on designing capability to elicit the same responses from individuals, as they would make in a real situation. This concerns correspondence issues that must be subject to empirical testing. Admittedly, this is also an important pre-requisite to developing causal models of travel behaviour where the relevant properties of the urban environment form one set of determinants of behaviour.

With increasing use of relevant technology in areas of transportation studies, we anticipate that the knowledge about travel behaviour can continue to expand due to their potentiality in helping researchers find answers to questions that have evaded adequate understanding before.

Amy A. W. Tan

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I wish to express my gratitude to Harry Timmermans, who as principal supervisor, placed confidence in my abilities. He has, on numerous occurrences, supported me to rise to the occasion to meet goals and targets. What I viewed as obstacles and difficulties were often quite surmountable after discussions with him. Likewise, my appreciation extends to Bauke de Vries, as co-supervisor whose oftentimes advice to, “just do it” imbued me with necessary impetus to keep things moving when I stall. Right from the outset, he has facilitated me tremendously, in setting up meetings with individuals and organizations, for me to explore opportunities as to how to proceed with the research. I am grateful to Joran Jessurun who not only provided key support in the programming aspects, but was also a contributor to Chapter 4 and credits are due him for Figures 4.1 to Figures 4.11. My cordial thanks go to Sjoerd Buma, who despite his tight schedule “never forgot” to attend to my technical requests – small and big, paramount of which was the set up of the several computers for the field experiment. Many thanks goes to Peter van der Waerden for his accommodating assistance in my quest for data, and to Theo Arentze for remaining unperturbed whenever I spring upon him with questions. My appreciation also goes to Marlyn Aretz and Mandy van de Sande van Kasteren, for the many occasions of translating from Dutch to English, and vice versa, and to Maciek Orzechowski, for the friendly chats that were outlets of my woes that sometimes one experiences.

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I had started out with not many expectations of what doing a PhD would be like, except that I would do my best. I am sure that my experiences of the twists and turns of events and the encounters with various people during the course of my four years in Eindhoven will always remain with me.

Amy A. W. Tan
Eindhoven, September 2003

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1 Introduction

1.1 Background

The strive towards collecting quality data compels researchers to exercise maximum level of control possible over their data collection. Wherever possible or appropriate a researcher will carry out a controlled experiment, either in a laboratory or in the outside world. The successful design of an experiment is demonstrated by the collection of the right amount of the right type of data to allow the hypothesis to be tested (Morgan, 1983; Diamond, 2001). All experiments, whether highly controlled or not, are designed to perform measurements, often with detailed procedures as to the collection of information. The classic laboratory experiment is in many ways the ultimate form of a controlled experiment. At the other end is the survey which is distinct in that there is no attempt to alter events by intervention but where we are only concerned with which events to observe, and how to record the results of observations. In simple terms, we call any data collection process that is not a controlled experiment a survey. Arguably, there are also examples of survey methods that incorporate experiments such as conjoint analysis that do have a high degree of control.

Surveys are very important measurement tools in transportation research, although it need not be emphasized that surveys are just as indispensable in many other fields of study. The main modes of data collection employed in transport surveys are self-completion questionnaires or diaries, and interviews (both telephone and face-to-face). These modes can either be computer-assisted or not. The difference being that there are potential advantages computer technologies can bring to the improvement of the quality of survey data. Many argue in favour of the automation and intelligence capabilities of computerization, although by no means is it possible to observe or predict a "replacement" of the paper-and-pencil.

De Leeuw and Nicholls (1996) report on the effects of computer-assisted data collection method on data quality. Although not without shortcomings pertaining to individual methods, they found that there are positive advantages, especially in complex questionnaires. A taxonomy of computer-assisted data collection methods can be found in the same report. In general, less interviewer error, recording error, and coding error can be expected from the employment of computers although extra effort (and hence higher costs) is required in the implementation of a computerized survey. However, they are also not without negative impacts. Computer-assisted data collection methods demand over and above that which is needed with a good paper and pencil method, for example in the efforts for testing the questionnaire design and in extra interviewer training. Costs of electronic surveys generally imply high initial investments. There is the unfamiliarity aspect of interacting with a computer interface although the effect may be variable across respondents. The respondents selected must have a computer or have a computerized survey instrument supplied to them. There are likely to arise problems with response rates in populations with low educational and literacy levels because their reception of new technologies tends to lag a little behind. Despite these drawbacks, recent rapid advances in computer technology can only lead to their increasing employment.

In recent years, increasing computer usage in transport surveys can be observed. For example, Bricka and Zmud (2003) and Adler et al (2002) reported experiences with the use of the Internet. Similarly, Adler (2000) explored the use of geographical information systems for geocoding the location of activities, others with instrumented vehicle studies (Wolf et al, 1999). Several computer-assisted tools for collecting activity-travel diaries, such as *Magic* (Ettema, Borgers, and Timmermans, 1994), *Chase* (Doherty and Miller, 2000), *iChase* (Lee, Doherty, and McNally, 2000), *Chase-GIS* (Kreitz and Doherty, 2002) and *REACT* (Lee, and McNally, 2001) have been developed. Also, the potential use of global positioning systems and personal electronic devices has been investigated (Guensler and Wolf, 1999; Draaijer, Kalfs, and Perdok, 1998, 2000; Murakami, Wagner, and Neumeister, 2000; Wolf et al, 2003; Stopher et al., 2003). The findings of these studies seem to suggest that the routes and destinations can be more or less accurately identified, but the activities that have been conducted probably require an additional data collection instrument. Marca (2003) suggested combining different technologies.

It seems no longer an issue when it comes to using the computer to assist in data collection. There is a whole spectrum of computer-assisted methods designed to achieve a high quality of the data assuming that the exact goals of the survey are a priori known. A consequence of the technological advancements in survey research discussed above is the increased validity and reliability of survey instruments. Technology endowed instruments posses the ability to randomize both within and across questions, to control the presentation of stimulus material, to deliver rich multimedia content, and to record a range of possible reactions, thereby facilitating experimentation; increasing the opportunity to use varying and diverse samples of respondents. Similarly, surveys are increasing the inclusion of experiments as an integral part of the data collection. For instance, interactive computer experiments (Ettema, Borgers, and Timmermans, 1993; 1994) can be used for data gathering involving complex tasks such as the elicitation of choice strategies in local environments and behavioural responses to scenarios. This would have not been easily achieved with the paper-based survey instruments. The adoption of developments outside the transportation domain for example, in the computer gaming realm, has also provided constructive hints to augment the quality of travel data gathering (Stathis and Sergot, 1996).

Nevertheless, there is one technology not yet fully explored - virtual reality, where in the most contradictory sense of the word, one can design controlled experiments for survey data collection. More specifically, it is one where we are substituting a controlled environment for the natural world, with as much of its complexities and uncertainties possibly achievable depending on current cutting edge virtual reality technology.

1.2 Purpose of the Study

Virtual reality is a technology that possesses immense potential and is useful in many diverse domains, for example in telemedicine, training, design, manufacturing, games, exploration (hazardous), etc., just to name a few. In the transportation domain, we want to introduce some possibilities that would contribute toward the development of a virtual reality travel survey measurement. We want to explore the certain advantages that can be envisaged from the application virtual reality technologies, and verify if possibly, virtual reality will enable us to collect travel behaviour data in a more valid and reliable manner.

With the progression of survey techniques from the questionnaire to the trip diaries and activity diaries, and then on to interactive computer experiments, the efforts to match the probing capability of a survey instrument to the level of recording complex travel behaviour is on the rise. In our study, by the introduction of virtual reality, we can extend the interactive computer experiments to beyond the use of words to include a wide range of stimulus content. Digital imaging capabilities empower us to manipulate images to alter elements of an environment (urban and/or rural) or generate several representations of scenery with varying attributes. This is therefore advantageous for experiments where different versions of scenarios are presented and adaptive behaviour recorded. In other words, there is a possibility to model a system of interaction between a subject and his/her environment that simulates the degree of complexity of travel behaviour. We foresee that the constraint of conventional techniques that requires one to craft more questions to convey complex ideas and elicit responses can be eliminated

Visualization in virtual reality can be so sophisticated to the state where the imagery is completely identical to that found in the real world such that users cannot distinguish between what is authentic. In addition, the auditory and haptic (touch) interfaces, the other two key characteristics of virtual reality systems although not used in this study, can potentially enhance the communication in the survey measurement process even further. These features can be exploited to improve respondent motivation and involvement. Conventionally, interviewers were central to this function besides purely asking questions and recording responses. Nevertheless, research on the effects of such visual, auditory, and haptic interactions, either on its own merits or in combination with each other, on survey responses is still very much in their infancy.

Along with the advanced visualization and simulation capabilities is the outcome of an increasing level of man-machine interactivity. This involves allowing a feedback loop to the above-mentioned stimulus and reacting to the respondent input. In this way, a "new" method of responding to survey questions is established, where the respondent points on, or clicks on, or otherwise manipulates the imagery.

All conjectures of the advantages offered by a certain technology are constructive only when the hypothesis of superiority of one over another has been tested. Each new technology extends the range of opportunities for improving the quality of survey data, but also introduces new challenges and issues. Therefore it is in important that we can be certain of the aspects of virtual reality that can be efficiently applied to travel surveys. More importantly, as researchers, we need to understand and quantify the effective use of this technology in the application of travel data collection. There are aspects in the design of a data collection instrument using virtual reality that can have influence data quality. We commence on such a study by first developing one design and then examining the impact of this design on data quality.

In order to evaluate the quality of a survey, the estimates of the measurement error has to be based on the true score of the variable. This is an impossible task because one will never know the true value of something one sets out to measure. However, it is possible to compare the result of a survey with other sources that are expected to be closer to the true values provided that the indicators are of the same characteristics.

It must be noted that these sources will be susceptible to errors, as well. One such source selected in our study is the data measured by direct observation and we have assumed this to be free from errors. This description of reality serves as a surrogate true measurement.

The goal of this study is therefore threefold: (i) to specify an appropriate conceptual model for conducting interactive computer experiments in virtual reality, (ii) to develop and design one such system, and finally (iii) to test the reliability and validity of this system by performing method-comparison studies between the data collected using the virtual reality system with the data from direct observation. The resulting degree of agreement between the virtual reality data and the “real” data is further compared with the degree of agreement between data collected using the paper and pencil method with the observed data. The latter comparison will indicate the level of improvement over an existing acceptable method.

1.3 Structure of Thesis

The thesis is organized in the following manner. First, we will introduce some of the terms and their definitions to situate the landscape of data collection and discuss the problems with travel survey data quality. We will review the potential effects that various survey methods can have on the quality of survey results. The different types of errors that compromises survey quality will also be looked at. However, we will examine only one error in detail, chiefly - measurement error. Areas that cause measurement errors are identified and the approaches to minimize them are outlined. In our view, respondents should be well supported in the tasks of providing reliable and valid information. We propose for two strategies to achieve this goal. The first is to remove possible sources of data entry errors and secondly to augment the performance of the respondents by providing aids in support of accurate recall and retrieval of information. The second strategy is central in our proposed concept for data collection discussed in chapter 3.

Chapter 3 describes the conceptual framework in the development of a virtual reality system to address the areas of measurement errors previously identified. The basis for the framework not only rests on aiding people in perpetrating less error with technological tools, but we elucidate on the technology of virtual reality and its relevance to the collection of travel and activity data in terms of accurate recall and retrieval of everyday events and activities. Based on the aspects of the tasks of respondents in activity travel surveys, we propose a design for information retrieval through activity-based recall in virtual reality.

In chapter 4, we first discuss how we specify the virtual reality system by integrating the technological possibilities with the design proposal in chapter 2. Then, we report on the implementation of a system specifically prepared for collecting data about travel and activity schedules.

The experiment to validate the proposed system of data collection is expounded in chapter 5. The procedures of two measurements by: the virtual reality instrument, and the paper-and-pencil instrument are described. There, we will also provide the details on the statistical analysis used in our comparison studies, where the measurements by the two instruments are examined for their degree of agreement to surrogate true values. Surrogate true values are data collected by direct observation of subjects and assumed to be free of measurement errors. In chapter 6, the results and findings of our analysis are presented. Following that in chapter 7, we summarize the results of our study and draw some conclusions. We then proceed to relate our findings to implications on data collection. Finally, we make several recommendations for possible future research.

2 Data Quality of Travel Surveys

2.1 Introduction

The chief aim of a survey is to collect information. More importantly, the information should ideally be valid and reliable. For the very important reason that valid and reliable data is extremely valuable the pursuit for better quality survey continues. Survey problems lead to either of the two effects: bias or variance. Bias is a type of error where there is a systematic tendency for a measurement to be off the mark of what it should be. Variance, on the other hand, has a variable effect that may cause measurements to be higher one time but lower the next.

Data collection in travel research suffers from the same problems that can undermine the quality of the results. These problems may arise at any point during the process of a survey and are unavoidable. Although they cannot be eliminated altogether, a logical strategy is to minimize the occurrence of errors at every step of the survey process. Any allusion to data quality in travel surveys refers to the total survey error, and that means addressing the sources of error from sampling errors, measurement errors, and processing errors. Table 2.1 summarizes the various types of errors typically encountered in surveys. Errors in defining and selecting the sample will bias the results by making the sample less representative of the target population. Even if the sample is correctly chosen, errors can be generated during the data collection process. Once the data have been coded and collated, errors can still occur during the processing stage.

Table 2.1 Possible Sources of Errors in Surveys

Category	Type	Description
Sampling Errors	Non-inclusion	People who should be are not included in the sample; they may be substituted by others thus changing the composition of the sample
	Non-response	Part of the sample do not respond, possibly changing the characteristics of the sample
Measurement Errors	Instrument	The approach of the enquiry might in itself influence the respondents and/or process of measurement.
	Question	The respondent interprets the question in the manner it was not meant to be and/or the question is unsuitably worded or misleading,
	Interviewer	The interviewer makes an error whilst asking the question
	Recording	The interviewer records incorrectly the answer given by the respondent, and/or the respondent makes incorrect entries
	Coding	Data on the survey form are wrongly encoded during the pre-processing stage
Processing Errors	Computational	The researcher makes errors in statistical calculations
	Inappropriate measures	The researcher uses analytical techniques that are inappropriate to the data.

Obviously these three main types of errors are largely human errors. There are several and varied ways for dealing with such errors. The incidence of sampling errors, for example, can be minimized by careful application of sound administrative practices. The efforts to reduce the likelihood processing errors lie in the hands of the researcher. However, it is less well understood how to deal with measurement errors and it is the most difficult area of research in survey design. This type of error forms the focus of our study and we will pay attention to examining the strengths and weakness of previous strategies that dealt with measurement errors with the intention of improving on existing approaches.

2.2 Threats to Reliable and Valid Measurements

Measurements must be reliable and valid in order that empirical generalizations and theoretical models may be derived from them. Reliability can be defined as the consistency or stability of empirical indicators from measurement to measurement. It can be referred to as the precision of a measuring instrument. Validity refers to the whether the instrument measures what it is meant to measure. An instrument can be reliable, but not valid. This is easily understood when a ruler of 1m is not 100cm but 96cm is used to measure the height of a young child who is 82cm tall. If upon repeated measurements this ruler consistently returns the same score then the reliability of the ruler is not in question, but the height of this child will be systematically underestimated by 4 cm for every 100cm. At the same time, Pedhazur and Schmelkin, (1991) warn researchers not to overlook that fact that "reliability is a necessary but not sufficient condition for validity." That is, a measure cannot be valid if it is not reliable but being reliable is not a guarantee of validity for its purpose.

Various procedures for assessing the reliability of measurements (Carmines and Zellers, ; Pedhazur and Schmelkin, 1991) have been formulated, mainly derived from the classical theory or the true score theory since it was proposed by Spearman (1904). Fundamentally, an observed or obtained score on an instrument can be divided into two parts.

$$\text{Observed Score} = \text{True Score} + \text{Error} \qquad (2.1)$$

This classical theory of error could lead one to assume that a measurement that produces fewer errors automatically has a higher reliability. As was noted earlier, measurement errors may emanate from various sources and different definitions and conceptions of error have led to different approaches to the estimation of reliability. Measurement theory assumes that the errors are random and the qualities that are measured remain constant. The process of measurement is basically ignored and this assumption is unrealistic since data are primarily collected through experimentation or surveys. At the same time, it is also just as obvious that the true score of a measurement is unknown. It is theoretically meaningful but cannot be used in any real practical sense. Then again, it is possible to compare the observed score to other sources closer to the true value although these sources are also not invulnerable to errors. So, a solution to (2.1) is possible with further assumptions.

Likewise, there are several dimensions to validity (Carmines and Zellers, ; Pedhazur and Schmelkin, 1991). In addition to being internally consistent and stable, measurements must demonstrate good indicators of the construct of interest. Due to the specific measurement procedure used, certain aspects of the procedure will influence the respondent's responses, to a greater or lesser degree depending on the aim and its contextual characteristics. But because it is not possible to know whether the measurement represents all the dimensions of the construct, one has to assume that all the measured dimensions represent the one construct. Where, a construct can be measured independently by several methods, estimates of the construct validity can be assessed by showing that the methods of measuring the same construct are strongly correlated with each other. The degree to which the two or more methods converge is the construct validity. For example, we can obtain the validity of an instrument by using another instrument that is proposed to measure the same construct and look for a correlation between the resulting outcomes of the two measurements. When one chooses to examine a measure or procedure, researchers are also preliminarily concerned about its face validity. What may appear to be a worthwhile study based on face value or intuition may sometimes be overturned upon asking, does it seem like a reasonable way to gain the information one is attempting to obtain? Does it seem well designed? Does it seem as though it will work reliably? Unlike construct validity, face validity does not depend on established theories for support (Fink, 1995).

Thus, errors or more precisely, biases can be estimated although it is of more importance to transportation researchers to reduce the occurrence of errors through better design of data collection methods. Measurement errors encountered in travel surveys (Table 2.1) can be attributed to the respondent and his interaction with the instrument that is designed for a specific purpose.

2.3 The Respondent

In our research topic, the "thing" we are trying to measure is the human being, the most complicated thing in the world. Travel behaviour is in itself a complex process, being the inevitable consequence of the pursuit of one's activities. If researchers desire to collect travel behaviour data with a survey, then a special kind of communication is called for because we are attempting to persuade people to provide information about themselves willingly and these responses must be maximally valid and reliable. If the communication is imperfect, the result is that either one or more of the three types of errors described in the previous section are likely to occur.

It is known that the various survey methods introduce errors by both the interviewer and the respondent. One can choose from numerous survey methods that belong to those that are either self-administered, or interviewer-assisted and they can either be computerized or not. Self-administrated methods such as mail surveys depend on the reading and comprehension skills of the respondents, and that is highly variable. In the use of a diary or questionnaire, it is very difficult to obtain any independent verification of what is recorded in the diary or questionnaire. There may be the incidence of selective reporting out of fear, or awe, or from the desire to please. In interview-assisted methods, bias can occur in the selection of interviewees. In face-to-face interviews, a tendency by the respondents to give the answer that they think the interviewer would like to hear is probable. Furthermore, the interviewer may make straightforward errors in asking the questions or more commonly, in recording the answers. Telephone surveys are subject to the mutual comprehension between interviewer and respondent and can only really employ simple questioning. These are just some of the examples of measurement errors that can be encountered. Not to mention that we have not distinguished the discussion between the different survey instruments designs and the questioning formulation. One can, therefore appreciate the challenges when faced with the issue of data quality.

In the progress of the pursuit for higher quality in travel survey data we have observed that the emphasis on collecting more data and at higher levels of detail has been taken as an indication of a higher quality; the higher number of reported trips, the better the data (Clark et al., 1981; Stopher, 1992). This is a reasonable but inadequate stance. Ceteris paribus, we prefer to expand the focus to reducing the task difficulty faced by respondents. Task difficulty can greatly influence the reliability and validity of the collected data. To produce an accurate answer to a question from a survey, the degree of task difficulty the respondent faces should ideally be as low as possible. This is not easily accomplished in surveys on travel behaviour where there is a tendency to use long and complicated designs. The reason for this is because of the increasing levels of sophistication in data collection techniques in attempts to parallel the increasing sophistication of forecasting models in planning and research. For example, the instrument of the diary is complex and is designed as such because of the desire to capture the complexity of travel behaviour. Contrary to expectations, they have generated better results than simple questionnaires (Clark et al., 1981; Stopher, 1992). It becomes apparent that in the domain of data collection on travel behaviour, simplification can lead to bias. Therefore, by reducing task difficulty we do not mean simplification of questions but we mean facilitating and enabling respondents to produce valid and reliable answers to complex questions through techniques that improve respondent motivation, involvement and engagement, as well as through error avoidance. In this section, we place the respondent at the forefront and examine ways that can support this notion. We can expect that increasing the complexity of the survey instrument increase respondent burden both in the aspect of question difficulty and time pressure. We take upon this task by both looking at the occurrence and avoidance of human errors, and the influence of activity-based travel survey methodology on the quality of data collection.

In order to avoid errors, we first need to look at where respondent can introduce errors or be induced to provide errors and we find that this situation arises solely from the measurement stage. Measurement errors will cause the observed or reported value to be different from the true values. Such errors are a consequence of missing and incorrect data.

Respondents can exhibit the following kinds of errors on their own or be influenced to do so:

- Failing to read question correctly
- Failing to understand and comprehend the question correctly
- Failing to understand the interviewer correctly
- Failing to answer question correctly
- Failing to answer all questions
- Failing to recall and retrieve the correct information
- Recalling biased information
- Perform selective memory (unconsciously)
- Perform selective reporting (consciously)

The above list should not be taken as exhaustive; instead it is indicative of the potential problems that data collection can face. In actual fact, it is not clear to a researcher when assessing the measurement errors, which of the above factors or combinations of them are the causes. However, there are logical strategies to reduce their occurrence with varying degrees of success in some but not all of them.

In travel surveys designs, the use of the paper-and-pencil method of data collection is common acceptance and widely applied. Questionnaires and diaries fall into this category. But this design also poses the greatest threat to quality from the point of view of recording errors. Only, in the case where an interviewer is not involved is the possibility of failure to comprehend the interviewer correctly eliminated. All other respondent errors previous listed are probable and non-preventable. With the introduction of computers, however, more respondent errors can be avoided. The use of computers to collect data through automation has great potential in increasing accuracy in many aspects such as reducing errors in data entry, in making consistency checks, in ensuring accurate following of skip patterns, in eliminating inconsistencies such as interviewer bias, and in the need for pre-processes in coding. The paper-and-pencil method is popular because it is the most logical way to collect information. Nevertheless, Stout (1981) expressed enough confidence in the data quality of computer-assisted methods as to put their acceptability over paper-and-pencil data gathering techniques, while Saris (1991) argued for its replacement of a paper questionnaire. Studies (e.g. Kalfs, 1993; 1995; De Leeuw, 1994; De Leeuw and Nicholls, 1996) have shown that the computerization is strong in tackling the respondents' failure to answer the questions correctly assuming that there is no reason for them to intentionally report selectively. They are also prevented from leaving questions unanswered. However, it is not common to find computerization methods that helped to prevent failure in comprehension, or retrieval and recall.

2.4 Activity Theory and Travel as Complex Human Behaviour

Since the 1970s, there is the trend towards data collection based on the activity-based travel approach; a fundamental notion to the understanding that travel is consequent to one's need to engage in activities. The so-called approach to understanding travel behaviour emphasized the need to view travel as an integral element of an activity pattern (Axhausen and Gärling, 1992; Ettema and Timmermans, 1997). Rather than focusing on trip making per se, the base of enquiry includes the role of travel in daily life – the forming of a sequence of events set in space and time. Activity patterns in the activity approach thus reflect an individual's response to needs and wants that may arise from psychological, social or other reasons (e.g. Bhat and Koppelman, 1999; Timmermans et al., 2002).

Thus, in the collection of data about travel behaviour, it has been recognized that travel behaviour is complex; arising out of the interplay of one's personal and household characteristics, his/her perception of the environment, the situational conditions and constraints, transportation system properties and policies (e.g. Fox, 1995). In such a context, the desired information is about the choice dimensions and explanatory factors underlying activity patterns. Hanson and Burnett (1981) categorized travel behaviour as complex behaviour as opposed to simple behaviour because travel patterns are sequences of events instead of a single observable event.

They point out that it is the inherent multi-dimensionality of an individual's daily travel pattern that poses a challenge to any researcher wanting to capture their full complexity in any measurement devices. Travel behaviour, like many other phenomena relating to human behaviours and decision-making, is a dynamic process and requires an accounting from its cognitive basis. Opportunities for activity participation are influenced and limited by social, institutional and environment constraints (e.g., Hägerstrand, 1970). Participation in activities are decided subjectively and needs to take account an individual's perception and choices of opportunities. Choosing activity locations, route choice and mode of transportation require a certain amount of stored environmental information. Given objective constraints such as physical locations and existence of facilities, their opening hours, availability and suitability of transportation and the like, participation in any kind of activity further depends on the subjective constraints such as attitudes, values, habits, and social roles (Hills and Mitchell, 1981; Havens, 1981; Tisher, 1981; Bichon and Benwell, 1981). As the relevant properties of the urban environment make one key determinant of the many opportunities that confront people when they make travel choices, there is consequently considerable value in observing if the activities of people change due to external environment (for example in the transportation system) or to internal factors.

In our study, we do not further argue for the use of the activity approach in order to understand complex travel behaviour in cities. Instead, we focus on ways to measure the activity pattern without diluting the complexity in the process.

2.5 Measuring Observed Activity Travel Patterns

In the measure of observed activity travel patterns, respondents are required to provide information identifying the different dimensions of daily travel pattern: the activities, the time schedule of those activities, their geographical locations, the modes and routes used to access those activities. These dimensions can be measured by two approaches. One approach is to measure the components of the activity pattern separately. The other is to treat the pattern as a whole. But because of the wide range and complexity encompassed in these dimension, Hanson and Burnett (1981) advised the use of both approaches as the knowledge on relations between complex travel and independent variables to understand the determinants of travel are limited. Jones (1979) identified four data collection procedures as being of potential value in activity-based travel studies: the diary, unstructured interviews, gaming techniques, and participant observation. According to Arentze et al. (1997), the three most viable methods are diaries, interactive computer experiments and conjoint experiments. These recommended methods appear to have characteristics that are differentiated by whether interactivity is incorporated. Diaries and participant observations are based on pure reporting, while unstructured interviews, gaming, conjoint experiments, and interactive computer experiments are interactive techniques. The dominance of interactive techniques may perhaps be explained by the value of introducing an additional ability to systematically obtain data on the respondent's choices and reactive behaviour that possesses potential explanatory power. This is an approach that attempts to consider many dimensions of activity patterns by concurrent examination of interaction among them.

The use of the observation method has been used in human activity studies but is rarely found in the travel context. In general, it can be used in two ways: observations obtained from laboratory experiments and real-world observations obtained from actual travel. In laboratory experiments, the conditions under which the respondents are observed are given, (e.g. choice situation, choice sets, attributes are controlled by the researcher). In real world observations, behaviour has to be observed under existing real conditions. Diaries, in contrast, has a long tradition in the survey of travel (Arentze et al., 1997) and can unquestionably be used to record what respondents are doing, with whom, when, where, and why, that form the main choice dimensions and explanatory factors of an activity pattern. Based on an extensive literature review, Arentze et al. (1997) dwelt on the diary format, detailing the pros and cons of the types of diaries, decisions on time horizon, recall period, frequency, questioning format, and the form of its administration (paper-and-pencil or computer), all of which are factors that are likely to influence the quality of the data.

In the comparison between the diary and the questionnaire, the diary is likely to outperform the questionnaire in terms of the validity of trip and activity data because the relationship between making of trips across some time horizon can be more systematically represented in a diary (see also Clark et al, 1981; Meyburg and Brög, 1981; Stopher, 1992). The use of full activity diaries, despite placing a high demand on respondents, has stood out among the various types of diaries (e.g. trip-based diaries, out-of-home diaries, activity diaries), as the best choice to capture detailed information about people's activities and related travel. High data quality however is not a guarantee unless the other aspects of the instrument design mentioned are also optimally incorporated (see Kalfs and van der Waard, 1994). Most activity diaries to date have used the paper and pencil format (Kalfs, 1993; Atentze et al., 1997). Hence, the diary framework is essentially static; it can provide a basis for discussing historical change but if we want a simultaneous observation of responses to what people will do due a change in their choice of opportunities for activity participation and why they did so, then a shift in the approach is needed. Jones et al. (1983) advocated the need for a methodological approach to examine the dynamics of change. The use of interactive methods can provide some form of direct dialogue between what is observed and the explanations behind the choices.

2.6 Interactive Techniques

A review on types and use of interactive travel survey methods can be found in Jones (1985). We find interactive methods that use gaming strategies and experimental simulations have been employed to help explain travel decision-making. For example, the Household Travel Simulator (HATS) (Jones, 1979) has been demonstrated to have positive influence on the data collected by tapping on interactive interviewing with the aid of visual diagrams. It was possible in HATS to elicit insights not previously expected or immediately obvious. In stated response surveys, where interactivity is also a key characteristic, they prove to be successful in eliciting behavioural outcomes or constraints or both. Lee-Gosselin (1995) classified

Table 2.2 A Taxonomy of Stated Response Survey Approaches

		CONSTRAINTS (expressed as attributes: personal/household/social/spatial/supply, etc)	
		Mostly given	Most elicited
BEHAVIOURAL OUTCOMES	Mostly given	STATED PREFERENCE (focus = tradeoff, utility) "Given the levels of attributes in these alternatives, which would you prefer: [A] ……? [B] .….? Etc ….?"	STATED TOLERANCE (focus = limits of acceptability, and threshold for change) "Under what circumstances could you imagine yourself doing: [r1] …..? [r2] ……? Etc ….."
	Mostly elicited	STATED ADAPTATION (focus = reactive and trail behaviour; problem-solving rules) "What would you do differently if you were faced with the following specific constraints: [detailed scenario]"	STATED PROSPECT (focus = learning process, information seeking; the imaging, formation and testing of choice sets; metadecisions) "Under what circumstances would you be likely to change your travel behaviour and how would you go about it […broard context]"

(Source: Lee-Gosselin, 1995)

4 approaches to stated response methods (see Table 2.2) according to whether the constraints and behavioural outcomes were mostly given or mostly elicited. All 4 approaches use interactive methods; in all SPro, most ST and SA, and some SP approaches. He recommended that the more complex the linkages between constraints, the more you move towards SA and SPro, in order to observe accommodating and adaptive behaviours to changes in constraints. Indeed, insights gained from the use of sophisticated interactive techniques of this type are likely to assist with explaining the changes in activity patterns that takes place as a result of varying social, institutional and environment constraints. The stated response method has contributed to this area by offering the capability to collect information about behaviours that occur infrequently or are otherwise difficult to observe. It's

ability to control co-varying factors, and to distinguish between genuine change as opposed to random variation in behaviour (Wang, et al., 1997) was a boon to researchers. The main difficulty for respondents lies in the imagination of circumstances and scenarios with which they are not familiar with or have limited knowledge of.

The conjoint approach assumes that the decision making process about choice alternative can be uncovered by asking respondents to choose among a controlled set their most preferred alternatives. It is postulated that choice alternatives are evaluated by individuals who will place a weighting importance the attributes of each choice according to their value system, motivation, knowledge about the attributes and the alternatives (Wang, D., 1998, Timmermans, 1982). Conjoint experimental designs are based on the assumption that the estimates of the interaction effects between preferences for participation in activities at different moments in time can be supported, for examples the sub-choices of timing, activity type and destination are interrelated and will influence the choice of the complete activity pattern. Representation of the co-varying factors of space-time constraints and attributes of destination in a simultaneous manner is not only difficult to achieve but also, the abstraction of these components of activity pattern choices poses comprehension and attention problems to the respondents.

The introduction of computers to experimental strategies may provide a potential solution to the abstraction of complex real travel. Computers have served to further augment the interactivity of the activity approach as demonstrated in the gathering of activity scheduling heuristic data (Ettema et al., 1996; Kalfs and Saris, 1997). The key feature of interactive computer experiment is the possibility to create a system of communication with the respondents such that their reactions to varying constraints is dynamically reflected and a feedback loop is established. An example of an interactive computer experiment is MAGIC (Ettema et al., 1993). In this system, individualized representations of the respondents' cognitive environment and their typical travel activity patterns in it are captured by a series of questions. This is then used to investigate their scheduling strategies in response to changes in the urban environment, transportation systems, or personal and institutional temporal and spatial constraints. Based on the experimental design, environments are created to meet the conditions and respondents are invited to make a series of interrelated choices. The developers of MAGIC have concluded that interactive computer experiments are potentially valuable in collecting activity-related information on individual's scheduling and rescheduling although they could not be certain that the behaviour recorded under quasi-experimental conditions are reflective of real world choices. They cautioned for the testing of tasks that are not representative of those found in the respondents, as the reliability and validity of the responses could be questionable.

The foregoing literature demonstrates that the effort to incorporate interactivity into the probing process to understand travel behaviour in its complexity is a constructive strategy, with interactive computer experiments at the top of the potential list of methods. However, the key question remains as to this method's ability to elicit from the same respondent the same responses, as he would make in a real-world situation. In the context of collecting data on travel patterns, Clark et al. (1981) concluded that the natural storing of information about daily events and the planning of activities can inform us on the retrieval of information on the day's activities. Furthermore, the positive relationship between task difficulty and recall error can be reduced by aided recall procedures especially if they are tailored to the actual situation experienced in the past (van der Vaart, 1996). In our opinion, central to the process of a survey is the level of psychosomatic engagement of a respondent because the task of providing a valid answer to a question involves, in often cases, interpretation in one's own (social) context, and recalling information from memory. What is especially needed to further improve the validity of interactive computer experiment responses is to tap on the emerging cross-disciplinary collaboration between (social-) cognitive psychologists and survey method researchers. These functions can be more supported in individuals to increase survey response validity. We presume that a higher level of engagement with the survey leads to higher quality result. Brög and Erl (1980) suggested that a chain of "objective circumstances – personal perception – subjective situation – individual decision – behaviour" must be reenacted to understand travel behaviour. It is therefore valuable to include cognitive processes in the study of better ways to improve survey practice. Koriat and Goldsmith (1996) pointed to Locke (1690) where perception has been viewed alternatively as passive reflection of the external environment, to Neisser (1967) where perception is an active construction of reality; to Malcolm (1977) where memory may be conceived as mirroring past experience, to Neisser (1967) where memory is an active reconstruction of past events. These concepts are generally not concerned with how much of the impinging information is remembered (perceived), but rather with the correspondence or "goodness of fit" between what is remembered and what actually occurred.

2.7 On Reconstruction of the Past

We have put forth that the social-cognitive framework can serve our quest to address respondent failure to recall and retrieve correct information about their activities participation and consequential travel, yet the process of recall memory admittedly suffers from its own errors. Forgetting, i.e., simply not being able to remember a certain item is a common occurrence. Parallel to this is the inability to distinguish between items because specificity of time and places is lost. Both types of forgetting will lead to under-reporting of events. Fortunately, in the area of survey methodology, it is generally claimed that 'forgetting' does not mean a loss of information from memory, but only an inability to retrieve the information (Laurent, 1970), and there are means to counter such failing episodic memory. Ideally, it would be preferable that respondents fill out the questionnaire or diary as and when they travel or conduct their activities. However, this is a demand that not many people will find easy to comply, if they remember to do as requested. It has been recognized by survey methods researchers that respondents are likely to remember recent events and states better than distant ones. A considerable amount of empirical studies showed that recency is in fact positively related to the accuracy of retrospective reports (Sudman and Bradburn, 1973). In practice, one can realistically expect that most respondents would fill out their diary or questionnaire at the end of the day at best. This means that the information provided is typically based on recall. The regrettable situation of one's amassing of data after the lapse of time is highlighted in Bernard et al. (1984). Since this is inevitable, we strongly recommend strategies to enhance recall.

Loftus (1982) demonstrated that when people try to recollect memories, the process of reconstruction plays and important part. The key theory on reconstruction of the past is the schema theory. According to this theory, what people remember is influenced by their prior knowledge, which is organized into independent sets. Memory representations of new experiences is assimilated into existing schemas and encoded. Information related in schemas is retrieved in accordance with the relevance and is thus easier to recall.

Schank and Abelson (1977) further added to the schema theory by identifying specific types of schema called scripts. Scripts refer to instances of detailed events, like going out to dinner, or taking the children to the zoo. A script describes the sequence of actions that are involved in such an event. Going out to dinner, for example, may have the following sequence: discussing with companion about desirable venues, making reservations by telephone for a table in a restaurant, getting dressed for the occasion, traveling to the restaurant, ordering the meal, eating dinner, paying the bill, leaving the restaurant, traveling to home. While the schema and script theory mainly focused on routine events, when it came to unusual and atypical events, Nakamura, et al. (1985) came up with the schema-plus-tag solution that explains why those deviant aspects are very memorable.

Schema based reconstruction has advantages for memory storing and retrieval but distortions can result from such a constructive process brought about by an individual's prior knowledge and expectations. New information and external influences can be injected into a reconstruction inducing distortion, for example, if default values of schemas are filled in for gaps in memory, or additional aspects of an event are inferred from a schema when they were actually not present (Diges, 1988; Loftus, 1979).

In our scrutiny on other ways of stimulating the respondent's memory, we bring the reader's attention to the study by Sudman and Bradburn (1974, ch.3) where they described the development of two types of questioning procedures to reduce recall loss: aided recall and bounding. Aided recall procedures uses checklists, multiple questions, and longer questions to stimulate memory, in the attempt to reduce omission or distortion errors. Bounding, by clearly marking the recall period the respondent has to report about, aims to prevent respondents from erroneously situating events within, or outside, the recall period. A famous example in the use of landmarks during recall is described by Loftus and Marburger (1983) where they used the eruption of a volcano that happened six months ago as a bounding technique to ask respondents if they had been a victim of crime since then. The 'landmark question' (since the eruption) gave more accurately dated events than when an exact date (since October 1) and when a duration (during the last six months) was used. Personal events as landmarks gave the best results (Baddeley et al., 1983).

In addition to using a time marker but we want to add that physical landmarks are just as important in the process of recall. The association of an activity to a specific location is a very relevant link that most people make. Several studies (Lynch 1960; Timpf et al., 1992; Tversky 1993) showed that most people use some kind of mental model of a region or of a portion of a city in order to generate and describe a route: they mentally visualize the salient elements characterizing the path when asked to describe their course covered. Since we know that people rely on mental imagery, we can hypothesize that augmenting this task by providing the matching imagery reduces memory recall and retrieval difficulty.

As a final note in this section on the topic of theories on reconstruction of the past, there is a distinction in the order of recall - forward and backward recall. Forward recall means that a sequence of events or states is recalled by starting to recall the most remote event in the past, and then proceed to recall the subsequent ones in the forward direction. In the case of backward recall the sequence is recalled by starting with the most recent event or state, and the next one before that, and so on, going backward in time. Results from a laboratory experiments shows that it is easier to recall events from an episode in the order in which they were experienced than in the reverse order. The order in which events or states are experienced is also the best order for retrieving (Kroll and Ogawa, 1988; Srull and Wyer, 1986).

On the whole, the reconstructive approach to memory that emphasizes the active role of the rememberer in creating meaningful and organized representation of past events is useful to understand ways in which this representation can deviate from reality (Korait and Goldsmith, 1996).

2.8 Summary

Collecting travel behaviour data can prove to be a challenging task to any researcher. On the one hand, any survey is bound to have weakness of measurement error and, on the other, one has to have the confidence that the data that is being collected is exactly what it sets out to measure. The responsibility for the quality of the data collection lies primarily on the researcher to pay due consideration to the many sources of errors that can arise.

Many improvements in data quality can be traced in the history of the progress of survey practice. They can be categorized as coming from the two angles. Firstly, data quality can be improved by reducing the opportunities of making errors, by the effective use of computer technology for controlling human errors. The aspect of failure in comprehension, or retrieval and recall however, is not addressed satisfactorily. Secondly, optimizing the design of questioning formulation in accordance to the socio (cognitive) framework reduces respondent task difficulty. Aiding the respondent in accurate recall and retrieval of relevant information about their travel patterns creates opportunities for increasing the validity of response data. The response to incorporate elements of the complexity in making travel decisions by collecting data based on an activity approach may provide more valid data as it is a close correspondence with natural planning of and execution of travel. Furthermore, it seems to be worthwhile to investigate the use of interactive techniques to facilitating and enabling respondents to produce valid and reliable answers to complex questions through motivation, involvement and engagement. In interactive computer experiments is the possibility to create a system of communication with the respondents such that their reactions to varying constraints is dynamically reflected. Elimination of infeasible choices in the space-time constraint can possibly be achieved

We have advocated for social-cognitive framework to address respondent failure to recall and retrieve correct information about their activities participation and consequential travel. Where respondent comprehension is concerned, it can be expected that respondent conceptualisation of the changes in a current existing environment on paper-and-pencil is difficult. Increasing the use of interactive methods such as visual aids reduces the abstraction level of interrelated choice situations and can lead to improved comprehension.

In this chapter, we have reviewed data quality problems in travel survey in particular with the reliability and validity of response data. In the next chapter, we will proceed to make our proposals not only to augment what solutions are already in place but also to address those that have not been adequately dealt with. In the subsequent chapters, we will provide a test of the applicability and usefulness of our proposed theoretical notions and report on our empirical findings.

3 Conceptual Model

3.1 Introduction

In the last chapter, we have examined the issues in the pursuit of collecting higher quality data in travel surveys. To add our point of view, there is a need to move away from merely the accounting of the numbers of errors perpetrated by respondents, and more towards enhancing the validity of responses. The use of activity-based methods in attempts to capture travel behaviour in its full complexity, such as activity diaries and interactive methods of data collection has resulted in an increasing the quantity of data with a higher level of detail. The activity patterns measured by the activity approach reflect the travel needs of individuals within the context of existing opportunities; and allow the consideration of the choices open to them. But by no means can we take it to mean that the evaluation of these choices are easily understood, nor do they reveal optimal or desired outcomes of travel behaviour. Introducing interactivity in the probing process in the context of realistic ongoing societal and environment change as constraints may increase explanation in travel choice process. The use of a computer potentially handles interactivity better than the paper and pencil and can be implemented with different levels of control; especially where verification and consistency checks of answers from respondents are easily handled. Furthermore, we may also expect that it is feasible to conduct real-time checks on the realism of anticipated responses in methods using interactive technique. But, even with electronic means, whether electronic diaries or interactive computer experiments, the main task of the respondents is still basically reporting. We require respondents to report on: their activities, where they will be conducted, when, for how long, with whom, and with which transport mode. The key element in this reporting process is the recall of all activities, and their associated aspects and details. As previously mentioned, there is no unequivocal strategy on how failure of the part of the respondents' to make accurate recall and retrieval of information can be circumvented. Where the level of abstraction of choice opportunities is low, and if further complicated by varying interrelated choices and their attributes, is likely to lead to poor comprehension and hence incorrect responses.

This is where we think that virtual reality can come into play. In particular, of interest and concern to us is how much more accurate and precise of the reporting of previous (everyday) events can be achieved in the enhancement of the recall process by situating respondents in a virtual environment where the activities were conducted. We have chosen, hereafter, to focus on interactive computer experiments and explore its potential by introducing an added element of virtual reality. Virtual reality decreases the level of abstraction of choice situations due to the nature of reality simulations. Not only is the visualization of a choice situation possible but also the respondent can actually experience it before his reaction is solicited. We will examine several methodological underpinnings that support this notion and they will be discussed in the next chapter.

In the following sections, we discuss how the aspects of establishing the chain of "objective circumstances – personal perception – subjective situation – individual decision – behaviour" that allows for people to reconstruct the past by the experience of re-enacting their behaviour can be accomplished with the use of virtual reality technologies.

The central concept underlying our research is to validate the belief that the technologies of virtual reality can contribute toward the collection of data about travel by providing situating contextual environments as a trigger for retrieval and recall. In particular, we set out to ascertain if the quality of the data collected employing this technology by investigating out-put bound correspondence (or "goodness-of-fit") with reality and compare this correspondence with that obtained from a conventional paper-and-pencil method.

3.2 Prospects of Virtual Reality

Virtual Reality is a perceived state whereby the implemented model in a computer replaces the real world. Several prospects of virtual reality can be aptly applied to improve the interaction between the respondent and the instrument of measurement. Firstly, being a simulation of the real circumstances it may be a less threatening environment because respondents are less self-conscious than in an in-depth interview; yet it can be in itself a stimulating experience. In general, individuals respond better when they are under less pressure, have more time to consider their views, and may be prompted to consider viewpoints or express opinions that may not emerge so readily. Furthermore, we like to think that the novelty and dynamics of the virtual reality technology should be able to sustain interest and concentration throughout an interview that could last for longer than a normal attention span dictates as effective. These aspects can be aimed at enhancing the motivation of an individual.

Secondly, virtual reality is especially strong in the manipulation of graphical content. The use of visual aids as a component of the tool can be considered a structuring mechanism. In particular, virtual reality enhances the subject's experience of an environment by the means of immersion and explicitly cutting off external distractions. Although visual aids is an important component of interactivity, we want to point out that the use of a visual technique does not automatically make it an interactive measurement device – it is the responsiveness to the circumstances of the individual. Providing such a flexibility of this nature allows for adjustment of the exploration process through re-ordering the questions to make the experiment relevant to the respondent. This presents an opportunity to enhance the interviewing (probing process) to take account of the insights that emerges even during the course of an experiment. An essential idea of interactive computer experiments is to automatically collect contextual information about daily human activities and their characteristics, and to use this information to help the later recall of past activities. The importance of contextual information in assisting the recall of activities is well known in the human memory literature (e.g., Smith, Glenberg & Bjork, 1978; Tulving, 1983).

Thirdly, a virtual environment provides a means to define complex travel dependent variables more realistically, more rigorously and with a greater sensitivity to the geographic (space and time) information than now is the case. Admittedly, relevant properties of the urban environment as one set of possible determinants of behaviour can be mirrored none better than in virtual environments. The environmental representation used in virtual reality can incorporate features of the activity framework (see section 2.4 and 3.5 on Activity Theory) including the deductive logic of the time-space format that aids in the comprehension of circumstances. We hypothesize that the use of virtual reality technology supports human memory by increasing the ability to recall or retrieve information by the visual stimulus of the environment that acts as a (passive visual) prompt, and serves as an aide-memoire.

Fourthly, we draw also on evidence that time-based contextual information is important in the way the various memories are structured. Barsalou (1998) described a theory of memory in which temporal cues link various memories. Time in virtual reality can manipulated easily, because it can be compressed (or relaxed) according to needs. Time in virtual reality can be simulated for both the past and the future.

Last but not least, the experience of navigation through an environment is only possible in virtual reality; only imagined on paper-and-pencil. In virtual reality, the flow patterns in one's visual field alone are enough to indicate how a person is moving in the environment. Furthermore, the concept of wayfinding expresses that recognition of locations (in our case in the virtual environment) closely approximates the way we deal with movement within familiar environments (Tulving, 1983; Gärling et al., 1981; Lynch, 1960).

3.3 Virtual Reality and the Concept of Presence

There are two psychological states present in a person that are advantageous to researchers when it comes to conducting a survey. Engagement and involvement are essential characteristics every surveyor would like to see in every respondent. In reality, this is not the case for a great majority of respondents. They can however, be influenced to be. This task is currently taken up by interviewers who themselves may have to be motivated.

In order to create a situation in which a respondent will be absorbed in the tasks of providing survey data, we presuppose that the experience of being present in a previous circumstances, back to the "where, when, what, and how" of one's travel and activities, can optimistically banish problems of lack of attention, and perception difficulties, all well-known to be associated with the filling out of travel diaries since it is commonly considered as boring tasks.

The technology of virtual reality is known to have the most potential in inducing experience in users. Virtual reality can be said to occur if a user has the experience of being present somewhere where he is not. Virtual Reality presents itself as the new media where a respondent can be immersed in the illusion of interacting within the contextual environment. However, high expectations of this new media and its valuable characteristic concept of presence can distort the efficacy of employing it as an option (to the extent of novel substitution) to the traditional methods of carrying out travel surveys. Therefore, it is imperative to know the effectiveness of the new media in our proposed model of data collection.

Of the six aspects of presence identified by Lombard and Ditton (1997), we identify "transportation", "realism", and "immersion" as immediate and relevant for our purpose. We reiterate the relevant aspects here in the Table 3.1 that describes the situation in which the inducement of experience in users of this media would occur. They are addressed in detail at the stage of the design of the virtual reality system for our purpose.

Table 3.1 Aspect of Presence and its Occurrence (Source: Lombard and Ditton, 1997)

Aspects of Presence	Occurrence
Realism	" Perceptual Realism", the objects in the program look as one would expect if they did in fact exist
	"Social Realism", the extent to which portrayal is plausible or "true to life" in that it reflects events that do or could occur
Transportation	"You are There", feeling like you are present in the environment generated by the computer
	"It is here", watching a television programme, we feel not so much that we are being taken out into the world, as that the world is being brought to us
	"We are Together", an experience of a shared space
Immersion	"Perceptual Immersion", the degree to which a virtual environment submerges the perceptual system of the user
	"Psychological Component", when users feel immersive presence they are involved, engaged, or engrossed

Due to fact that the cognitive process underlying the response is incited by the occurrence of presence, it was necessary to draw upon research in communication, psychology, and other fields that expound on psychological and physiological processes as they occur in non mediated settings; how humans organize and interpret information in their environment, store and retrieve memories, make decisions, in order to ensure that they are similarly exhibited in a mediated environment. Taking a step further, Marsh (2003) expounded on not just about ' being there' instead he drew focus on sustaining the illusion by "staying there". This can be effected if one succeeds to make the entailing equipment transparent and maintaining continuity of interaction within the virtual social and cultural environment.

3.4 Effects of Virtual Reality on Memory, Recall, and Retrospection

Previous researches have found recall of spatial layout in a virtual environment to be high. The following logical questions would be, "Would subjects be able to give the route they have taken in real-life in the virtual environment of the same?" and "Would participants recognize landmarks in the virtual environment that they use in the real world?" This constitutes an ecological validity investigation.

Exploratory experiments using VR technology to investigate memory by Brooks et al. (1996,1999) found that memory enhancement occurred for spatial layout following active participation and for object memory following passive observation. They reported no difference between active and passive participants' recall and recognition of virtual objects, or in their recall of the correct locations of objects in the virtual environment.

Even more specifically, Selten et al. (2002) advocated, "If one wants to investigate results of day to day route choice which can be transferred to more realistic environments, it is necessary to explore individual behaviour in an interactive environment set-up." We are looking for answers to the similar questions of: Does behaviour converge to equilibrium? Does more feedback reduce fluctuations? What is the structure of individual responses to recent experiences?

In our proposed concept, it is therefore necessary to incorporate two categories of reconstructive memory. (i) explicit memory where subjects would be instructed to remember information, for example the recall of activities, events, and scenarios, and the recognition of locations, and (ii) implicit memory test where subjects had to perform a cognitive task, which was facilitated by a previous experience, for example, in retracing the route travelled.

Our framework for the design of interactive mediated environments is further informed and guided by concepts from activity theory particularly in the designing a practical computer interface. It is a framework in which to reason about human practice and experience of performing activities in scenarios in the context of use (familiar immediate urban environment depicted virtually) within mediated environments. Stemming from Russian psychology (Leont'ev, 1981), the activity theory approach connects the functionality of the interface to real life problems

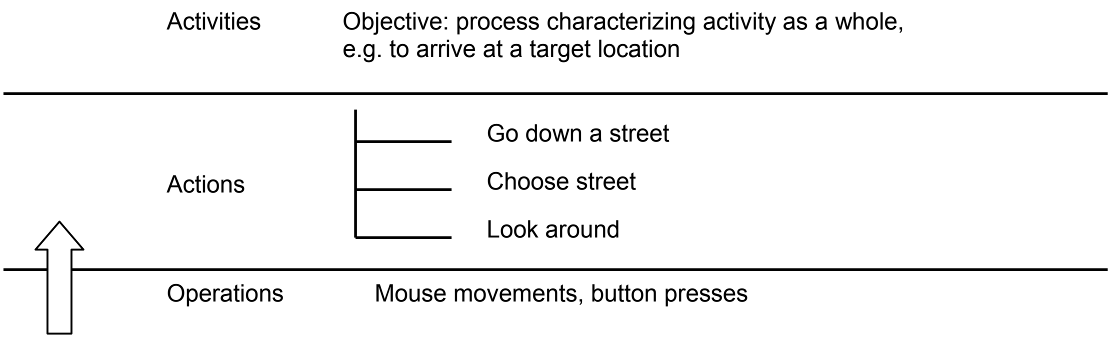
(Vygotsky, 1978). What is even more remarkable is the compatibility of the context of the performing a real-life activity with the concepts of activity theory for putting in place an interface to create the illusion of interacting directly within the mediated environment.

3.5 Activity Theory and Interaction in Virtual Reality

The activity theory provides a paradigm for the description and understanding of the way humans interact with computers within the context of the user's environment, providing an informed means to the dilemma of the HCI researchers when they found themselves crossing into the terrain of cognitive sciences. (Bannon and Bødker, 1991; Verenikina and Gould, 1997; Bødker, 1991). We will base our interactivity framework on the findings of such research.

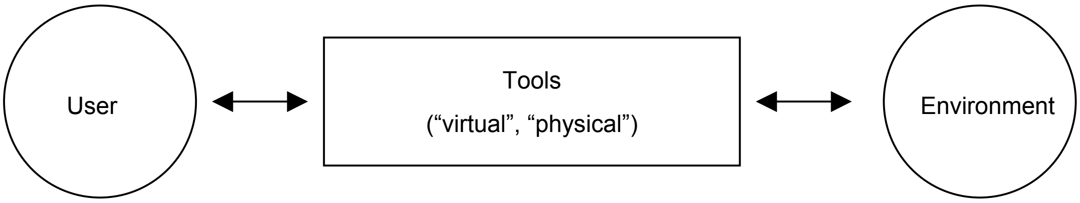
To illustrate Leont'ev's hierarchical structure of an activity (see Figure 3.1), the action of navigations through the 'streets', made up of three sub-actions, is to arrive at a target location. A sub-action is directed to a sub-goal of "looking around" with a collection of sub-goals contributing towards the activity's objective.

Figure 3.1 Achieving a Goal Through Actions and Operations



(Adapted from Marsh, 2003)

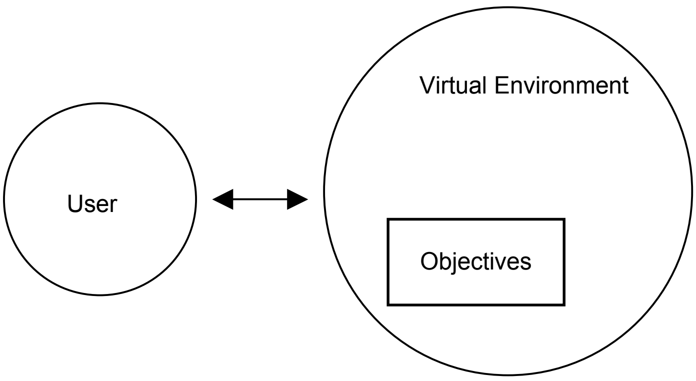
Figure 3.2 Interaction between Humans and Environment Mediated Through Artefact



(Adapted from Marsh, 2003)

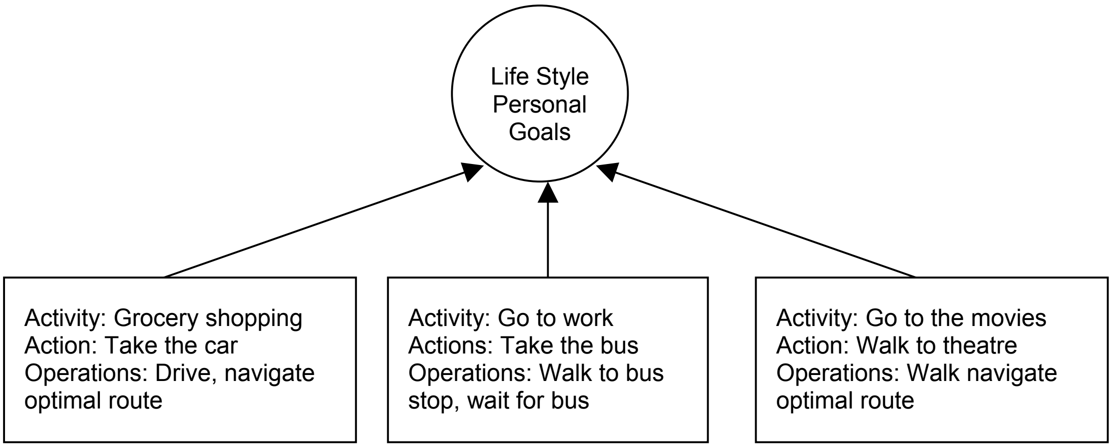
In virtual reality, operations of mouse movements, button presses, are executed in order to perform actions. Operations are unconsciously performed processes in the use of tools triggered by conditions of actions. According to activity theory, the central idea is that cultural and social tools, signs, and language, etc mediate the relationship between humans and their environment. These "psychological tools" merge with physical tools in an interactive mediated environment. The interactive tool/artefact is the 'link' between the user and the mediated environment. As a consequence, the user acting directly within a mediated environment experiences the formation of functional organs, in Figure 3.2. While in Figure 3.3 which illustrates a situation where the objective of an activity is achieved within the mediated environment without exchange with the real world, effective interaction is achieved by users that maintain their focus of attention and carry on in the 'flow' of performing activities within the illusion of the mediated environment (Marsh, 2003).

Figure 3.3 Objectives are Present within the Mediated Environment



(Adapted from Marsh, 2003)

Figure 3.4 A Narrative Using Activity-Based Scenario



(Adapted from Marsh, 2003)

Finally, we encounter the overlap of the activity theory, where the unit of analysis is activity, with travel research, where the motivation of the travel is the need to perform activities in order to achieve objectives. Every individual undertakes activities to fulfil objectives within social, cultural, and institutional constraints (time constraints, availability of resources, opening hours, appointments, commitments, etc.). The sequence and time order are as varied as each person. Hence, having made a full round circle, we have established a methodology that empowers users to formulate their own narrative of activities (see Figure 3.4) within a mediated virtual environment that formed the interface based on activity theory.

3.6 Information Retrieval Through Activity-based Recall in Virtual Reality

The computer is indispensable in many ways. We can hypothesize that the use of computer technology in any form is better than not, not to say the least, inevitable in today's technology biased context. The most basic and easiest area example is in the reduction of human errors by replacing data entry with automatic capture of responses. We have also encountered the computer in the checking of data, in guiding the interview process, and in interactive experiments, with the possibility of either incorporating one or more of these function singly or in combination.

From the review of the literature as presented in this and the previous chapters, we are motivated to make a proposition in the design of an alternative data collection tool. Primarily, we can add to the progression of interactive computer experiments by proposing they be performed in virtual reality. The reason behind this is that virtual reality possesses potential to provide a conducive environment that evokes presence and thus engages the respondent to be involved in the task at hand. Naturally, the task that we are talking about is the data collection itself. The data collection takes the form of the reconstruction of one's past activities in a contextually relevant virtual environment. By creating a conducive environment, we establish that the appropriate stimulus and cues presented to the respondent aids in memory retrieval. Therefore, a survey conducted employing virtual reality includes the element of contextual-dependent recall through visual cues of the environment. The virtual environment will provide another level of stimulus in the form of physical landmarks that creates a trigger for the narrative of one's reconstruction of events. Not only is the visualization of the situation given but also the participant actually experiences it before his reaction is solicited. Expectedly, in built is the automated means of recording and checking data and guiding the interviewing process. With this combination we attempt to both reducing measurement errors and increasing reliability and validity.

A key feature of the proposed alternate instrument is in the provision of visual aids; a set of prompts. The level of abstraction of the choice situation decreases when one moves from the pure paper-and-pencil experiments to those that involve visual aids. Simulations concern even a lower level of abstraction. Visual aids also serve to ensure that respondents have not forgotten to mention an aspect that they feel to be of importance. An ordinary map can serve this function by providing a base on which travel route and alternative destinations can be recorded. Alternatively, providing scenes of the environment in virtual reality can in a fairly passive, non-directive way bring to light relevant information to the respondents' attention. Since on a daily basis one would not carry a map when making a tour in a familiar environment, we have chosen not to include a map view in the virtual environment

With possible conceived advantages of the virtual reality approach comes the liability to determine that there is correspondence of the scenarios in the virtual environment with peoples' perception in actual choice situations. The value of this approach depends largely on the ability to consistently elicit from the same respondent the same response as he would make in a real situation. This is pre-requisite to testing of hypothetical alternatives and the corresponding sets of attributes because of the necessary congruence with real choice situations.

3.7 Summary

This chapter has dealt with the concepts of deploying virtual reality in a survey instrument. We have first examined the technology of virtual reality and then reviewed its relevance to activity schedules. This has been followed by the development of a concept of information retrieval through activity-based recall in virtual reality.

The concept has been developed with the intention to put the participants "back to the where, when, what, and how" supported by virtual reality technology. A virtual environment serves to provide the stimulus and cues for an individual to re-enact events and 'perform' past activities. High expectations of this key concept in the new media can distort the efficacy of employing it as an option in carrying out travel surveys. On the other hand, we anticipate that by the experience of presence, problems with attention and perception, engagement and involvement, so often found in subjects that consider participating in filling out travel diaries as boring tasks, can optimistically be banished. But it is imperative to know the effectiveness of presence. Therefore, our research placed emphasis on the data needs and requirements of a study rather than on a system-centred approach to the design of synthetic environments. That is to say, if the varying effects of the diverse aspects of presence incite the same response from subjects as they would in real life could be recorded, we can then deem the dimensions of presence as specified and significant in a particular inquiry. In particular, we are pursuing a method to create experiences that are psychologically real and not the actual production of reality. In the next chapter, a system in accordance with the concepts described in this chapter will be specified. Therein, we subsequently elaborate on the design and implementation of the system.

4 Design and Implementation of Interactive Virtual Reality Environments

4.1 Introduction

Although the facilitation of virtual reality technology has been touted for naturalistic human interaction for a diverse range of audience, from the informed to naive users, it is not inherently so. Rather, it requires appropriate design. It has to be moderated by the realization that factors of human perception play an important role in effective interaction in virtual environments; namely the perception of the context effect such as differences among travel scenarios and how close this is to real world situations (Steed, 1996). But making the assumption that the virtual environment experience is analogous to the exploration of a real environment makes it necessary to examine the transfer of information from the real world to the virtual. Which leads to the specification of perception and visualization capabilities of systems that can combine both physical and abstract information. Abstract information is one of the difficult areas that we had to address. We discuss our experience in representing non-visual abstract information with language, such as with text descriptions and symbols.

The terms of virtual reality systems and virtual environments have both been mentioned and although they are used interchangeably in most literature we are in favour to be more precise to avoid any ambiguity about their meanings. By our definition virtual reality refers to the technologies that are used to create virtual environments. Virtual environments are created by generating displays that resemble the views a person would experience if s/he would move through an analogous surround or neighbourhood. Thus, virtual environments function as an interface (sometimes in three-dimensional) to a repository of images (and sounds). These can include web-based HTML or VRML representations, object or image based, or simple text-based description for individual browsing or group interaction (e.g. Chiu et al., 2000). They can be further categorized into immersive, semi-immersive or desktop virtual reality based on the how much of the scene of the simulated environment occupies the visual field with the immersive type more or less completely engaging the ocular sense. Applications using each type of representation can be found in the literature (Steed, 1993; Hubbold et al., 1995; Davis et al., 1996). Each has its own advantages and disadvantages and most certainly should be chosen for its merits in the context of the relevant application.

4.2 Interactive Experiences

In accordance with our conceptual model of information retrieval through activity-based recall outlined previously in Chapter 3, Section 3.7, we undertake to specify a system to function as virtual reality survey instrument. One qualitative research by Murray et al. (2000) studied participant interaction with a virtual city and observed that people attributed real world properties and expectations to the contents of the virtual world, suggesting a continuous relationship between real and virtual worlds. In reality, virtual environment will never possess the same complexity or the richness as the real world. For our purpose, the chief target is to establish a medium for creating synthetic interactive experiences. Therefore in the specification of such an operating system we take upon ourselves to satisfy the following criterion:

1. Invoking presence or sense of a place

People can recognize their environment because they can perceive the atmosphere in the setting under circumstance of location, occasion, routine, and populace of which they are familiar with. While current VR technologies claims to enable the imitation of all possible human sensors, visual and acoustic information constitutes the major environmental information (Ingram et al., 1996; Lotan, 1997; Chiu et al., 2000). In other words, users should perceive the atmosphere and sense of a place or experience presence (Witmer and Singer, 1998; Ijsselsteijn et al, 2001; Schubert et al., 2001).

2. Facilitate tasks of navigation and wayfinding

Besides addressing the issue of spatial awareness it is necessary that the system facilitates the tasks of navigation and wayfinding (Passini, 1984; Dieberger, 1994; Darken and Sibert, 1996; Dieberger and Frank, 1998; Hunt and Waller, 1999; Modjeska, 1999). Navigation within virtual environments is not as straightforward as in the real world and we can expect a higher tendency of a user becoming lost (Witmer et al., 1996). Additionally, Attree et al (1996) found that active negotiation of a virtual environment enhances the spatial memory ability more than from that of a passive viewing of the environment. If the recall of spatial memory is similarly more efficient due to active participation, then the negotiation through a familiar (virtual) environment should reduce the task difficulty. People recognise an increasing number of different places and routes when their familiarity of an environment increases (Gärling et al., 1986). We are concerned with familiarity that is obtained through the exposure due to a range of activities in the environment (Milgram et al, 1972). Experience is important in route choice situations because of improved spatial orientation and wayfinding in a given (familiar virtual) environment (Gärling et al, 1981; 1983).

3. Exchange of information and feedback

After having successfully situated users in their environment, the next key purpose is to permit us to capture the users' actions within the virtual environment via "re-construction of the past", thus creating individual narratives of "what happened" Cognitive assessments carried out in virtual environments has demonstrated that a VR setting can provide the means for the measurement of incidental memory – an aspect of memory which is part of real-life experience (Andrews et al, 1995; Attree et al, 1996; Pugnetti et al, 1998; Brooks et al., 1999). The systems should respond to each individual by creating an exchange loop of relevant contextual information. A useful area of feeding the narrative back to the user allows for confirmation of the information provided thus improving on accuracy.

Based on our analysis of the above requirements, we came to the conclusion a stereo panoramic representation of a situation contains just enough information so that certain aspects of the original situation can be re-created. Panoramas were preferred over of 3D-objects as we concluded that we would not add significant value to the research by “re-describing” in whole an existing environment. Besides, the building of an urban environment in object form still required photographs as a source for the graphical representation, which could have already formed the initial part of making panoramas by taking panoramic picture instead. Moreover, one could not do away with the synthetic feel of an environment comprised mainly of object blocks unless substantial effort is put in to create elements of realism. The choice of stereo panoramic virtual reality addressed the element of realism to a good degree because a good deal of the environmental characteristics is present albeit only at a certain point in time. Panoramas, which are simply pictures captured by rotating a camera in 360 degrees (e.g. in Chen, 1995), accurately captures the existing environment while possessing the flexibility to be augmented by means of addition and deletions of characteristics in the environment to the pictures. We conjectured that a stereo (3D better than 2D) effect was superior over a mono view. The representational richness of stereographic panoramas sets vividness of the virtual environment to a high degree. Testing for effect of the third dimension is as easy as switching on the stereo effect. In preliminary tests, only 1 out of 8 persons opted for non-stereo.

Stereo panoramas make a quality choice to represent the urban environmental information because they represent compelling views of the real environment, however, they apparently can only remain as substitutes. The sense of presence invoked in a person in a virtual environment can enhance the desire to travel and move around. It is possible for a user to choose different routes very quickly and unobtrusively while keeping aware of his/her whereabouts, thereby providing an engaging, and highly interactive experience. But we were not able to escape from having to put together a large database of images and data describing the states of the environment even though the area under study was limited to some urban part of the city of Eindhoven from where the respondents will be selected.

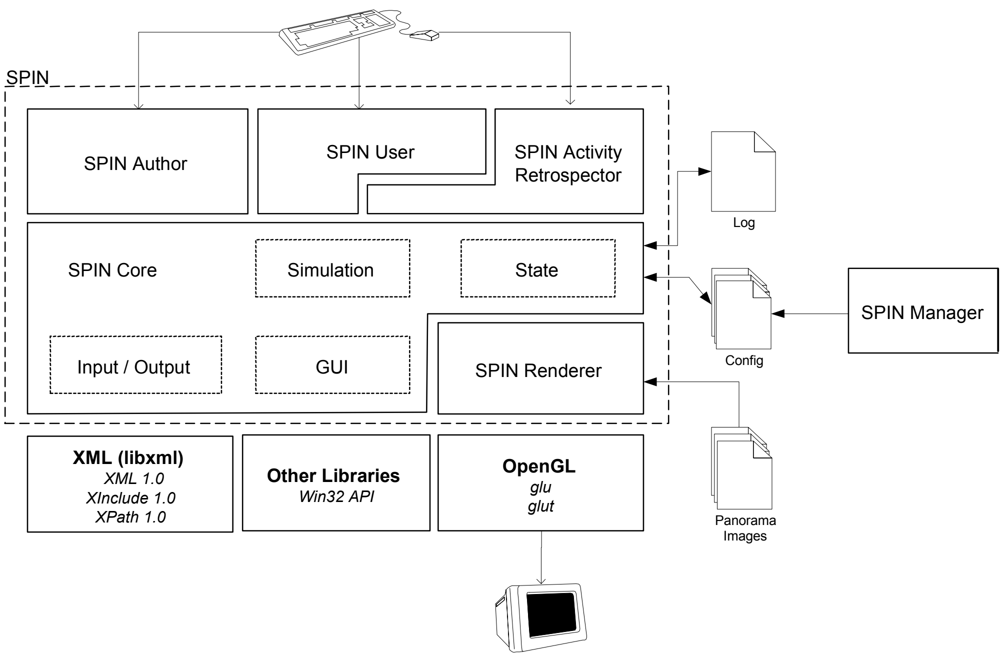
Where an attempt is made to maintain some perceptual similarity between the form of the representation and the thing being represented, this is called simulation. In describing our system, it was necessary for us to make a decision on the level of fidelity of simulations. Specifically, two elements of fidelity can be distinguished: realism (accuracy in physical representation) and comprehensiveness (degree of completeness of representation of all functions, environmental characteristics, etc.). In our system we have used a combination of stereo panoramas and a scripting methodology for a photo-realistic simulation of an urban environment for the purpose of travel behaviour data collection in real life situations. We call our system the Stereo Panoramic Interactive Navigation (or SPIN for short). In the following sections we describe the design of the SPIN and give details as to how it is used to collect activity-based travel data.

4.3 The System

Figure 4.1 shows an overview of the concept of the SPIN system. We briefly describe four key modules control the workings of the system; the SPIN Renderer, the SPIN Core, the SPIN Activity Retrospector, and the SPIN Author. The function of each module will be explained individually but in the context of an integrated whole to support the fifth module – the SPIN User module – where the respondent will execute activities in SPIN. In Section 4.4, we will describe the organization and structure of SPIN further.

Starting with the SPIN Renderer module, it handles the rendering of the stereo panoramas in order to display the images of an environment. It supports different methods for generating stereo images, such as Quad-Buffered Stereo, Interlaced Stereo both falling under the category of the traditional Active stereo requiring the

Figure 4.1 System Description



use of CRT projectors and Passive Polarized Stereo that uses LCD projectors. These are methods to generate perceived depth in views (or 3D effect) by giving input to our eyes separately and the use of glasses (shutter for active and polarized for passive) is necessary to view the stereo effect. There is also a possibility to render in 'mono' where only one of the images will be rendered for both eyes thus giving no depth in viewpoint of the images where no glasses are necessary. The Renderer also includes additional elements to allow one to compose the user interface, such as icons, menus, etc. OpenGL (www.opengl.org) and GLUT - OpenGL Utility Toolkit (http://www.opengl.org/developers/documentation/glut.html) are used to output its images. It also reads in the image files, and allows the researcher to make adjustments in the SPIN Author to render the panoramas correctly in stereo (See Panorama Preparation in Section 4.6).

The SPIN Core implements all other functionality. The Input/Output sub module is used to read and write the *config* and *log* files. These files are used to establish the internal state of the system. These files are XML files and the Input/Output sub module uses an open source XML parser called libxml (http://www.xmlsoft.org/) to read and validate them. Libxml implements the XML (http://www.w3.org/TR/REC-xml), Xinclude (http://www.w3.org/TR/xinclude/), and Xpath (http://www.w3.org/TR/xpath) standards. The Simulation sub-module implements functions like tracking the simulation and experiment time, handling the display of the weather and all the other iconic information, and calculating travelled distances, etc. The State sub-module manages all data in the system. The State sub-module together with the Input/Output sub-module handles the loading and saving of the *log* files and supports the SPIN Author module. The GUI sub-module is used to present the user interface. It will draw the icons and other user elements using the SPIN Renderer.

The SPIN Author module is a special module that can be used to visually make corrections to the panorama. It adds a user interface to set the viewpoints of the panoramic images in the correction direction with links to other viewpoints. It's other utility is in adjusting the images for a correct stereo effect. The SPIN Author module is disabled when the system is used to conduct an experiment. The SPIN User module adds the user interface for the 'normal' users and handles the user input from keyboard and mouse. It is connected closely with the GUI sub-module in the SPIN Core and also with the SPIN Activity Retrospector. The SPIN Activity Retrospector is a special module that will ask the user about their activities during the virtual travel, and it will add extra entries to the log files containing this information. Its role is to respond to the user by actively generating the contextual and relevant information.

The SPIN system is able to read and create l*og* files, read and create *config* files and it will also read in the panorama images. A separate program called SPIN Manager can be used to manage the *config* and *log* files. In the SPIN Manager, users (respondents) can be added to a database. For these users a directory is created and the *config* files are updated with data for the SPIN System about the file locations for each user.

4.4 Organization and Structure of SPIN

To define the relationships between the panoramas, the actions that can be performed, the calibration per panorama, the links between the panoramas and additional technical data, XML was has been used extensively. The global structure of the XML description is as seen in Figure 4.2 Config.xml.

There are many reasons for using XML, namely:

- It is a legible format that can be read and written by both humans and computers.
- There are public XML parsers available which reduces the time needed for writing a custom parser and makes it possible to use these files on many different platforms.
- The availability of standards like XInclude to compose XML data by including other XML documents or XPath for searching through XML documents without having to code it from scratch.
- Automatic validation of read in documents because of the specifications in a Document Type Definition (DTD), which allows one to instantly arrest most syntax errors.
- It is relatively easy to extend elements with extra attributes or sub elements without breaking the parsing.

The main part of the XML config file (Figure 4.2) contains system information. It defines the *window* size and the *render mode*. The different render modes define which hardware function is used in stereo or mono mode. The *segments* specify the number of parts that build up the rendered sphere. The *eye separation* sets a global correction for the eye distance. The eye distance is already captured into the left and right panoramas, but some people prefer a bigger or smaller eye distance, which can be locally overruled with this property. The parameter can also be changed from within the Renderer. The *mouse* tag sets up the way the mouse is used to navigate through the environment. The *xinclude* lines are used to include other XML files into

Figure 4.2 Config.xml

```
<?xml version="1.0" encoding="UTF-8"?>
<!DOCTYPE config SYSTEM "config.dtd">
<config xmlns:xinclude="http://www.w3.org/2001/XInclude" debug="false">
  <window left="0" top="0" width="640" height="480" fullscreen="true"/>
  <render mode="quadbuffered">
    <segments count="100"/>
    <eyes seperation="-0.010000"/>
  </render>
  <xinclude:include href="panoramas.xml"/>
  <xinclude:include href="start.xml"/>
  <xinclude:include href="log.xml"/>
  <mouse mode="normal" sensitivity="200.000000" relsensitivity="5.000"/>
  <xinclude:include href="world.xml"/>
  <xinclude:include href="weather.xml"/>
</config>
```

the config file. Some of these files are static files that are kept outside the config file to keep it well organized. The SPIN Manager, to set up an environment for a specific user, creates these files. Below, the contents of these files are explained.

A *panorama* (Figure 4.3) is defined by its *name*, which can be used in other parts of the configuration to reference to it. The *location* is specified in world coordinates. The advantage of identifying a panorama to its location in the real world not only makes the task of linking them together easier but also viewing directions are also related to reality. A panorama definition also contains a *file source* for the left and right panorama. This information has to be added to the configuration file for the system to know of the existence of the panorama. A panorama configuration file (see Figure 4.3) can contain multiple panorama definitions. The *north* line specifies in what direction the north lies on the panorama images; this is used for automatic determination of the direction of the exits (see Figure 4.7) from one street and entrance into another. The *correction* lines contain the information needed to display the panorama correctly in stereo (see section 4.6). A correction is defined by specifying a pitch and a yaw rotation of the left and right sphere in the given viewing directions (*pos* parameter). The values of the north direction and the corrections are created using the SPIN Author program. SPIN Author reads in a configuration file and lets the user visually make corrections and then writes it to a new configuration file.

Figure 4.3 Panorama.xml

```
<panoramas>
  ...✂...✂...✂...✂
  <panorama name="K1408">
    <location x="161233.812500" y="384224.687500"/>
    <north yaw="-93.800110"/>
    <left>
      <file src="Left Panorama/K1408L.jpg"/>
      <correction pos="3" pitch="0.752269" yaw="0.200000"/>
      <correction pos="55" pitch="0.257214" yaw="0.400000"/>
      <correction pos="124" pitch="0.442911" yaw="-0.400000"/>
      <correction pos="171" pitch="0.569400" yaw="-0.400000"/>
      <correction pos="254" pitch="0.900979" yaw="0.000000"/>
      <correction pos="320" pitch="1.162074" yaw="-0.200000"/>
    </left>
    <right>
      <file src="Right Panorama/K1408R.jpg"/>
      <correction pos="3" pitch="1.912991" yaw="0.000000"/>
      <correction pos="55" pitch="0.241464" yaw="0.000000"/>
      <correction pos="124" pitch="-0.383200" yaw="0.000000"/>
      <correction pos="171" pitch="-0.200000" yaw="0.000000"/>
      <correction pos="254" pitch="1.918926" yaw="0.000000"/>
      <correction pos="320" pitch="2.000000" yaw="0.000000"/>
    </right>
  </panorama>
  ...✂...✂...✂...✂
</panoramas>
```

Figure 4.4 World.xml

```
<world>
  <hotspot angle="45"/>
  ...✂...✂...✂...✂
  <link from="K1313" to="K1408" noaccess="car bus" street="DEMER"/>
  <link from="K1408" to="K1313" noaccess="car bus" street="DEMER"/>
  <link      from="K1407"      to="K1408"      noaccess="car      bus"
street="VRIJSTRAAT"/>
  <link      from="K1408"      to="K1407"      noaccess="car      bus"
street="VRIJSTRAAT"/>
  <link from="K1408" to="K1409" noaccess="car bus" street="MARKT"/>
  <link from="K1409" to="K1408" noaccess="car bus" street="MARKT"/>
  <link from="K1408" to="K1434" noaccess="car bus"
        street="RECHTESTRAAT"/>
  <link from="K1434" to="K1408" noaccess="car bus"
        street="RECHTESTRAAT"/>
  ...✂...✂...✂...✂
</world>
```

The *weather* element is described (Figure 4.5) by specifying weather situation at certain points in time and where applicable weather changes over a period of time. This element is used to update the weather icon in the user interface of SPIN.

The *start* element specifies the starting location and the simulation start time. The log element specifies where the log file is located. If the log file already exists, it will be read in and the state of SPIN will be changed as if all actions in the log have been executed. This functionality is used to offer the capability to the user to interrupt the

Figure 4.5 Weather.xml

```
<weather>
  <weatheritem type="brokenclouds" wind="none" temp="13"
     time="9:00:00"/>
  <weatheritem type="fewclouds" wind="none" temp="15" time="10:00:00"/>
  <weatheritem type="clear" wind="none" temp="17" time="11:00:00"/>
  <weatheritem type="clear" wind="none" temp="18" time="12:00:00"/>
</weather>
```

Figure 4.6 Start.Xml with Link To Log.Xml

```
<start name="K1408" time="08:15:00" />

<log file="D:\SPIN\users\User01\log.xml"/>
```

Figure 4.7 Panorama Links

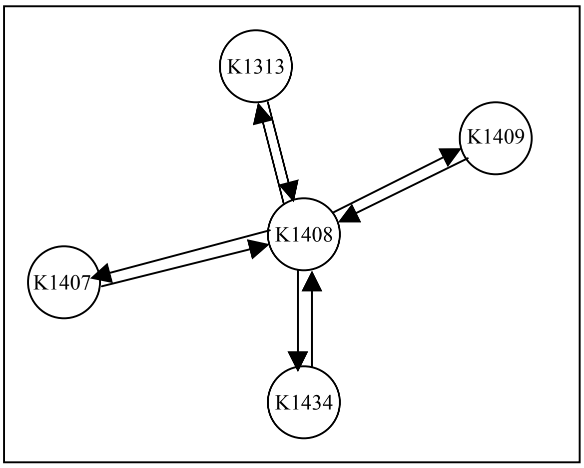


Figure 4.8 Hotspot Angle

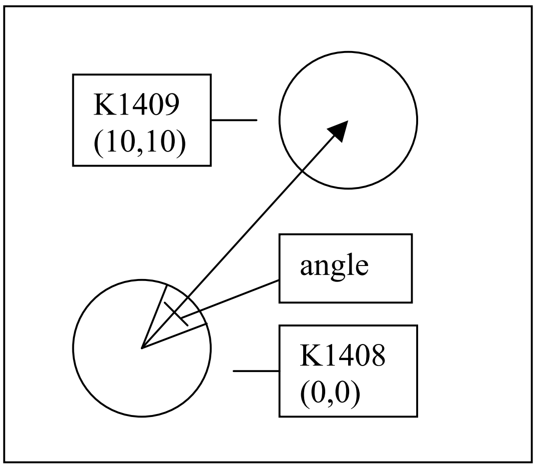


Figure 4.9 Log.xml


```
<log date="25-06-2002">
  <event type="start">
    <snapshot type="begin" name="L1202" pitch="7" yaw="220"
       simtime="13:12:20" fixed="false" exptime="15:36:31" mode="walk"
       speed="5" />
    <duration time="0" fixed="true"/>
    <snapshot type="end" name="L1202" pitch="7" yaw="220"
      simtime="13:12:20" fixed="true" exptime="15:36:31" mode="walk"
      speed="5" />
    <event type="link">
      <snapshot type="begin" name="L1202" pitch="-5" yaw="169"
        simtime="13:12:20" fixed="false" exptime="15:38:49" mode="walk"
        speed="5" />
      <duration time="41" fixed="false"/>
      <snapshot type="end" name="L1201" pitch="-5" yaw="130"
        simtime="13:13:01" fixed="false" exptime="15:38:50" mode="walk"
        speed="5" />
      <link congestion="notasked"/>
      <event type="activity">
        <snapshot type="begin" name="K1434" pitch="-3" yaw="216"
          simtime="13:13:01" fixed="false" exptime="15:39:12"
          mode="walk" speed="5" />
        <duration time="300" fixed="true"/>
        <snapshot type="end" name="K1434" pitch="-3" yaw="216"
          simtime="13:18:01" fixed="false" exptime="15:39:59"
          mode="walk" speed="5" />
        <activity type="C2"><planned value="today"/></activity>
      </event>
    </event>
  </event>
</log>
```


simulation and continue at a later time. During the simulation the system will write new user actions to a log file. A sample of a log file is found in Figure 4.9.

4.5 System Preparation

It is in the interest of many that we can be certain of the aspects of virtual reality that can be applied to surveys to address the shortcomings found in the conventional methods. It is the objective of the Eindhoven experiment that was carried out to offer answers as to whether this technology can go towards collecting more valid and reliable data. In this experiment, a real network is chosen – the main city of

Eindhoven, Netherlands demarcated within a predominating ring road was described in the form of Stereo Panoramic Virtual Reality.

In the aspect of environmental representation the compilation and organization of data can be described as arduous. As already foretold in other literature on the extensive data preparation prepare for setting up experiments of this nature, we can say that our experience has confirmed this. As indication of the effort that was undertaken the following procedures took place: On a map of Eindhoven city, the urban area selected for study was marked out into grids e.g., H12, J12, L13, etc. 36 in total. Each intersection within a grid was labelled 01,02, 03.....etc. The average number of intersections in each grid is about 30. Total numbers of panoramas that can be anticipated is therefore approximately (36x30) 1080. For stereoscopic panoramas, pairs of images imitating the left and right eyes means twice the numbers making it up to 2160. A substantial amount of storage space must be prepared. With each uncompressed panoramic picture at over 6MB for a high enough resolution, disk space of no less than 12 GB has to be put aside. Altogether, the data amounted to in excess of 6240 photographs. Again disk space has to be allocated for the pictures before stitching but they can be put away once the panoramas were created.

In the Netherlands, cities such as Delft and Rotterdam already possess databases of the urban environment collected in the form of panoramas. At least one commercial company has taken the initiative to build up a database for the whole country. Ideally, the travel possibilities and navigation in a panoramic virtual environment of the whole of the Netherlands can be incorporated, if desired. In addition, the complexity of a transportation network under investigation can escalate from the neighbourhood level, to a city level, on to a regional level, and finally at a national level.

4.6 Panorama Preparation

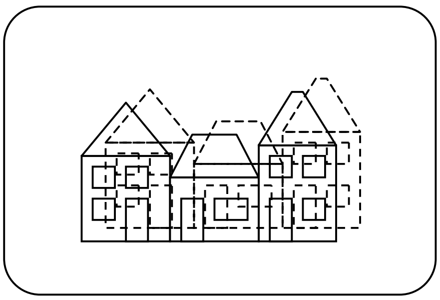
The process of preparing the stereo panoramas comprises of the following steps: (1) shooting photos with two digital camera's, one for each eye, and (2) stitching the digital images onto two corresponding spheres. Both steps introduce imperfections. When making the photos, a special tripod was used with two cameras mounted upon it. The tripod was equipped with a turntable that could be adjusted to level the cameras out in a horizontal position (See Figure 4.12 and Figure 4.13). The levelling construction was however not very sophisticated (accuracy of +/- 1 degree). To create a 360-degree panorama could theoretically be done with two photos, because a 180 degree fish-eye lens was used. But since some overlap is needed in the scenes, three photos were made per location/per eye. Using stitching software, the three photos for one view per eye are 'manually' fitted together.

For mono-panoramas this method is acceptable, but when making stereo-panoramas the following stereo related problems occur:

1. There is a vertical displacement between the images of the left and right eye (see example of displacement in Figure 4.10). This problem arises when the tripod platform is not perfectly horizontally levelled in every direction.

2. Moving obstacles are on different positions for the left and right eye. A time lag occurs because the photo shooting of both cameras in one position is operated manually and because it took time to rotate the camera from one position to the next. Lens flares create confusing stereo effects, especially when the lens flare is more prominent on only one of the spheres. Photos were shot over a period of more than 6 months. The panoramas show profound differences in season, weather conditions etc. Problems like flare can easily be

Figure 4.10 Vertical Displacement of Left and Right Image



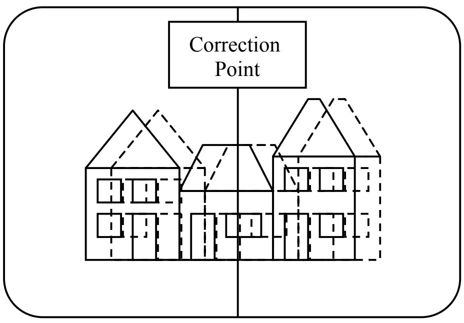
avoided when the time is available to wait for the perfect conditions.

3. The contrast and brightness of the left and right panoramas are not the same. The reasons as indicated in (2) also account for the problem here.

4. The eye-distance of the panorama is not consistent in every viewing direction. This problem is introduced by the stitching process because the overlaps between the three photos are manually adjusted.

At first the problems for the eye distance and vertical displacement were solved by making corrections iteratively with the stitching software until the results were acceptable. Although this was a feasibly approach it was very laborious and time consuming because in the project around 1080 stereo-panoramas were needed to cover the ground planned for the experiment. Therefore another approach was researched, specifically to perform interactive visual calibration and this was implemented in the SPIN Author module. Using this method you can visually correct the eye-distance and the vertical displacement. This is done by displaying the panorama using the SPIN Viewer and locating visual disturbances. At a location of a visual disturbance, a correction point can be inserted where the left and right images can be translated up and down to remove the vertical displacement and left and right to correct the eye-distance (See Figure 4.11). Normally, one image is held constant and adjustments are done only for the other. Corrections can theoretically be done at every degree of the 360 degree viewing directions, but it was not necessary because

Figure 4.11 Visual Calibration In SPIN Author



the SPIN Viewer is able to use a limited number of corrections to display a visually acceptable image. This is possible because the sharp focus of a person's viewpoint is confined to a small angle of approximately 30 degree between two eyes. Therefore, as long as the visual disturbances did not occur within this limit, the stereo panoramic view was apparent. Other visual disturbances such as an illogical scene were corrected using photo-editing software. This is also commonly done for the case where the brightness and contrast of the left and right photographs were adjusted to match. In some instances retaking of the images was carried out if it was found to be more time effective.

For the project the SPIN viewer has been developed based on the basic principles of stereoscopic vision (Peleg and Ben-Ezra; 1999,2000). However, our SPIN viewer for the purpose of displaying stereo views has extended features to adjust for the pitch and the yaw at a specific focal point in the panorama to correct for visual disturbances as outlined above. In one panorama the vertical correction at a correction point is recalculated into a pitch of the sphere.

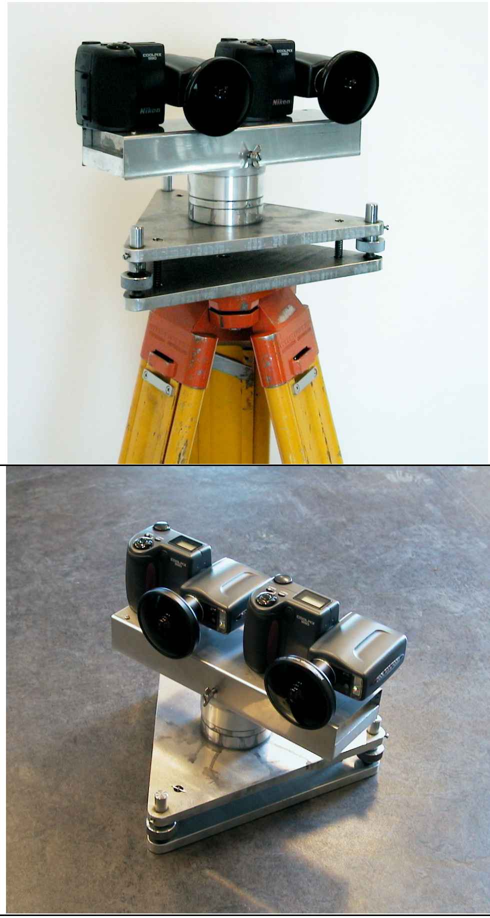
Likewise horizontal corrections are recalculated into a yaw of the sphere. Pitch and yaw in between two correction points are calculated by interpolating the values between the two correction points. Thus viewing in a specific direction is built up from a pitch and yaw that is related to the viewing direction and a correction of the pitch and yaw using the nearest neighbour corrections points. The process, but not the correction, is identical for both eyes.

4.7 Experiencing a Virtual Tour

To provide timely, visible, comprehensive information a user interface communicates with text, symbols, icons and alerts, etc. providing information of (1) scenario description, for example, congestion along the routes (including the changes at time step t) or current weather (including the changes at time step t) (2) the tasks that the user has to execute for example, a shopping activity, within the time available at a

Figure 4.12 Stereographic Photography Equipment Set-Up

Figure 4.13 Turntable with Level Adjustments and Rotating Arm Supporting Twin Cameras



specific time of day, (3) destination attributes and their levels, for example, parking facilities at the shopping centre and parking fees (including the changes at time step t). A person experiences virtual reality by being fed information about the characteristics of a virtual environment. The visual sense is considered the most important in this operating system. The following defines the environment in which the user is able to:

Experience travel

Mode of travel chosen is displayed with icon of car, taxi, public bus, bike, walk as chosen by user. The transfer of one mode to another is selected in sequence accordingly. Some modes of travel possess properties e.g. the selection of the car mode will restrict travel to only non-"pedestrianized" zones, and the user is obliged to observe traffic regulations. A user begins at a "start" panorama, and then "navigates" to new positions using an "mouse clicks" to indicate the desired path. A trip progresses from intersection to intersection without actually traversing the link connecting the two intersections. Instead, travel is simulated when panoramic views of one intersection are swapped by successive ones along the route of travel. This method is quick and flexible – a crucial factor in allowing for different route choice. Majority of the links fall within 100m so the successive views on the route were able to keep the user aware of his/ her movement. Users are able to make turns at intersections. The disadvantage of this method is the lack of information between the intersections. To overcome this it is recommended that panoramas are no less than 100m to minimize a "jumping" effect that may cause disorientation.

Experience congestion

When a user is standing at a particular intersection or node, and has chosen the path of travel, s/he is asked to indicate the level of congestion during travel. This question is only applicable when the mode of travel selected is a non-walking mode.

Experience time

The "current" time is displayed on screen (HH:MM) and shows the elapsed time during travel or the conduct of an activity. As to the treatment of time, it was practical to run the clock as the user travels to the locations of the activities using the chosen mode, at an accelerated rate. At the intersections the clock is suspended. We anticipate that respondents make decisions during the pauses (at intersections) although, in reality, decisions on route choice could very well be happening along a route (not simulated).

Experience weather

Weather icons display the current situation in which the user experiences the environment. This information can sometimes be in conflict with the depiction in the panorama; and is meant to “over-ride” the static situation at when the photograph was taken.

As participant behaviour can vary according to individual we sought to minimize the level of irrelevance and maximize the attractiveness of a task. One matter to be attended to was with the limited “space” in the virtual environment that had been established for our experiments. It would not be feasible to conduct experiments where respondents had to travel beyond the boundaries of “virtual Eindhoven”. This shortcoming can be overcome by a couple of options. Respondents can be selected such that the tasks and travel decisions can be accomplished within the virtual environment. Secondly, the given conditions and/or scenarios and hence activities can be confined to that which is possible within the virtual environment. The activities are further divided into work activities (or school and other considered mandatory activities) and entertainment and leisure activities (flexible activities). In our application we chose to combine the two options by searching only for the relevant activities that are possible to conduct within the virtual environment and by this means selecting the respondents from that sample.

4.8 The User Interface

The user interface displays environmental information supplemented by text, symbols, and icons. The icons are transparently overlaid over the panorama in order not to obstruct viewing the environment. The icons that are shown in Figure 4.4 are meant to serve dual purposes; first they describe the scenario, second the user having situated him or her in the scenario, uses the icons for performing actions. There are two exceptions: the radar icon and the weather icon. These icons are purely for providing information to the user

The radar icon (first from top left of Figure 4.14) displays which direction one has come from and which directions one can proceed on to. Normally, the direction indicating where one has come from points southward and is highlighted in a

Figure 4.14 View of An Environment Scene At An Intersection

different colour from the rest of the other lines of direction. The only other information icon is the weather icon, placed adjacent to its right. The weather icon shows the "actual current" weather conditions including the temperature.

The subsequent icons are both informational and action icons. The speed icon indicates the corresponding speed associated with the selected travel mode. Speed can be adjusted by clicking on the desired speed on the speed icon. Moving on the next action icon, we encounter the transport icons. Clicking on the transport mode icon will pull down the icons of the other transport modes that are available at that location (if any). On the top right corner of the screen, the last icon in the row, we see time. The time can be adjusted by clicking on it - "left mouse click" operation; a window opens that allows the user to in/decrease hours, minutes and seconds.

For the icons in the left bottom corner of the screen, the activity (gear) button will open a window where the activities can be specified that were executed at that location. An activity is selected from a list while the starting time and the duration are entered manually. The starting time is equivalent or later then the simulation time at that location. These icons (see also Table 4.1) and their use are illustrated further in Section 4.11 on the data collection process. Clicking on the information icon will pop up a window with a log record of all actions that were performed. The log record lists for each of the actions, the starting time, the duration and a description. The description is compiled from that actions that were performed, e.g. “Travel in the bus to Wall Street”, “Had to wait 10 minutes for the bus to arrive”. A forward and backward button allows the subject to scroll through the event log. This option enables the user to make modifications to the log record. When scrolled back, a new track in the log record is introduced.

4.9 User Actions

In the Stereo Panoramic Interactive Navigation System the following actions can be performed:

Follow a link
The virtual environment is constructed of interlinked panoramas. Every panorama has one or more entries and exits. Navigation from one panorama to another is conducted by clicking on the arrow sign. As is the convention in panoramic representations, the arrow sign will only show up when there is a link that will take the user in the direction of view; in our case this always indicates a street entrance. A stop sign indicates that with the current transport medium, the street is inaccessible. During loading of panoramic images, a loading bar is presented for a few seconds that informs the user of the time and distance travelled on a link from intersection to intersection. This is displayed not an indication for the actual loading of the image in display memory, but because instant change of panoramas confuses people.

Table 4.1 Action Icons

Action Icons	Transport Modes Icons	
Display Travelogue	Walk	Bicycle
Conduct an activity at current location	Moped	Motorbike
Go back one step	Car	Taxi
Go forward one step	Public Bus	

Do an activity

At each location an activity can be performed. The list of activities that one can choose from contains items such as "shopping", "visit café", etc. Any number of activities can be performed at any one location.

Change transport mode

Transport mode can be changed if a different mode is available at that location (e.g. a bus stop). When changing transport mode the waiting time can be entered.

Do nothing

While the user takes a pause for reflection or for any other reason during the experiment, simulation time is suspended although real time ticks on. The system recognizes three time zones (1) experiment time: the real world time when doing the experiment, (2) simulation time: time according to the simulation, and (3) the original time: the time in the real world doing real actions.

Look around

For the data collection the user looks around to orientate him/herself by trying to remember the location.

Set new time

The system calculates a simulation time from the previous simulation time, the travel speed and the distance that was covered. Experiment time is the real time during the experiment. The user can overrule the simulation time if he/she knows the exact time of the duration a travel link or duration of an activity.

Set new speed

Each transport mode has a default travel speed. The user is allowed to select a desired speed.

4.10 Data Logging of User Actions

In the data logging most of the actions of the user will be captured. Actions are classified in a number of events. Examples of events are: the movement from one location to another location, change in speed or transport mode, or executing an activity. As explained in the user interface description, it is possible to undo some actions, these actions will still be present in the log; consequently, the events can contain child events giving a tree of events. By using this event tree the corrections of the user can be used in the analysis of the data. However, very fine-grained events like looking around or moving the mouse are not logged.

There are two types of times used in the log: The simulation time, indicating the time in the simulated world and the experiment time indicating the time in the real world. When a simulation time or duration is fixed, it means that the indicated time is entered by the user, non-fixed times and durations are calculated by the system. For example when the user travels from one location to the other, the duration will be calculated by taking the travelled distance and dividing it by the travel speed. Each event has a begin and an end snapshot. A *snapshot* contains the current status of the system like location, looking direction, simulation time, experiment time, travel speed and travel mode. The begin snapshot remembers the state before executing an event and the end snapshot remembers the state after the execution of the event. Most events also contain a duration that indicates how long the event took. Depending on the event type additional data can be added. The activity event contains information about what activity was conducted and related data.

At the start of virtual tour with the purpose of re-enacting a sequence of activities, a scenario is set by activating the start panorama, the start time, the start travel mode and the current weather. As the virtual tour commences, three types of data are logged:

1. A user's movement in the virtual environment is automatically captured by recording the panoramas selected during the virtual tour. Linking up the panoramas reveal the route taken.

2. Time elapsed is calculated according to the mode of choice with its characteristic speed as a route is selected link by link. Users are able to override the calculated time if they have a different recollection of the elapsed time of travel and activity durations. Users activate the time edit window by clicking on the time icon and time may be moved "forwards" or backwards" by means of the arrow keys as shown in Figure 4.15.

Figure 4.15 Time Duration Adjustment

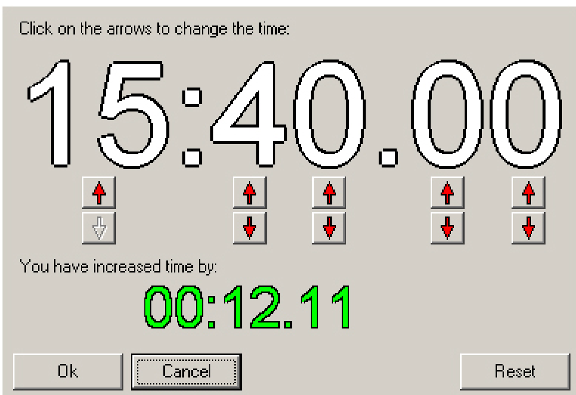
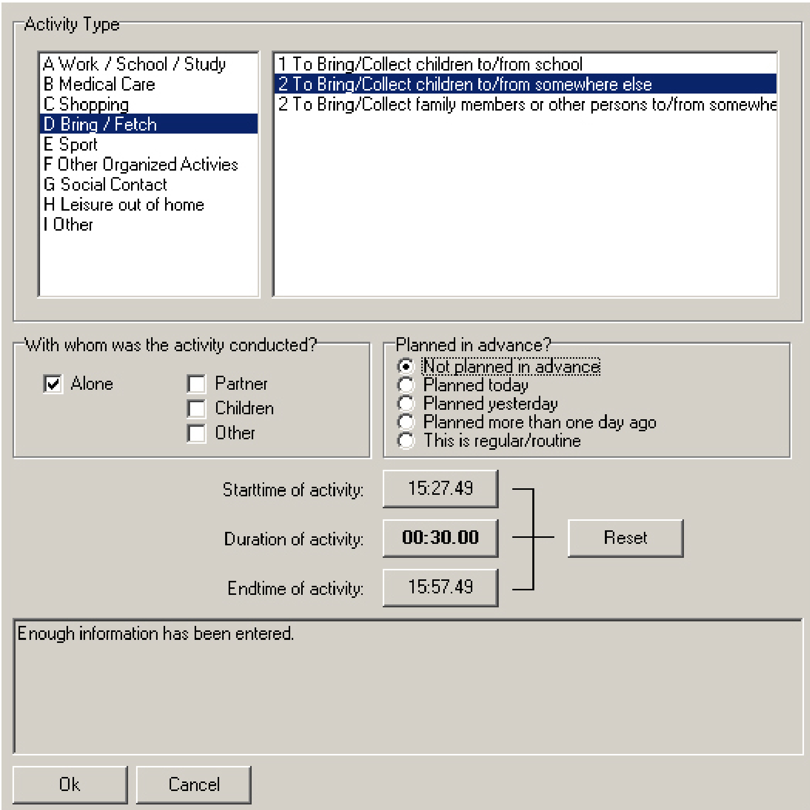


Figure 4.16 Activity Specification



3. Users provide information of their activities at locations (at a specific panorama) that they have conducted during the tour in the city centre by activating the activity button and entering the requested data as displayed in the window. An example of such a window is shown in Figure 4.16.

A user is able to refer to the sequence of records by activating the information button and view his/her schedule records which follows a chronological format. By using the "step-backward" and the "step-forward" buttons s/he is able to review the narrative (Figure 4.17) and check for correctness. Corrections can be performed by stepping backwards to the point of error and re-doing subsequent events. For example in Figure 4.17, further new recordings commence from the row "Insertion Point" and the current list of recordings below that row will be discarded. This allows for a

Figure 4.17 Travelogue: a Narrative of Activities

Travelogue

Time	Duration	Description
15:22:00		Start of the experiment. Default travel mode is walking. You are standing at the crossing of KEIZERSGRACHT and WILLEMSTRAAT
	±00:00:42	Traveled on foot to the crossing of KEIZERSGRACHT, VRIJSTRAAT and KLEINE BERG.
	±00:01:59	Traveled on foot to the crossing of RECHTESTRAAT, MARKT, VRIJSTRAAT and DEMER.
	±00:01:08	Traveled on foot to the crossing of HOOFFSTRAAT, JAN VAN and RECHTESTRAAT.
	±00:00:28	Traveled on foot to the crossing of HOOGHUISSTRAAT and RECHTESTRAAT.
	±00:01:32	Traveled on foot to the crossing of RECHTESTRAAT, HAGESTRAAT,TEN, KERKSTRAAT and STRATUMSEIND.
═══ Insertion Point ═══		
±15:27:49	00:30:00	Conducted **unplanned** activity 'To Bring/Collect children to/from somewhere else' **alone**.
	±00:01:32	Traveled on foot to the crossing of HOOGHUISSTRAAT and RECHTESTRAAT.
	±00:00:28	Traveled on foot to the crossing of HOOFFSTRAAT, JAN VAN and RECHTESTRAAT.
	±00:01:08	Traveled on foot to the crossing of RECHTESTRAAT, MARKT,

feedback loop, which is a crucial step in minimizing potential errors and inaccuracies that may arise from user input.

4.11 Summary

We have brought attention to bear on the potential that virtual environments have become important new research tools and could even be the future (virtual) laboratories. However, this is somewhat assumptive if we are not able to corroborate that the reactions of people to virtual environments are similar to those in real environments. For example, in our study framework, it is important to understand and incorporate perceptual differences between the virtual travel scenarios and real world situations such that the interactive experiments might yield reliable and valid data. In this chapter, we have reviewed and outlined as the fundamental specifications in what constitutes an interactive virtual travel experience. It is not our intention to replace the real with the virtual but rather to create a “psychologically real” experience.

In describing our system, a high level of realism (accuracy in physical representation) and comprehensiveness (degree of completeness of representation of all functions, environmental characteristics, etc.) has been deemed necessary and has been achieved by a combination of stereo panoramas and an XML scripting methodology for a photo-realistic simulation of an urban environment for the purpose of travel behaviour data collection. We have called our system the Stereo Panoramic Interactive Navigation (or SPIN for short). Such a synthetic environment can offer flexibility to alter the views of an existing environment and to formulate meaningful contexts affording researchers to examine the learning and adaptation processes in activity travel choice.

Interactivity in the SPIN virtual environment depends on the exchange of information by presenting and requesting the right information at the right time in the correct manner. “Informational” displays form an essential feedback loop. The use of the common symbols ensured that the meanings are clear and need no further explanation. Examples where we adopted plain and logical symbols are, to signify the mode of travel (man walking, riding the bike, etc.), to indicate the weather conditions (a big sun for fine weather), to point to the numerous route possibilities using ”a radar”, to indicate the passage of time by the progress of the digital clock, and to mean “information” using ⓘ Symbol. The forward and the backward symbols obviously need no further explanation. Several icons using such symbols have dual uses in SPIN: to convey and augment the description of a current scenario, and as input responses from the user. Thus SPIN supports a user to navigate and travel with the virtual environment and perform tasks simulating the conduct of activities, for the purpose of creating a narrative that is in correspondence with real personal events. Interaction in the virtual environment is effected by only the use of one peripheral – the mouse. The use of mouse movements and button presses are sufficient to perform the task of re-construction of one's activity schedule.

In this chapter, we have explored several aspects of virtual reality technology in order to investigate whether an opportunity exists to improve the quality of travel survey data by the design and implementation of an interactive survey in a virtual environment. The design of the procedures to test this opportunity is described in the next chapter, chapter 5.

5 Research Design

5.1 Introduction

The goal of our research study is to provide evidence that interactive virtual reality computer experiments make a more valid form of collecting data on travel behaviour. We have examined in Chapters 2 and 3 that the technology of virtual reality is relevant and viable in the collection of data on activity-based travel. It is particularly feasible in the following four aspects: firstly in enabling interactivity in the data collection process, secondly in the support of respondent memory recall of past activities through visual cues of photo-realistic surrounds of activity locations, thirdly in enabling reconstruction of an activity schedule by the respondents through re-enactment of events in a virtual environment, and lastly to exercise control over the data collection process. In view of these potential benefits that can be reaped from the use of virtual reality interactive experiments, its performance remains to be verified. In short, we aim to determine the value of interactive virtual reality computer experiments by testing on its ability to elicit from the same respondent the same response as he would make in a real situation. This can be considered in parallel to the question, “What is the correspondence of the scenarios in interactive virtual reality computer experiments with peoples’ perception in actual choice situations?”

A system designed in accordance with these desired benefits culminating in Stereo Panoramic Interactive Navigation (SPIN) is described in Chapter 4. In this chapter, we describe how we conducted the verification of SPIN by defining the procedure to carry out an investigation if this method will provide better if not equivalent performance than the existing prevalent method of paper-and-pencil. We first discuss the procedure of carrying two separate measurements on respondents' activity-travel schedules one of which will be using SPIN. Each of these measurements is individually described in detail. We then delineate the comparison study between the two methods against "reality" - the revealed choice data that is measured by direct observation, for the different facets of an activity schedule.

5.2 Procedure

In our study, two separate methods have been devised to collect data on individuals' activity-travel schedules. The first method is based on self-registration by the respondent where the instrument of Stereo Panoramic Interactive Navigation (SPIN is used. The second method is based on respondent self-registration by the paper-and-pencil (PAPI) instrument. Both methods are intended to measure the same data: the choice dimensions of subjects that describe their activity pattern. Therefore, although in two different forms, the coding structure of activity, location, time, mode and related information about the schedules are kept the same. The two methods of data collection record the following critical information with variations in the administration of each method described in the sections 5.5 and 5.6:

- "Nature of Activity" to be performed,
- "Mode of travel to Location",
- "Start of Travel Time to Location",
- "End of Travel Time to Location",
- "Duration of Conduct of Activity"
- "Route taken"
- "Accompanying person(s)", if present
- "Planned" or "Unplanned" Activity
- "Route taken"

Table 5.1 Overview of Procedure

	Group 1	Group 2
Part 1	Measurement sequence 1. PAPI 2. SPIN	Measurement sequence 1. SPIN 2. PAPI
Part 2	Analysis of agreement between A. OBS and PAPI B. OBS and SPIN	Analysis of agreement between A. OBS and PAPI B. OBS and SPIN
Part 3	Comparison between A and B	Comparison between A and B

The two methods of SPIN and PAPI are analysed for performance by a test of agreement between their data with "reality", the data from observations of revealed choice (OBS). Table 5.1 shows an overview of the structure of the approach of our measurements and the analysis of the measured data. There are two groups of subjects. The difference in the groups lies with the order in which subjects are measured by the different instruments. For the 1st group, the PAPI instrument is administered before SPIN and the order is reversed for the 2nd group. After the travel-activity data has been collected, the analysis will be performed in two parts. For both groups, an analysis of agreement is conducted between data from the OBS method and that of PAPI, in the first instance. In the second instance, the data from the OBS method is analysed for agreement with the data from SPIN. Thereafter, a comparison study is performed for the outcomes of both instances, and for both groups. The method to assess the reliability and validity of the SPIN method using method comparison studies discuss further in detail in section 5.7.

5.3 The Subjects

Interviewers recruited subjects by interception. Interception locations selected were at exits from car and bicycle parking lots and at bus-stops. It was anticipated that persons would have apparently arrived in the city center either with the car, or bicycle, or bus and had intentions to carry out activities in the area. Therefore, people entering the city center at such points were invited to participate in the study. They were asked if they would be willing to answer some questions when they completed their visit to the city center, without telling them exactly about the purpose and contents of the questionnaire. If they indicated they were happy to participate, an unobtrusive signal was giving to an observer, who 'tracked' the subject from a distance. Observers recorded the number of stops, the nature of the conducted activities, their start and end times and duration, and the route that was followed. Although these measurements are not necessarily error-free, we assumed that these observations measure the actual 'real-world' behaviour of the sampled pedestrians.

The procedure outlined imposed several limitations on the variety of subjects that were investigated. Firstly, since it was not practically possible for the observers to record activities with very long durations, e.g. work or school, they screened potential subjects to eliminate such a possibility, and thus the study only included (a) subjects performing several activities with short durations, or (b) of one activity with multiple locations (e.g. shopping). Secondly, as interviewers observed the subjects on foot, it was not realistic to include subjects who conducted activities using fast travel modes, so only pedestrians were selected.

When the pedestrian, agreeing to participate in the study, returned to the entry point, he/she was invited to complete two different measurement instruments. The first was a traditional paper and pencil activity-travel diary referred to as PAPI, the second was the virtual reality-based system – the Stereoscopic Panoramic Interactive Navigation that allows subjects to re-enact their activity-travel patterns. To avoid the problem of aggregation, subjects completed both tasks.

Interviewers were instructed on the operations of measuring a subject according to that found in Figure 5.2 "Instructions for the Interviewer". Personal information and socio-demographics of subjects were filled in when they performed the PAPI measurement. Separate instructions for each method were prepared for subjects.

Figure 5.3 gives instructions to the subject on how to perform the SPIN measurement and the instructions for the PAPI is found in Part I of the questionnaire. The full questionnaire for the PAPI method can be referred to in Appendix A.

5.4 Observations of Revealed Choices

After a subject has been identified, the experiment starts. First and foremost before the subject will perform any task, s/he is sent off to carry out his/her activities as s/he intended. This is also the stage when the data collection swings into action. That is to say that the subjects will always undergo observation of revealed choices, but the consecutive measurement could be either SPIN or PAPI. Observation of a subject by an observer will take place from activity 1 to activity N, where the subject returned to the starting point after the Nth activity, or when the (N+1)th activity was a long duration activity such as work, or school, or when the time elapsed at the end of the Nth activity exceeded 2 hours.

The role of the observers is crucial to the experiment because the data collected by this method forms the basis against which other methods will be compared. The data set is an account of “reality”. The objective of the observers is to observe in an unobtrusive manner (‘tracking’ inconspicuously) and record the revealed choices of the subjects as they carry out their schedules in the prescribed form of records as shown in a sample in Figure 5.1 below. The data collected by the observers in this manner is regarded as a “benchmark” to compare with that provided by the subjects using the next two following instruments. The “instructions for the investigator” in Figure 5.2 spells out the necessary actions to achieve this, which also includes other functions as an interviewer in this data collection process concerning the administration of the other two methods, for SPIN and PAPI described in the following sections.

Figure 5.1 Schedule of Activity Records

Saturday 31 August 2002
Weather:

Subject Identification:

Start of Recording Location (Street/Parking/Shop):
Start of Recoding Time:
Start Travel Mode:

Activity Record

Activity	1st [ ]	2nd [ ]	3rd [ ]
Location of Activity	Name of Street: …………………… Name of Enterprise: ……………………	Name of Street: …………………… Name of Enterprise: ……………………	Name of Street: …………………… Name of Enterprise: ……………………
Mode of travel to Activity Location	○ Walk ○ bike ○ moped ○ motorbike ○ car ○ bus ○ taxi	○ walk ○ bike ○ moped ○ motorbike ○ car ○ bus ○ taxi	○ walk ○ bike ○ moped ○ motorbike ○ car ○ bus ○ taxi
Start of Travel Time to Activity Location	….. : …..(hh:mm)	….. : …..(hh:mm)	….. : …..(hh:mm)
End of Travel Time to Activity Location	….. : …..(hh:mm)	….. : …..(hh:mm)	….. : …..(hh:mm)
Duration of Conduct of Activity	….. : …..(hh:mm)	….. : …..(hh:mm)	….. : …..(hh:mm)
Current Traffic Conditions On-route	○ Not congested ○ Lightly ○ Medium ○ Heavily ○ I don't remember	○ Not congested ○ Lightly ○ Medium ○ Heavily ○ I don't remember	○ Not congested ○ Lightly ○ Medium ○ Heavily ○ I don't remember
With whom was this activity conducted?	○ Alone ○ Partner ○ Children ( ) ○ Other ( )	○ Alone ○ Partner ○ Children ( ) ○ Other ( )	○ Alone ○ Partner ○ Children ( ) ○ Other ( )
Was this activity planned in advanced?	○ No, but was included because ______________ ○ Yes, today ○ Yes, yesterday ○ Yes, >1 day ago ○ Is regular/routine	○ No, but was included because ______________ ○ Yes, today ○ Yes, yesterday ○ Yes, >1 day ago ○ Is regular/routine	○ No, but was included because ______________ ○ Yes, today ○ Yes, yesterday ○ Yes, >1 day ago ○ Is regular/routine

Figure 5.2 Instructions for the Investigator

Introduction

The research involves the study of the subjects in the process of providing data about their travel behaviour in an urban as an effect of carrying out activities to meet the needs of everyday living. The study covers observation of the subjects during the study period. This constitutes the field part. You will be given the opportunity to be familiar with a Stereographic Panoramic Navigation system (SPIN) in order to assist subjects should they have difficulty in completing the experiment.

Your functions are three fold. Firstly you are required to seek subjects to participate in a research study. Secondly, you will observe them as they carry out their activities and to record this data in a prescribed *Activity Record* form (attachment 2). Thirdly, you will administer to the subjects (a) a pen-and-paper questionnaire and (b) a computer form of measurement in SPIN. You may be required to perform one or all of the above functions randomly.

Field study

Tasks

1. Place yourself at your assigned following locations, e.g., exits of car park, bike storage, and at bus stop.
2. Approach a probable candidate who has just arrived to the study area in any form of transport. A probable candidate is someone who has planned to carry out one or more activities in the city.
3. Introduce yourself (interviewer from a research study at TU/e) and explain your intent to recruit him/her as a subject for participation.
4. Check if the candidate has a preliminary plan/schedule of his/her activities. Eliminate those who have activities of duration longer than two hours.
5. Explain the purpose of the experiments in the following manner:
   "This is a study to examine the quality of the information provided by subjects in a data collection process using two separate media. The two media are (1) a pen and paper method (PAPI), and (2) an computer-mediated means (SPIN). The data to be collected is about the travel performed by subjects who conduct activities in the study area. Travel is necessary to get to the different locations where the various intended activities can be conducted. Activities may be obligatory such as "going to work/school" and "shopping for food" or discretionary such as "going to the cinema" and "walk in the park".
6. Explain the tasks involved: (a) Stereo Panoramic Interactive Navigation, and (b) Pen-and-Paper Questionnaire. It is expected that the duration of the study will take approximately a half hour.
7. The subjects are required to provide information in one or both of the two following methods:
   (a) SPIN

Same as in PAPI but the subject will perform virtual travel in a simulated environment of Eindhoven in stereoscopic panoramas.

(b) PAPI

The Questionnaire is meant for the subjects to provide information about their activities they performed in the city and namely at locations within a limited area of Eindhoven (see map in Attachment 4).

8. The PAPI Questionnaire contains two sections: Personal Particulars (Attachment 1) and Activity Record (Attachment 2).
9. An "Activity List" (Attachment 3) is available to assist the subject in filling out his/her activity record.
10. Indicate the compensation given for participation (10 Euros worth voucher for La Place restaurant).
11. Enquire about the possibility of a detour to OpenbareBibliotheek Eindhoven or La Place Restaurant (V&D) at the end of his/her activities to carry out the following stages of the experiment in SPIN and PAPI.
12. When candidate agrees to be a subject. Thank the candidate. Inform the candidate that you will be waiting for her/him at the current location when s/he returns.
13. Signal to the "observer" interviewer who is looking on that the candidate is a subject for the experiment.
14. The "observer" interviewer to start with recordings of the activities of the subject. The recorded information is the same as what the subjects would fill in later. See "Activiteiten Enquête" booklet (fill out Attachment 2). The "observer" interviewer to mark route taken by the subject in Attachment 4 (map).
15. Give the subject an ***identification number,*** note ***start time***, ***start location***, and ***current weather***.

5.5 The First Method: Stereo Panoramic Interactive Navigation

The first method that is described here does not pertain to the order in which the subjects were measured. Interviewers had the free choice to decide which method should be administered first, mainly for the purpose of minimizing inconvenience to the subjects and also according to interviewer preference. Upon returning to the interviewers after their tour, the subjects are invited to where the computers are located. In our field study, we arranged for them to be housed in the heart of the city center at two locations: in the main public library of the city and in the dining area of a popular restaurant. Initially, the subjects will be presented with documentation (Figure 5.3) the SPIN system describing SPIN and the instructions on how to operate SPIN. This will enable the subjects to understand the procedure for providing their activity schedule data. To ensure that the subjects were clear as to how to provide the necessary activity schedule data they were instructed by a tutorial Appendix B. For the full description of the SPIN system, readers are requested to refer to Chapter 4.

Figure 5.3 Instructions to Subjects: Stereoscopic Panoramic Interactive Navigation

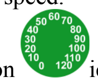
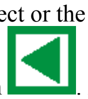
Stereoscopic Panoramic Interactive Navigation

About SPIN

This is a simulated environment of a limited part of the center of Eindhoven. It is composed of stereographic panoramas and stereoscopic glasses are needed to see a 3-D effect.

In this virtual environment you can choose the path of travel from origin to destination. The path will be made up of interconnecting nodes. Nodes are at ***intersections*** of streets.

What you can do

- Link to another node; follow a link.
  A ***possible*** link is indicated when the mouse changes to an ***arrow***. To move to another node click on the ***right mouse button***.
  Tip: Place the mouse as close as possible along the path to go where you want to be and not directly on the target location.
- Activity, conduct activity.
  Click on . Follow the instruction in the dialog boxes.
- Change travel mode.
  E.g. from Walking  to Bike , etc.
  Each travel mode has its own characteristics and accessibilities.
- Speed; change the traveling speed.
  Click on the desired speed on  icon. If you do not select your desired speed, a normal speed for the current mode is automatically used.
- Look around.
  Hold down the left button and move mouse left, right, up or, down.
- Time, changing the time.
  Click on digital clock. Enter a ***definitive*** time. Do this when you know the exact time that has elapsed for travel or conduct of an activity.
- Check Your Information, Travelogue
  Click on . A description of the events you have performed in the virtual environment is displayed for you verification. If you realized that some data is not correct or the sequence of events is not as you intended, you can go Back by click the Back button . A Forward button  is also provided. Only the 10 most recent actions are displayed. To see the whole history, use the Back and Forward buttons to scroll up and down.

5.6 The Second Method: Paper-and-Pencil Questionnaire

A paper-and-pencil questionnaire used in this study was designed to be on par with the current standards of activity-based data collection. We adapted an activity-based diary, developed by Arentze and Timmermans (2000) for the *Albatross* model system, for our purpose. In the design of our questionnaire, we concerned ourselves only with the out-of-home, geographically specific activities.

This instrument was meant for a subject to provide the same information about their activities as s/he had performed during the period under study, and namely at locations within the city center limits of Eindhoven, The Netherlands where this research was based. Besides the socio-demographics attributes (age, gender, occupation, level of education, level of income), vehicle ownership, other questions were included to ascertain the familiarity of a subject with the city center of Eindhoven, for example, the number of years the subject had lived and worked in the city, the frequency of visits to the area under study, etc. This was to rule out the factor of wayfinding in unfamiliar environments.

The questionnaire used an open time interval. The activity type and activity location description was in a free format. In addition, an “Activity List” was provided to assist the subject in filling out his/her activity type. A hierarchical classification of activities was used, allowing subjects to go quickly to the general type of activity (e.g., work, versus leisure), and then look for the most appropriate, more detailed description of the activity. The pre-coded scheme consisted of 11 general activity types with 34 sub-types (see Appendix A2, Attachment 3).

The forward recall is motivated by the arrangement of entering the sequence of the activities starting from the first to the last. Although instructed to do so, the subjects were free to decide if this was the best method for them to be accurate and precise about the recollection of their schedule.

The questionnaire that was administered during the field experiment was prepared in Dutch as the target subjects were Dutch literate nationals or residents. The full Dutch document is found in Appendix A1 with an English translation in Appendix A2.

The following discusses the dimensions of the activity pattern included in the questionnaire and outlines how each individual dimension will be measured in our study:

Time

Activity time is measured in terms of clock time, i.e., the particular time of day in which participation in an activity occurs.

Duration

The duration of activities is related to the time aspect. This is the amount of time individuals spend in a particular activity.

Location

The location of an activity is especially important for transportation planners and is associated with the land use classification at that location where the activity is undertaken. We will focus on the locations of out-of-home activities to us although the in-home activities should be included if the trade-off between the in-home and out-of-home is of interest to a study. The locations of the out-of-home activities are geo-coded to street addresses.

Travel mode

The transportation of choice used by individuals to travel from location to location. This dimension is related to the time aspect as the travel mode influences the travel time. It is also related to the sequencing of activities because the end-time of an activity signals the start time of an activity (or possibly the start time of another travel).

Sequence of activities

The organization the data collection is be driven by the forwards sequence of the activities and hence follow the forward recall procedure. This strategy may have the advantage to evoke more detailed and accurate recollections. Lists of probable activities may trigger associations and recall memories that would otherwise be forgotten, and thus has been incorporated.

Accompanying persons

The individual's participation in activities is influenced by the subjective constraints of his/her social roles. Of interest is whether the activity is undertaken with other members of the family.

Planning Horizon

Participation in some activities may occur on the spur of the moment whereas in some, advanced planning has been involved. The level of repetition over time for some activities may imply characteristics of routine or regularity.

Route

The choice of the travel route is specified at the level of streets and a real map (scale 1:12.500) has been selected instead of a schematic representation. The actual route paths followed by individuals possess characteristics that may, for example, explain why some trips have interim stops.

5.7 Method-Comparison Studies

To determine whether the new method of interactive experiments in virtual reality (aka known as SPIN) is a valid and reliable one we have chosen to compare this method with a surrogate "true" method - which is the revealed choice of the subjects, registered by the interviewers (OBS). The method comparison study is also carried out between the PAPI method and the OBS method. The revealed-choice method is assumed to be error-free. In method comparison studies, if the “test” method compares favourably with the revealed-choice method, it is judged to be acceptable.

Two statistical analyses namely the least-squares analysis and the t-tests were performed. According to Westgard and Hunt (1973), who have studied the usefulness of common statistical tests in method comparison studies, least square parameters (slope of least squares line, its y-intercept and the standard error of estimate in the y direction) provide specific estimates of proportional systematic error, constant systematic error, and random error. Least-squares analysis is potentially the most useful statistical technique, because the parameters provide accurate estimates of all types of errors and, especially applicable to our study where the data is used to demonstrate a linear relationship between methods. The use of correlation coefficients between the results of two measurements is not a good indicator of agreement because the approach is known to be misleading as the correlation coefficient describes association and not agreement. Bland and Altman (1986) have pointed out that perfect agreement between two measurements exists if the scores lie on the line of equality but it is possible to find perfect correlation if the plot of scores lie on any straight line. A change in the scale of measurement is also known not to affect the correlation, but will certainly affect the agreement between two measurements. Correlation will be high when the range of the measured quantity is wide. We summarize their results on sensitivity of the types of error according to the use of the least-squares regression, the t-test, and correlation coefficient in Table 5.2.

Random error. From the Table 5.2, it is apparent that S_y , SD_d , and r all respond to random error. SD_d is also influenced by proportional error, which means that this parameter does not provide a specific estimate of random error when proportional error is present. S_y and r are sensitive only to random error, but they differ in units and numerical values. S_y is in units of number or in duration of minutes. The r parameter is unitless and its difference from 1.00 indicates the magnitude of random error. However, r is dependent on the range covered and poses difficulty in interpretation in terms of actual random error between two methods as previously mentioned. S_y is thus a more useful parameter for quantifying random errors.

Constant error. Table 5.2 shows that the Y-intercept, *a*, and bias are both sensitive to constant error. However, proportional error does affect the bias parameter; therefore, *a* is a more useful parameter for quantifying constant error.

Proportional error. Table 5.2 shows that *b*, *bias* and SD_d are all sensitive to proportional error. The difference of b from 1.00 provides an exact estimate of the magnitude of the proportional error. The *bias* and SD_d, on the other hand, are not useful in the specific estimation of proportional error because of they are also affected by other errors. Thus, proportional error is best quantified by *b*.

We can generally say that the method that reveals the smaller proportional errors, smaller constant errors, the more valid it is and the smaller random error (the more reliable the method is), assuming that the revealed-choice method is error free. When a measurement (either by SPIN or PAPI) is not equal to the revealed choice, it is plausible to assume that the measured response is erroneous although we cannot rule out that in fact the measurement of the revealed choice is in itself erroneous.

Table 5.2 Sensitivity of Statistical Parameter to Different Types of Errors

Statistical Tests	Random	Constant	Proportional
Least squares			
Slope, *b*	No	No	Yes
Y intercept, *a*	No	Yes	No
Standard Error of estimate in the y direction, S_y	Yes	No	No
t-test			
Bias	No	Yes	Yes
Standard Deviation of Difference, SD_d	Yes	No	Yes
Correlation Coefficient, *r*	Yes	No	No

Source: Westgard and Hunt (1973)

5.7.1 T-test

T-test analysis, considered as complementary to least-squares analysis can provide estimates of constant and random errors, but only when proportional errors are absent. More importantly, in t-tests, the calculated t-values are intended to indicate whether differences between two methods under scrutiny are statistically significant. It can be generally concluded that when the calculated t-value is larger than the critical value, the difference between the methods is large and cannot be attributed to only sampling error. When small t-values are the result, it can generally be concluded that these two methods agree well. Since the revealed-choice method is assumed to have no errors, the method that agrees well with the OBS method can in turn be deemed to have smallest errors. Thus, the closer a method is to OBS, the more reliable and valid it is taken to be.

The t-test, specifically the pairwise t-test, is used to test differences in means between two related groups: 1) between the group SPIN and group OBS, 2) between group PAPI and group OBS. When we refer to related groups, we mean groups in which subjects were measured more than once; i.e. using 2 different forms of measuring situations with the same people. A group is distinguished by the measurement method. To illustrate, the same subjects in the group measured by the SPIN method are also found in the group measured by PAPI. In other words, the subjects for each of the two groups were paired in the t-test analysis. Pair-wise tests concern the comparison of the same group of individuals, or matched pairs, being measured twice, once using SPIN and again using PAPI. Using this methodology means the subjects function as their own control, lowering the level of unexplained variance or 'error'. The null hypothesis is that there is no difference between the two methods. The alternative hypothesis is that there is a difference between the two methods. The level of significance is 0.05, and a one-tailed test is used.

$$H_0 : |OBS - SPIN| = |OBS - PAPI| \qquad (5.1)$$

$$H_1 : |OBS - SPIN| < |OBS - PAPI| \qquad (5.2)$$

To apply the t-test for related groups we first differenced individual scores, found the mean of these differences and then divided it by the standard error of the differences.

t = [means of differences]/standard error of the mean of differences.

Random error is investigated by calculating the standard deviation between the scores obtained from PAPI (and SPIN) and that from OBS, abbreviated by SD_d in the discussion on results.

The bias between two test procedures is calculated as part of the t-test statistic and provides an estimate of the average difference between the scores collected by the two methods for a sample group. This estimate of the bias applies at the mean of the data, i.e., it represents the average or overall systematic error.

Thus, the t value also can be seen as the ratio of the constant and random terms where $t = (Bias/SD_d)\sqrt{N}]$, further provides information on the relative magnitudes of the constant and random error terms. It is the not a measure of total error. Hence the t values should not be seen in isolation as the defining factor in determining accuracy and precision levels. We provide further analysis of the data by least squares regression.

5.7.2 Least Squares Analysis

The least-squares regression line (Y= a + bX) provides an equation that can used to describe the strength of a relationship between X and Y. In our comparison study, we examined the relationship between the scores obtained by the PAPI method and scores from the revealed-choice (OBS) method. The relationship is examined likewise for the SPIN method. The revealed-choice method (OBS) being the criterion variable is plotted on the Y-axis and the methods to be compared with (SPIN and PAPI) being the practical variable is plotted on the X-axis.

Ideally, if a method is perfectly valid, the regression between the methods of either PAPI or SPIN with OBS should have the slope of 1.00 and an intercept of 0.0. This can ideally be expected since each of the two methods measures the same data type. Hence we are interested in how close the slope and intercept results of PAPI and SPIN compare with OBS. More importantly, we inspect the degree to which each of the two comparisons fair against each other.

If the value of the slope does not reveal a 1.00 then the deviation reveals a proportional error between the methods. If the value of the intercept does not register a 0.0, then the method deviates from the revealed-choice by a constant error. Random error shows up in the plot as scatter in the points around the regression line. The effect of random error can be observed in Sy, the standard deviation of the difference of the actual Y values from the Y value calculated from the least-squares equation also referred to as the residuals of the estimate in the y-direction.

However, a disadvantage of this approach is that the interpretation of the regression coefficients becomes problematic if the intercept is significantly different from zero if we want to examine the line of equality for agreement between a method and revealed choice. Therefore, in addition to standard regression, a regression through the origin was conducted. Validity between the measurements by an instrument with the revealed choice is interpreted from their agreement. If both measurements are valid, the instrument measure should be equal to the revealed choice. In this situation, we interpret that when a regression coefficient smaller than 1.0 it is indicative of over-reporting, whereas a coefficient larger than 1.0 suggests under-reporting.

We warn the reader to take caution regarding regression through the origin due to the fact that the coefficient of determination may turn out to be negative since the sum of the squared residuals for this type of regression may exceed the total sum of squares. This can occur when the data form a curvilinear pattern or a linear pattern with an intercept away from the origin. Hence, the coefficient of determination R-sq

= 1 - SSE/SSTO may turn out to be negative. Consequently, the coefficient of determination R-squared has no clear meaning for regression through the origin (Neter et al p.163, 1996). According to Myers (p.30): "In the intercept model the variations in the numerator (SSreg) and denominator (SStotal) of R-sq are calculated around the response mean, while in the non-intercept model those variations are calculated around zero. Such statistic cannot be used for performance comparison with the intercept model because the R-sq of the non-intercept model tends to be larger than the R-sq of the intercept model. This is because uncorrected (around zero) sum of squares are used. If R-sq was calculated around the response mean in the non-intercept model it could be negative in some cases." Anyhow, both the correlation coefficient for a standard least squares analysis and one for a regression through the origin are reported for who wish to have a deeper understanding of the analysis.

5.7.3 Levenshtein Distance for Route Comparison

The data on route choice is recorded as a sequence of the nodes along the path of travel. Every node has a unique identifying name. A node occurs at the intersection of roads. The stereoscopic panoramas display the views of the urban environment at the nodes.

We are interested in comparing the sequence from OBS method to that from PAPI and to that from SPIN. The validity of the PAPI sequence or the SPIN sequence can be recognized by comparing which sequence is more similar to the observed sequence. Sequence Comparison (http://www-igm.univ-mlv.fr/~lecroq/seqcomp/) can be used to ascertain the similarity between each pair of measurements. A dual notion to the similarity between two strings is the distance between them. This distance, is known as the Levenshtein distance. So, in sequence comparison, we are trying to minimize the distance between the strings from OBS and PAPI (and from OBS and SPIN) which also implies a maximizing of the similarity between them. A high similarity translates into a low Levenshtein distance. A high similarity of route data between either SPIN or PAPI with OBS foretells that the measurement by that method resembles the real route taken.

If sequence s is the data from the measurement by PAPI, and sequence g is the data from the measurement by OBS, three kinds of basic operations were used to transform sequence s into sequence g: the substitution of a node of sequence s by a node of sequence g, the deletion of a node in sequence s or the insertion of a node in sequence g. A cost is associated to each of these operations.

The equation for the 'weighted' Levenshtein distance is:

$$d(\boldsymbol{s},\boldsymbol{g}) = d(\boldsymbol{s}^m,\boldsymbol{g}^n) \quad (5.1)$$
$$d(s^0,g^0) = 0 \quad (5.2)$$
$$d(s^0,g^j) = d(s^0,g^{j-1})+w_i(\phi,g_j) \quad (5.3)$$
$$d(s^i,g^0) = d(s^{i-1},g^0)+w_d(s_i,\phi) \quad (5.4)$$
$$d(s^i,g^j) = \min\,[d(s^{i-1},g^{j-1})+w(s_i,g_j),\ d(s^i,g^{j-1})+w_i(\phi,g_j),\ d(s^{i-1},g^j)+w_d(s_i,\phi)] \quad (5.5)$$

with

$$w(s_i,g_j) = \begin{cases} w_e(s_i,g_j) = 0 & \text{if } s_i = g_j \\ w_s(s_i,g_j) > 0 & \text{if } s_i \neq g_j \end{cases} \quad (5.6)$$

where: $i, j \geq 1$; $d(s,g)$ is the total cost of equalization of s (= s^m) with g (= g^n); m and n are the number of elements in sequences s and g, respectively; $d(s^i,g^j)$ is the cost of equalization of s^i with g^j, cumulated from the equalization of s^0 to g^0. In this study, the weight for the identity operation was set equal to zero, while the weights for the other operations were all set equal to 1.

The sequence of the nodes is registered by each method as the route taken by the subjects. Therefore, for each subject, there are three such sequences based on the 3 measurements, by the OBS, PAPI and SPIN methods as in the following example where:

Route taken by subject ID 082223 when measured by SPIN is (J1441 K1407 K1408 K1434 K1438 K1409 K1334 K1311 K1409 K1408 K1407)

Route taken by subject ID 082223 when measured by PAPI is (J1441 K1407 K1408 K1409 K1311 K1409 1438 K1434 K1435 K1436 K1439 K1407 J1441)

Route taken by subject ID 082223 when measured by OBS is (J1441 K1407 K1408 K1409 K1311 K1310 K1307 K1303 K1306 K1431 K1430 K1429 K1428)

By assigning the sequence from SPIN to sequence s and the sequence from OBS to sequence *g*, we get:

s = (J1441 K1407 K1408 K1434 K1438 K1409 K1334 K1311 K1409 K1408 K1407)

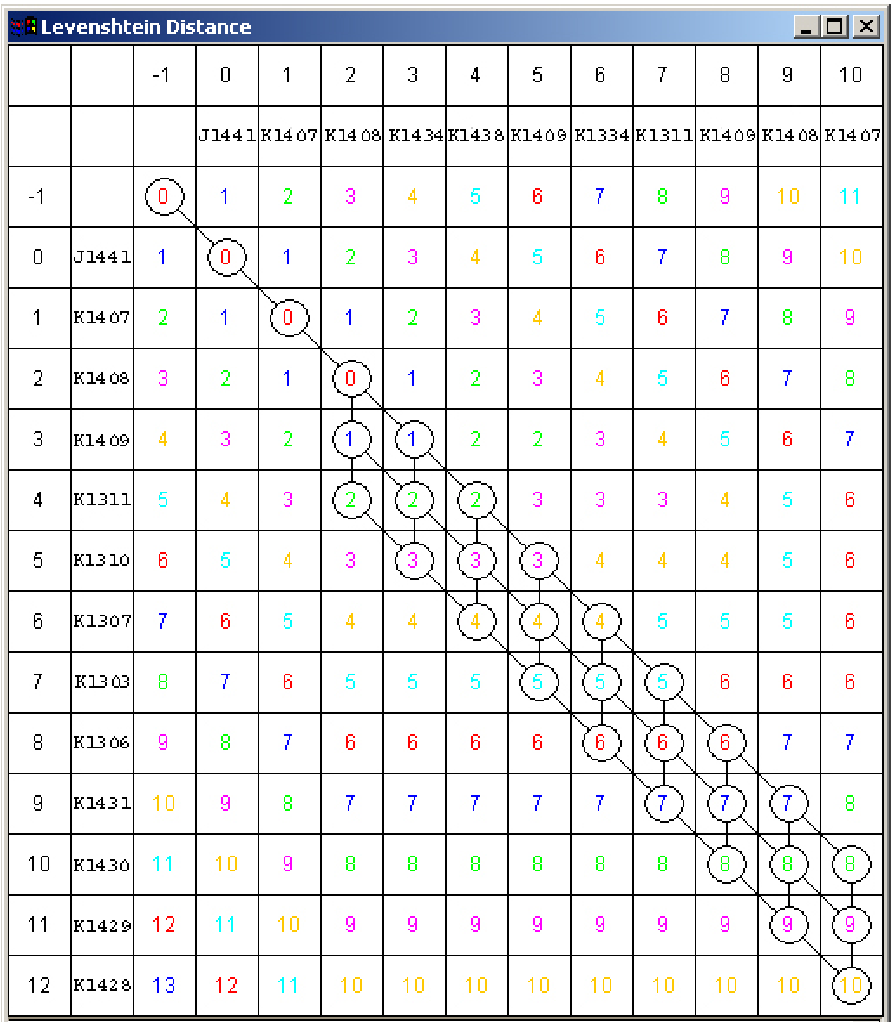
g = (J1441 K1407 K1408 K1409 K1311 K1310 K1307 K1303 K1306 K1431 K1430 K1429 K1428)

The minimum cost to transform sequence *s* to sequence *g* is 10, or Levenshtein distance is equal to 10 as indicated by the bottom right cell in Figure 5.5. There are altogether 9 possible ways to transform sequence *s* to sequence *g* at a minimum cost of 10 using the combinations of substitution, deletion, and insertions. An example of one sequence of operations at minimum cost is shown in Figure 5.5.

Figure 5.4 Extract of Route Choice from Travelogue Data of Subject ID “082223”


```
<pathdata>
  <user name="082223">
    <path type="computer">
      <item pan="J1441" />
      <item pan="K1407" />
      <item pan="K1408" />
      <item pan="K1434" />
      <item pan="K1438" />
      <item pan="K1409" />
     <item pan="K1334" />
     <item pan="K1311" />
     <item pan="K1409" />
     <item pan="K1408" />
     <item pan="K1407" />
   </path>
   <path type="questionnaire">
     <item pan="J1441" />
     <item pan="K1407" />
     <item pan="K1408" />
     <item pan="K1409" />
     <item pan="K1311" />
     <item pan="K1409" />
     <item pan="K1438" />
     <item pan="K1434" />
     <item pan="K1435" />
     <item pan="K1436" />
     <item pan="K1439" />
     <item pan="K1407" />
     <item pan="J1441" />
   </path>
   <path type="followed">
     <item pan="J1441" />
     <item pan="K1407" />
     <item pan="K1408" />
     <item pan="K1409" />
     <item pan="K1311" />
     <item pan="K1310" />
     <item pan="K1307" />
     <item pan="K1303" />
     <item pan="K1306" />
     <item pan="K1431" />
     <item pan="K1430" />
     <item pan="K1429" />
     <item pan="K1428" />
   </path>
  </user>
</pathdata>
```

Figure 5.5 Graph of Transformation of Sequence *s* To Sequence *g*



		-1	0	1	2	3	4	5	6	7	8	9	10
			J1441	K1407	K1408	K1434	K1438	K1409	K1334	K1311	K1409	K1408	K1407
-1		0	1	2	3	4	5	6	7	8	9	10	11
0	J1441	1	0	1	2	3	4	5	6	7	8	9	10
1	K1407	2	1	0	1	2	3	4	5	6	7	8	9
2	K1408	3	2	1	0	1	2	3	4	5	6	7	8
3	K1409	4	3	2	1	1	2	2	3	4	5	6	7
4	K1311	5	4	3	2	2	2	3	3	3	4	5	6
5	K1310	6	5	4	3	3	3	3	4	4	4	5	6
6	K1307	7	6	5	4	4	4	4	4	5	5	5	6
7	K1303	8	7	6	5	5	5	5	5	5	6	6	6
8	K1306	9	8	7	6	6	6	6	6	6	6	7	7
9	K1431	10	9	8	7	7	7	7	7	7	7	7	8
10	K1430	11	10	9	8	8	8	8	8	8	8	8	8
11	K1429	12	11	10	9	9	9	9	9	9	9	9	9
12	K1428	13	12	11	10	10	10	10	10	10	10	10	10

5.8 Summary

In this chapter, we have described how we intend to verify the reliability and validity of SPIN. Two separate measurements on a subject's activity-travel schedules, using the SPIN and PAPI instruments to collect data on the choice dimensions of an individual's schedule. A subject's revealed choice is first recorded by direct observation (OBS). Data collection thereafter ensues by self-registration using either the SPIN instrument or the PAPI instrument. The procedures of these measurements have been adequately specified to for the purpose of ensuring standardization of the data collection process. The data collected by the two instruments will be analysed for their degree of agreement with that recorded by direct observation. The data from the direct observation can be referred to as the "benchmark" against which the other two measurements will be compared. Here, the revealed choices recorded by the observers are assumed to be surrogate "true" values. Thus, the comparison between the PAPI and the OBS data will reveal the degree of agreement PAPI data has to the "real" values. Similarly, the same applies for the comparison between SPIN data and OBS data. The "closer" the data from a method is to the OBS method, that method is deemed to perform with a higher degree of reliability and validity. Finally, the degree of agreement between an instrument measure and the revealed choice also relates to the occurrence of errors that is incumbent in the process of measurement, assuming that the measurement was performed immediately where possible thereby involving the shortest recall interval.

Two statistical tests, the least squares regression and t-tests, are used to estimate the amount of proportional systematic error, constant systematic error, and random error between pairs of data sets. The t-test is used to test for significant differences in means between the two related sets of data (e.g. OBS vs. SPIN). A significant difference (set at 95% confidence limit) implies a deviation from "true" values and the method performs poorly for the facet of the activity schedule under examination. Whereas the least square regression test gives an indication of whether the method demonstrates a high or low degree of equality relationship with the revealed choice observations. A method with a high linearity with the observed data performs with a higher degree of validity.

Additionally, if the two methods prove to perform well, in other words demonstrate an agreement with revealed choice, a check is made on the magnitude of errors; the method with lower random errors translate into a higher degree of reliability and lower systematic errors translate into a higher degree of validity. Thus, the parameters examined for the magnitude of systematic errors is the slope of the regression line through origin, b, and the parameter examined for the magnitude of random errors is S_y, the residuals of the estimate in the y-direction.

In the analysis of the route choice dimension where a route is defined as a sequence of node identities, the distance between the sequences recorded using SPIN (or PAPI) and the observed sequence gives the degree of agreement between methods. A ratio of the minimum (Levenshtein) distance and the maximum distance is used in the comparison of similarity of the route measured by a method with the “true” route. A ratio of the minimum (Levenshtein) distance and the maximum distance gives us a basis of examining the results of the comparison between OBS with SPIN and OBS with PAPI. The ratio of minimum to maximum cost is an important indicator of the degree of similarity of a pair of reported route sequences. A small ratio implies a higher degree of similarity while a high ratio implies a lower degree. A perfect match between two route sequences results in a ratio of 0.0 between them.

The methods described in this chapter outline the approach taken to carry out the experiments to investigate the reliability and validity of the system designed for collecting activity-based travel data in an interactive virtual reality environment. The next chapter will be concerned with the analysis and discussions on the data that has been collected based on the approach.

6 Results of the Study

6.1 Introduction

The data used to test the reliability and validity of interactive computer experiments was collected in the context of an out-door activity trip made within a limited commercial area in the heart of the city of Eindhoven, The Netherlands. The area is a location for shopping and important key services of the city, including the main civic services of the town hall, the bus and the train stations.

Each subject was measured once using each of the two methods described in chapter 5. Prior to their performing the experiment, the real travel during the period of the conduct of the subject's intended schedule is registered by an observer, thus establishing a "benchmark" set of data for each subject. The second measurement took place after the subject has returned to the start (interception) point. At this juncture, the subject were requested to filled out the PAPI questionnaire followed by SPIN or in the reverse sequence. In the second and third measurement subjects were instructed to provide information on the activities that were carried out from the time after the interview until their return to the interviewers.

We will examine the results of the comparison of PAPI and SPIN with the revealed-choice method in the following sections. In the following section, we report on the sample selected for the study. We first examine the registration effects of each instrument in terms of missing data and incorrect data found in the results. The results of the analysis of least squares regression and t-test between the measured scores and "real" data are then presented in the subsequent sections. Section 6.4 covers the results for the whole sample while in section 6.5, we will discuss the results for the groups where the subjects were divided into those who were measured by PAPI first and those who were measured by SPIN first. Detailed examination of the travel durations between activities is conducted in section 6.6.

6.2 Sample Description

A sample of individuals was interviewed on each day of a two-week period stretching between August and September 2002. During 9 days in August, from 20th to 24th and from 28th to 31, and 1 day in September, on the 1st, subjects were intercepted and invited to participate in a survey about their activities they intended to carry out in the study area. There were altogether 2 Saturdays, 1 Sunday, and 7 weekdays. The one Sunday was a shopping Sunday that was normally scheduled on the first Sunday of the month and the shops were opened from 12:00 to 17:00. On Saturdays, shopping hours were from 09:00 to 17:00. Shopping hours on weekdays ranged from 09:00 to 18:00 with the exception on Fridays when closing times were extended till 21:00.

A total of 57 subjects participated in the experiments and were measured by both the two methods and their corresponding activity schedules were pre-recorded by direct observation. Table 6.1 shows the distribution of our sample between the two different methods of measurement. In 41 cases, the subjects were measured by SPIN first (SPIN_1st) and then followed by PAPI while the remaining 16 were measured by PAPI first (PAPI_1st) and then by SPIN. The total number of subjects in the SPIN_1st group was much higher than in the PAPI_1st group due to the fact the interviewers have had to explain the procedure of the experiment by demonstrating the SPIN system, it turned out that more subjects were enthusiastic to start with the SPIN measurement first. Ideally, random assignment was the protocol, but in practice there was also the need to consider the time pressure of the subjects such that they (and accompanying persons of the same party) would not be inconvenienced. At the same time, to get the flow of the participants going, whenever a computer system was available, subjects were measured in SPIN. As turned out, the experiment time was of a considerable shorter duration for SPIN than for PAPI with the eventual outcome was that more subjects had been steered towards starting with SPIN first. In the PAPI_1st group, there was one incident of system error in SPIN and this case was eliminated from the analysis reducing the cases for SPIN in the PAPI_1st group from 16 to 15. The subjects were not screened for computer experience. The incidental expenses incurred for participation was a restaurant voucher valued at 10 Euros per subject.

Table 6.1 Sample of Subjects

	SPIN_1st	PAPI_1st	Total No of Usable Cases
OBS	Not Applicable	Not Applicable	56
SPIN	41	15	56
PAPI	41	16	57

Table 6.2 provides the summary of the socio-demographics of the sample. The sample was almost equally split between male and female. The average age was 31.6 years. Most subjects indicated they felt fairly well to very well familiar with Eindhoven. There appeared to be a bias to higher-educated people, partly caused by the relative large share of students in the sample. The reason for this large share is twofold. First, as a university city, the percentage of students in the population is relative large. Secondly and more importantly however, the entry point to the city centre where subjects were selected is close to a school. Thus, the sample was probably representative of the pedestrians who enter the city centre at that point, but not for the Eindhoven population at large. Given the purpose of the study, however, this is not a real issue.

6.3 Registration Effects

Time and duration entries had the biggest difference in registration. Again in the PAPI method, all time entries required the subject to write the details. However, in SPIN, once the experiment has started with the initial begin time of the schedule, progressive lapse of time is calculated based on the consecutive action of the subject. It is possible in SPIN not to make conscious effect to make time entries, unless the subject wishes to stipulate an over-ride of deduced time.

The results of the occurring inconsistencies show that SPIN is superior to PAPI when it comes to minimizing registration errors. This can be expected due to the fact that the computerized form of the questionnaire made sure that the subject did not forget to make an entry before moving on to the next action. Simple errors of mathematics mostly encountered in time duration estimations were not possible in SPIN. This is indicated in the absence of wrong entries in SPIN. This is not the case in PAPI. Subjects clearly made the most number of missing entries and this is especially serious in the data on activity type. At almost half the time, the activity type was not entered in PAPI compared to less than 1% in SPIN. We can only reason that subjects might have trouble to specify the activity since it was in a free form format, although there was aid with a prompt list which means referring to a separate sheet of paper. Another remarkable missing item is the route choice. In PAPI, the subjects were instructed to mark the route on a prepared map. Almost half of them did not perform this task in PAPI. It was not a task in SPIN. Either the subjects felt that this was not important or ignored the instructions due to other unknown reasons. In SPIN, the controlled sequence of the data collection process ensured that the subjects were not able to ignore or avoid the questions if they were obligated to complete the schedule. The structuring of the "obligatory" form of questioning, in this case it proved to be effective in addressing the shortcoming of missing entries.

Table 6.2 Sample Description

		%	% of missing entry
Gender	Females	49	0
	Males	51	
Age	Average Age	31.6	2
Familiarity with Eindhoven	Bad	2	0
	Fair	33	
	Good	65	
Educational Level			0
	University	25	
	HBO (Higher Vocational)	39	
	MBO (Vocational)	14	
	VWO (Pre-U)	5	
	HAVO (High Secondary)	5	
	MAVO (Low Secondary)	9	
	LBO (Primary)	4	
Employment	Students	25	11
	Retired	4	
	Unemployed	31	
	Employed	69	
Income Level	No Income	10	14
	<€5.000	20	
	€5.000 - €10.000	16	
	€10.000 - €15.000	2	
	€15.000 - €20.000	8	
	€20.000 - €25.000	12	
	€25.000 - €30.000	0	
	€30.000 - €35.000	16	
	>€35.000	14	
	Possess Car License	71	2
	Use of car	55	2
	Posses Motorbike License	9	2
	Use of motorbike	4	5

Table 6.3 Wrong Entries by Methods

	Total Wrong Entries		% Total Wrong Entries	
Inconsistencies	PAPI	SPIN	PAPI	SPIN
Activity Type	0	0	0.0	0.0
Location	0	0	0.0	0.0
Mode	0	0	0.0	0.0
Travel Start	5	0	2.4	0.0
Travel End	6	0	2.9	0.0
Travel time	2	0	1.0	0.0
Activity Duration	0	0	0.0	0.0
Congestion	0	0	0.0	0.0
Acc. Persons	0	0	0.0	0.0
Planning	0	0	0.0	0.0
Route	-	-	-	-

Table 6.4 Missing Entries by Methods

	Total Missing Entries		% Total Missing Entries	
Inconsistencies	PAPI	SPIN	PAPI	SPIN
Activity Type	98	1	47.3	0.5
Location	1	1	0.5	0.5
Mode	1	0	0.5	0.0
Travel Start	9	0	4.3	0.0
Travel End	11	0	5.3	0.0
Travel time	15	0	7.2	0.0
Activity Duration	10	1	4.8	0.5
Congestion	7	0	3.4	0.0
Acc. Persons	4	0	1.9	0.0
Planning	10	1	4.8	0.5
Route	26	0	45.6	0.0

6.4 Results and Discussion

In this section we examine the error parameters for the two statistical tests conducted on the method comparison studies as described in section 5.7. Based on the previous discussion on the threats to reliable and valid measurements (section 2.2), we can now make our interpretation on reliability where the measurements from an instrument are compared with the (surrogate) true values as related to the amount of random errors. As argued previously (section 5.7), *Sy* is the most useful parameter for quantifying random errors and will be used in our study as the measure of reliability. Low random errors translate into high reliability while high random errors translate into low reliability. Validity is interpreted as the degree of equality with reality. Where the instrument is able to measure data in perfect correspondence with reality, the parameter, *b* that indicates the linearity between two sets of data should have the value of 1.0. In our assessment of the measurements from the two separate instruments, higher *b* values imply a higher degree of validity and lower *b* values a lower degree of validity.

In addition to the analysis where the measurements from each instrument are compared with the (surrogate) true values, error parameters are also examined for the differences between the measurements taken from the two instruments. In this comparison, we are mainly interested in whether there is a significant difference between them and where found will be highlighted in the footnotes of the different facets. As it is not the intention of the study to test for the performance of the instruments against each other, especially where both instruments possess inherent errors of measurement, the results of the other error parameters are presented for reference to interested readers only and will not be elaborated in the analysis.

The discussion of the error estimates is broken down into the various components of the activity schedule. The nine components studied are:

1. # of stops made by the subjects from start to finish of the schedule,
2. # of different activities performed,

3. Duration of all the activities,
4. Duration of the services activity,
5. Duration of the shopping activity,
6. Duration of the out-door leisure activity,
7. Duration of travel between activities, and
8. Duration of the whole schedule,
9. Route choice.

In the following sub-sections, the results for the whole sample are examined and discussed starting with the first facet of the # of stops, followed by the rest of the eight as listed.

6.4.1 # of stops

Statistical results for # of stops in Table 6.5 shows that there is no significant difference between the number of stops reported by the observers and the number of stops recorded during the virtual reality re-enactment sessions. In contrast, the t-value of 2.298 suggests a significant difference between PAPI and actual behaviour. The positive sign of the t-values suggest that on average both instruments has led to an under-reporting of the number of stops. The estimated slope of the regression equation through the origin, which accounts for respectively 31.3 and 27.4 percent of the variance, is equal to 1.115 for PAPI and 1.044 for SPIN, implying that the proportional error for PAPI is higher than the proportional error of SPIN. Results indicate that both instruments under-report the number of stops, but SPIN is closer to the observations. Figure 6.1 (a) indicates that a single subject has a major impact on the results. The higher value of the standard deviation of residuals suggests a higher degree of heterogeneity in the SPIN responses compared to PAPI but the differences are small.

Table 6.5 Statistical Results for # of Stops

Error Parameters	OBS – PAPI	OBS – SPIN	SPIN -PAPI
N	56	56	56
b*	1.115	1.044	1.007
Sy*	2.202	2.269	1.407
Bias	0.661	0.364	0.304
SD_d	2.151†	2.247†	1.374
t	2.298†	1.200	1.653
r*	0.560	0.523	0.633
r	0.595	0.552	0.720

*Regression parameters through origin
†The difference is significant at the 5% probability level

6.4.2 # of Different Activities

The second facet of the activity-travel patterns concerns the number of different activities. Table 6.7 shows that SPIN again has generated more valid responses than PAPI indicated in the t-value of SPIN that is lower than the t-value for PAPI. However, because both t-values are lower than the critical t- value at the 95% significance level, both instruments record the number of different activities reasonably well. The regression through the origin and the

t-values shows evidence of slight over-reporting for both SPIN and PAPI. This is especially true for a higher number of activities as visualized in Figures 6.2(a) and 6.2(b).

6.4.3 Duration of all activities

As for duration of all activities, (Table 6.6) the high t-value of SPIN beyond the critical value indicates that this instrument does not record the duration very precisely. The bias and the estimated slope of the regression equation indicate that this instrument results in an over-reporting of the duration for both instruments. The over-reporting is slightly lower for PAPI. However, PAPI produces more

Regression | Regression Through Origin

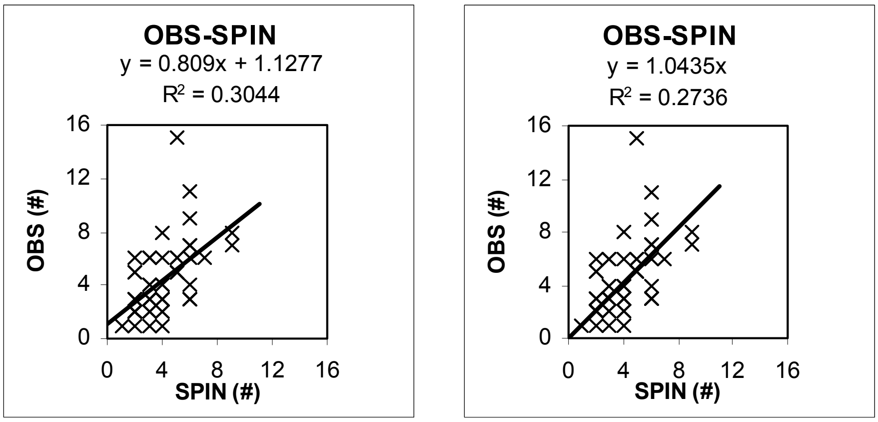


Figure 6.1 (a) # of Stops by OBS vs. SPIN

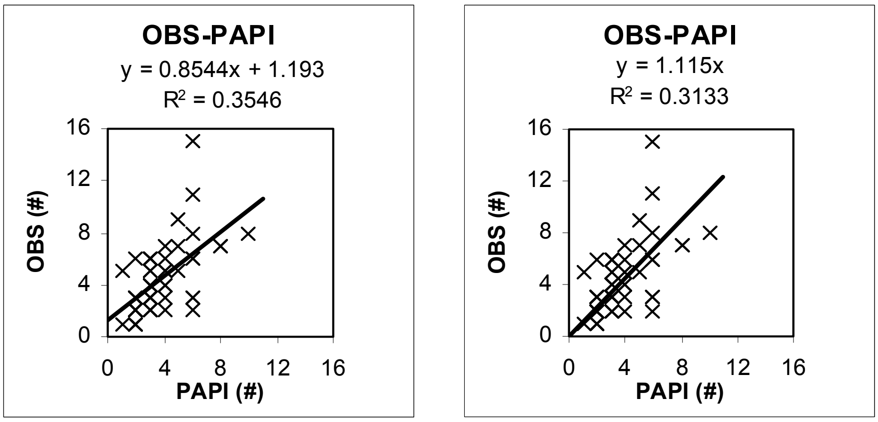


Figure 6.1 (b) # of Stops by OBS vs. PAPI

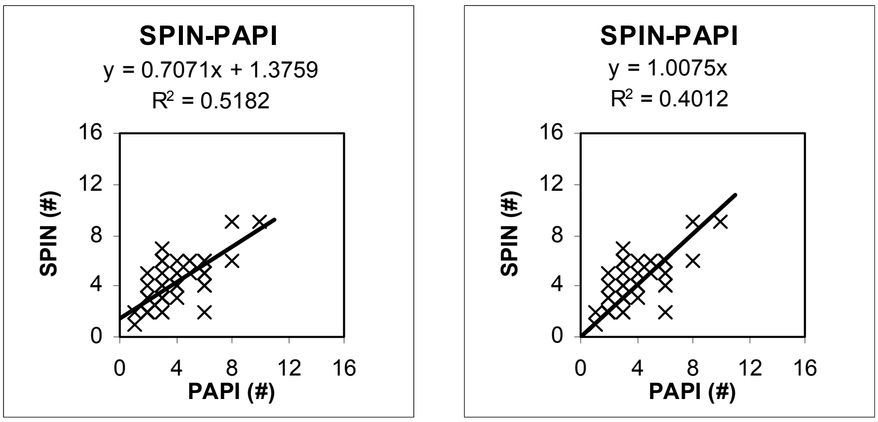


Figure 6.1 (c) # of Stops by SPIN vs. PAPI

heterogeneous results, where the random errors are indicated to be higher (S_y). Figure 6.3a and 6.3b show that there is a tendency for some subjects to substantially over-report the duration across all activities with increasing duration, and this tendency is higher for SPIN than for PAPI.

Table 6.6 Statistical Results for Duration of all Activities

Error Parameters	OBS – PAPI	OBS – SPIN	SPIN – PAPI
N	39	41	51
b*	0.812	0.819	0.991
Sy*	20.77	16.81	15.26
Bias	-5.154	-7.805	1.745
SD_d	22.90	18.29	15.16
t	-1.405	-2.717[†]	0.822
r*	0.625	0.767	0.868
r	0.690	0.778	0.880

*Regression parameters through origin
[†]The difference is significant at the 5% probability level

Table 6.7 Statistical Results for # of Different Activities

Error Parameters	OBS – PAPI	OBS – SPIN	SPIN – PAPI
N	56	56	56
b*	0.874	0.864	0.942
Sy*	0.944	1.019	0.828
Bias	-0.161	-0.091	-0.089
SD_d	0.987	1.076	0.837
t	-1.219	-0.626	-0.798
r*	-0.342	-0.531	0.619
r	0.376	0.397	0.763

*Regression parameters through origin

Regression | Regression Through Origin

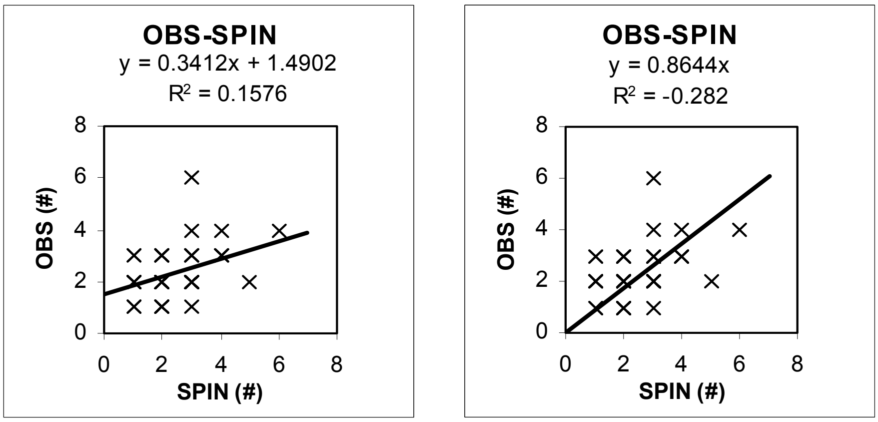


Figure 6.2 (a) # of Different Activities by OBS vs. SPIN

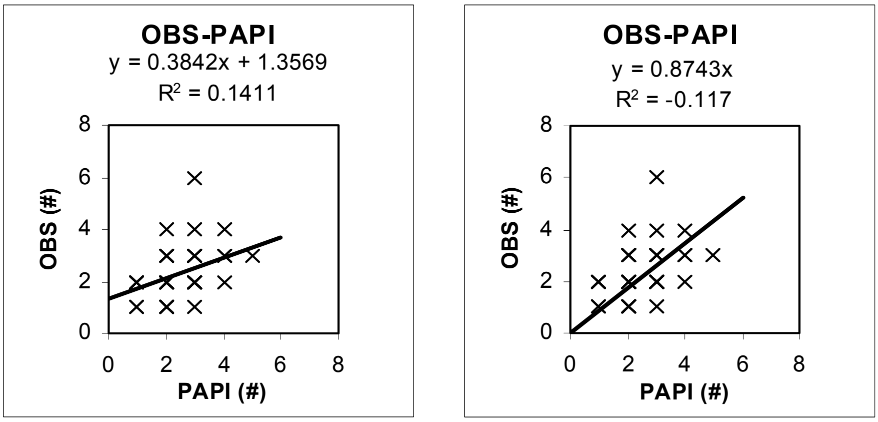


Figure 6.2 (b) # of Different Activities by OBS vs. PAPI

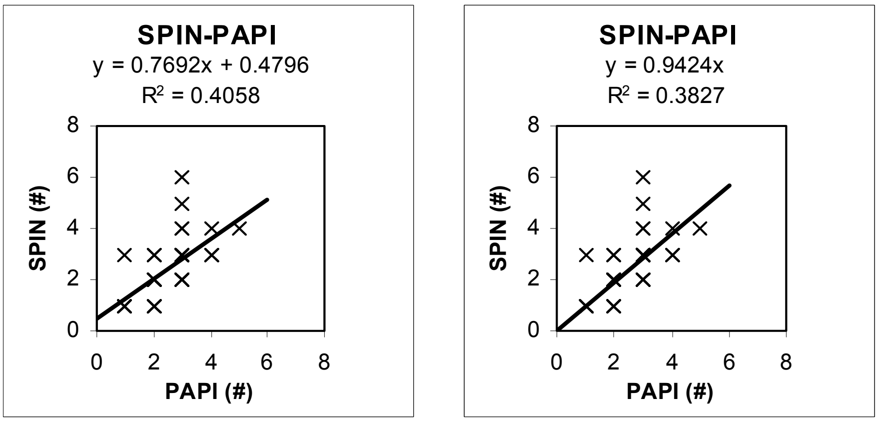


Figure 6.2 (c) # of Different Activities by SPIN vs. PAPI

Table 6.8 Statistical Results for Duration of Services Activity

Error Parameters	OBS – PAPI	OBS – SPIN	SPIN – PAPI
N	11	8	10
b*	0.820	0.922	0.951
Sy*	8.633	3.398	7.261
Bias	-6.727	-2.375	1.300
SD_d	8.742	3.962	7.379
t	-2.552†	-1.696	0.557
r*	0.951	0.994	0.971
r	0.957	0.994	0.975

Regression parameters through origin
†The difference is significant at the 5% probability level

6.4.4 Duration of Services Activity

The next facet concerns the duration of the services activities. Again, the results indicate that SPIN is more valid than PAPI, although both over-report the duration of the services activity. PAPI introduces substantially more variability in the responses. The explained variances of the regression are high for both instruments, although the relatively small degrees of freedom should be kept in mind here. The graphs in Figures 6.4 (a) and 6.4 (b) illustrate the small scatter for the few points about the least-squares regression line.

6.4.5 Duration of Shopping Activity

Unlike the durations of previous mentioned activities in the schedule, subjects seem to have reported the duration of the shopping activity realistically. The t-values for both instruments indicate that the recorded duration of shopping in both instruments is not significantly different from the duration reported by the observers. Again, this facet is over-reported by both SPIN and PAPI; however, the PAPI appears to perform slightly better, but the difference is not significant. On the other hand, the variability in the responses, as indicated by the standard deviation of error, is slightly higher for PAPI.

Regression | Regression Through Origin

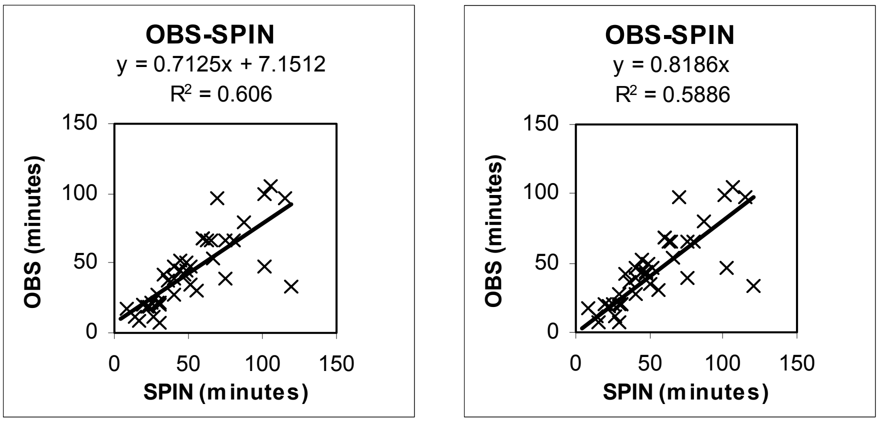


Figure 6.3 (a) Duration of all Activities by OBS vs. SPIN

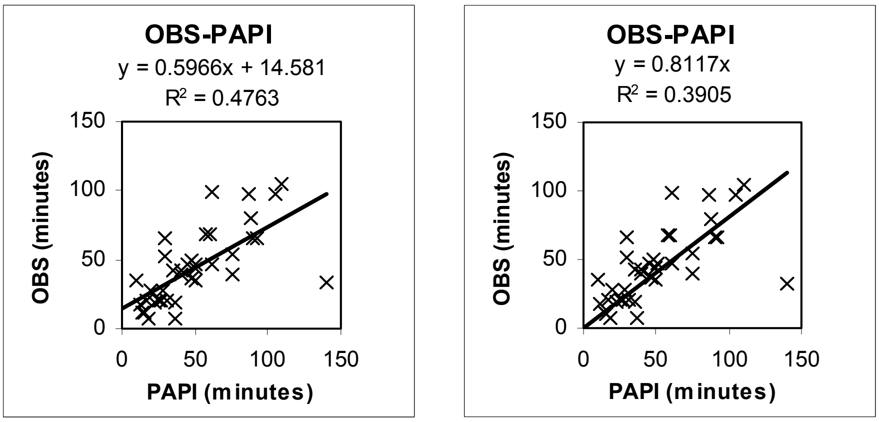


Figure 6.3 (b) Duration of all Activities by OBS vs. PAPI

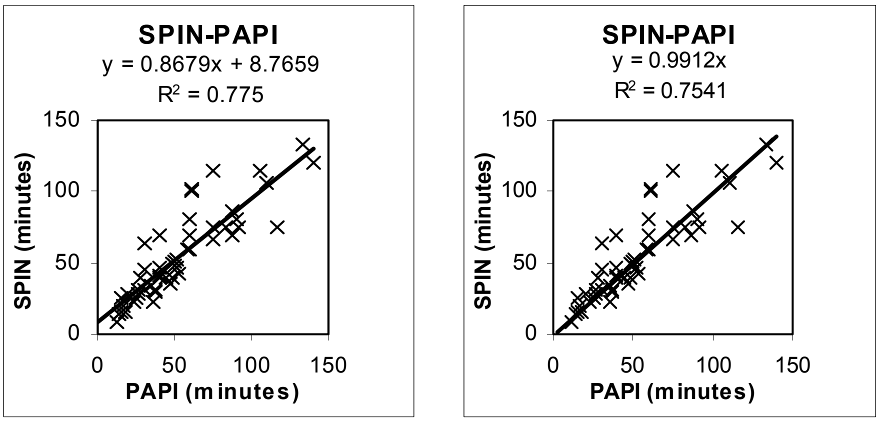


Figure 6.3 (c) Duration of all Activities by SPIN vs. PAPI

Regression | Regression Through Origin

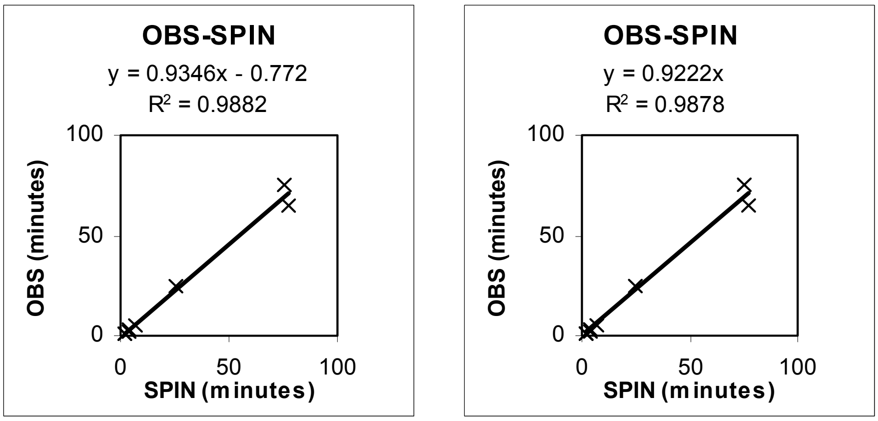


Figure 6.4 (a) Duration of Services Activity by OBS vs. SPIN

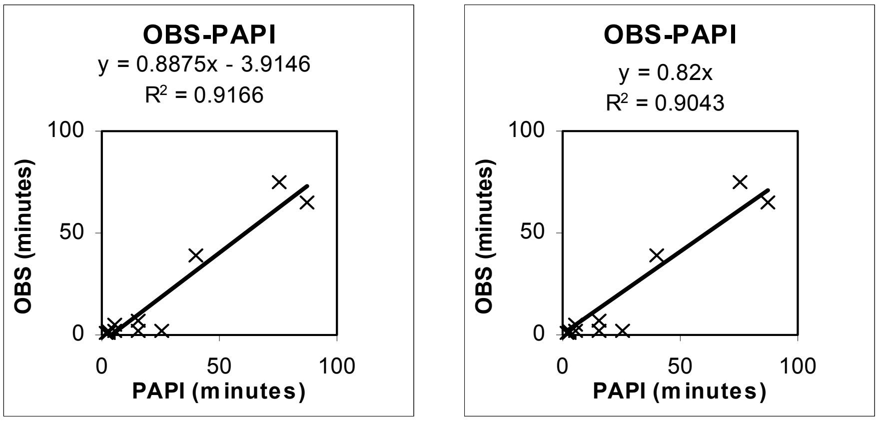


Figure 6.4 (b) Duration of Services Activity by OBS vs. PAPI

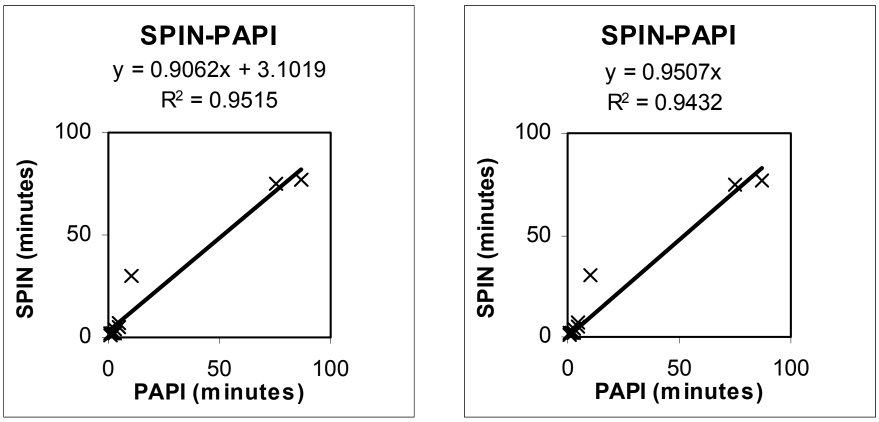


Figure 6.4 (c) Duration of Services Activity by SPIN vs. PAPI

Regression | Regression Through Origin

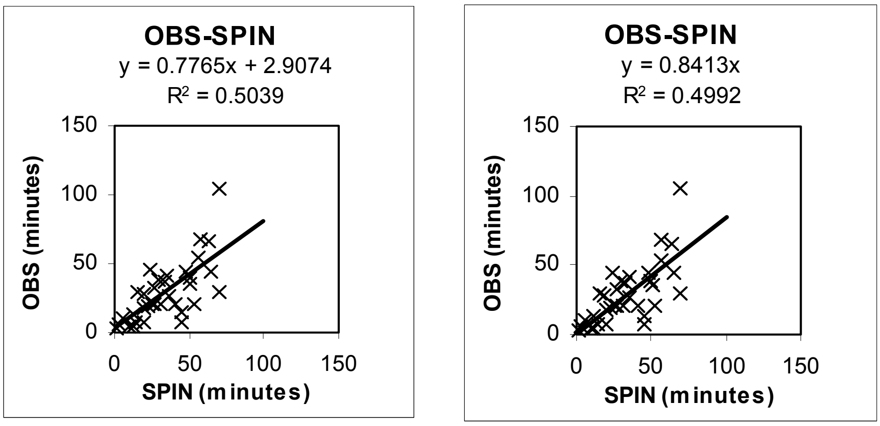


Figure 6.5 (a) Duration of Shopping Activity by OBS vs. SPIN

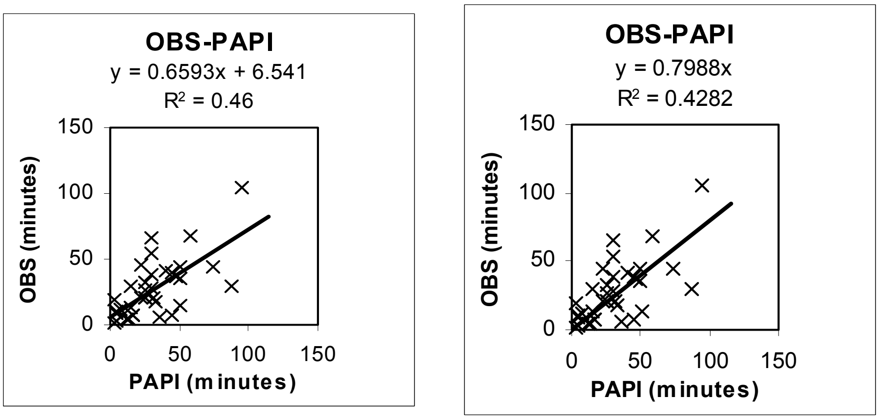


Figure 6.5 (b) Duration of Shopping Activity by OBS vs. PAPI

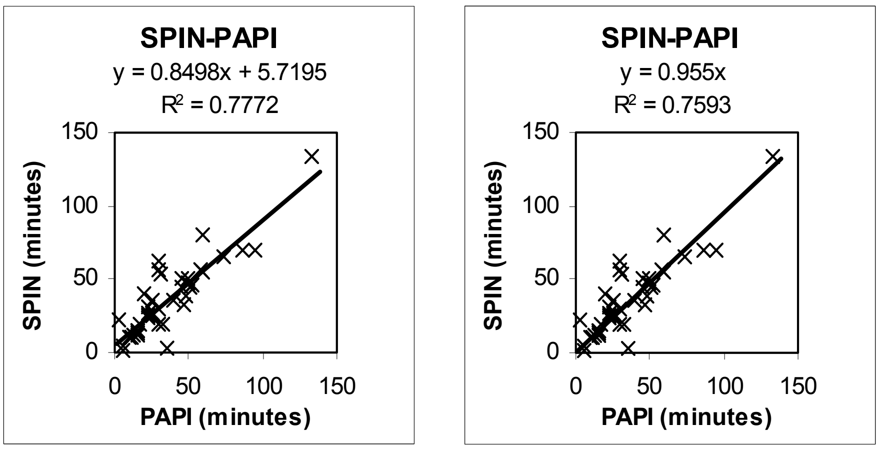


Figure 6.5 (c) Duration of Shopping Activity by SPIN vs. PAPI

Table 6.9 Statistical Results for Duration of Shopping Activity

Error Parameters	OBS – PAPI	OBS – SPIN	SPIN – PAPI
N	37	34	43
b*	0.799	0.841	0.955
Sy*	16.66	15.39	12.30
Bias	-3.838	-4.559	0.302
SD_d	17.94	15.94	12.46
t	-1.301	-1.667	0.159
r*	0.654	0.707	0.871
r	0.678	0.710	0.882

*Regression parameters through origin

6.4.6 Duration of Out-of-Home Leisure Activity

Another facet concerned the duration of leisure activities. PAPI records the duration of these activities better, as indicated by a non-significant t-value at the 95% probability level. On average, both instruments over-report the duration of these activities. Over-reporting is especially serious for SPIN as seen from the comparatively low outcome of the regression (slope). Furthermore, the explained variance for SPIN is also very low.

6.4.7 Duration of Travel between Activities

This facet is concerned with travel between activities. Table 6.11 shows that SPIN clearly outperforms PAPI. The t-value is not significant for SPIN, but it is for PAPI. Besides, the case of over-reporting that occurs in PAPI is significant despite the indication of lower variability. Less disparity between real observations and SPIN can be accrued to the fact the duration of travel is implicitly registered during navigation in the virtual environment according to route choice and mode choice. Subjects had an opportunity to 'over-ride' the calculated time if it was deemed incorrect. Less effort in recall of travel duration between activities is entailed in SPIN than in PAPI appears to have a positive effect on results.

Table 6.10 Statistical Results for Duration of Out-of-Home Leisure Activity

Error Parameters	OBS – PAPI	OBS – SPIN	SPIN – PAPI
N	14	14	16
b*	0.829	0.521	1.040
Sy*	15.39	15.35	15.76
Bias	-4.714	-11.79	4.063
SD_d	15.87	19.82	15.25
t	-1.112	-2.225†	1.065
r*	0.770	0.356	0.647
r	0.770	0.436	0.702

*Regression parameters through origin
†The difference is significant at the 5% probability level

Table 6.11 Statistical Results for Duration of Travel between Activities

Error Parameters	OBS – PAPI	OBS – SPIN	SPIN – PAPI
N	45	47	51
b*	0.672	0.833	0.582
Sy*	7.757	9.343	7.806
Bias	-3.854	0.920	-5.098
SD_d	9.211	9.570	9.972
t	-2.899†	0.680	-3.651†
r*	0.301	-0.590	-0.321
r	0.450	0.177	0.354

*Regression parameters through origin
†The difference is significant at the 5% probability level

6.4.8 Duration of Schedule

If we examine the total duration of the complete schedule (duration of activities plus the duration of travel) Table 6.12 shows that both instruments gather the data on total duration quite well. The t-values for both instruments are not beyond their critical values. However, the results in Table 6.12 also indicate that PAPI outperforms SPIN: the t-value is lower, the explained variance is higher, the average degree of over-reporting is less and also PAPI produces more consistent results across subjects.

Although the durations of all travel is better measured in SPIN, and the durations of all activities is measured better in PAPI, in the overall scheme, the sum effect of the durations appears to tip in favour of PAPI

6.4.9 Route Choice

In the analysis of the data on route choice, the comparison of route choices is performed by determining the similarity between two string sequences describing the routes. This difference is the Levenshtein distance calculated based on the minimizing the distance between the strings. A high similarity translates into a low Levenshtein distance. A high similarity of route data indicates that the measurement by that method resembles the real route taken. Table 6.13 shows the statistical results of the comparison of the ratios of Levenshtein distances between OBS - SPIN and OBS - PAPI. The smaller mean of ratio of Levenshtein distances found in OBS - PAPI than in OBS - SPIN shows that the method of PAPI was able to register route sequences at a higher degree to revealed choice than that registered by SPIN.

Table 6.12 Statistical Results for Duration of Schedule

Error Parameters	OBS – PAPI	OBS – SPIN	SPIN – PAPI
N	36	38	49
b*	0.924	0.809	0.942
Sy*	20.65	26.16	25.42
Bias	-1.351	-7.359	1.714
SD_d	21.15	28.14	25.71
t	-0.389	-1.633	0.467
r*	0.669	0.229	0.576
r	0.710	0.455	0.691

*Regression parameters through origin

Table 6.13 Statistical Results for Route Choice

Error Parameters	OBS – PAPI	OBS – SPIN	SPIN – PAPI
N	32	39	44
Mean	0.195	0.255	0.184

Regression | Regression Through Origin

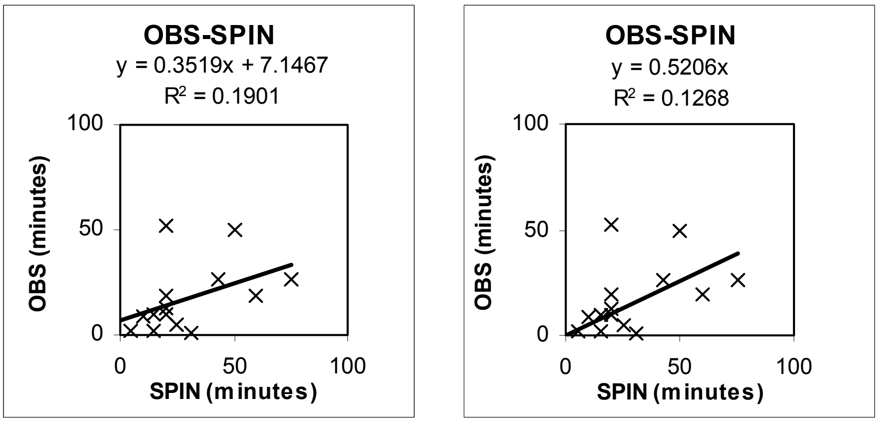


Figure 6.6 (a) Duration of Out-of-Home Leisure Activity by OBS vs. SPIN

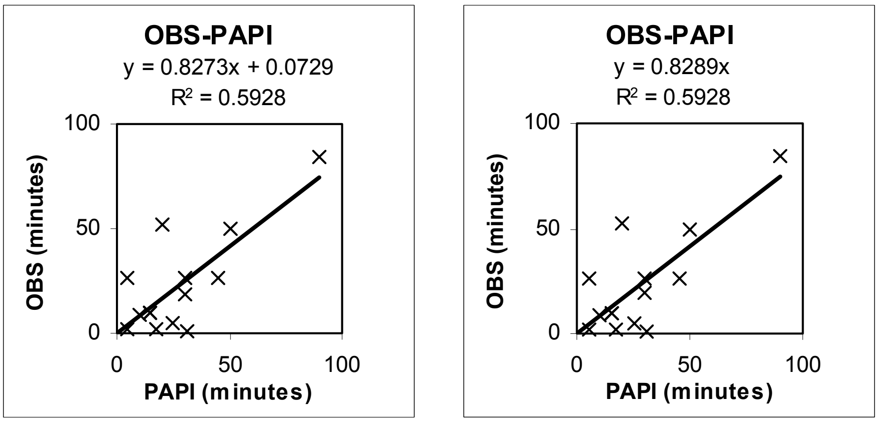


Figure 6.6 (b) Duration of Out-of-Home Leisure Activity by OBS vs. PAPI

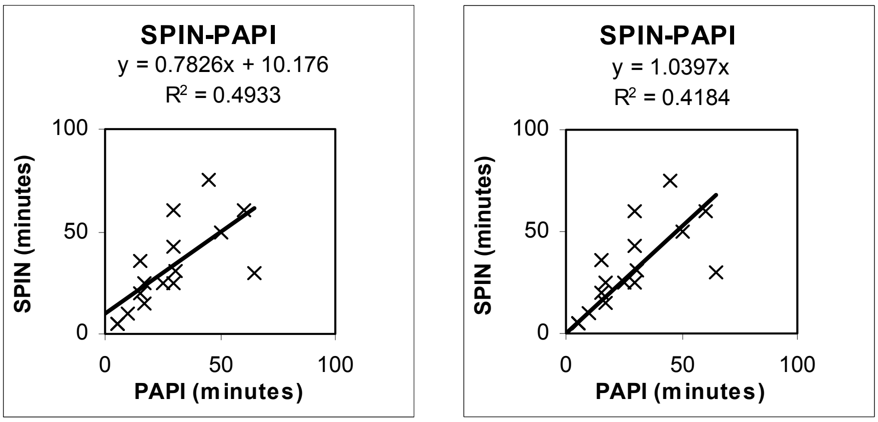


Figure 6.6 (c) Duration of Out-of-Home Leisure Activity by SPIN vs. PAPI

Regression Regression Through Origin

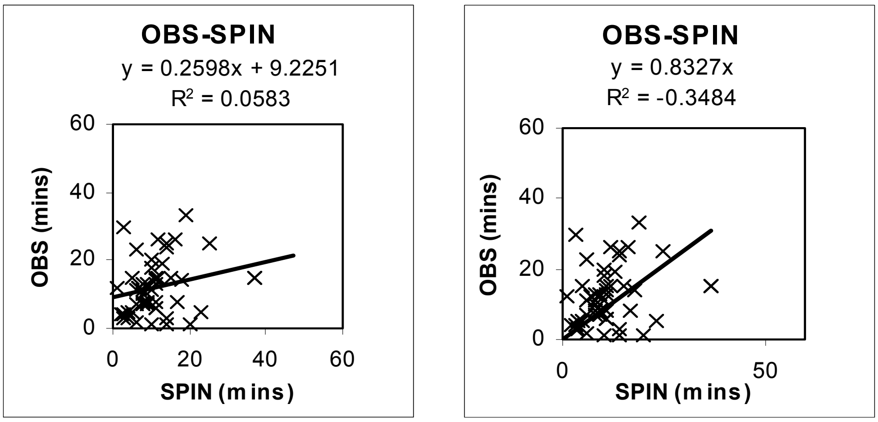


Figure 6.7 (a) Duration of Travel between Activities by OBS vs. SPIN

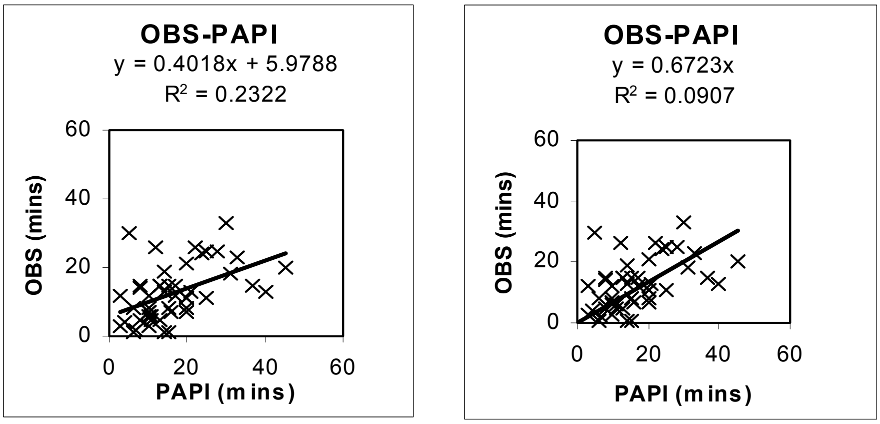


Figure 6.7 (b) Duration of Travel between Activities by OBS vs. PAPI

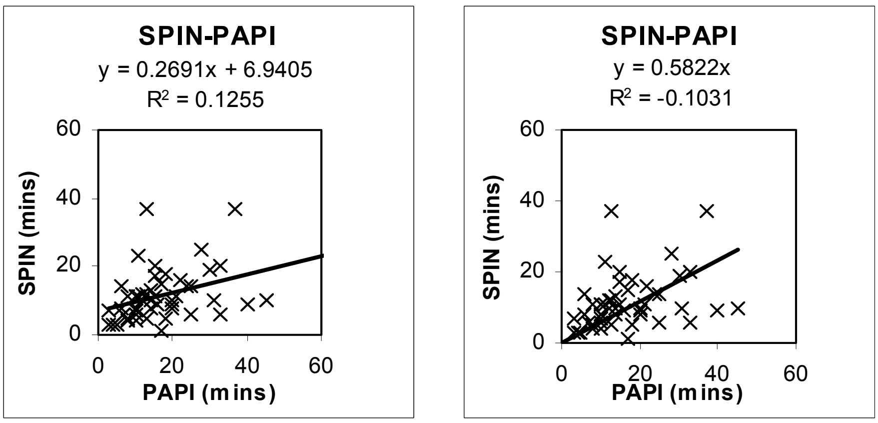


Figure 6.7 (c) Duration of travel between activities by SPIN vs. PAPI

Regression | Regression Through Origin

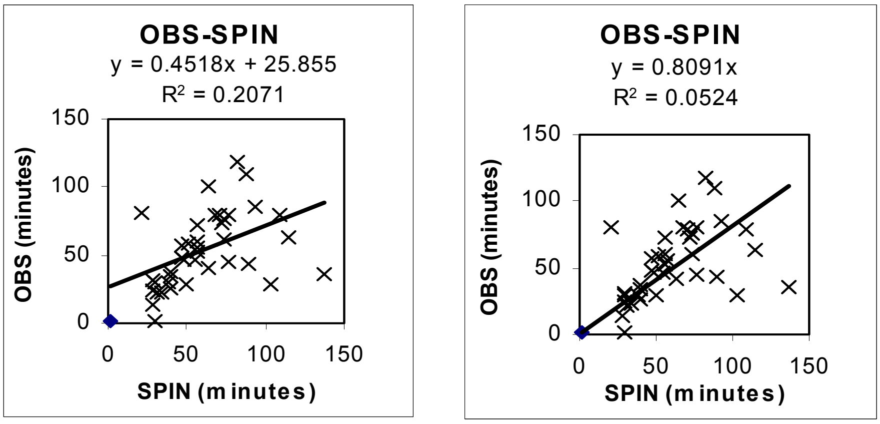


Figure 6.8 (a) Duration of Schedule by OBS vs. SPIN

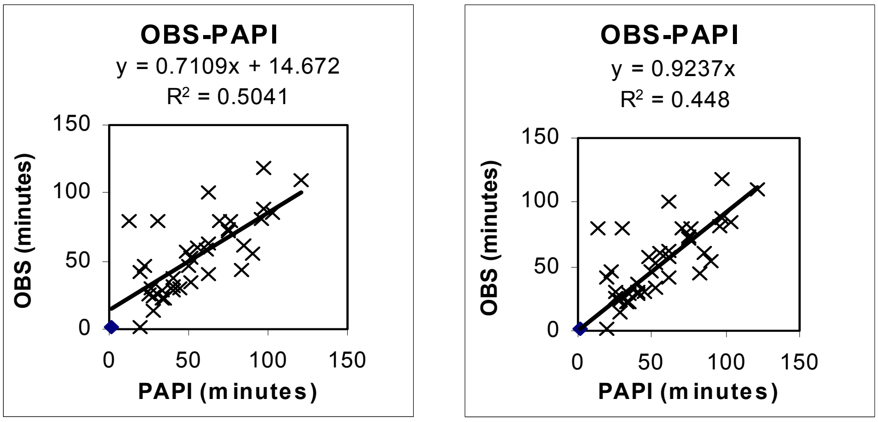


Figure 6.8 (b) Duration of Schedule by OBS vs. PAPI

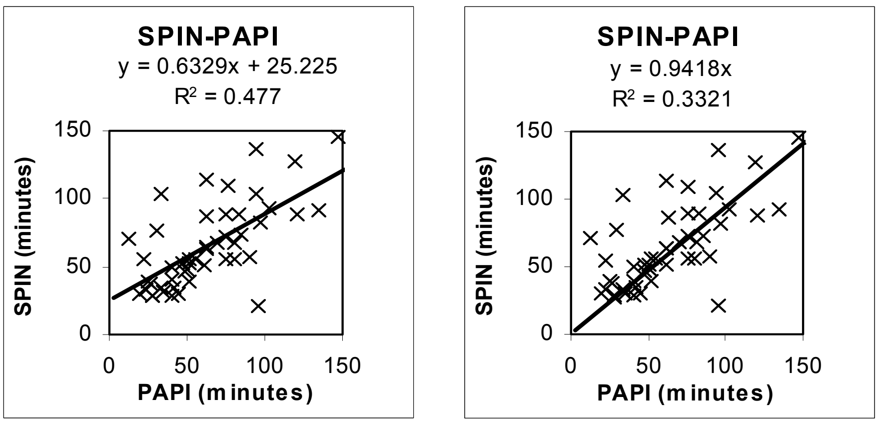


Figure 6.8 (c) Duration of Schedule by SPIN vs. PAPI

6.4.10 Summary

In our comparison where a survey instrument is tested for agreement with a revealed-choice method, we will base our assessment on the overview of the error parameters calculated for the nine facets examined from Sections 6.4.1 to 6.4.9. They are summarized in Table 6.14. If a method is comparable based on a non-significance difference with the revealed choice, it is indicated by a “Y” and “N” if it is not. We can distinguish the nine facets in 3 separate dimensions – the # of stops and the # of different activities can be considered as structural in nature, the durations are another important dimension of the activity schedule, and the route choice forms the last and 3rd dimension.

Our experiment demonstrates that data collection in the structural dimensions of an activity travel schedule, such as the number of stops, the types and numbers of activities is well executed. The SPIN scores show better measurements for the # of stops and the # of different activities than PAPI. In particular, not only does the PAPI measurement of the number of stops turn out worse, the disparity between the revealed-choice and PAPI is significant. Whilst the performance for both SPIN and PAPI is equivalent to OBS for the # of different activities, we can place a higher degree of agreement on SPIN over PAPI in performance because SPIN has generated smaller t-values.

When it came to the measurement of durations, PAPI demonstrates more instances of less disparity between its measured score and revealed-choice as seen from the smaller t-values in PAPI than in SPIN for 4 out of the 6 duration indicators. The duration of all activities and the duration of leisure activities are better measured by PAPI as shown by a significant level of difference of SPIN measurement from revealed-choice scores. On the other hand, there are better capabilities in SPIN to measure the travel durations between stops and duration of the services activity. In the duration of shopping and duration of the whole schedule, the PAPI measurement compares better than the SPIN measurement, although both methods prove to be good measures of both these duration dimension.

Table 6.14 Comparison of Agreement with Revealed-Choice (OBS) between Methods

Method vs. OBS	PAPI	SPIN	Comparability
# of Stops	N	Y	S(PIN)>P(API)
# of Different Activities	Y	Y	S > P
Duration of all Activities	Y	N	S < P
Duration of Services Activities	N	Y	S > P
Duration of Shopping Activities	Y	Y	S < P
Duration of Out-of-Home Leisure Activities	Y	N	S < P
Duration of Travel between Stops	N	Y	S > P
Duration of Schedule	Y	Y	S < P
Route Choice	N	N	S < P

"Y": non-significant difference (at 5% probability level) with revealed choice
"N": significant difference (at 5% probability level) with revealed choice
">": performs better
"<": performs worse

In the dimension of the route choice, both the SPIN and PAPI instruments are not able to measure with agreement to the revealed choice. A further examination of the t-test error parameters shows that SPIN is the instrument with poorer performance in this dimension. Nevertheless, both the SPIN and PAPI instruments are able to pick up the level of under-reporting for the # of stops and over-reporting for the rest of the aspects. Therefore, if a method is comparable based on a non-significance difference with the revealed choice it is indicated by a "Y" and "N" if it is not (Table 6.14). Overall, SPIN has performed better in the structural dimensions, but not in the duration dimension and route dimension.

Reliability has been examined on the comparison of the standard deviations (S_y) of the differences between each method and the revealed-choice. There is an apparent lead in reliability in the PAPI method for the structural aspects of the activity-travel schedule. We find that reliability is higher for the PAPI method when used in the measurement of the facets of the # of stops and # of different activities. The reliability of methods for the duration facets is not clearly differentiated between methods. On the one hand SPIN is able to record with higher reliabilities the durations of individual activities, the sum durations of them. On the other hand, PAPI has the higher reliability for the measurement of the travel durations between stops. In the eventual outcome of the measurement of the duration of the whole schedule, the PAPI method demonstrates more instances of higher reliability than for the SPIN method. The method that measures route choice with a higher level of reliability is SPIN.

Validity has been assessed by comparing the linearity of the PAPI and SPIN data with the OBS data. The notion that the OBS is a set of data closer to "true" values means that the method that demonstrates a closer proximity to OBS indicates a higher level of validity. The value of b*, the slope of the least-squares regression line (through origin) that approaches to 1.00 gives us an indication of that. In Table 6.16, we summarise the comparison of the b* values between OBS - PAPI and OBS – SPIN. Linearity between SPIN and observed revealed choice is higher in the # of stops, but not for the # of different activities. PAPI registers a higher degree of validity for the facets of the duration of out-of-home leisure activities, the duration of travel between

Table 6.15 Comparison of Reliability between Methods

Facets	Comparability
# of Stops	S(PIN) < P(API)
# of Different Activities	S < P
Duration of all Activities	S > P
Duration of Services Activities	S > P
Duration of Shopping Activities	S > P
Duration of Out-of-Home Leisure Activities	S < P
Duration of Travel between Stops	S < P
Duration of Schedule	S < P
Route Choice	S < P

">" higher reliability
"<" lower reliability

Table 6.16 Comparison of Validity between Methods

Facets	Comparability
# of Stops	S(PIN) > P(API)
# of Different Activities	S < P
Duration of all Activities	S = P
Duration of Services Activities	S > P
Duration of Shopping Activities	S > P
Duration of Out-of-Home Leisure Activities	S < P
Duration of Travel between Stops	S < P
Duration of Schedule	S < P
Route Choice	S < P

“>” higher validity
“<” lower validity

stops, and in the duration of the schedule. The validity of the recording of the duration of all activities appears to be equally valid for both PAPI and SPIN while SPIN does better than PAPI in the duration of services activity, and in the duration of shopping activity.

In sum, PAPI is ahead of SPIN by one facet in the duration dimension. In the route choice dimension PAPI surpasses SPIN. A higher validity of the route choice can be determined by looking at the lower mean ratio of the Levenshtein distances, which occurs in PAPI. Overall, the dimension of durations and the dimension of route choice returned a higher validity in the PAPI method, while neither method can be said to return more valid responses for structural dimensions.

6.5 Results by Sequence of Measurement

In this section, we discuss the results of the analysis where the sample is divided into two groups. In one group PAPI _1^{st}, subjects conducted the experiment using the PAPI instrument first followed by the SPIN instrument, while in another group SPIN _1^{st}, subjects conducted the experiment using the SPIN instrument first and then followed by the PAPI instrument. Due to the fact that the subjects are each measured once with the instruments of PAPI and SPIN each, and there was no considerable time lapse between the two measurements, it is important to know if there are any carry-over effects (for example, training effects) or other damning internal factors (e.g. decreased level of motivation or plain tedium). Thus, the nine aspects of the activity schedule are once again examined, this time to determine the effect of the sequence in which the subjects completed the two tasks. In this section, we pay particular attention to the cases where the instruments are the second in the sequence. As the second instrument, data may reflect either a positive effect where after completion of the task in one instrument perhaps stimulated more reflection and retrieval of more accurate information, or negative effects due to pure boredom or possible time limitations. Positive effects can be observed if the results show lower errors in the second instruments and the inverse is true for negative effects.

In the following sub-sections according to the various facets of the activity schedule, we present the results of this investigation obtained using regression through origin and the t-test.

6.5.1 # of Stops

In the number of stops there is indication of consistent under-reporting across all cases for this aspect of the activity schedule regardless of sequence. However, in the PAPI group where subjects used SPIN first, there is significant under-reporting between PAPI recordings and actual behaviour while in the SPIN recordings, no effect of the sequence is observable. Furthermore, the highest variance is found in PAPI and when PAPI is conducted first. The highest bias also occurs in this situation. Thus, SPIN still delivers the better recordings for the # of stops in general we also note that they attain lower b* values when compared with the observed data as both first instrument and second instrument.

Table 6.17 Statistical Results for # of Stops by Sequence of Measurement

Error Parameters	OBS – PAPI		OBS – SPIN		SPIN – PAPI	
	PAPI_1st	PAPI_2nd	SPIN_1st	SPIN_2nd	PAPI_2nd	SPIN_2nd
N	15	41	41	14	41	14
b*	1.052	0.733	1.025	1.111	1.017	0.978
Sy*	2.426	2.139	2.348	2.080	1.587	0.779
Bias	0.467	0.732	0.317	0.500	0.415	0.000
SD_d	2.386	2.086	2.329	2.066	1.533	0.784
t	0.757	2.246†	0.872	0.905	1.732	0.000
r*	0.307	0.618	0.505	0.598	0.546	0.842
r	0.417	0.645	0.540	0.591	0.681	0.882

* Parameters of regression through origin

† The difference is significant at the 5% probability level

6.5.2 # of Different Activities

In the recording of the number of different activities, we see the general trend to over-report in all instances and for both instruments. Although the results for PAPI in the SPIN_1st group show a lesser amount of over-reporting on average, there is higher variability. The over-reporting for PAPI in the PAPI_1st group is significant while for SPIN in the SPIN_1st group is not. There is an improvement of the result for PAPI after the use of SPIN but no such sequence effect is reflected for SPIN.

6.5.3 Duration of all Activities

In the measure of duration of all activities, in general, over-reporting is apparent. The over-reporting is much reduced in the PAPI instrument after the subject recorded their data in SPIN first. A similar trend is observed for SPIN for the PAPI_1st group. The t-values for SPIN show that the duration is no longer significantly different from the observed real data after the use of PAPI.

SPIN_1st SPIN_2nd

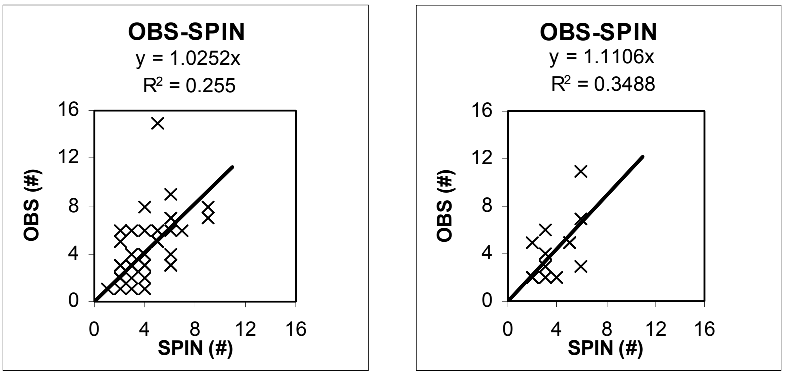


Figure 6.9 (a) # *of* Stops by OBS vs. SPIN

PAPI_1st PAPI_2nd

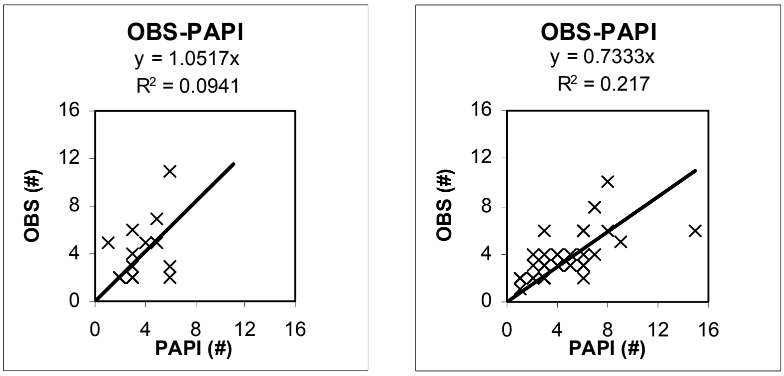


Figure 6.9 (b) # *of* Stops by OBS vs. PAPI

PAPI_2nd SPIN_2nd

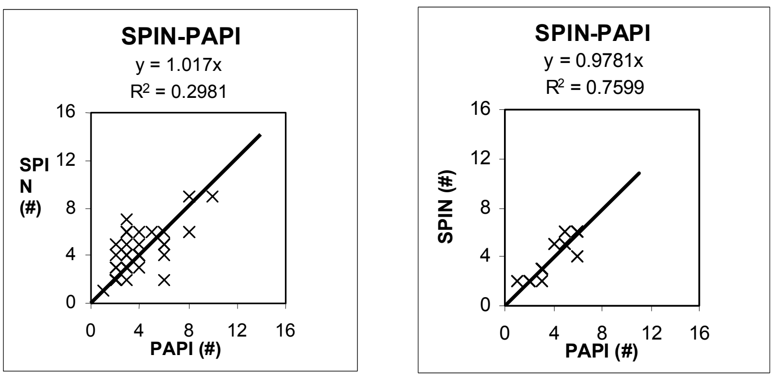


Figure 6.9 (c) # *of* Stops by SPIN vs. PAPI

Table 6.18 Statistical Results for # of Different Activities by Sequence of Measurement

Error Parameters	OBS – PAPI		OBS – SPIN		SPIN -PAPI	
	PAPI_1st	PAPI_2nd	SPIN_1st	SPIN_2nd	PAPI_2nd	SPIN_2nd
N	15	41	41	14	41	15
b*	0.765	0.932	0.863	0.869	0.992	0.848
Sy*	0.693	0.998	1.127	0.638	0.880	0.596
Bias	-0.533	-0.024	-0.049	-0.214	0.024	-0.400
SD_d	0.834	1.012	1.182	0.699	0.880	0.632
t	-2.477†	-0.154	-0.264	-1.147	0.177	-2.449†
r*	0.176	-0.284	-0.614	0.478	0.590	0.797
r	0.580	0.346	0.340	0.676	0.603	0.800

* Parameters of regression through origin
†The difference is significant at the 5% probability level

Table 6.19 Statistical Results for Duration of all Activities by Sequence of Measurement

Error Parameters	OBS – PAPI		OBS – SPIN		SPIN -PAPI	
	PAPI_1st	PAPI_2nd	SPIN_1st	SPIN_2nd	PAPI_2nd	SPIN_2nd
N	11	29	31	10	38	14
b*	0.500	0.944	0.882	0.572	0.996	0.986
Sy*	21.28	15.78	14.09	18.59	15.57	14.93
Bias	-14.36	-1.000	-5.710	-14.30	2.421	0.857
SD_d	34.12	16.07	14.77	26.71	15.37	14.93
t	-1.396	-0.335	-2.152†	-1.693	0.971	0.215
r*	-0.513	0.814	0.849	0.356	0.849	0.899
r	0.487	0.826	0.851	0.568	0.869	0.903

* Parameters of regression through origin
†The difference is significant at the 5% probability level

6.5.4 Duration of Services Activity

There is a considerable improvement of the correspondence of results with the observed (OBS) in the PAPI data when the SPIN has been conducted first as indicated by the differences in the parameters of regression slope and t-values. The same phenomenon is demonstrated in the SPIN results albeit at a lesser degree. We note the reduction in bias when subjects have been measured using PAPI first is substantial.

SPIN_1st SPIN_2nd

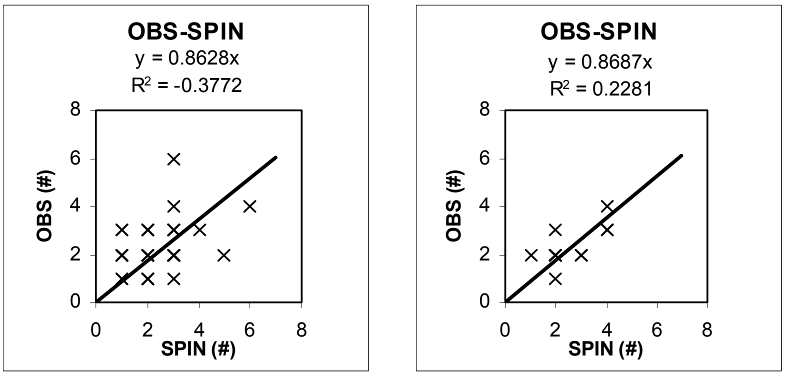


Figure 6.10 (a) # of Different Activities by OBS vs. SPIN

PAPI_1st PAPI_2nd

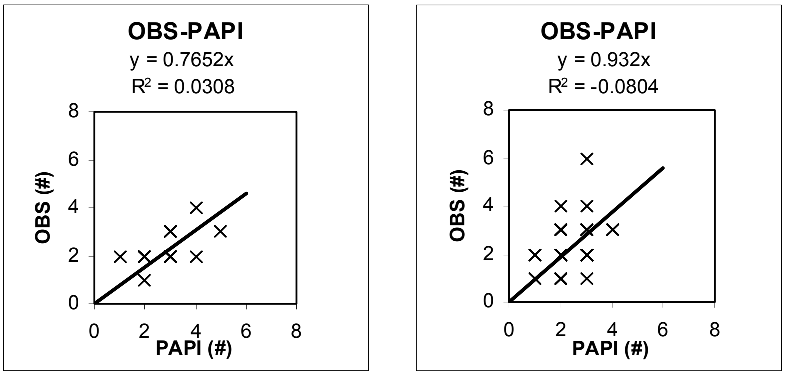


Figure 6.10 (b) # of Different Activities by OBS vs. PAPI

PAPI_2nd SPIN_2nd

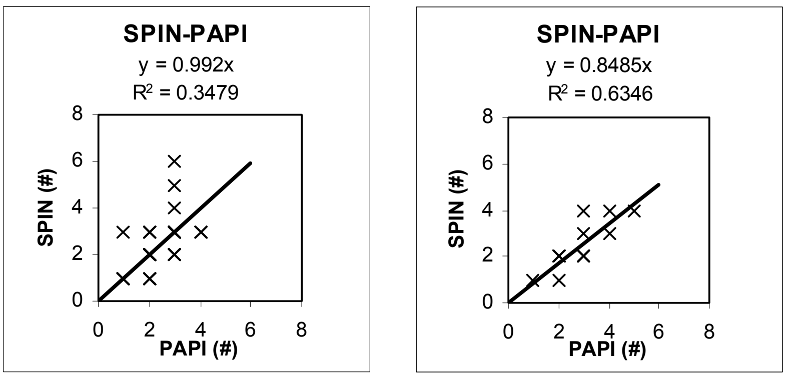


Figure 6.10 (c) # of Different Activities by SPIN vs. PAPI

SPIN_1st SPIN_2nd

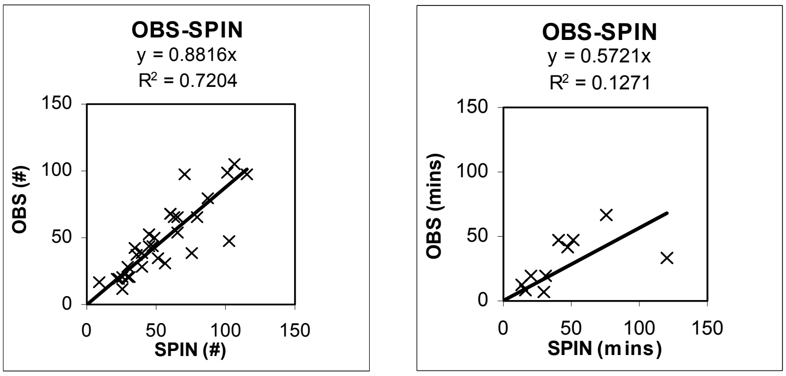


Figure 6.11 (a) Duration of all Activities by OBS vs. SPIN

PAPI_1st PAPI_2nd

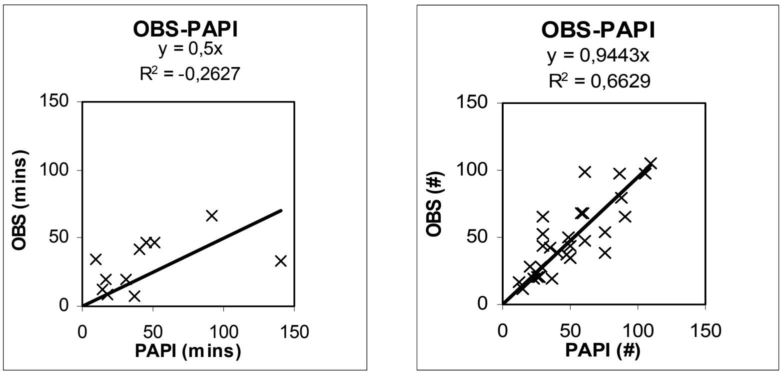


Figure 6.11 (b) Duration of all Activities by OBS vs. PAPI

PAPI_2nd SPIN_2nd

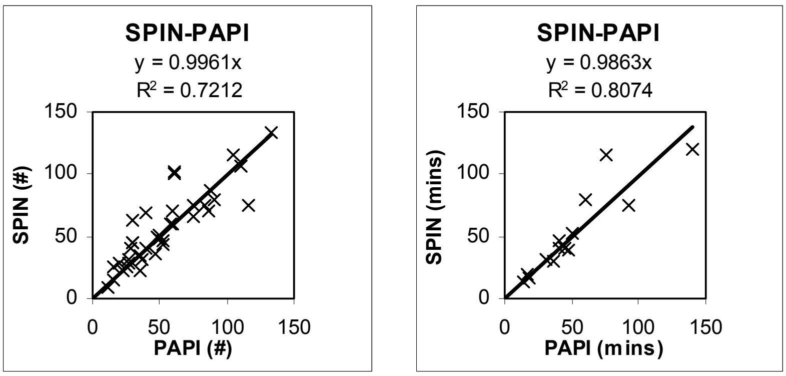


Figure 6.11 (c) Duration of all Activities by SPIN vs. PAPI

SPIN_1st SPIN_2nd

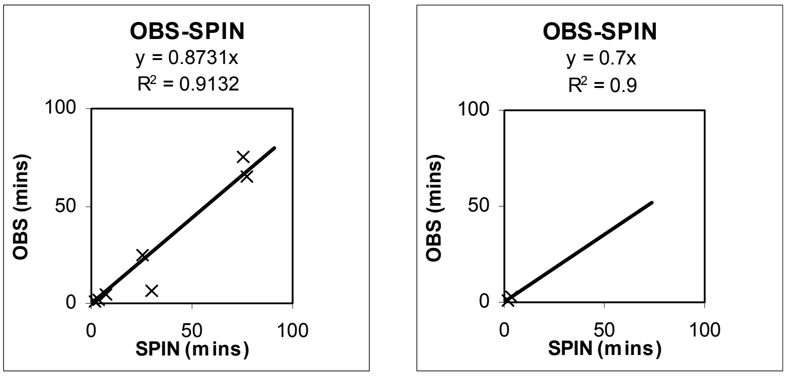


Figure 6.12 (a) Duration of Services Activity by OBS vs. SPIN

PAPI_1st PAPI_2nd

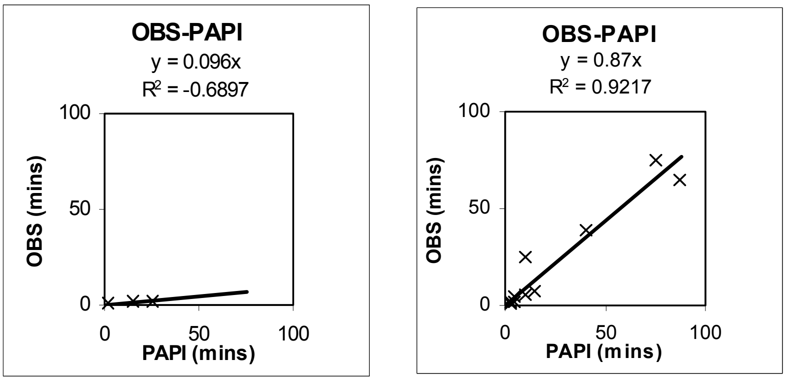


Figure 6.12 (b) Duration of Services Activity by OBS vs. PAPI

PAPI_2nd SPIN_2nd

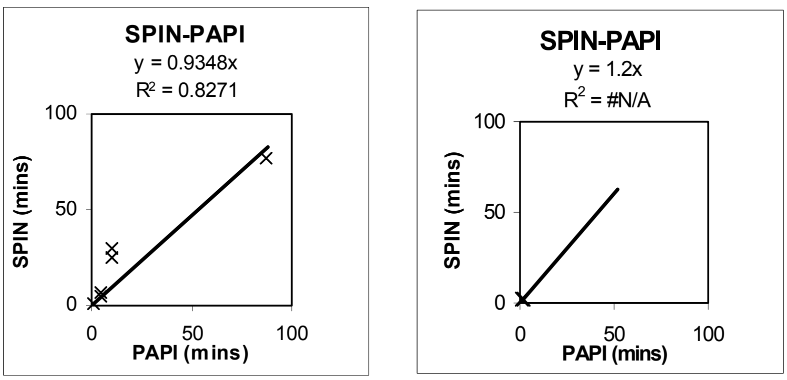


Figure 6.12 (c) Duration of Services Activity by SPIN vs. PAPI

Table 6.20 Statistical Results for Duration of Services Activity by Sequence of Measurement

Error Parameters	OBS – PAPI		OBS – SPIN		SPIN -PAPI	
	PAPI_1st	PAPI_2nd	SPIN_1st	SPIN_2nd	PAPI_2nd	SPIN_2nd
N	3	10	7	2	2	2
b*	0.096	0.870	0.873	0.700	0.935	1.200
Sy*	0.750	7.785	9.286	0.447	11.80	0.894
Bias	-12.33	-2.600	-5.857	-1.000	4.500	0.500
SD_d	11.015	9.046	9.026	0.000	11.02	0.707
t	-1.939	-0.909	-1.717	N/A	1.000	1.000
r*	-0.830	0.960	0.956	0.949	0.909	1.000
r	0.901	0.961	0.960	1.000	0.948	N/A

* Parameters of regression through origin

Table 6.21 Statistical Results for Duration of Shopping Activity by Sequence of Measurement

Error Parameters	OBS – PAPI		OBS – SPIN		SPIN -PAPI	
	PAPI_1st	PAPI_2nd	SPIN_1st	SPIN_2nd	PAPI_2nd	SPIN_2nd
N	12	32	31	10	31	13
b*	0.706	0.620	0.650	0.682	0.937	1.024
Sy*	11.67	22.02	21.13	11.75	13.22	9.161
Bias	-7.417	-7.719	-8.355	-10.20	-0.258	1.615
SD_d	13.89	27.08	25.31	14.29	13.55	9.051
t	-1.850	-1.612	-1.838	-2.257†	-0.106	0.643
r*	0.778	0.155	0.266	0.787	0.869	0.908
r	0.781	0.459	0.471	0.788	0.879	0.911

* Parameters of regression through origin

6.5.5 Duration of Shopping Activity

In the duration of shopping activity data the opposing movements in situations of sequence effect is conveyed. When PAPI has been conducted first, the t-values in SPIN measurements deteriorates to a distinctive difference with the real scores. The bias also jumps to a highest value of all comparisons although the variance suffers a drop. Results in PAPI become better in the SPIN_1st group.

Table 6.22 Statistical Results for Out-of-Home Leisure Activity by Sequence of Measurement

Error Parameters	OBS – PAPI		OBS – SPIN		SPIN -PAPI	
	PAPI_1st	PAPI_2nd	SPIN_1st	SPIN_2nd	PAPI_2nd	SPIN_2nd
N	8	7	9	6	10	8
b*	0.489	0.972	0.888	0.315	0.884	0.489
Sy*	11.09	16.20	14.63	5.250	13.91	11.09
Bias	-8.125	1.286	-2.111	-24.00	0.200	-8.125
SD_d	14.98	16.19	14.84	18.95	14.62	14.98
t	-1.534	0.210	-0.427	-3.102†	0.043	-1.534
r*	-0.529	0.830	0.594	0.842	-0.482	-0.529
r	0.179	0.841	0.600	0.843	0.693	0.179

* Parameters of regression through origin
†The difference is significant at the 5% probability leve

6.5.6 Duration of Out-of-Home Leisure Activity

In the aspect of the duration of the leisure activity, the results of PAPI shows an improvement after SPIN has been conducted first. However, the opposite situation occurs for SPIN. Better data is returned when the subjects have used the SPIN instrument first, another instance where the measurement by SPIN instrument does not improve but worsens to a significant level after a possible practice with the pen-and-paper tool but we have to keep in mind the very low number of subjects.

6.5.7 Duration of Travel between Activities

The PAPI measurement shows a significant difference from the observed when SPIN has been conducted first. This indicates that the experience of conducting the virtual reality experiment does not contribute towards providing better data in the PAPI instrument. The tendency to over-report on the duration of travel is widespread among the subjects regardless of instrument. The SPIN data shows slightly less over-reporting and higher proximity to real scores after having done the PAPI first.

SPIN_1st SPIN_2nd

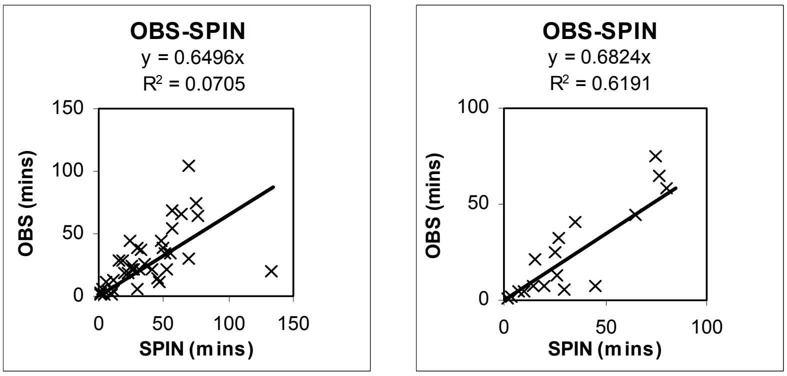


Figure 6.13 (a) Duration of Shopping Activity by OBS vs. SPIN

PAPI_1st PAPI_2nd

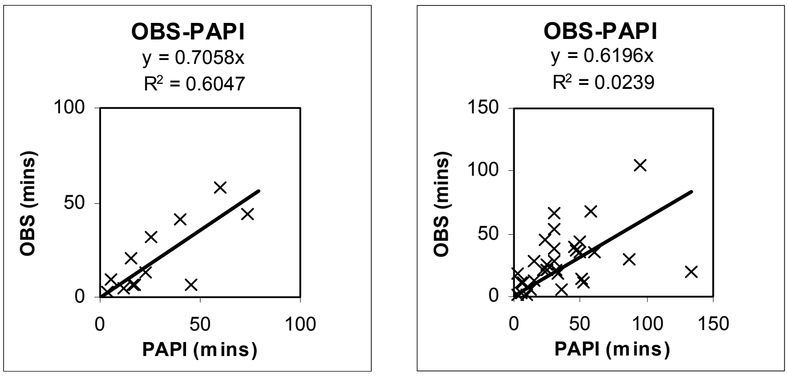


Figure 6.13 (b) Duration of Shopping Activity by OBS vs. PAPI

PAPI_2nd SPIN_2nd

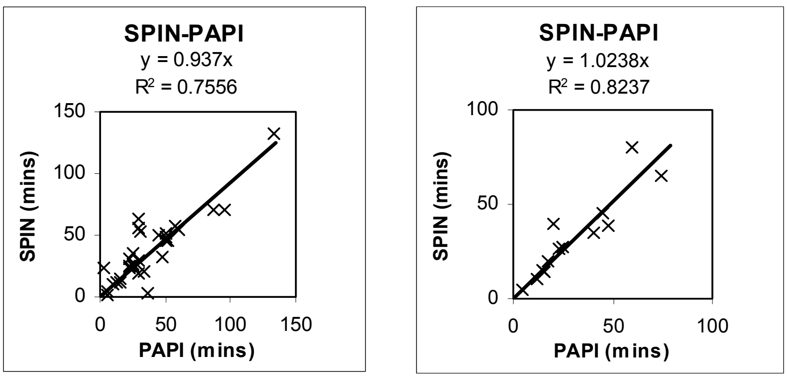


Figure 6.13 (c) Duration of Shopping Activity by SPIN vs. PAPI

6.5.8 Duration of Schedule

As shown in the data in Table 6.24 there is an improvement in the results PAPI in the SPIN_1st group. Likewise for SPIN, a higher level of agreement with the observed data is achieved after the subjects have used the pen-and-paper instrument first. The improvement in PAPI has overtaken SPIN in performance although both instruments measure the duration of the schedule well.

Table 6.23 Statistical Results for Duration of Travel between Activities by Sequence of Measurement

Error Parameters	OBS – PAPI		OBS – SPIN		SPIN – PAPI	
	PAPI_1st	PAPI_2nd	SPIN_1st	SPIN_2nd	PAPI_2nd	SPIN_2nd
N	11	39	40	11	40	15
b*	0.717	0.661	0.837	0.822	0.573	1.345
Sy*	9.718	7.048	9.140	10.34	6.804	61.15
Bias	-2.091	-4.444	0.900	1.545	-5.350	10.40
SD_d	11.16	11.85	9.336	10.59	8.952	60.61
t	-0.622	-2.250†	0.610	0.484	-3.780†	0.665
r*	-0.635	0.465	-0.591	-0.644	0.225	-0.124
r	0.307	0.551	0.218	0.334	0.451	0.090

Parameters of regression through origin
†The difference is significant at the 5% probability level

Table 6.24 Statistical Results for Duration of Schedule by Sequence of Measurement

Error Parameters	OBS – PAPI		OBS – SPIN		SPIN – PAPI	
	PAPI_1st	PAPI_2nd	SPIN_1st	SPIN_2nd	PAPI_2nd	SPIN_2nd
N	9	29	32	9	37	13
b*	0.838	0.887	0.857	0.590	0.927	1.008
Sy*	13.50	24.33	24.69	29.37	27.26	19.10
Bias	-8.111	-3.420	-6.000	-8.444	1.946	-0.615
SD_d	14.82	31.31	25.85	38.71	27.77	19.09
t	-1.642	-0.517	-1.313	-0.654	0.426	-0.116
r*	0.861	0.486	0.389	-0.925	0.461	0.824
r	0.863	0.631	0.500	0.290	0.667	0.828

Parameters of regression through origin

SPIN_1st SPIN_2nd

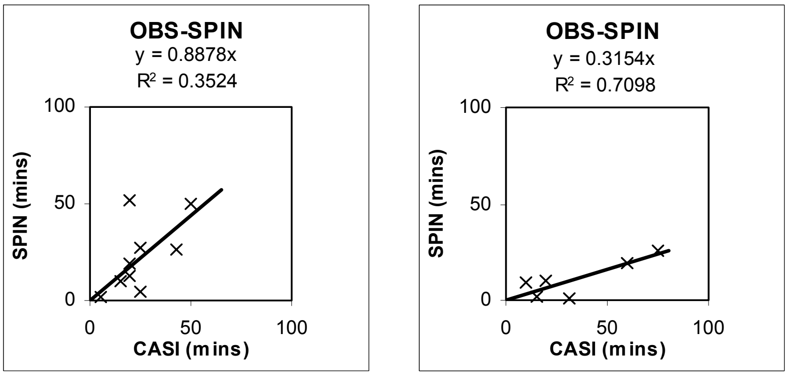


Figure 6.14 (a) Duration of Out-of-Home Leisure Activity by OBS vs. SPIN

PAPI_1st PAPI_2nd

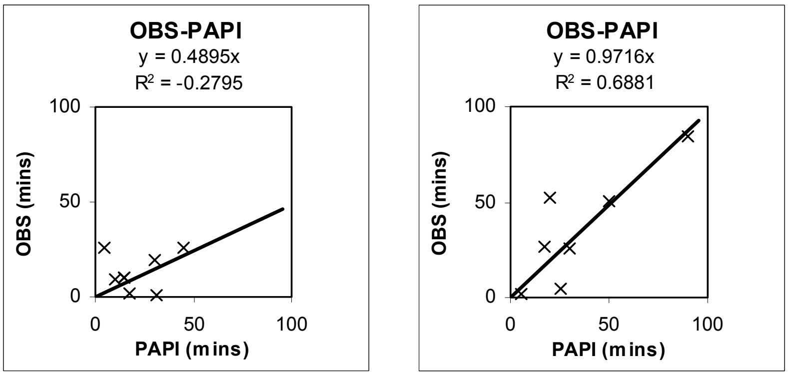


Figure 6.14 (b) Duration of Out-of-Home Leisure Activity by OBS vs. PAPI

PAPI_2nd SPIN_2nd

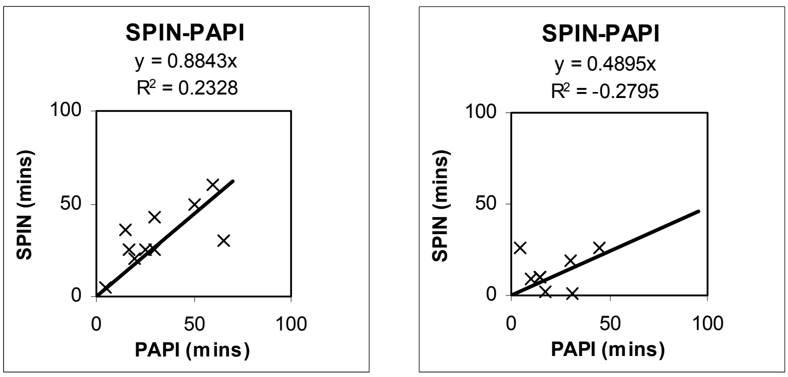


Figure 6.14 (c) Duration of Out-of-Home Leisure Activity by SPIN vs. PAPI

SPIN_1st SPIN_2nd

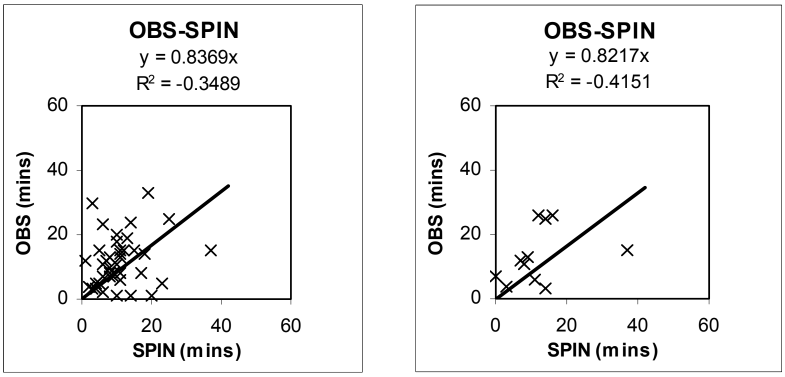


Figure 6.15 (a)Duration of Travel between Activities by OBS vs. SPIN

PAPI_1st PAPI_2nd

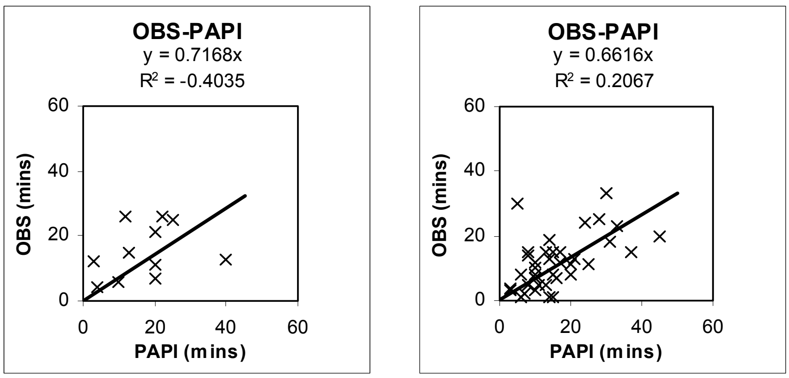


Figure 6.15 (b) Duration of Travel between Activities by OBS vs. PAPI

PAPI_2nd SPIN_2nd

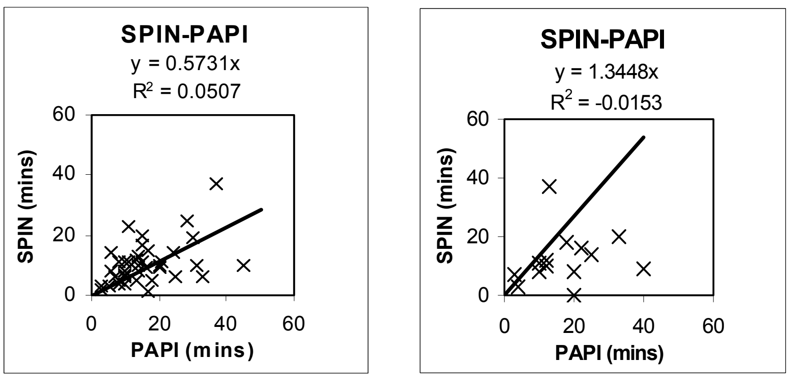


Figure 6.15 (c) Duration of Travel between Activities by SPIN vs. PAPI

SPIN_1st SPIN_2nd

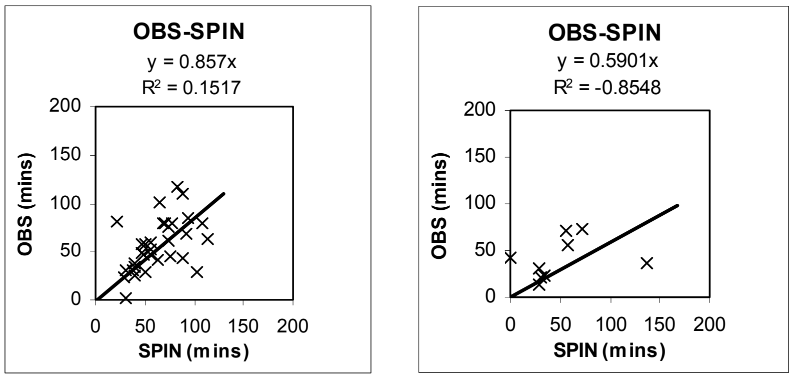


Figure 6.16 (a) Duration of Schedule by OBS vs. SPIN

PAPI_1st PAPI_2nd

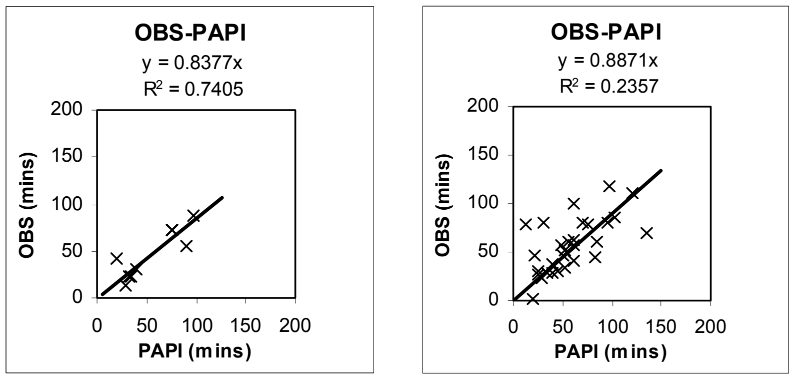


Figure 6.16 (b) Duration of Schedule by OBS vs. PAPI

PAPI_2nd SPIN_2nd

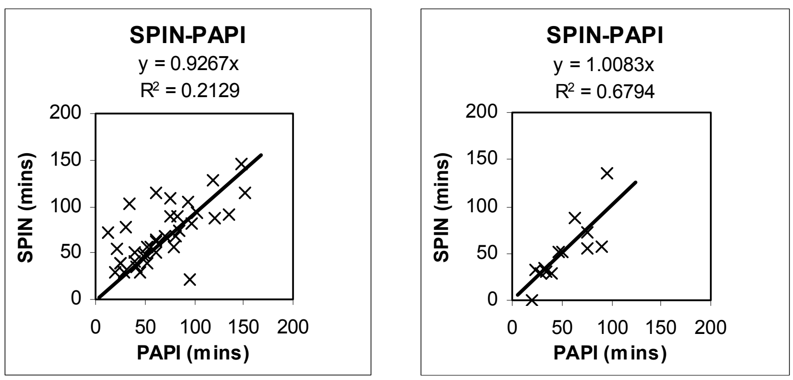


Figure 6.16 (c) Duration of Schedule by SPIN vs. PAPI

Table 6.25 Statistical Results for Route Choice by Sequence of Measurement

Error Parameters	OBS - PAPI		OBS - SPIN		SPIN – PAPI	
	PAPI_1st	PAPI_2nd	SPIN_1st	SPIN_2nd	PAPI_2nd	SPIN_2nd
N	5	27	32	7	36	8
Mean	0.162	0.201	0.236	0.342	0.169	0.255

6.5.9 Route Choice

Table 6.25 shows the statistical results of the comparison of the ratios of Levenshtein distances between OBS - SPIN and OBS – PAPI. In the situation where PAPI is the second measurement, we find that there is a smaller mean of ratio of Levenshtein distances. As low Levenshtein distance implies high similarity of route sequences, this shows that the method of PAPI is able to register route sequence at a closer degree to revealed choice than that registered by SPIN. The same can be observed even when PAPI is the first measurement. The results do not show an improvement in the second measurement but instead a decrease in the degree of agreement with the real route choice data.

6.5.10 Summary

As for the effect of sequence in which the subjects were measured we wish to examine the results in SPIN where the PAPI has been conducted first and in PAPI where SPIN has been conducted first. Here, we detect some indication of training effects in the facets of the duration of the all activities, and the duration of the whole schedule. For these two facets the results returned in the second instrument are an improvement over the first. There is no such indication in the other facets. In the facet of the # of different activities, the duration of shopping activity, and duration of leisure activities, there is a mixed effect in that improvement is seen in PAPI but deterioration is seen in SPIN. The reverse phenomenon is observed for the duration

Table 6.26 Comparison of Agreement with Revealed-Choice (OBS) between Methods As 1^{St} Measurements

Method vs. OBS	PAPI	SPIN	Comparability
# ofStops	Y	Y	S(PIN) < P(API)
# of Different Activities	N	Y	S > P
Duration of all Activities	Y	N	S < P
Duration of Services	Y	Y	S > P
Duration of Shopping	Y	Y	S > P
Duration of Leisure	Y	Y	S > P
Duration of Travel between Stops	Y	Y	S > P
Duration of Schedule	Y	Y	S > P
Route	Y	N	S < P

“Y”: non-significant difference (at 5% probability level) with revealed choice
“N”: significant difference (at 5% probability level) with revealed choice
“>”: performs better
“<”: performs worse

of travel between activities where the measurement by the SPIN instrument does improve after a possible practice with the paper-and-pencil method. Furthermore, in the # of stops and the route choice, the experience of conducting the virtual reality experiment does not contribute towards providing better data in the PAPI method, and neither is the result better in the SPIN method after doing PAPI. Overall, there is no observable systematic pattern of training effects.

Table 6.26 present the results where the instruments used by subjects are the first and in Table 6.27 as the second. For the comparability of the methods with the observed and as second instruments, SPIN is a good measure for the # of stops and for # of different activities but PAPI is better for the # of different activities while it is a poor measure for the # of stops. The following is observable for the dimension of duration: the instances of agreement of SPIN to OBS are found to be somewhat reduced after a measurement with PAPI whilst PAPI demonstrates increased instances of agreement to OBS when the subjects use this instrument after SPIN.
It is noteworthy that SPIN as the first instrument shows the most instances of agreement with OBS. (Table 6.26) in the dimension of durations. Consistently in all

the facets of durations with the exception of the duration of all activities, SPIN demonstrates a higher degree of agreement than PAPI especially when both emerge as good measures. Few instances of agreement occur in PAPI when the first instrument of the subjects is PAPI (the route choice and the duration of all activities). Both SPIN and PAPI as first instruments measure the # of stops well but it appears that PAPI captures this facet better than SPIN when it is used as the first measure.

Comparison of the standard deviations of the differences between each method and the revealed-choice gives us a measure of reliability. In Table 6.28, for dimension of durations there is a lead in the SPIN method as the first measurement of the subjects; in 4 out of the 6 facets of durations examined, SPIN reveals higher reliabilities. As the second measurement, one duration facet moves in favour of PAPI and reliability equalizes for both SPIN and PAPI. In the route choice dimension, SPIN shows consistently higher reliability than PAPI regardless of the sequence of measurement. The same is observed for the # of stops but in the # of different activities, reliability for PAPI is higher as the first measurement but performance drops as the second measurement. In the cases where the reliability is higher in PAPI when both are the first measurements to be followed by a reversal in the situation when both are the second measurement, this is observed for the # of different activities and for the duration of shopping activities, and for the duration of leisure activities. Whilst higher reliability switches from SPIN to PAPI when they are second measurements for the duration of all activities, the duration of travel between stops, and the duration of schedule.

Linearity between SPIN and PAPI data and observed revealed choice (OBS) gives us an indication of the degree of "proximity" of the method to reality or the degree of validity. Whether the sequence of measurement has any impact on validity is examined and results shown in Table 6.29. The SPIN method as the first measurement has more instances of validity but does not maintain the same level when it is the second measurement. Results are rather mixed for all the facets with

Table 6.27 Comparison of Agreement with Revealed-Choice (OBS) between Methods As 2nd Measurements

Method vs. OBS	PAPI	SPIN	Comparability
# ofStops	N	Y	S(PIN) > P(API)
# of Different Activities	Y	Y	S < P
Duration of all Activities	Y	Y	S > P
Duration of Services	Y	Indeterminate	Indeterminate
Duration of Shopping	Y	N	S < P
Duration of Leisure	Y	N	S < P
Duration of Travel between Stops	N	Y	S > P
Duration of Schedule	Y	Y	S < P
Route	N	N	S < P

“Y”: non-significant difference (at 5% probability level) with revealed choice
“N”: significant difference (at 5% probability level) with revealed choice
“>”: performs better
“<”: performs worse

Table 6.28 Comparison of Reliability between Methods for Sequence Effects

Method vs. OBS	As the 1st Measurement	As the 2nd Measurement
# ofStops	S(PIN)> P(API)	S(PIN) > P(API)
# of Different Activities	S < P	S > P
Duration of all Activities	S > P	S < P
Duration of Services Activity	S < P	S > P
Duration of Shopping Activity	S < P	S > P
Duration of Leisure Activity	S > P	S > P
Duration of Travel between Stops	S > P	S < P
Duration of Schedule	S > P	S < P
Route	S > P	S > P

“>” higher reliability
“<” lower reliability

the exception of the route choice and the # of stops where SPIN remains consistently as the measure with lower validity for the route and the measure with higher validity for the # of stops. The duration of the shopping activity is initially measured with a lower validity in SPIN when it is measured first but turns out to be better than PAPI when it is measured following PAPI. The # of different activities, the duration of travel between stops, the duration of services activities, the duration of leisure activities, and the duration of schedule suffers a drop in validity when these facets were measured in SPIN following a measurement in PAPI.

Although there is no discernible consistent carry-over effects in the results, the analysis of the reliability and validity of SPIN and PAPI with regards to the sequence of measurement nevertheless are interesting in that the route choice measured by SPIN is consistently more reliable and consistently less valid and the # of stops measured by SPIN is consistently with higher reliability and validity regardless of sequence of measurement.

Table 6.29 Comparison of Validity between Methods for Sequence Effects

Method vs. OBS	As the 1st Measurement	As the 2nd Measurement
# of Stops	S(PIN) > P(API)	S(PIN) > P(API)
# of Different Activities	S > P	S < P
Duration of all Activities	S > P	S = P
Duration of Services Activity	S > P	S > P
Duration of Shopping Activity	S < P	S > P
Duration of Leisure Activity	S > P	S < P
Duration of Travel between Stops	S > P	S < P
Duration of Schedule	S > P	S < P
Route	S < P	S < P

“>” higher validity
“<” lower validity
“=” similar validity

6.6 Results On Durations of Travel between Activities

In this section, we present the results of the analysis where the unit of analysis is the travel between the activities. In the sample, the maximum number of activities conducted was seven for 95% of the subjects. The consecutive travel durations between activities did not yield any meaningful statistical result because there were too few subjects. The comparison of the data from the SPIN instrument with that from OBS is performed for the travel duration between one activity and the next. Similarly for the comparison of the data from the PAPI instrument with that from OBS. The analysis, however, do not in incorporate the effects of the under reporting of stops. The error parameters discussed here (t, b and S_y) are based on the regression through origin and the t-test. Strictly speaking therefore, the results may include the combined effects of non-reported stops and travel.

6.6.1 Duration of Travel between Activity 1 and Activity 2

For the record of the first travel duration between the first and second activity, the error parameters for the SPIN instrument reveal that it results in a better performance than the PAPI instrument. We are able to observe that the difference between PAPI and the revealed choice data is significantly different with a serious instance of over-reporting. All other indicators support this outcome: a lower value of explained variance, a higher bias, and a higher variability in responses. The scatter of points about the regression line for SPIN (Figure 6.17 (a)) shows a tendency for under-reporting although this is not significant.

6.6.2 Duration of Travel between Activity 2 and Activity 3

For the travel duration between the second and the third activity, SPIN performs better than the PAPI, as t-values for PAPI clearly registers a significance difference between their measures and those from the observed real data. Over-reporting occurs in both instruments but the degree appears to be less in SPIN. The durations of travel recorded in the SPIN instrument tend to be on the low side with more instances of durations at 5 minutes or less. In contrast, the graph for PAPI (Figure 6.18 (b)) shows a bigger variation in duration of travel durations.

Table 6.30 Statistical Results for Duration of Travel between Activity 1 and Activity 2

Error Parameters	OBS – PAPI	OBS - SPIN	SPIN - PAPI
N	55	54	55
b*	0.328	0.652	0.310
Sy*	3.454	3.300	3.649
Bias	-2.545	0.259	-2.691
SD_d	5.930	3.635	6.055
t	-3.184†	0.524	-3.296†
r*	-0.721	-0.591	-0.574
r	0.119	0.279	0.121

*Regression parameters through origin
†The difference is significant at the 5% probability level

Table 6.31 Statistical Results for Duration of Travel between Activity 2 and Activity 3

Error Parameters	OBS – PAPI	OBS - SPIN	SPIN - PAPI
N	50	51	50
b*	0.496	0.641	0.617
Sy*	3.042	2.924	3.185
Bias	-1.420	-0.333	-1.100
SD_d	3.834	3.357	3.688
t	-2.619†	-0.709	-2.109†
r*	-0.366	0.230	0.331
r	0.228	0.367	0.431

*Regression parameters through origin
†The difference is significant at the 5% probability level

Regression | Regression Through Origin

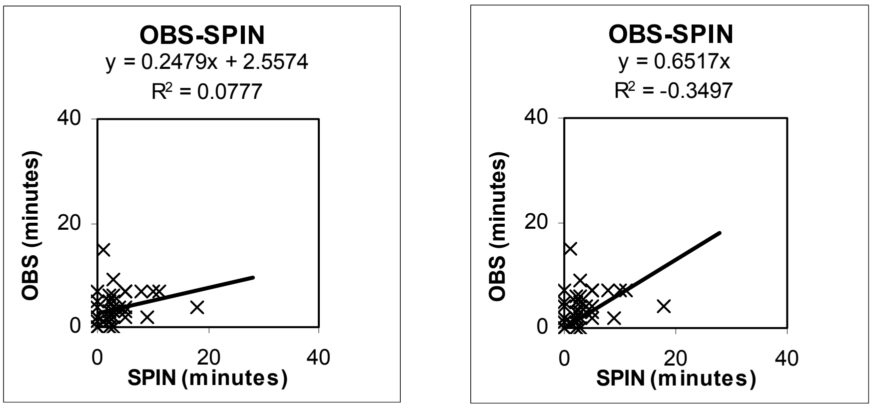


Figure 6.17 (a) Duration of Travel between Activity 1 and Activity 2 by OBS vs. SPIN

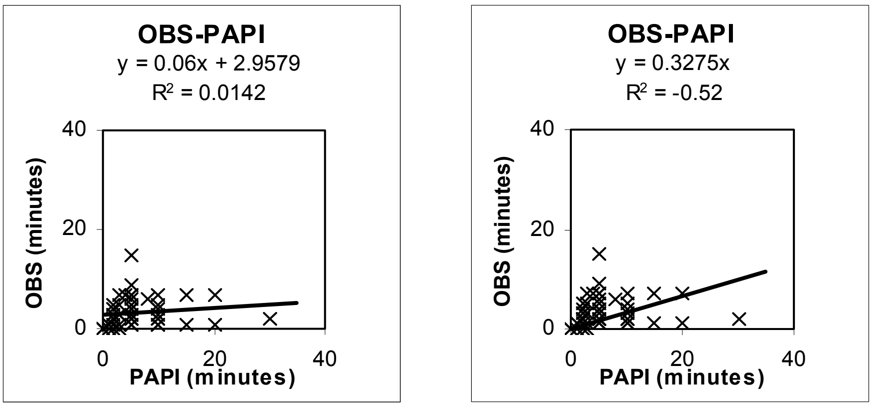


Figure 6.17 (b)Duration of Travel between Activity 1 and Activity 2 by OBS vs. PAPI

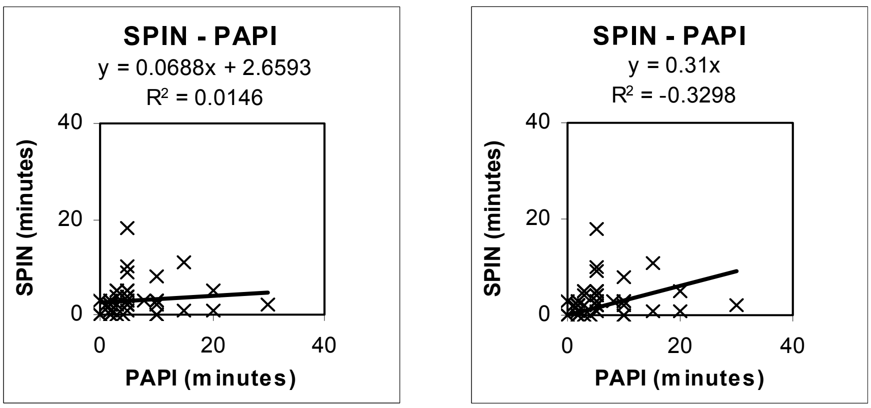


Figure 6.17 (c)Duration of Travel between Activity 1 and Activity 2 by SPIN vs. PAPI

Table 6.32 Statistical Results for Duration of Travel between Activity 3 and Activity 4

Error Parameters	OBS - PAPI	OBS - SPIN	SPIN - PAPI
N	32	33	31
b*	0.452	0.403	0.594
Sy*	2.308	1.888	2.406
Bias	-1.938	-0.576	-1.419
SD_d	3.162	2.818	2.814
t	-3.647†	-1.174	-2.808†
r*	-0.185	-0.790	0.444
r	0.302	0.182	0.477

*Regression parameters through origin

†The difference is significant at the 5% probability level

6.6.3 Duration of Travel between Activity 3 and 4

For the travel duration between the third and fourth activity, we are able to detect that SPIN measures this unit with agreement to that of the revealed choice data. On the other hand, the estimation of the slope was slightly better in PAPI than in SPIN. Nevertheless, based on the significant difference with ovservations in the calculated t-values found in PAPI, we conclude that on average SPIN is ahead of PAPI in performance.

6.6.4 Duration of Travel between Activity 4 and Activity 5

In the fourth travel duration record, for the same measurement, over-reporting occurs in PAPI but under-reporting occurs in SPIN, although it is not significant. We also observe a higher variation in the responses in SPIN but with a lower bias. Despite the opposite signs in the t-values, the two instruments measure the travel duration equally well. However, more error parameters point in favour of PAPI; including a slightly higher value for the slope, lower standard errors, and a higher explained variance.

Regression | Regression through origin

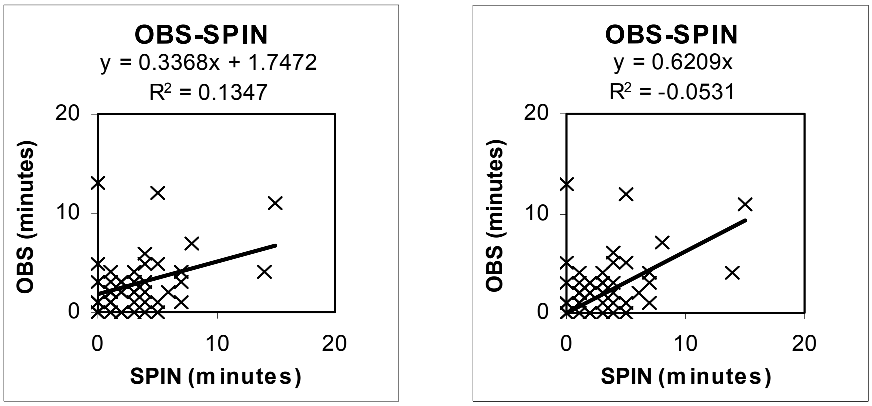


Figure 6.18 (a) Duration of Travel between Activity 2 and Activity 3 by OBS vs. SPIN

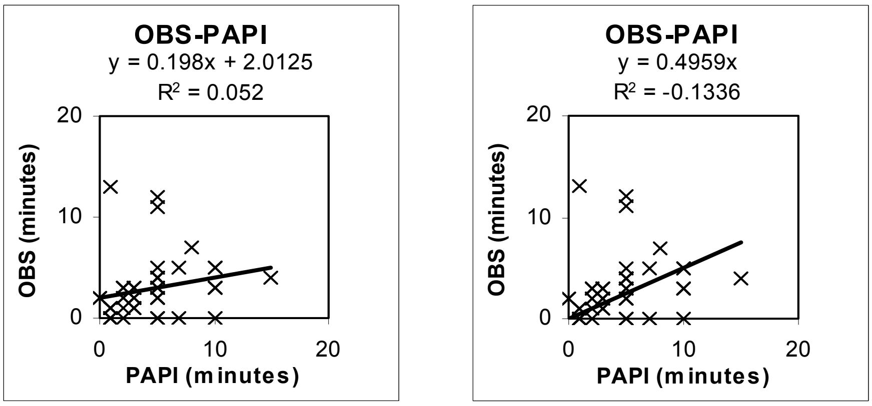


Figure 6.18 (b)Duration of Travel between Activity 2 and Activity 3 by OBS vs. PAPI

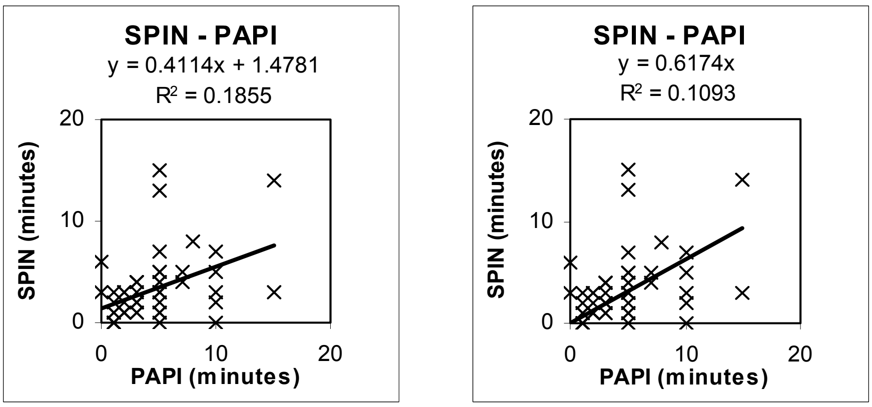


Figure 6.18 (c) Duration of Travel between Activity 2 and Activity 3 by SPIN vs. PAPI

Regression | Regression through origin

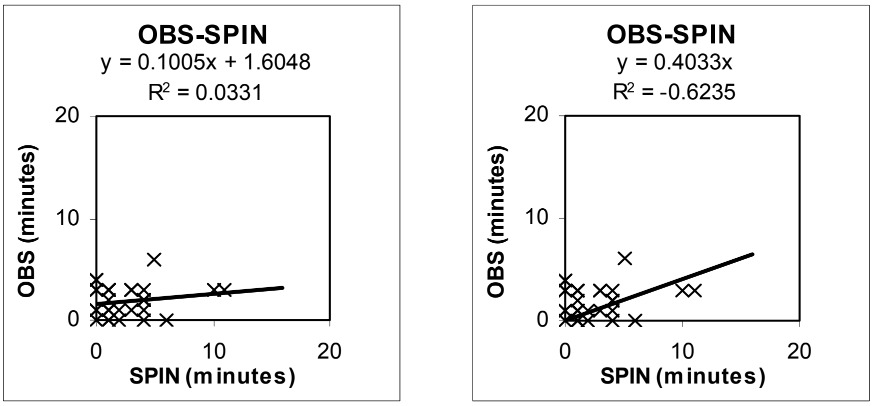


Figure 6.19 (a)Duration of Travel between Activity 3 and Activity 4 by OBS vs. SPIN

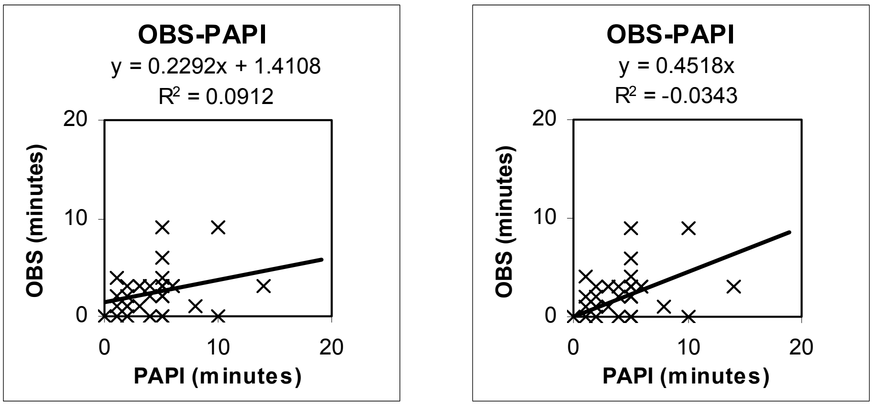


Figure 6.19 (b)Duration of Travel between Activity 3 and Activity 4 by OBS vs. PAPI

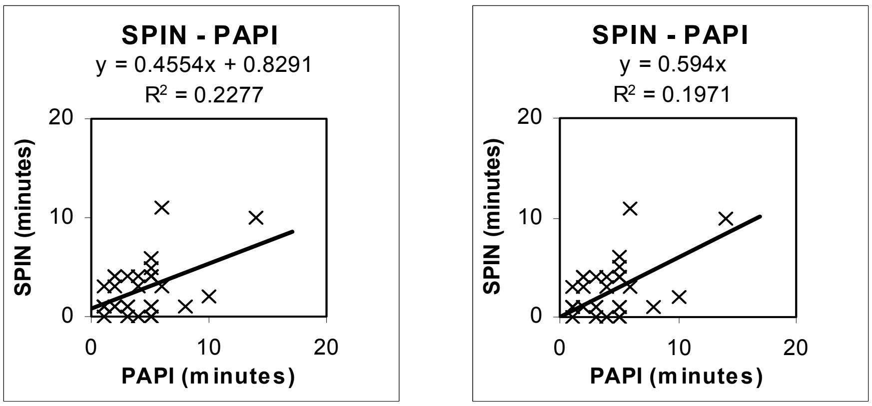


Figure 6.19 (c) Duration of Travel between Activity 3 and Activity 4 by SPIN vs. PAPI

Table 6.33 Statistical Results for Duration of Travel between Activity 4 and Activity 5

Error Parameters	OBS – PAPI	OBS - SPIN	SPIN - PAPI
N	16	21	18
b*	0.693	0.621	0.452
Sy*	2.113	3.340	3.746
Bias	-1.063	0.857	-2.056
SD_d	2.516	3.582	4.795
t	-1.689	1.097	-1.819
r*	0.664	-0.921	-0.389
r	0.689	0.236	0.163

* Parameters of regression through origin

Table 6.34 Statistical Results for Duration of Travel between Activity 5 and Activity 6

Error Parameters	OBS – PAPI	OBS -SPIN	SPIN - PAPI
N	10	14	9
b*	0.418	0.325	0.594
Sy*	5.619	4.748	2.047
Bias	-0.300	0.714	-1.788
SD_d	6.482	5.283	2.774
t	-0.146	0.506	-1.923
r*	-0.755	-0.799	-0.706
r	-0.342	-0.363	0.718

Parameters of regression through origin

6.6.5 Duration of Travel between Activity 5 and Activity 6

Table 6.27 shows the measurement of travel durations for the travel between activity 5 and activity 6, Subjects, again on average, over report using PAPI, but the t-value is very low indicating a low instance of this occurrence. The t-value for SPIN is slightly higher but again not significantly different from observed choice. Conversely, for SPIN, we observe slight under reporting. We are able to observe that there is an instance where the travel duration was reported at 0 minutes by subjects when using the SPIN instrument but the observed real time taken was 15 minutes (Figure 6.21 (a)). In this travel duration, between activity 5 and activity 6, PAPI emerges as the better instrument.

Regression | Regression Through Origin

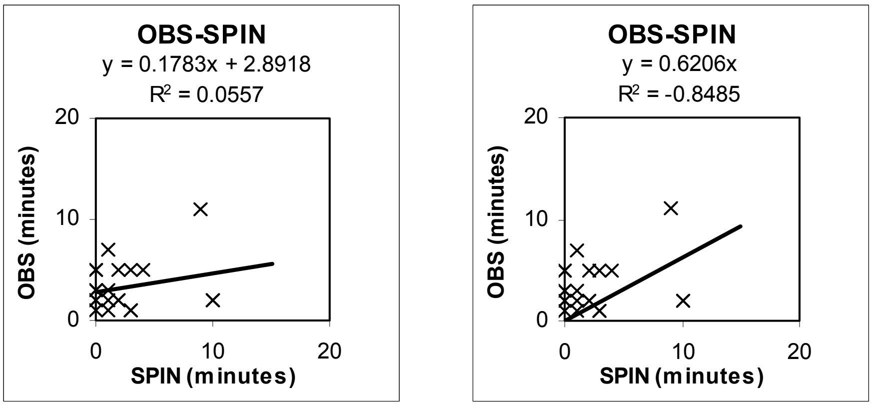


Figure 6.20 (a) Duration of Travel between Activity 4 and Activity 5 by OBS vs. SPIN

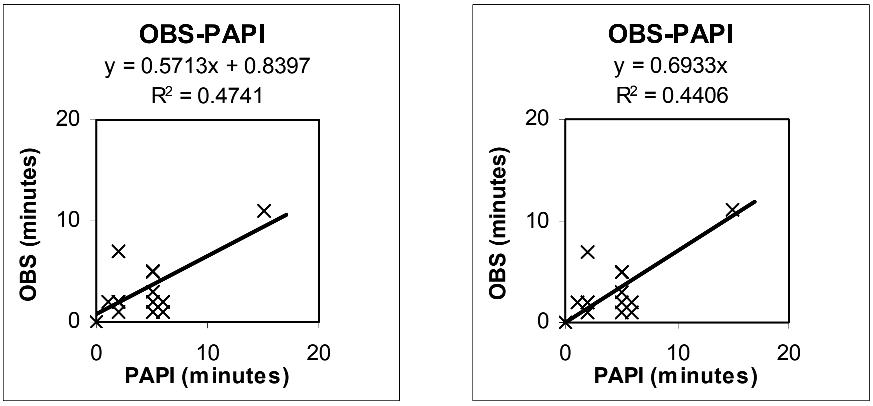


Figure 6.20 (b)Duration of Travel between Activity 4 and Activity 5 by OBS vs. PAPI

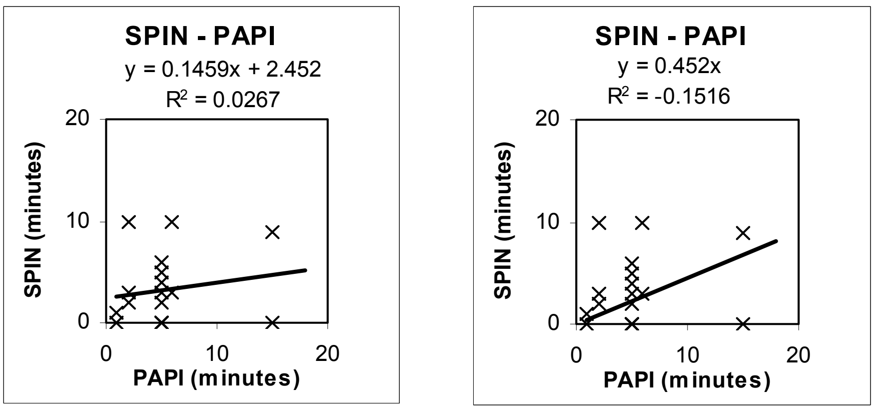


Figure 6.20 (c) Duration of Travel between Activity 4 and Activity 5 by SPIN vs. PAPI

Regression | Regression Through Origin

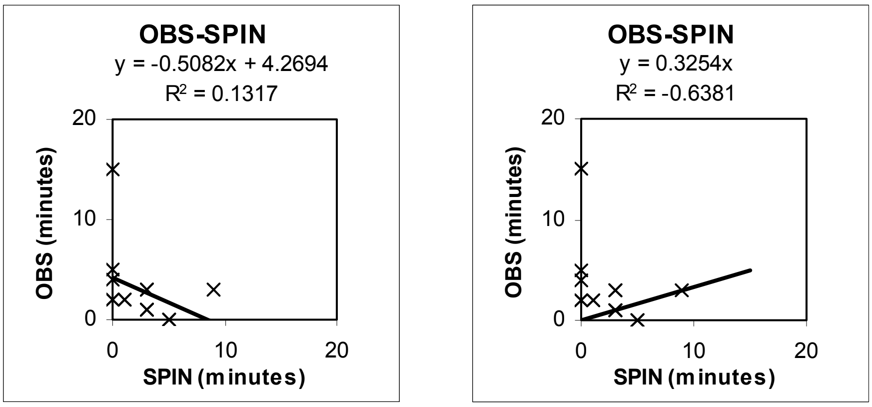


Figure 6.21 (a) Duration of Travel between Activity 5 and Activity 6 by OBS vs. SPIN

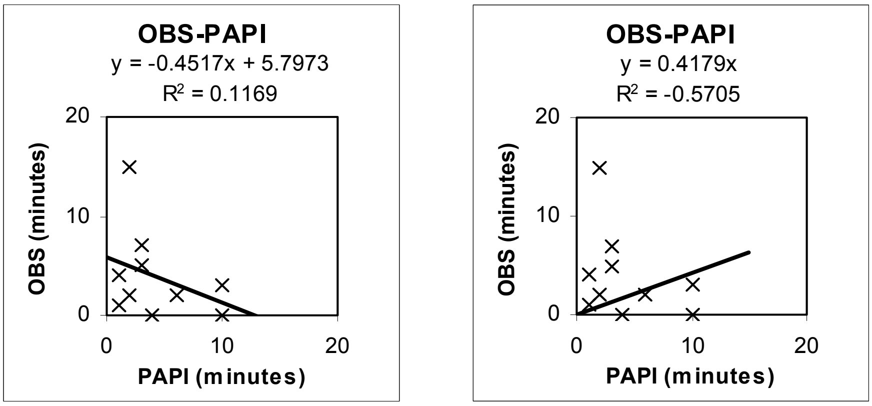


Figure 6.21 (b) Duration of Travel between Activity 5 and Activity 6 by OBS vs. PAPI

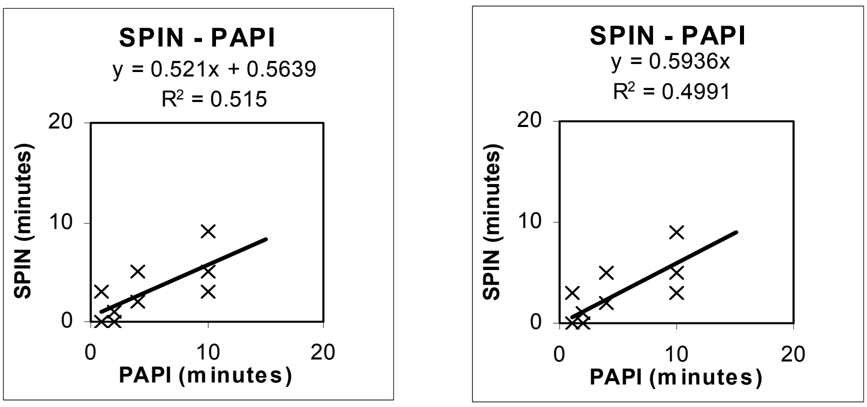


Figure 6.21 (c) Duration of Travel between Activity 5 and Activity 6 by SPIN vs. PAPI

Regression Through Origin

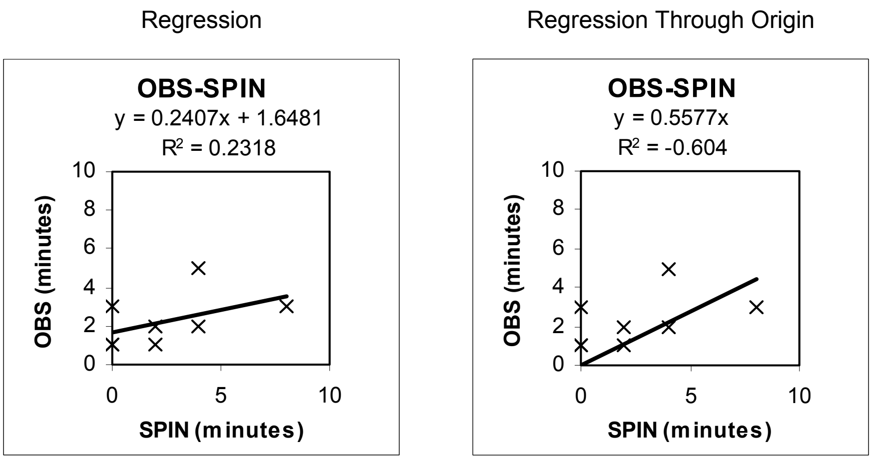


Figure 6.22 (a) Duration of Travel between Activity 6 and Activity 7 by OBS vs. SPIN

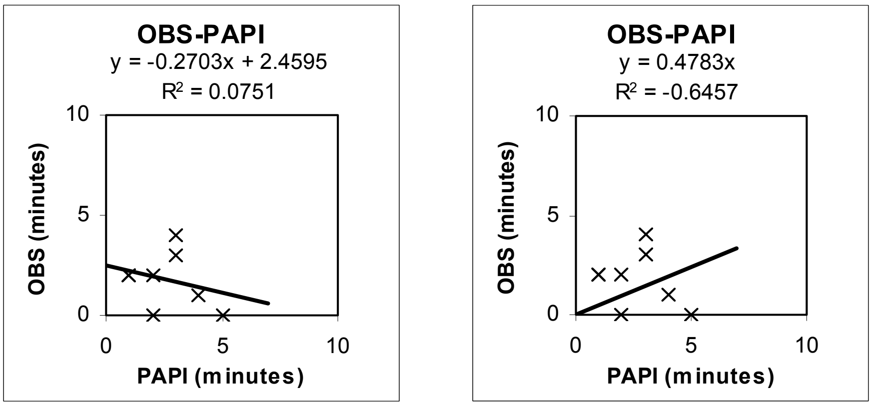


Figure 6.22 (b) Duration of Travel between Activity 6 and Activity 7 by OBS vs. PAPI

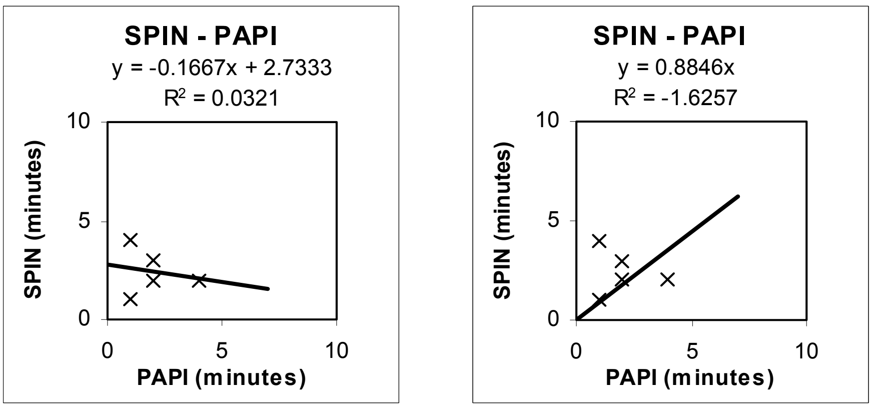


Figure 6.22 (c) Duration of Travel between Activity 6 and Activity 7 by SPIN vs. PAPI

6.6.6 Duration of Travel between Activity 6 and Activity 7

In this last travel duration examined, both instruments do not show significant deviations from revealed choice but we have to keep in mind the very low number of subjects. Over reporting occurs in both instruments but at higher degree for PAPI. PAPI also demonstrates a higher bias and lower value for slope estimation. There is a negative correlation between the OBS and PAPI data that suggests a higher tendency to over report with increasing durations.

Table 6.35 Statistical Results for Duration of Travel between Activity 6 and Activity 7

Error Parameters	OBS – PAPI	OBS - SPIN	SPIN - PAPI
N	8	8	5
b*	0.478	0.558	0.885
Sy*	1.782	1.759	1.848
Bias	-0.875	-0.250	-0.400
SD_d	2.232	2.435	1.817
t	-1.109	-0.290	0.492
r*	-0.804	-0.777	-1.275
r	-0.274	0.481	-0.179

* Parameters of regression through origin

6.6.7 Summary

When it came to the measurement of the durations of (segment) travel between activities, performance in SPIN proves to be nearly equally equivalent to the real travel durations in all durations. In the first three travel segments, there were significant differences the PAPI and observed values but not in the following consecutive three travel segments. At the same time, in our examination of the error parameters for the last three travel segments, it is revealed that PAPI outperforms SPIN in the travel durations. The overview of the comparison of methods is shown in Table 6.36 where S > P indicates a better performance by SPIN and where S < P indicates a better performance by PAPI.

Over reporting of the travel durations by the subjects occurs in more instances than under reporting. In all cases of the capture of the travel durations in PAPI, over-reporting ruled the day. We note that only 3 cases of under-reporting for SPIN occur out of the 6 travel durations examined. Thus, the tendency to over report took place more often in PAPI.

We can attribute the superiority of SPIN in measuring travel durations between activities to the fact that the automatic deduction of travel durations is present in SPIN but not in PAPI. Thus, the task difficulty of estimating the travel durations has been reduced somewhat to just confirming that the deduced time matches the subjects' personal estimated value. In PAPI, the subject is compelled to make retrieval of time durations of both activity durations and travel durations to create a coherent schedule. The time format is meant to be entered in the free format, and at such a juncture, subjects can introduce errors.

Table 6.36 Comparability of Methods with Revealed-Choice (OBS) Method for Travel Durations between Activities

Facets	PAPI	SPIN	Comparability
Duration of Travel between Activity 1 and Activity 2	N	Y	S(PIN) > P(API)
Duration of Travel between Activity 2 and Activity 3	Y	Y	S > P
Duration of Travel between Activity 3 and Activity 4	Y	Y	S > P
Duration of Travel between Activity 4 and Activity 5	Y	Y	S < P
Duration of Travel between Activity 5 and Activity 6	Y	Y	S < P
Duration of Travel between Activity 6 and Activity 7	Y	Y	S < P

"Y": non-significant difference (at 5% probability level) with revealed choice
"N": significant difference (at 5% probability level) with revealed choice
">": performs better
"<": performs worse

Table 6.37 Comparison of Reliability between Methods for Travel Durations between Activities

Facets	Comparability
Duration of Travel between Activity 1 and Activity 2	S(PIN) > P(API)
Duration of Travel between Activity 2 and Activity 3	S > P
Duration of Travel between Activity 3 and Activity 4	S > P
Duration of Travel between Activity 4 and Activity 5	S < P
Duration of Travel between Activity 5 and Activity 6	S < P
Duration of Travel between Activity 6 and Activity 7	S > P

“>” higher reliability
“<” lower reliability

Table 6.38 Comparison of Validity between Methods for Travel Durations between Activities

Facets	Comparability
Duration of Travel between Activity 1 and Activity 2	S(PIN) > P(API)
Duration of Travel between Activity 2 and Activity 3	S > P
Duration of Travel between Activity 3 and Activity 4	S < P
Duration of Travel between Activity 4 and Activity 5	S < P
Duration of Travel between Activity 5 and Activity 6	S > P
Duration of Travel between Activity 6 and Activity 7	S > P

“>” higher validity
“<” lower validity

Reliability has been examined on the comparison of the standard deviations of the differences between each method and the revealed-choice (Table 6.37). A higher standard deviation implies a lower reliability. We find that reliability is higher for the SPIN method for 4 out of the 6 numbers different travel durations. In the overall outcome of the measurement of the travel durations, the SPIN method demonstrated a higher reliability.

Comparing the value of the slope of the regression equation for each method with the revealed choice observations will indicate which of the two methods gives a higher degree of validity. A slope value nearing 1.000 is the method that is closer to the observed real data. Table 6.38 show the summary of such a comparison for the data on travel durations between activities. There are 4 out of 6 instances of travel duration where the validity for SPIN was higher than for PAPI.

In the facet of the duration of the travel between activities, we have detected that more instances of these measurements in SPIN demonstrated a higher degree of reliability and validity.

7 Conclusions and Discussion

The goal of this study is to assess the reliability and validity of virtual reality interactive computer experiments in the context of collecting data about activity travel behaviour. Several issues pertaining to the concepts of reliability and validity were effectively examined to arrive at the attainment of this aim. We were able to identify the areas of errors that potentially undermine the quality of the travel survey data and weigh advantages and disadvantages of the strategies to deal with them, so as to incorporate the most effective ones into our proposed method using the technology of virtual reality. Virtual reality is a promising technology that waits us to tap on, and that is best carried out by matching the relevance of our goal to the strengths it can offer. This concept has culminated in a virtual reality data collection system, which was subjected to performance testing in a method comparison study. This chapter summarizes the findings of our study and discusses the potential of the proposed system and possible follow-up research.

7.1 Summary of the Study

This research was designed to yield outcomes that will enable us to understand the value of using virtual reality technologies in contributing towards increasing the reliability and validity of the survey of a person's daily activities. We have taken the activity-based approach to travel data collection because of its realistic representation of behaviour in travel demand modelling, travel demand analysis, transportation, and urban planning. Although researchers favour the activity-based approach, difficulties lie with the high demands of the data requiring all activities, both in-home and out-of-home, over the course of one or more days. The activity diaries used for such data collection depend on the subjects' ability to remember the events that took place in the past. Conscientious effort is necessary on the part of the subjects to give as much detailed and accurate information as possible. This is known to be a difficult task notwithstanding the mistakes that come with making entries using paper-and-pencil. This leads to the exploration of alternate ways of collecting information that not only reduce the demands required of the subjects but also with improved quality and accuracy in the data. Increasingly, computer aided techniques are getting popular and in particular the electronic means are starting to gain ground over the paper-and-pencil means. Even with electronic means, the main task of the subjects is on reporting. The key element in this reporting process is the recall of all activities, and their associated aspects depending on the design of the diary or questionnaire and administration of data collection. At the same time, in interactive computer experiments, the initial set of data concerning personal contextual information about daily human activities and their characteristics is a pre-requisite. Only when that has been established can there be value to conduct experiments on solicitation of responses to hypothetical situations. Of interest and concern to us is how much more accurate and precise of the reporting of previous events can be achieved by enhancing the recall process. Retrieval of information from semantic memory is possible because of the meanings and concepts that are associated with events and actions that took place in that environment. By both providing a visual stimulus, and structuring the data collection to mimic the order in which events occur, we tap on the known principles of organization of daily life to trigger recognition memory and memory for temporal order. We thus based our design of the interactive computer virtual reality system on findings and insights derived from studies about how people behave in the recall of everyday activities. We further based our research design on the theory that recognition of locations in virtual environments closely approximates the way we deal with movement within familiar environments. These are characteristics that can be supported by providing contextual virtual environments where people can navigate. In the process, individuals are re-constructing the execution of past activities thereby creating a narrative of what happened, the answers to “what”, “when”, “where”, and “how”. When recalling a past narrative in virtual reality, there is the opportunity to use the “experience” of the situation in a virtual environment to aid recall of past sequence of events and therefore the analogous “experience” of the future events and actions.

A virtual reality system was developed along the lines of such a proposed conceptual framework. It is a system that uses panoramas of the urban environment for the visualization process, accordingly called Stereo Panoramas Interactive Navigation (SPIN). The view is chosen to be displayed in a stereoscopic form to create a realistic representation with the intention of psychologically situate subjects in the state of the conduct of previous events. We explored the potential of such a system by carrying out small-scale field experiments to test its validity by comparing the data collected with that of the traditional paper-and-pencil questionnaire. Based on the assumption that the results of such a limited study can be generalized to more comprehensive and complex activity-travel diaries, we focused on the activity-travel patterns of pedestrians visiting the city centre of Eindhoven, The Netherlands. For practical reasons, the experiment was designed such that observers record (unobtrusively) subjects’ activities whilst they conducted their tour in the city centre. This is the set of revealed-choice data that forms the surrogate true values against which the other two methods will be compared. Thus, the study included (a) subjects performing several activities with short durations, or (b) of one activity with multiple locations (e.g. shopping). The sample included only subjects who conducted activities by walking from location to location.

Data was collected on the activity travel of 57 subjects. Interviewers who recorded their activity travel schedule first observed subjects who agreed to participate in the study. Upon completion of their tour in the study area, subjects were requested to complete a questionnaire in two ways; one using the pen-and-paper method and another using SPIN. A proportion of the sample had the sequence of the completion reversed by completing the questionnaire in SPIN first. The observations by the interviewers were assumed to be error-free. These measurements of real behaviour in the form of revealed choices served as the basis for comparison for those recorded by the subjects using the paper and pencil instrument and the SPIN instrument. We have chosen to assess the quality of the collected data using a direct approach – comparing the data with a source closer to true values. Thus, comparison tests of the data collected from the two instruments, SPIN and PAPI, with the observed revealed choice, OBS, were performed separately using the least squares regression and the t-test. Where there is no significant difference found at 95% confidence level, we take it that that instrument measures an activity facet well because of its proximity to real world true values. If two instruments are equally good measures, we favour the one with smaller statistical tests errors. Nine facets of an activity schedule were studied in detail: 1. the number of stops made by the subjects from start to finish of the schedule executed, 2. the number of different activities performed, 3. the duration of all the activities, 4. the duration of the service activities, 5. the duration of the shopping activity, 6. the duration of the out-door leisure activity, 7. the duration of travel between activities, and 8. the duration of the whole schedule, and 9. route choice.

7.2 Discussion of the Study

The study outcome gives non-uniform indications as to whether the interactive virtual reality system performed better than the traditional paper and pencil questionnaire.

We have examined three different dimensions of an activity travel schedule – categorized into (1) structural dimension– the number of stops and of the number of activities, (2) durations – durations of all activities, shopping activity, services activity, out-of-home leisure activity, travel between activities, whole schedule, and (3) route choice.

One of the findings is that the structural dimensions were better measured by the virtual reality system. This indicates that the re-enactment process of the schedule in the virtual environment might have contributed towards a better retrieval of the structural dimension of the activity schema. Aspects of the re-construction process had perhaps “forced” this effect for example, by the forward recall sequence, and the structuring control of follow-on actions.

The assessment on the dimension of durations is that the paper-and-pencil questionnaire yielded better quality responses. The duration of all activities, the duration of shopping, the duration of out-of-home leisure activity, and the duration of the whole schedule were better measured by PAPI while the travel durations between stops and duration of the services activity were measured better by SPIN.

It is probable that the design of the virtual reality instrument has an unconstructive influence on the way subjects approached the task of providing time durations. In the virtual environment experience, time is compressed during the re-enactment of activities and travel. Besides, there is a background calculation of elapsed travel time between activities. This, together with the proportionality of compressed time to real time may cause some amount of confusion in judgments. The experience of time in SPIN is possibly unfamiliar to most people. There is also a different process of entering activity durations in SPIN. Time is “moved forward” to indicate the duration for the conduct of an activity. Perhaps this imposes a higher cognitive load on an individual’s perception of time resulting in less accurate reporting. In PAPI, one only needs to “figure” out the number of minutes and write them down.

Regardless of the instrument, the results of the study demonstrate over-reporting by the subjects. On average, all choice facets were over-reported except the number of stops. At the same time, over-reporting increased with increasing values on all choice facets.

Regarding the collection on route choice data, the results indicated that the virtual reality instrument was not able to measure this dimension better than PAPI that used a map. A map obviously can provide an overview but this was not presented in the virtual reality system, as it was deemed not necessary for the re-enactment process. We are not clear as to whether subjects have more trouble in recognizing how a location view in the virtual environment fits into the larger urban environment or with the navigational aspects of the virtual reality system. To improve the performance of the SPIN instrument inclusion of a map is recommended as a replacement to the mental maps. However, this will require additional research, especially if significant improvements on the measurement of route choices by individuals who use a map in SPIN can be achieved.

In addition, we have verified that the virtual reality technology as used in SPIN was able to exercise control over the data collection process, through acquiescent of standardized questioning. The results of the control were positive, in that there were less registration errors, counting both missing entries and wrong entries, hence leading to a higher data quality.

In conclusion then, this study has provided some evidence that virtual reality may be another potentially relevant technology for collecting data, especially about the structural facets of activity-travel pattern, such as the number of stops, and type and number of activities. As an alternative approach, virtual worlds could provide tools for conducting experiments in a controllable environment, as we had qualified in our experiments in the aspect of the conduct of everyday human activities. It is therefore feasibly to place human subjects in a virtual environment that allows for the probing of cognition and behaviour in short (daily) and middle term activity scheduling.

7.3 Ramifications

This study can be considered an investigation into the correspondence of virtual environments with real environments since we have assessed the comparison of the measures carried out in a real-world setting to that of the same setting constructed with virtual reality. Our experience in constructing a replica of a study environment demonstrates that stereo panoramas make a quality choice to represent the urban environmental information because they represent compelling views of the real environment; however, they apparently can only remain as substitutes. The sense of presence invoked in a person in a stereoscopic panoramic virtual environment can enhance the desire to travel and move around. It was possible for a user to choose different routes very quickly and unobtrusively while keeping aware of his/her whereabouts, thereby providing an engaging, and highly interactive experience. In some ways, navigating the virtual environment has added an entertainment value, a rare dimension in a survey process. The motivational contribution of SPIN can be considered to be higher than the paper and pencil questionnaire.

The use of SPIN as a alternative form visual aid to comprehension and an aide memoire, albeit a more sophisticated one, allowed us to introduce different types of structuring elements into the interviewing process. The computer form of survey has provided better control surfaces that do paper surveys, such as taking advantage of radio buttons (select one) and check boxes (check all that apply), and pull down lists. Indeed, by tailoring the questioning structure to the personal circumstances and "on-line" choices input from the individual, SPIN supports well the interactive measurement methodology. Rather than administering a long series of boring questions normally practiced in stated preference techniques, SPIN creates an opportunity to start the interview via reconstructing existing patterns of behaviour thus both enabling subjects to familiarize themselves with the equipment and concepts, as well as ensuring that subsequent deliberations takes place in terms of modifying established behaviour, rather than as an idealistic assessment of the effects of the intended study measure, divorced from their actual situation.

SPIN can be considered as probably the one and only instrument of the kind that the subjects have ever encountered, so we can conclude that the subjects have had contact with it for the first time. Such an encounter may have impact on the some subjects by introducing a higher variability than the paper-and-pencil. But the fact that is it new and perhaps more appealing may motivate the subject to give more effort in their participation. However, we are not able to be conclusive about whether the subjects were more distracted by SPIN than if it helped in their concentration on performing their tasks. Logically, we can assume some form of learning is necessary and the learning curve is not necessarily the same for all subjects. A practice opportunity is presented prior to the subjects performing the actual experiment and the subjects did not show any difficulty with neither understanding nor with the handling of the equipment. We can likewise assume that the trigger effect that we intend to incite will not ensue at the same level for all subjects.

With the use of SPIN, paradata generated as a byproduct of automated systems is available to inform us about the behaviour of subjects in the automated environment. The time stamps, for example, are especially useful to reveal the duration of the survey, although this was not utilized in our study. The paradata on the route choice is however the designated implicit way to collect the information in the reconstruction of conduct of past activities. If desired, researchers can have access to such similar auxiliary data about the data process collection.

We are not able to say with high confidence that using technology as in SPIN can replace the function of interviewers. But we can say the instrument was able to serve as a support tool to facilitate and enhance the work of interviews in the automated environment. There were no instances of anyone giving up halfway and the subjects apparently did not have difficulties conducting the experiment, although we must highlight that the interviewers were in their presence throughout the self-interviewing experiment in SPIN. This might have given the subjects some impetus to complete the experiments to the end. On the other hand, the interviewers were able to assist the subjects if they find any difficulty and were at hand to answer questions on the spot. The interviewers in our study, although not directly involved with the questioning process, were invaluable in the recruitment of subjects at the initial contact during the intercept sampling process.

The results of the study cannot provide answers on the acceptability of a method; however, they can provide specific estimates of the type and magnitude of errors.

This is the essential information for deciding whether a method is acceptable. The absence (or rarity) of errors substantiates acceptable performance. Decisions on acceptability would have to be based on the judgments as to what amount of error is tolerable. Other quality criteria important in the choice of a certain data collection mode to be considered over and above the measurement error expected are the survey non-coverage, the non-response, and the costs involved in conducting a survey.

We were able to demonstrate that it is possible for the subjects to reconstruct the conduct of past activities in virtual reality for the purpose of eliciting their choice dimensions of travel. Therefore, interactive virtual reality computer experiments can be considered to have extended the existing capabilities of surveys, as it is possible to do things that we were not previously possible. We can expect that our study will contribute to the research on a new alternative survey instrument prior to adoption. Such evidence, as this needs to be accumulated pending a transition to new technology.

7.4 Possible Future Research

It goes without saying that the technology used in this study cannot yet be readily applied to city-wide data collection. However, even during this study, considerable advances have been made in automating the process of building panoramic views of cities. Soon such data will become available for many cities, at least in Europe. At the same time, virtual reality is a fairly recent technology with two areas relevant to survey researchers still undergoing verification studies - the handling of time simulation to match human cognitive perception of time and "naturalistic" navigation of a virtual environment. The implication of such a developments means that further investigation into more wide-ranging surveys using the technology as the basis is needed as virtual reality becomes more accessible.

The technology considered here can, however, be already immediately applied, for example, to examine whether a proposed modification to a subject's environment can eliminate impracticable answers, such as unaccounted-for gaps in the day, or in the subject attempting to be in two places at one time or doing several things at once, thus acting as experimental, semi-closed systems, in which the subject is forced to consider many of the direct and derivative repercussions of any change to in his/her choice behaviour.

Furthermore, this new type of measurement can be used in combination with other existing types using the advantages of each instrument. At the current time, the technology is easy to use on the Internet and can be used in self-reporting Internet surveys. Mixed mode systems can also be developed. For example, GPS technology can be used to record the routes, stops, and durations, and research can identify the missing information or questionable segments. These GPS data can then be used in-sync with the virtual reality system, for instance through the Internet, and subjects can then be asked to re-enact their trips in virtual reality and provide information about the type of activity that was conducted at the various stops, with whom the activity was conducted and other questions that are deemed relevant for the application but cannot be collected using GPS technology. There is opportunity to obtain better results by combining the strongest properties of these technologies in the best possible way. The explorations of these ideas present themselves as interesting and worthy follow-on research.

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Appendix A1 Activiteiten Enquête

ACTIVITEITEN ENQUÊTE

ONDERZOEK NAAR VERPLAATSINGS - EN
ACTIVITEITENPATRONEN VAN PERSONEN

augustus / september 2002

HARTELIJK DANK VOOR UW MEDEWERKING

ONTWERP SYSTEMEN DESIGN SYSTEMS

Urban Planning Group

TU/e

Instructies voor respondenten

A. Introductie

In dit onderzoek van de groep Urbanistiek, Faculteit Bouwkunde, Technische Universiteit Eindhoven, wordt u verzocht gegevens te verstrekken over uw activiteiten en verplaatsingen op een reeds plaatsgevonden dag. Dit betreft de dag waarop u geselecteerd bent om deel te nemen. Slechts de informatie vanaf die dag/tijdstip en locatie is relevant.

B. Het onderzoek bestaat uit twee delen en wel de volgende:

1. Virtuele verplaatsingen

In een gesimuleerde omgeving binnen Eindhoven bent u in de gelegenheid zichzelf virtueel te verplaatsen. U kunt het beschouwen als een soort van computerspel. De verwachting is dat dit deel van het onderzoek ongeveer een uur van uw tijd in beslag zal nemen.

2. Enquête

De enquête bestaat uit vier delen:

Deel 1: Persoonlijke gegevens (bijlage 1)
Deel 2: Invulformulier activiteiten (bijlage 2)
Deel 3: Activiteitenlijst (bijlage 3)
Deel 4: Aangeven route en vervoermiddel op plattegrond (bijlage 4)

U wordt verzocht informatie te verschaffen over uw activiteiten op locaties in de stad binnen de periode aangegeven in de bijlagen.

Een Activiteitenlijst (bijlage 3) is bijgevoegd ter ondersteuning bij het invullen van uw activiteitenvelden.

Tenslotte wordt u verzocht op de bijgevoegde plattegrond (bijlage 4) te markeren welke route u gevolgd hebt naar de verschillende locaties voor uw activiteiten en van welk vervoermiddel u daarbij gebruikt hebt gemaakt.

C. Hieronder volgt enige toelichting op de verschillende vragen in bijlage 2:

Vraag 1
Wat is de straatnaam en naam van de gelegenheid van de locaties waar uw activiteiten hebben plaatsgevonden?

Vraag 2
Welk vervoermiddel hebt u gebruikt om zich naar de locatie te begeven?

Vraag 3
Hoe laat bent u naar de locatie vertrokken?

Geef aan hoe lang en wanneer de activiteit uitgevoerd is door het geven van: starttijd en duur; of duur; of eindtijd; of eindtijd en duur; of starttijd en eindtijd.

Vraag 4
Hoe laat bent u op de locatie aangekomen?

Vraag 5
Wat was de reisduur naar de verschillende locaties?

Vraag 6
Wat was de duur van de activiteit?

Vraag 7
Hoe zou u de verkeersdrukte op de route naar de verschillende locaties willen omschrijven?

Vraag 8
Met wie heeft u deze activiteit verricht?

Vraag 9
Was deze activiteit vooraf gepland? En zo ja, wanneer?

Bijlage 1

Datum

Respondent Identificatie:
Start opname locatie (Straat/Parkeerplaats/Winkel):
Start opname tijd:
Start vervoermiddel:

Persoonlijke Gegevens

1. Naam	………………………………………………………………
2. Leeftijd	………………………………………………………………
3. Geslacht	❑ Man ❑ Vrouw
4. Contact telefoonnummer en email	………………………………………………………………
5. Hoe goed bent U bekend in Eindhoven	❑ *Goed bekend* ❑ Redelijk bekend ❑ Niet goed bekend
6. Hoe vak bezoekt u de binnenstad van Eindhoven Bijv. Iedere dag naar het werk	……*keer per/maand/jaar voor winkelen/boodschappen* ……keer per/maand/jaar voor Vrije tijd ……keer per/maand/jaar voor werk of zakelijk ……keer per/maand/jaar voor bezeoken vriendin/familie
7. Wat is Uw Hoogst genoten opleiding? Opmerking: indien nog op school dan is dat de hoogst genoten opleiding!	❑ Lagere school ❑ LBO ❑ MAVO ❑ HAVO ❑ VWO ❑ MBO ❑ HBO ❑ Universitair Onderwijs
8. Beroep	………………………………………………………………
9. Inkomensgroep (per jaar)	❑ Geen inkomen ❑ Tot € 5.000 ❑ €5.000 – € 10.000 ❑ €10.000 – 15.000 ❑ €15.000 – € 20.000 ❑ €20.000 – € 25.000 ❑ €30.000 - €35.000 ❑ meer dan €35.000
10. Bent U in het bezit van een rijbewijs?	❑ Ja, ik heb een autorijbewijs ❑ Ja, ik heb een motorrijbewijs ❑ Nee
11. Heeft U de beschikking over een auto?	❑ Ja ❑ Nee
12. Heeft U de beschikking over een motor?	❑ Ja ❑ Nee

Datum:
Het weer:

Respondent Identificatie:
Start opname locatie (Straat/Parkeerplaats/Winkel/andere zaken):
Start opname tijd:
Start vervoermiddel:

Invulformulier Activiteiten

Activiteit	1e [ ]	2e [ ]	3e [ ]
1. Locatie activiteit	Straatnaam: …………………… Naam gelegenheid: ……………………	Straatnaam: …………………… Naam gelegenheid: ……………………	Straatnaam: …………………… Naam gelegenheid: ……………………
2. Vervoersmiddel naar locatie?	❑ te voet ❑ fiets ❑ brommer ❑ motor ❑ auto ❑ bus ❑ taxi	❑ te voet ❑ fiets ❑ brommer ❑ motor ❑ auto ❑ bus ❑ taxi	❑ te voet ❑ fiets ❑ brommer ❑ motor ❑ auto ❑ bus ❑ taxi
3. Starttijd reis naar locatie	….. : …..(uu:mm)	….. : …..(uu:mm)	….. : …..(uu:mm)
4. Eindtijd reis naar locatie	….. : …..(uu:mm)	….. : …..(uu:mm)	….. : …..(uu:mm)
5. Reisduur	….. : …..(uu:mm)	….. : …..(uu:mm)	….. : …..(uu:mm)
6. Duur activiteit	….. : …..(uu:mm)	….. : …..(uu:mm)	….. : …..(uu:mm)
7. Verkeer op de route	❑ rustig ❑ middelmatig ❑ druk ❑ weet ik niet meer	❑ rustig ❑ middelmatig ❑ druk ❑ weet ik niet meer	❑ rustig ❑ middelmatig ❑ druk ❑ weet ik niet meer
8. Met wie heeft U deze activiteit verricht?	❑ Alleen ❑ Partner ❑ Kind(eren) ( ) ❑ Anders ( )	○ Alleen ○ Partner ○ Kind(eren) ( ) ○ Anders ( )	○ Alleen ○ Partner ○ Kind(eren) ( ) ○ Anders ( )
9. Was deze activiteit vooraf gepland?	❑ Nee ❑ Ja, vandaag ❑ Ja, gisteren ❑ Ja, >1 dag geleden ❑ Regelmatig of routine	❑ Nee ❑ Ja, vandaag ❑ Ja, gisteren ❑ Ja, >1 dag geleden ❑ Regelmatig of routine	❑ Nee ❑ Ja, vandaag ❑ Ja, gisteren ❑ Ja, >1 dag geleden ❑ Regelmatig of routine

Respondent Identificatie:

Start opname locatie (Straat/Parkeerplaats/Winkel/andere zaken):
Start opname tijd:
Start vervoermiddel:

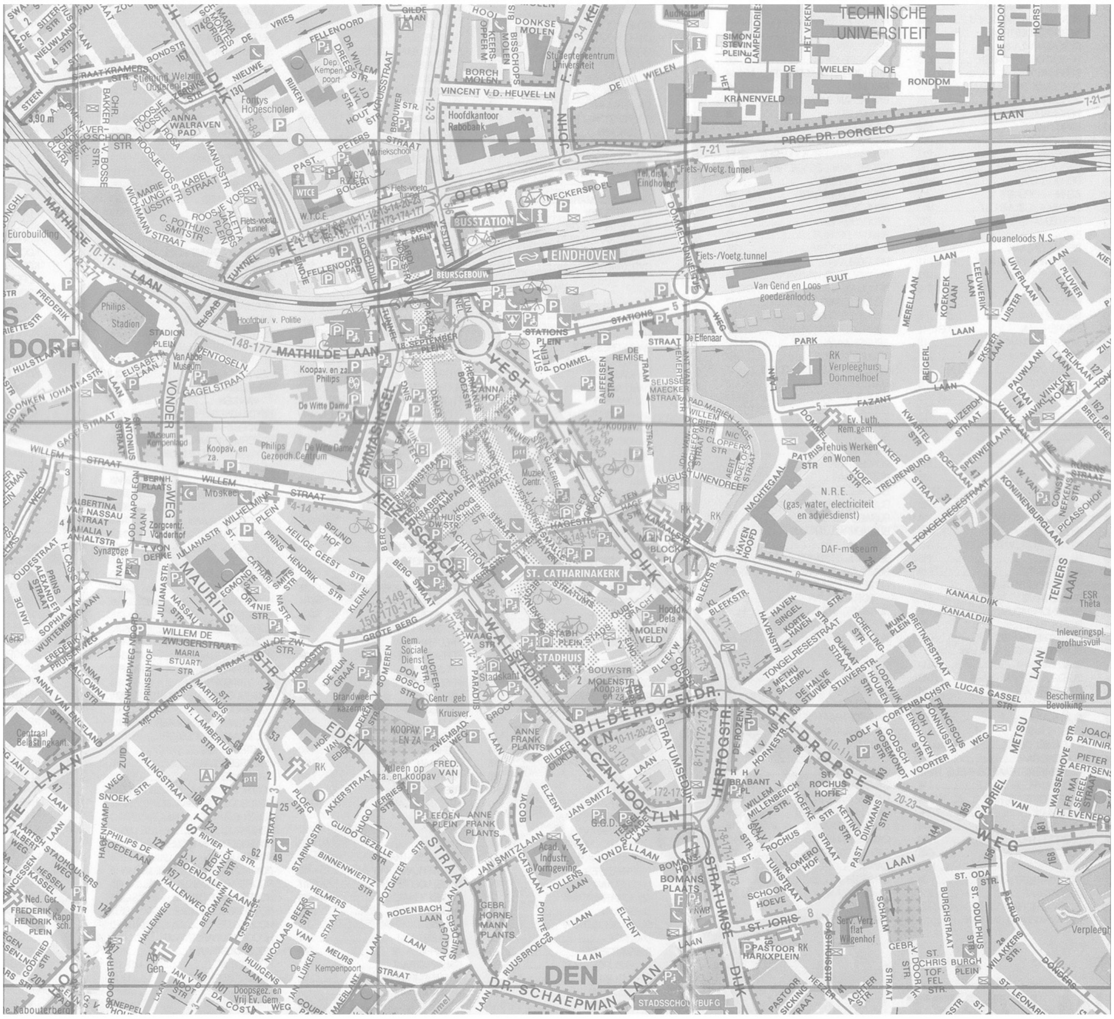
Invulformulier Activiteiten

Activiteit	4e [ ]	5e [ ]	6e [ ]
10. Locatie activiteit	Straatnaam: …………………… Naam gelegenheid: ……………………	Straatnaam: …………………… Naam gelegenheid: ……………………	Straatnaam: …………………… Naam gelegenheid: ……………………
11. Vervoersmiddel naar locatie?	❑ te voet ❑ fiets ❑ brommer ❑ motor ❑ auto ❑ bus ❑ taxi	❑ te voet ❑ fiets ❑ brommer ❑ motor ❑ auto ❑ bus ❑ taxi	❑ te voet ❑ fiets ❑ brommer ❑ motor ❑ auto ❑ bus ❑ taxi
12. Starttijd reis naar locatie	….. : …..(uu:mm)	….. : …..(uu:mm)	….. : …..(uu:mm)
13. Eindtijd reis naar locatie	….. : …..(uu:mm)	….. : …..(uu:mm)	….. : …..(uu:mm)
14. Reisduur	….. : …..(uu:mm)	….. : …..(uu:mm)	….. : …..(uu:mm)
15. Duur activiteit	….. : …..(uu:mm)	….. : …..(uu:mm)	….. : …..(uu:mm)
16. Verkeer op de route	❑ rustig ❑ middelmatig ❑ druk ❑ weet ik niet meer	❑ rustig ❑ middelmatig ❑ druk ❑ weet ik niet meer	❑ rustig ❑ middelmatig ❑ druk ❑ weet ik niet meer
17. Met wie heeft U deze activiteit verricht?	❑ Alleen ❑ Partner ❑ Kind(eren) ( ) ❑ Anders ( )	○ Alleen ○ Partner ○ Kind(eren) ( ) ○ Anders ( )	○ Alleen ○ Partner ○ Kind(eren) ( ) ○ Anders ( )
18. Was deze activiteit vooraf gepland?	❑ Nee ❑ Ja, vandaag ❑ Ja, gisteren ❑ Ja, >1 dag geleden ❑ Regelmatig of routine	❑ Nee ❑ Ja, vandaag ❑ Ja, gisteren ❑ Ja, >1 dag geleden ❑ Regelmatig of routine	❑ Nee ❑ Ja, vandaag ❑ Ja, gisteren ❑ Ja, >1 dag geleden ❑ Regelmatig of routine

Activiteiten CodeLijst (Buitenshuis)

Categorie	Activiteiten	Code
A. Werk	Werk buitenshuis (ook vrijwillgerswerk)	A1
	Studie/School buitenshuis	A2
B. Zakelijk	Zakelijk bezoek	B1
C. Voorzieningen	Dienstverlening zaken (reisbureau, kapper, bank, postkantoor, etc.)	C1
	Overige persoonlijke zaken (notaris, garage, gemeentehuis, etc.)	C2
	Medische zorg (bezoek huisarts, tanderts, specialist, fysiotherapeut, ergotherapeut, etc.)	C3
D. Boodschap	Dagelijkse boodschappen (supermarket, groenteboer, slager, etc.)	D1
	Winkelen (kopen van goederen, incl.)	D2
	Winkelen voor plezier	D3
E. Brengen/Ophalen	Kind(eren) naar school/opvang brengen/ophalen	E1
	Kind(eren) ergens anders heen brengen/ophalen	E2
	Gezinsleden of andere personen ergens heen brengen	E3
F. Sport	Wedstrijd kijken (niet op TV)	F1
	Gaan joggen	F2
	Buitensport beoefenen (bijv. voetbal, wielrennen, zwemmen, etc.)	F3
	Sport beoefenen in sporthal/gymzal	F4
	Fitness-centrum/aerobics-centrum bezoeken	F5
G. Overige georganiseerde activiteiten	Kerkbezoek (of andere levenbeschouwelijke bijeenkomsten)	G1
	Politiek activiteiten, bijeenkomsten	G2
	Club- of verenigingsactiviteiten (geen sport)	G3
H. Sociale contacten	Visite vrienden, familie	H1
	Vrienden, familie, kennisen bezoeken	H2
I. Vrije tijd buitenshuis	Uit eten gaan	I1
	Naar een café, bar, discotheek, etc.	I2
	Naar een bioscoop, schouwburg, theater, concert	I3
	Naar een museum, tentoonstelling	I4
	Naar een bibliotheek	I5
	Wandelen in the directe omgeving (ook hond uitlaten)	I6
	Wandelen in een park (ook hond uitlaten)	I7
	Wandelen in de natuur (ook hond uitlaten)	I8
	Recreatief fietsen	I9
	Toeren met de auto	I10
J. Wachten	Wachten	J1
K. Overigen (niet zijn opgenomen)		K...

Subject ID:


TECHNISCHE UNIVERSITEIT
PROF. DR. DORGELO LAAN
BUSSTATION
EINDHOVEN
BEURSGEBOUW
Philips Stadion
DORP
MATHILDE LAAN
EMMASINGEL
VEST
ST. CATHARINAKERK
STADHUIS
DAF-museum
KANAALDIJK
GELDROPSE WEG
STRATUMSE DIJK
DR. SCHAEPMAN LAAN
DEN

Appendix A2 Activity Questionnaire

ACTIVITY QUESTIONNAIRE

RESEARCH INTO PERSONAL ACTIVITY TRAVEL PATTERNS

August / September 2002

THANK YOU FOR YOUR COOPERATION

Instructions for Respondents

A. Introduction

In this research study conducted by the Urban Planning Group of TU/e, you will provide data about your travel schedule you have just completed. The period of the schedule has been selected to start from the time you were recruited to participate. Only the information starting from that time and location is required.

B. There are two parts to the research study. Your tasks include:

1. Virtual Travel

   In a simulated environment of Eindhoven, you will be able to perform virtual travel. It can be considered as a form of computer game. It is expected that the duration of this part of the study will take approximately no more than one hour.

2. Questionnaire

   The Questionnaire contains four sections:

   Part 1: Personal Particulars (Attachment 1)
   Part 2: Activity Record (Attachment 2)
   Part 3: Activity List (Attachment 3)
   Part 4: Route choice and mode on map (Attachment 4)

   You are requested to provide information about your activities that you have performed in the city and namely at locations within the period as stated in the Attachments.

   An “Activity List” (Attachment 3) is available to assist you in filling out your activity record.

Finally, you are requested to mark on the map (Attachment 4) the route you have taken to travel from one activity location to the next.and the transport mode used for your travel.

**C.	The following pertain to questions regarding your personal travel and activity pattern and are to be answered in Attachment 2.**

Question 1
What is the name of the street or the types of enterprise of your first activity and consecutive activity locations?

Question 2
By what mode of travel have you used?

For Questions 3,4 and 5, you may choose to give the time you took for the duration of the travel or the start and end times of your travel.

Question 3
At what time did you start your travel to an activity?

Question 4
At what time did you arrive at the location of your activity?

Question 5
What was the duration of the travel?

Question 6
What was the duration of the activity?

Question 7
What the the level of congestion on the way to your activity location?

Question 8
Who did you do this activity with?

Question 9
Was the activity planned in advance? If so, when did you planned it?

Attachment 1

Subject Identifications:
Start of Recording Location (Street/Parking/Shop):
Start of Recoding Time:
Starting Travel Mode:

Personal Particulars

1. Name	………………………………………………
2. Age	………………………………………………
3. Gender	❑ Male ❑ Female
4. Home Address	Street & House Nr…..………………………. Postcode…………………………………….. City………………………………………….…
5. How familiar are you with Eindhoven	❑ Good ❑ Fair ❑ Not at all
6. Frequency and purpose of visiting Eindhoven	…… times per month/year for shopping …… times per month/year for shopping …… times per month/year for work or business …… times per month/year for visitng family and friends
7. Highest Education Attained	❑ Primary ❑ Secondary ❑ Vocational/Polytechnic ❑ Tertiary/University ❑ Others
8. Occupation	………………………………………………..
9. Income Class	❑ No Income ❑ Up to € 5.000 ❑ €5.000 – € 10.000 ❑ €10.000 – 15.000 ❑ €15.000 – € 20.000 ❑ €20.000 – € 25.000 ❑ €25.000 – € 30.000 ❑ €30.000 - €35.000 ❑ Higher than €35.000
10. Do you possess a Driver's License	❑ Yes ❑ No
11. Do you have the use of a car?	❑ Yes ❑ No
12. Do you have the use of a motorcycle?	❑ Yes ❑ No

Subject Identification: Date:
Start of Recording Location (Street/Parking/Shop): Weather:
Start of Recoding Time:
Start Travel Mode:

Activity Records

Activity	1st [ ]	2nd [ ]	3rd [ ]
Location of Activity	Name of Street: …………………… Name of Enterprise: ……………………	Name of Street: …………………… Name of Enterprise: ……………………	Name of Street: …………………… Name of Enterprise: ……………………
Mode of travel to Activity Location?	❑ walk ❑ bike ❑ moped ❑ motorbike ❑ car ❑ bus ❑ taxi	❑ walk ❑ bike ❑ moped ❑ motorbike ❑ car ❑ bus ❑ taxi	❑ walk ❑ bike ❑ moped ❑ motorbike ❑ car ❑ bus ❑ taxi
Start of Travel Time to Activity Location	….. : …..(hh:mm)	….. : …..(hh:mm)	….. : …..(hh:mm)
End of Travel Time to Activity Location	….. : …..(hh:mm)	….. : …..(hh:mm)	….. : …..(hh:mm)
Time of travel	….. : …..(hh:mm)	….. : …..(hh:mm)	….. : …..(hh:mm)
Duration of Conduct of Activity	….. : …..(hh:mm)	….. : …..(hh:mm)	….. : …..(hh:mm)
Current Traffic Conditions On-route	❑ Not congested ❑ Lightly ❑ Medium ❑ Heavily ❑ I don't remember	❑ Not congested ❑ Lightly ❑ Medium ❑ Heavily ❑ I don't remember	❑ Not congested ❑ Lightly ❑ Medium ❑ Heavily ❑ I don't remember
With whom was this activity conducted?	❑ Alone ❑ Partner ❑ Children ( ) ❑ Other ( )	❑ Alone ❑ Partner ❑ Children ( ) ❑ Other ( )	❑ Alone ❑ Partner ❑ Children ( ) ❑ Other ( )
Was this activity planned in advanced?	❑ No, but was included because ❑ ________________ ❑ Yes, today ❑ Yes, yesterday ❑ Yes, >1 day ago ❑ Is regular/routine	❑ No, but was included because ❑ ________________ ❑ Yes, today ❑ Yes, yesterday ❑ Yes, >1 day ago ❑ Is regular/routine	❑ No, but was included because ❑ ________________ ❑ Yes, today ❑ Yes, yesterday ❑ Yes, >1 day ago ❑ Is regular/routine

Subject Identification: Date:
Start of Recording Location (Street/Parking/Shop): Weather:
Start of Recoding Time:
Start Travel Mode:

Activity Records

Activity	4th [ ]	5th[ ]	6th]
Location of Activity	Name of Street: …………………… Name of Enterprise: ……………………	Name of Street: …………………… Name of Enterprise: ……………………	Name of Street: …………………… Name of Enterprise: ……………………
Mode of travel to Activity Location?	❑ walk ❑ bike ❑ moped ❑ motorbike ❑ car ❑ bus ❑ taxi	❑ walk ❑ bike ❑ moped ❑ motorbike ❑ car ❑ bus ❑ taxi	❑ walk ❑ bike ❑ moped ❑ motorbike ❑ car ❑ bus ❑ taxi
Start of Travel Time to Activity Location	….. : …..(hh:mm)	….. : …..(hh:mm)	….. : …..(hh:mm)
End of Travel Time to Activity Location	….. : …..(hh:mm)	….. : …..(hh:mm)	….. : …..(hh:mm)
Time of travel	….. : …..(hh:mm)	….. : …..(hh:mm)	….. : …..(hh:mm)
Duration of Conduct of Activity	….. : …..(hh:mm)	….. : …..(hh:mm)	….. : …..(hh:mm)
Current Traffic Conditions On-route	❑ Not congested ❑ Lightly ❑ Medium ❑ Heavily ❑ I don't remember	❑ Not congested ❑ Lightly ❑ Medium ❑ Heavily ❑ I don't remember	❑ Not congested ❑ Lightly ❑ Medium ❑ Heavily ❑ I don't remember
With whom was this activity conducted?	❑ Alone ❑ Partner ❑ Children ( ) ❑ Other ( )	❑ Alone ❑ Partner ❑ Children ( ) ❑ Other ( )	❑ Alone ❑ Partner ❑ Children ( ) ❑ Other ( )
Was this activity planned in advanced?	❑ No, but was included because ❑ ________________ ❑ Yes, today ❑ Yes, yesterday ❑ Yes, >1 day ago ❑ Is regular/routine	❑ No, but was included because ❑ ________________ ❑ Yes, today ❑ Yes, yesterday ❑ Yes, >1 day ago ❑ Is regular/routine	❑ No, but was included because ❑ ________________ ❑ Yes, today ❑ Yes, yesterday ❑ Yes, >1 day ago ❑ Is regular/routine

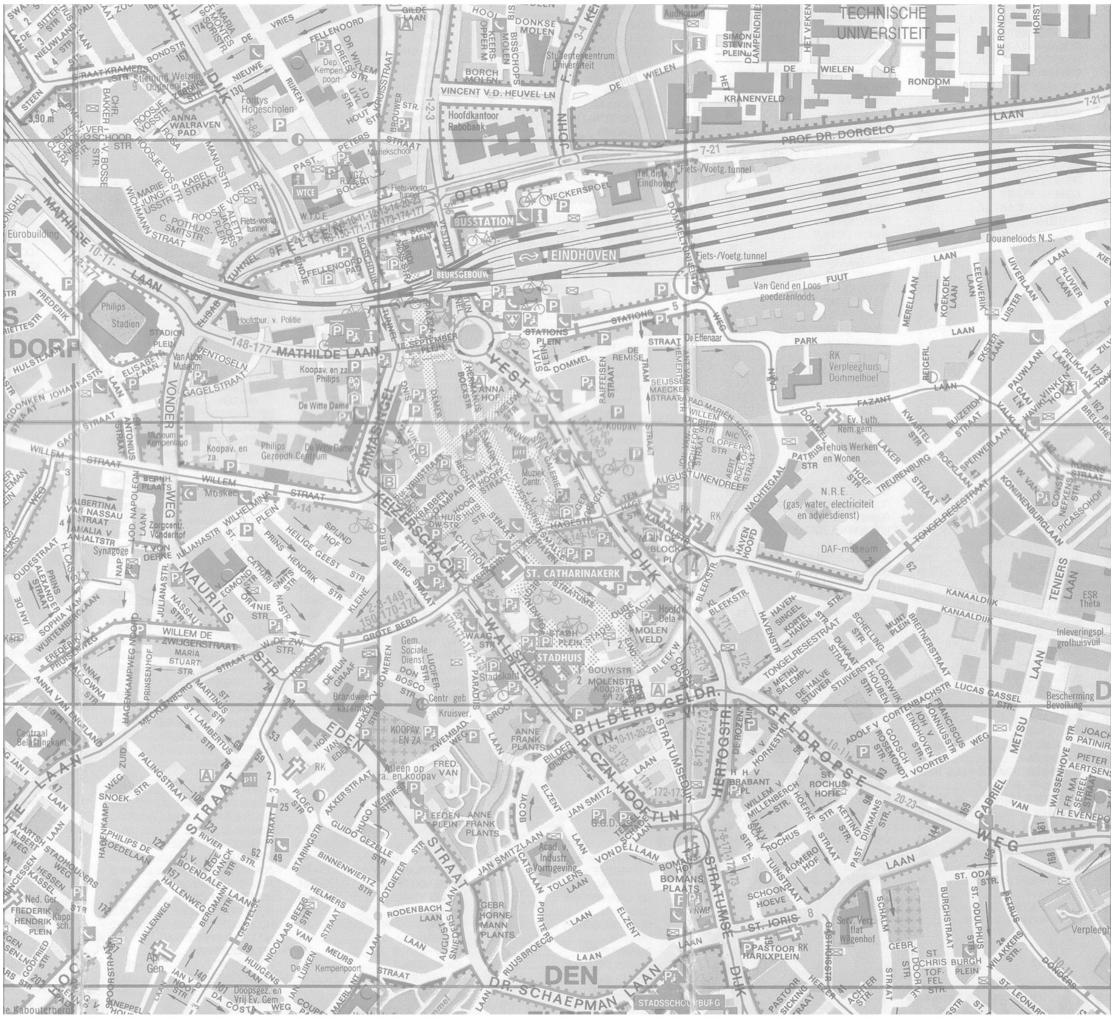
Attachment 3

Activity List (Out-of-home)

Category	Activity	Code
A. Work	Work out of home (including volunteer work)	A1
	Study/School out of home	A2
B. Business	Appointment and meetings	B1
C. Services	Personal services(travel bureau, hairdresser, bank, post-office, etc.	C1
	Other personal business (town-hall, attorney, etc.)	c2
	Medical Care (doctor, dentist, therapist, and other medical specialists)	C3
D. Shopping	Shopping for daily necessities (supermarket, greengrocer, butcher, etc.	D1
	Shopping for non-daily necessities	D2
	Shopping for pleasure / window shopping	D3
E. Bring/Fetch	To Bring/Collect children to/from school	E1
	To Bring/Collect children to/from somewhere else	E2
	To Bring/Collect family members or other persons to/from somewhere else	E3
F. Sport	Watch a game/match (not on TV)	F1
	Jogging	F2
	Outdoor Sports (e.g., football, hockey, swimming, etc.)	F3
	Indoor Sports (e.g., basketball, judo, fencing)	F4
	Visit to the Gymnasium/Fitness Centre	F5
G. Other Organized Activities	Church (or other religious meetings)	G1
	Political Activities or Meetings	G2
	Clubs or Associations (non-sport)	G3
H. Social Contact	Visit / receive friends, family	H1
	Meet friends / family	H2
I. Leisure out of home	Eating out	I1
	Café, bar, discothèque	I2
	Cinema, Theatre, Concert	I3
	Museum, Exhibition	I4
	Public Library	I5
	Walk in the neighbourhood (including taking dog for a walk)	I6
	Walk in a park (including taking dog for a walk)	I7
	Walk in the woods (including taking dog for a walk)	I8
	Cycling for recreation	I9
	Car tour	I10
J. Waiting	Waiting	K1
K. Others (Not in mentioned category)		K…

Attachment 4

Subject ID:



Appendix B1 Stereo Panoramic Interactive Navigation Tutorial (Nederlands)

Les: Een simpel reisverhaal creëren

Introductie

Deze lessen beschrijven hoe men

- Navigeert van punt naar punt
- Informatie toevoegt over de uitvoering van een activiteit
- De tijdsduur van de gebeurtenissen instelt
- De iconen gebruikt

Aan het eind van deze lessen heeft u een reisverhaal gemaakt die de activiteiten beschrijven die iemand heeft ondernomen. Na afronding van de lessen bent u in staat om uw eigen reisverhaal, gebaseerd op uw ervaringen, te maken.

Aan het begin van de lessen:

- Bevindt U zich aan de voorkant van het Hoofdgebouw van de TU/e
- De huidige tijd is 13:12.20 zoals u kunt zien op de klok (rechtsboven in de hoek)
- U heeft nog geen transportmiddel geselecteerd, standaardmode is te voet

Keuze van transport

Selecteer de huidige transport mode

1. Selecteer de huidige transport mode door op het icoon transport mode te drukken (vierde knop van links). Het icoon laat standaard de “loop”mode zien. Door de muis over het icoon te bewegen krijgt men een lijst van alle andere transport mogelijkheden.

2. Klik met de linker muisknop op het fietsicoon. Vanaf dit punt reist U per fiets. Dit geeft aan dat er een verandering van transport is van lopen naar fietsen.

Een verandering van transportmiddel kan ook betekenen dat U uw voertuig, welke u gebruikt heeft, heeft geparkeerd. Bijvoorbeeld: als u transportmiddel van fiets naar lopen veranderd geeft dit aan dat u de fiets heeft geparkeerd terwijl u zich op de locatie bevindt waar de verandering is geeffectueerd.

Navigeren van de route

Het is mogelijk door het volgen van de link te reizen. Een pad is gemaakt door onderlinge verbindingen.

Knooppunten zijn op de kruisingen van de straten

Een *mogelijke* link om naar een richting te reizen wordt aangegeven door middel van veranderen van kruisje naar pijltje van de muisaanwijzer.

Oriëntatie tips

U kunt op het radar icoon (eerste icoon linksboven) de route die u genomen heeft zien. Dit pad wordt door aangeduid door een amberkleurige lijn. Alle andere mogelijkheden op dit kruispunt worden door groene lijnen aangeduid.

3. Om rond te kijken in de omgeving klikt u eenmaal op de linkse muisknop en houdt u de muis ingedrukt. Door de muis te bewegen van links naar rechts en boven naar onder kunt u de omgeving verkennen.

Selecteren van de snelheid

4. Op de snelheid icoon (derde van links linksboven), klik met linkermuisknop op nummer 5. The geeft aan hoe snel (5 km per uur) u zult reizen in de geselecteerd transport mode. Als u die niet heeft geselecteerd op dit punt zal een nominale snelheid worden gehanteerd.

Een link volgen

5. Kijk links door middel van het ingedrukt houden van de linkermuisknop en beweeg naar links. Beweeg de muis zodanig dat u kijkt naar de dichtstbijzijnde uitgang 25 meter vanaf het punt waar U momenteel bent (Den Dolech). U ziet de muisaanwijzer veranderen in een pijl.

6. Klik op de **rechtermuis knop**. De tijdsduur en afstand van huidige punt naar het volgende punt zal worden aangeduid met een tijdsbalk.

Het pad traceren

7. Blijf de volgende 6 kruispunten rechtdoor gaan over de KENNEDYLAAN, JOHN F. tot u de MONTMOGERY VELDM. Nadert.

8. Steek niet over maar sla links af in de richting van het centrum.

9. Volg het fietspad aan de linker kant van de weg, voorbij de VESTDIJKTUNNEL richting STATIONSPLEIN

10. Kijk richting BIJENKORF op de rotonde en steek over naar het 18 SEPTEMBERPLEIN.

11. Ga door naar de EMMASINGEL en MATHILDELAAN.

12. Sla linksaf op het kruispunt en ga richting EMMASINGEL. U arriveert op uw bestemming. De Witte Dame bevindt zich aan uw rechterzijde.

Tijd

De huidige tijd staat aangegeven op de klok (rechter bovenhoek)

U hoeft de tijd niet tot op de seconde nauwkeurig in te vullen. Een schatting binnen de limiet van 5 minuten is voldoende.

De berekening van de verstreken reistijd is gebaseerd op de tijd vanaf het startpunt van de eerste kruising tot de aankomsttijd op plaats van bestemming met de snelheid van het huidige transport middel.

Instellen van de **definitieve** huidige tijd

13. De huidige tijd is 13:18.20. Klik op de klok.

14. Gebruik de pijltjes om de tijd vooruit te zetten tot 13 uur 30 minuten. U moet de tijd op de klok aanpassen als de aangegeven tijd niet overeenkomt met de tijd die verstreken is.

Een activiteit uitvoeren

15. Kijk in de richting was de activiteit is uitgevoerd (Witte Dame). Positioneer de locatie in de buurt van het kruisteken in het midden van het beeldscherm.

16. Klik op de activiteitenknop  (tweede van linksonder). In het dialoogvenster kunt U alle gevraagde informatie invoeren.

    Selecteer het type activiteit

    H Vrije tijd buitenshuis (linker kolom van het window)

    4 Museum, tentoonstellingen (rechter kolom van het window)

17. Vink ‘Anders’ aan bij ‘Met wie heft u deze activiteit gedaan?’

18. Vink de knop ‘Meer dan een dag geleden gepland’ aan.

19. Voer de eindtijd van de activiteit in als 15:05.00. Gebruik de reset knop om de tijd te herstellen naar het moment van invoeren.

20. Klik op OK knop om het window te sluiten.

Bedenk dat er aangenomen wordt dat de fiets is geparkeerd op de locatie waar de activiteit is uitgevoerd daar er geen verandering van vervoermiddel is aangegeven.

Controleer uw informatie

21. Klik eenmaal op . Een beschrijving van de gebeurtenissen die u heeft doorlopen in de virtuele omgeving wordt getoond in een pop-up window ter controle.

22. Klik nogmaals op het icoon om het window te sluiten. Het is een goede oefening wanneer u dit meerdere malen doet.

23. Ga de weg terug naar het punt waarvan u gestart bent. Het is mogelijk om een andere route nemen.

Aanbrengen van correcties

Als u zich realiseert dat sommige data niet correct is of dat de volgorde van gebeurtenissen niet is zoals u bedoeld had dan kunt u terug door op de terugknop te klikken. .

De vooruitknop  is ook ter beschikking.
Als u het punt bereikt heeft waar de correctie heeft plaatsgevonden kunt u met de standaard procedure doorgaan en hoeft u de vooruitknop niet te gebruiken.

Appendix B2 Stereo Panoramic Interactive Navigation Tutorial (English)

Tutorial: Creating a Simple Travelogue

Introduction

This tutorial describes how to

- Navigate from point to point
- Enter information about the conduct of activities
- Set the times of the duration of events
- Use the Icons

By the end of this tutorial you would have created a travelogue that describes the activities that someone had previously undertaken. After the tutorial you will have the opportunity to create your own travelogue based on your own experience.

Before you begin the tutorial, put on the stereographic glasses to see the environment in 3D.

At the start of the tutorial,

- you will be located in the front the main building of the TU/e,
- the current time is 13:12.20 as shown on the clock (top right corner),
- you have not selected any transport mode, default mode is walk.

Choice of transport

<u>Select the current transport mode</u>

1. Select the current transport the mode icon (fourth from the left). The icon initially shows the ***walk*** mode . By putting the mouse over it a list of all other available transport modes will be displayed in a drop down list.

2. Left click on the bicycle icon . You will proceed from this point on your bike. This indicates that there was a change in the travel mode from walking to cycling.

A change in the transport can also indicate that you have parked a vehicle that you were previously using. For example, if you change the transport mode from “bike” to “walk”, this implies that you have parked the bike while you were at the location when you effected the change.

Navigating the route

- It is possible to travel the path of the route by following a link. A path is made up of inter-connecting nodes.

- o Nodes are at intersections of streets.

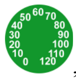
- o A ***possible*** link along a street is indicated when the mouse placed in the direction of the path changes from a “cross-hair” to an ***arrow***.

Hint: Orientation.
You should see on the radar icon (first from top left) the path you have taken indicated in ‘amber’ while all other possible paths at this node are indicated in ‘green’.

3. To look around in the environment, click the left mouse button, hold and move the mouse to the left, or to the right (or up, or down).

4. Release the left mouse button to stop looking around.

Select the speed of travel

5. On the speed icon (third from the top left) , left click on the number “5”. This indicates how fast (@ 5km/h) you will travel on the selected travel mode. If you did not select the speed at this point, a nominal speed is automatically used.

<u>Follow a link.</u>

6. Look left by holding down left mouse and moving left. Put the mouse pointing towards the nearest exit 25 metres from where you are (DEN DOLECH). You will see it change to an arrow. Click on the ***right mouse button***. A progress bar will appear indicating the time and distance taken to move from current node to the new node.

Tracing the path

7. Keep going straight ahead for the next six nodes crossing the KENNEDYLAAN, JOHN F. until the approach to MONTMOGERY VELDM.

8. Do not cross the street. Turn left in the direction towards the City Centre.

9. Follow the bike path on the left side of the road, past the VESTDIJKTUNNEL and towards STATIONSPLEIN /

10. At the roundabout, look right towards BIJENKORF and cross over to the SEPTEMBERPLEIN, 18.

11. Continue ahead towards the crossing of EMMASINGEL and MATHILDELAAN.

12. At the crossing, turn left and follow the link on EMMASINGEL. You will arrive at the intended destination of the Witte Dame Building on the right hand side.

Time

- o The current time is indicated on the clock (top right corner).

- o Always check the time before you perform an action.

- o When entering time, it is not necessary to be absolutely accurate to the seconds. Just a close estimate to somewhere within the limits of +/- 5 minutes will suffice.

- o Elapsed time for travel is calculated based on the time from the start of path from first node to the time of arrival end of path at second node depending on the speed of the current transport mode.

Setting a **definitive** current time

13. Clock shows 13:18.20. Click on the clock.

14. Using the up buttons, increase the time to "13" hours and "30" minutes. You should perform a time update when the indicated time on the clock does not show the time that you knew had elapsed.

Conducting an activity

15. Look towards where an activity was conducted (the Witte Dame building). and position the location in the vicinity of the cross-hair at the center of the screen.

16. Click on the activity button  (second from bottom left). In the dialog box, enter all the information as requested.

Select Activity Type

H Leisure out of home (left column of window)

4 Museum, Exhibition (right column of window)

17. Check the box 'Other' for 'With whom was the activity conducted?'

18. Select the button 'Planned more than one day ago'.

19. Enter the endtime of the activity as 15:05.00. The reset button will restore the time to before any entries were made.

20. Click on OK button to close the window.

Note that the assumption will be made that the bicycle was parked at the location of where the activity was conducted since no change of mode was indicated.

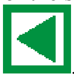
Check Your Information

21. Click once on . A description of the events you have performed in the virtual environment is displayed in a pop-up window for your verification.

22. Click on icon again to close the window. It is good practice to do this regularly.

23. Make the return trip back to where you started. It is possible to choose a different route.

Making Corrections

If you realized that some data is not correct or the sequence of events is not as you intended, you can go back by clicking on the Back button . A Forward button  is also provided to complement the scrolling of your travelogue back and forth.

Once you reached the point where the correction has been made, you should proceed in the standard way and not use the forward button.

Author Index

Subject Index

V

W

Samenvatting

Dit proefschrift presenteert de resultaten van een onderzoek naar de betrouwbaarheid en geldigheid van interactieve computer experimenten, gebaseerd op virtual reality systemen, voor het meten van activiteitenpatronen. Het project komt voort uit de wens meer inzicht te krijgen in de mogelijkheden van deze nieuwe technologie voor het verzamelen van gegevens over activiteitenpatronen, zoals die in de literatuur is geuit. In het verleden werden virtual reality systemen vooral gebruikt voor het visualiseren van omgevingen. Dit project heeft tot doel de potentie van VR systemen te verkennen om gegevens te verzamelen over het gedrag van gebruikers in interactieve computer experimenten. Een belangrijk aspect hiervan vormt het vastleggen van reeksen van activiteiten en de daaraan gerelateerde routekeuzes. Dit project, gesubsidieerd door NWO, concentreert zich daarom op de studie naar vertoond gedrag van individuen in een virtuele omgeving.

Het doel van deze studie was drieledig: (i) specificeren van een conceptueel model voor het uitvoeren van interactieve computer experimenten in een virtuele omgeving, (ii) het ontwerpen en ontwikkelen van een virtual reality systeem en (iii) het bestuderen van de geldigheid en betrouwbaarheid van dit systeem in vergelijking met een traditionele “paper and pencil (PAPI)” methode.

De basisveronderstelling is dat een virtual reality systeem kan leiden tot een hogere graad van betrokkenheid. Bovendien kan de visuele representatie van de omgeving

een positieve invloed hebben op het herinneren van bepaalde gebeurtenissen, hetgeen kan resulteren in meer geldige en betrouwbare metingen.

Teneinde deze veronderstellingen te toetsen is eerst een VR systeem ontwikkeld. Dit unieke systeem biedt gebruikers de gelegenheid door middel van stereo panorama's zich te verplaatsen in een stedelijke omgeving met als doel het oproepen van een gevoel van aanwezigheid – de illusie van 'daar te zijn'. Dit creëert een verhoogd niveau van geheugen en herkenning, waardoor het terughalen van informatie wordt gestimuleerd. Om te bevorderen dat gebruikers zich konden concentreren op het uitvoeren van de experimentele taak, en niet hun aandacht nodig hadden om het systeem goed te kunnen bedienen, is erg veel aandacht besteed aan een gebruikersvriendelijke interface: het complexe systeem kan volledig bediend worden door het klikken van een muis.

Het VR systeem werd gebruikt voor het meten van activiteitenpatronen van voetgangers in het stadscentrum van Eindhoven. De keuze voor dit specifiek onderwerp werd met name ingegeven door het feit dat het VR model en de experimentele taak hierdoor relatief beperkt bleven. Respondenten werden aan het begin van hun bezoek aan de binnenstad gevraagd of zij bereid waren mee te werken aan een onderzoek.. Degenen, die bereid waren dat te doen, werden onopvallend gevolgd tijdens hun bezoek aan de binnenstad. Hun gedrag werden door observatoren vastgelegd en deze metingen werden gezien als het werkelijk, vertoond gedrag. Respondenten werd gevraagd, aan het eind van een bezoek van het stadscentrum, hun activiteiten te herhalen binnen de virtuele omgeving. Ze werden ook gevraagd hun activiteiten te rapporteren door middel van een PAPI-instrument. De steekproef omvatte 57 respondenten.

De volgende analyses werden uitgevoerd: (i) Een statistische analyse van de mate van overeenkomst tussen de metingen volgens PAPI en het vertoond gedrag, (ii) een statistische analyse van de mate van overeenkomst tussen de metingen door middel van het VR systeem en het vertoond gedrag, en (iii) een vergelijking van de uitkomsten van (i) en (ii). Deze analyses werden uitgevoerd voor de structurele facetten van de activiteitenpatronen (aantal stops, aantal verschillende activiteiten, etc), de tijdduur van de verschillende activiteiten en de reistijd tussen stops, en de routekeuze. Regressie-analyses en t-toetsen werden uitgevoerd voor de meeste analyses. Alleen voor de vergelijking van het meten van routes werd een sequence alignment methode (Levenshtein afstand) toegepast.

De resultaten van de analyses gaven aan dat het ontwikkelde virtual reality systeem meer geldige en betrouwbare antwoorden geeft voor de structurele facetten van activiteitenpatronen dan PAPI. Blijkbaar heeft het ontwikkelde VR systeem een positieve invloed gehad op de herinnering van activiteiten. Daarentegen leidde PAPI tot betere resultaten voor de meting van de tijdsduur van de activiteiten en de gevolgde routes. Dit suggereert dat een VR systeem minder geschikt is voor het meten van tijdsduur en dat de typische representatie van locale omgevingen het herinneren van routes bemoeilijkt, althans voor het ontwikkelde VR systeem. De algemene datakwaliteit was beter voor het VR systeem.

Curriculum Vitae

Amy A. W. Tan was born and raised in the city country Singapore. She received her university education in the National University, graduating with a Bachelor of Civil Engineering. For her further education, she completed a postgraduate study in Architectural Design and Computing (Masters of Science with Distinction) at the University of East London, United Kingdom. The pursuit of her research interest in man-machine interaction led her to The Netherlands to be involved with the Urban Planning Group at the Eindhoven University of Technology. Her current preoccupation lies in the diverse applications of virtual reality technologies to areas ranging from the everyday work and social context to specialized domains of engineering and industry.