EXPLORING THE POSSIBILITIES OF CONJOINT MEASUREMENT AS A DECISION-MAKING TOOL FOR VIRTUAL WAYFINDING ENVIRONMENTS

J. DIJKSTRA, H. J. P. TIMMERMANS

Eindhoven University of Technology,
Faculty of Architecture, Building and Planning
P.O. Box 513, 5600 MB Eindhoven, The Netherlands

Abstract. Virtual reality systems may have a lot to offer in architecture and urban planning when visual and active environments may have a dramatic impact on individual preferences and choice behavior. Conjoint analysis involves the use of designed hypothetical choice situations to measure individuals’ preferences and predict their choice in new situations. Conjoint experiments involve the design and analysis of hypothetical decision tasks. Alternatives are described by their main features, called attributes. Multiple hypothetical alternatives, called product profiles, are generated and presented to respondents, who are requested to express their degree of preference for these profiles or choose between these profiles. Conjoint experiments have become a popular tool to model individual preferences and decision-making in a variety of research areas. Most studies of conjoint analysis have involved a verbal description of product profiles, although some studies have used a pictorial presentation of product profiles. Virtual reality systems offer the potential of moving the response format beyond these traditional response modes. This paper describes a particular aspect of an ongoing research project which aims to develop a virtual reality based system for conjoint analysis. The principles underlying the system will be illustrated by a simple example of wayfinding in a virtual environment.

1. Introduction

Conjoint analysis is a generic term coined by Green and Srinivasan (1978) to refer to a number of paradigms in psychology, economics and marketing that are concerned with the quantitative description of consumer preferences or value trade-offs (Timmermans, 1984; Louviere, 1988). Conjoint analysis sometimes referred to as stated preference modeling involves the use of hypothetical choice situations generated according to the principles underlying the design of statistical experiments to measure individuals’ preferences, examine consumer behavior and/or predict their choice in new situations (Oppewal, 1995). In a conjoint study, a researcher
i selects the characteristics (attributes) that are assumed to influence the choice behavior of interest,
ii classifies these attributes into numerical or categorical levels, and
iii combines these attribute levels into profiles according to some statistical design.
Implicitly it is assumed that choice alternatives can be viewed as a set of attributes. Respondents are assumed to trade-off the attributes of interest according to some algebraic rule to arrive at an overall preference. In order to estimate the preference function, a set of profiles designed according some experimental design is presented to respondents who are requested to express their overall preference. These profiles are typically represented verbally. While a verbal description might be a valid means of describing profiles in many contexts, one could argue that some attributes are better represented visually. A framework for a virtual reality based system of conjoint analysis has been outlined in Dijkstra et al (1996). Such a system is of particular interest when subjects have to experience the context of choice and/or the attributes describing the choice alternatives. This paper takes this argument one step further and explores the possibilities of using this framework as a decision-making tool for virtual wayfinding environments.

The paper is organized as follows. First we will discuss some basic principles of conjoint analysis and virtual reality. Then, in section 3, we will discuss the potential of the integration of conjoint measurement and virtual reality. This is followed by a discussion of concepts of wayfinding. Next, aspects of wayfinding will be used in the illustration. Finally, we point at some avenues of future research.

2. Basic Concepts

2.1. CONJOINT MEASUREMENT

Conjoint analysis is a family of related techniques for measuring consumer preferences or choice behavior. It helps to understand why consumers prefer or choose certain products (or services or new conditions). The application of conjoint analysis technique implies the study of the joint effects of multiple product attributes on product preferences or product choice. The researched products (or services or new conditions) are described in terms of product profiles. Each profile is a combination of attribute levels for the selected attributes.

![Figure 1. Relationship among a profile, attributes and levels](source-url)
Conjoint analysis has two major objectives:
1. to determine the contributions of predictor variables (attribute levels) to consumer overall preferences,
2. to establish a valid model of consumer judgments useful in predicting the consumer acceptance of any combination of attributes, even those not originally evaluated by consumers (Hair et al., 1995).

In order to achieve these objectives, coefficients called ‘utilities’ (or part-worths) are estimated for the various attribute levels making up the alternative of interest by decomposing measured preferences for product profiles into these part-worth utilities according to some a priori defined combination rule that specifies how subjects are assumed to integrate those separate part-worth utilities to arrive at an overall preference or choice.

**Attribute level utility (part-worth):** a numerical expression of the value that consumers place on each level of an attribute.

**Profile utility:** overall utility of a profile calculated by summing all utilities of attribute levels defined in that profile. Hence preferences toward different profiles can be compared based on their profiles.

Simply: \[ U = \sum_{j=1}^{M} x_j \]

whereby: \[ U = \text{overall utility or “worth” of the profile alternative} \]
\[ x_j = \text{“part worth” of the } j\text{-th level of the } x\text{-th attribute} \]
\[ M = \text{number of attributes} \]

*Figure 2. Preference measurement in conjoint analysis*

The estimation of these part-worth utilities is based on experimental designs. Profile construction in conjoint analysis involves determining which attributes to present to subjects, and how to present these attributes. First, the attributes of products or services are defined. Next, the specific levels of each
attribute are specified. The chosen attributes and their levels should be realistic and relevant to the problem. Also, the ultimate definition of attributes and their levels will be influenced by the possibilities of constructing a suitable experimental design. That is, the design should satisfy the necessary and sufficient conditions, required to estimate the assumed preference or choice model that describes the way in which individuals are assumed to arrive at some choice or overall preference.

Conjoint experiments thus require subjects to express their preference for various experimentally designed, hypothetical alternatives. These hypothetical alternatives are descriptions of potential real-world alternatives in terms of their most relevant attributes. Two or more fixed levels are defined for each attribute and these are combined to create different profiles. For example, hypothetical shopping centers are described in terms of number of stores, distance from home, and parking conveniences as used by Timmermans et al. (1984).

<table>
<thead>
<tr>
<th>Number of shops:</th>
<th>small</th>
<th>[medium; large]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Travel time:</td>
<td>15 minutes</td>
<td>[30; 45]</td>
</tr>
<tr>
<td>Parking search time:</td>
<td>4 minutes</td>
<td>[12; 20]</td>
</tr>
</tbody>
</table>

Figure 3. Profile of a hypothetical shopping centre, as used by Timmermans et al. The right-hand column displays other possible levels to define alternative profiles.

Full profile descriptions are an attempt to represent real world decision alternatives in a realistic manner. Respondents are invited to express their preference for the experimentally varied profiles by rating or ranking these in terms of overall preferences. Alternatively, respondents may be asked to choose the profile they like best. In the latter case, a choice set design needs to be constructed. Because the full factorial design expands the number of profiles in an exponential fashion, the number of factors and levels considered in early studies were small. For example, six attributes, each with three levels produce $3^6 = 729$ possible combinations. The evaluation of all these possible combinations is an unmanageable task. Fortunately, the data collection can be greatly reduced by using fractional factorial design techniques (Montgomery, 1991). The use of fractional designs implies that the researcher often assumes that only main effects are estimated. In that example, the use of a fractional factorial design reduces the 729 possible profiles to only 18 profiles. Therefore an experimental design is defined by an optimal subset of profiles of a fractional factorial design, which can be presented to subjects without negatively influencing responses in terms of boredom or fatigue.
2.2. VIRTUAL REALITY
VR is a natural extension from 3D modeling and simulation. The additional realism conveyed through real-time interaction, stereoscopic visualization and the sensory ‘immersion’ in the illusory world provides designers with new powers of expression on the one hand and the means to compose new spatial experiences on the other. What distinguishes VR is the crucial role played by the user. That is, the user has an active involvement and is not a passive observer. The user becomes an essential ‘participant’ in the virtual environment with unlimited freedom to explore, control and change it. The only limits are those set by the designers of the virtual environment.

In architectural design and real estate simulations, it is interesting to get as realistic as possible impressions of a designed model by means of virtual reality. Besides, consideration can be given to modeling autonomous objects and to the simulation of operations on objects. The visionary design studio embedded in a VR environment is an example of a vision of a new design environment, equipped with a modeling tool that allows intuitive and interactive modification of intelligent objects (Engeli and Kurmann, 1996).

Another research and application area for VR is in new product research or services. Advances in VR techniques now enable consumers to be immersed in new environments and experience new product or services. This aspect is of interest to get better insight into consumer behavior and support product testing in its most general meaning.

3. Integration of Conjoint Measurement and Virtual Reality
3.1. STRATEGY
Most studies of conjoint analysis involve verbal descriptions of product profiles. In recent years, some studies have been conducted with a pictorial presentation of product profiles. Klabbers et al (1996) propose a multimedia engine for stated choice and preference experiments. This engine enables researchers to use varying presentation formats (textual, pictorial, auditory, presentations and combinations), thereby measuring the influence of the presentation format. Pictorial presentation of attributes can lead to more reliable and valid measurements of respondent utilities for the presented product or services. To get a better insight into consumer behavior, it is desirable to improve realism of the hypothetical situation to ensure that the respondent is making a ‘real’ decision. In this research project, the focus is on profiles presented by a virtual reality presentation format, thereby emphasizing yet other aspects of decision-making compared to multimedia engines.
The ultimate objective of the research project is to investigate and develop possibilities of a VR-DIS (Virtual Reality - Distributed Interactive Simulations) environment for those cases where choice behavior and decision-making processes of consumers may be of importance. This is based on the idea that a VR-presentation of a design is not only a matter of simulation and visualization, but virtual reality research could be a key to a mechanism for measuring responses to particular design characteristics. One means of measurement could be to have subjects choose between profiles by exploring the building features in the virtual environment. Taking (prospective) users of a building into account, the CA&VR concept could be a decision-making tool in choosing among particular design variant characteristics. The virtual wayfinding illustration is a simple try-out of a conjoint experiment.

3.2. SYSTEM APPROACH

![Diagram of VR-DIS Environment]

*Figure 4. CA&VR system components*
The scheme before is derived from a more extensive scheme given in Dijkstra et al (1996). The CA&VR (Conjoint Analysis & Virtual Reality) concept is situated in the ‘Virtual Reality - Distributed Interactive Simulations’ environment, which can be used in various decision support processes. In the CA&VR concept, virtual reality depicts profiles in a three-dimensional environment and allows respondents to interact with profile attribute levels. A profile consists of a virtual environment model and dynamic objects model representing the attributes with their levels. Both the environment model and objects model can be designed by 3-D graphical and virtual reality-development software. In the CA&VR concept, the generated profile alternatives will be subject of the examination in a conjoint experiment by means of the simulating device which is called ‘profile simulation system’. The ‘data analyzer’ part concerns the decision part of the CA&VR concept and includes the analysis of the performances of the measurements.

4. Wayfinding
4.1. CONCEPTS
Most settings are laid out in a plan people can relate to and which allows them to determine their location within the setting, determine their destination within that setting, and form a plan of action that will take them from their present location to their desired destination. The representation people have of their surrounding environment is a psychological concept that underlies the notion of spatial orientation. This is called a cognitive map, which is an overall mental image of the spaces and the layout of a setting. Wayfinding concerns the spatial organization of the setting, the circulation system and architectural as well as graphic communication. It can be described as all perceptual, cognitive, and decision-making processes necessary to find one’s way, that is as a mental and physical act of reaching destinations (Arthur and Passini, 1992). The process of reaching a destination is best defined as spatial problem solving, comprising the interrelated processes of decision-making (make a plan of action) and decision execution (transform the plan of action into appropriate behavior). Besides the spatial problem solving aspect, there is also the architectural and graphic communication aspect of wayfinding. The spatial organization of a setting and the circulation system determine the nature of wayfinding problems. Environmental communication provides the information necessary to solve wayfinding problems. In terms of wayfinding communication, designers have to respond to three major questions: what information should be presented, where and in what form (Passini, 1996). Therefore, the design part provides information, identified by three aspects:
content of information location of information form of information

In the virtual wayfinding illustration the emphasis is on the graphic components.

4.2. VIRTUAL WAYFINDING

People tend to feel disoriented when they cannot situate themselves within a spatial representation and when, at the same time, they don’t have or can’t develop a plan to reach their destination. The decision to find one’s way can only be made by receiving adequate information through perception, cognition and exploration. Wayfinding difficulties can be solved by developing signs. Therefore, we will focus on the aspect of graphic communication which often is of crucial importance in facility management.

In virtual wayfinding, the visual environment will be simulated and people are located at a virtual setting in this environment. They find their way from the present location to a desired destination by making a walk-through in the virtual environment. During virtual wayfinding, people will select that information which is relevant to their task. Information, based on the three aspects of information mentioned before, will be presented as different virtual design objects in the virtual environment.

5. The Virtual Wayfinding Illustration

Wayfinding is part, and an important part, of architectural design (Arthur and Passini, 1992). Still, graphic communication may at least partially compensate for possible flaws in architectural design. Therefore, we will focus on this aspect which often is of crucial importance in facility management. In the illustration, only the design part of wayfinding, especially graphic communication as part of the environmental communication will be considered. Generally speaking, graphic communication includes sign, maps, directories and good sign-posting. For example, we could emphasize those things that people need in information settings, such as:

◊ information about the settings (the way it is organized)
◊ information directing them to their location
◊ information identifying the destination on their arrival.

In our illustration, we will focus on information directing people to the way out. This will be realized by graphic communication on exit-signs. How to test exit-signs for their suitability, is the underlying idea. Besides the aesthetic aspect we could measure, we will also have a mechanism to measure the effectiveness of exit-signs. In the conjoint analysis subject we design an experiment with three attributes. Each of these attributes has two levels.
Together, the number of attributes and their associated levels comprise the experimental design specifications in the illustration.

<table>
<thead>
<tr>
<th>Attribute</th>
<th>Level</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>◊ Directional Exit-</td>
<td>⇒ fixed at wall, column</td>
<td>Guides people along</td>
</tr>
<tr>
<td>sign Location</td>
<td>⇒ fixed at ceiling</td>
<td>exit-route to exit</td>
</tr>
<tr>
<td>◊ Directional Exit-</td>
<td>⇒ Symbol sign I</td>
<td>Guides people along</td>
</tr>
<tr>
<td>sign Type</td>
<td>⇒ Symbol sign II</td>
<td>exit-route to exit</td>
</tr>
<tr>
<td>◊ Exit Identification</td>
<td>⇒ Exit-sign look I</td>
<td>Information provided</td>
</tr>
<tr>
<td></td>
<td>⇒ Exit-sign look II</td>
<td>at exit</td>
</tr>
</tbody>
</table>

Figure 5. Experimental design specifications

The scenario of the virtual wayfinding illustration implies the walk-through of an individual through a building, going to a destined meeting-room. In a fire drill simulation, during a smoke production, the individual should find his way from that present location to the exit within a certain time-period. The individual selects information from the available indications for finding the way-out (profile alternative 1). After this, the individual will be placed back into the meeting-room. After a new fire drill simulation, he finds the way-out again. Hereby, the individual selects information from altered indications (profile alternative 2). After the simulation, the individual will be requested to choose between these profile alternatives.

6. Discussion

In this paper we have advocated the development of a virtual reality-based system for conjoint measurement. Such a system should allow a better representation of attributes, thereby hopefully also increasing the reliability of the measurement. However, in addition to the graphics aspect, virtual reality systems offer the potential of simulation, taking conjoint analysis into a completely new direction. Subjects can actively search for attribute information, change attribute levels, extract information and move through virtual environments.

To illustrate this potential, we have developed a simple example of wayfinding. The reader might wonder about the relationship between the theory that we presented and this example. This is correct. Traditionally, conjoint analysis has been developed for measuring preferences, using either ranking or rating data. All subsequent steps are consistent with this data format. Later on, model and design strategies have been developed for choice data. Strictly
speaking, our wayfinding example does not follow either of these response format. We, therefore, plan to extend the conventional statistical basis of the system in the near future. In fact, developing appropriate theoretical and statistical formulas and perhaps design strategies, represents a challenge for the unique opportunities that virtual reality systems potentially offer. Such breakthroughs requires original and fundamental research efforts. In the meantime, however, we feel that we have demonstrated the technical potential of virtual reality systems in interactively measuring consumer response to new designs, products or services.

References