Extending the engineering trade-off analysis by integrating user preferences in conjoint analysis

Sylvia Kowalewski [a,*], Katrin Arning [a], Andreas Minwegen [b], Martina Ziefle [a], Gerd Ascheid [b]

[a] Human Computer Interaction Center (HCI-C), RWTH Aachen University, Germany
[b] Institute for Communication Technologies and Embedded Systems (ICE), RWTH Aachen University, Germany

ARTICLE INFO

ABSTRACT

The ongoing technical improvements in architecture design with improved features of mobile or smartphones do not automatically guarantee user acceptance, because technical and commercial aspects primarily drive the development of mobile communication systems and devices. Especially in early stages of technology development, user preferences and values are not adequately considered, which might even have a negative impact on acceptance issues. The aim of this study was the implementation of a quantified understanding of user needs in terms of values into the system design process of cell-phone processors. Moreover, we aimed for an extension of the engineering's trade-off analysis by using conjoint analysis in order to investigate trade-offs between specific device characteristics. Finally, our aim was the evaluation of empirically based user-oriented research methods.

Results of the first study revealed that battery life, speech quality, signal quality and data-transmission rate are the most important device characteristics. Results from conjoint analysis indicated a clear trade-off between battery life and the three other characteristics. Moreover, this research demonstrated that technology acceptance research benefits considerably from an interdisciplinary and multi-method approach. Besides, implementing the users' preferences into early stages of the product development process offers several advantages concerning effectiveness as well as economic aspects of development.

© 2012 Elsevier Ltd. All rights reserved.

1. Introduction

FACING the continuous improvement and growth of mobile phone networks, the demand for technical developments in the area of mobile devices rises as well. Since mobile internet is accessible via mobile or smartphone, a multitude of services and applications has been developed and is used by a growing number of users (Cisco visual networking index, 2012). Technical improvements and changing user demands require a higher performance of mobile devices, which, in turn, require new and more powerful system architecture designs. Additionally, short technical life cycles and growing market pressure demand fast and customer tailored solutions.

There are many options to improve today's mobile systems. One of the main optimization targets in mobile system design is throughput, e.g. Universal Mobile Telecommunications System (UMTS) towards UMTS LTE (Long Term Evolution). Furthermore, system designers can choose algorithms for implementation that enhance the connection stability in certain environments (e.g. high velocity). If, for example, a mobile phone user is in an area with weak radio signals or he is travelling with high velocity, algorithms could improve the connection stability. On the other hand, such algorithms increase the computational load of the system, which directly leads to higher energy dissipation. This has to be taken into account during the system design process.

2. Background and theory

2.1. System design process

The typical system design process starts with the design phase, where requirements or characteristics are specified, which are supposed to be implemented in the novel or improved product (Fig. 1) (Blanchard & Fabrycky, 2006). For processors of cellular phones the specification is usually focused on application and cost, whereas design cost and power consumption are the biggest challenges for chip designers. While a design option may be used to increase performance, it usually comes at an energy cost or even in terms of increased chip size (higher production costs). For example, high throughput and low energy dissipation are contradicting optimization targets (Fig. 2). The system designer, therefore, has to select the technical parameters to focus on and, in a second step, the task of the designer is to find a solution that best achieves the design goals.

In general, items such as cost, speed and flexibility, as well as power and optimization, all have to be considered. In addition, be-

---

* Corresponding author. Tel.: +49 241 8025501; fax: +49 241 8022493.
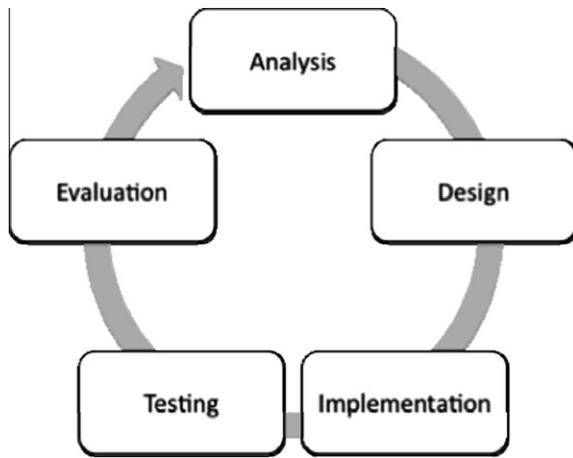 *E-mail address:* kowalewski@comm.rwth-aachen.de (S. Kowalewski).

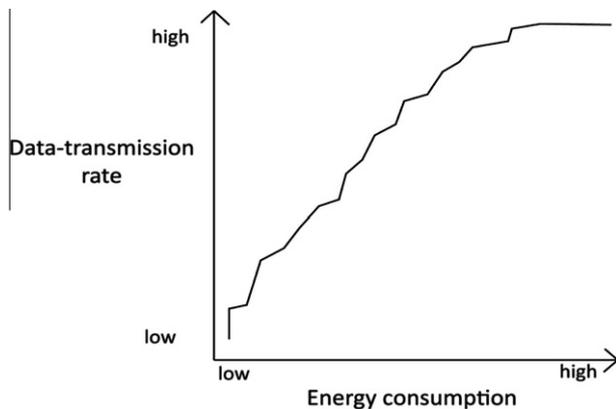**Fig. 1.** System design lifecycle (Blanchard & Fabrycky, 2006).

Fig. 2. Example of the contradicting relation between throughput and energy dissipation.

sides power consumption constraints also design costs have to be considered during such trade-off decisions (Chattopadhyay et al., 2006). Thus, determining the best solution for energy as well as for performance of a processor in complex applications, such as cellular phones, is a challenging task for design engineers. Although in practice, the engineers' trade-off decision is purely driven by technical and financial constraints, users of (future) cellular phones might have another weighting of importance of the design options. It might for example be that users do not care whether they have to charge their device several times or at least once per day. Hence, the engineers' trade-off decision could be extended by the input of potential users in early stages of system development.

In practice, most technology-driven companies have installed organizational processes that facilitate the assessment and integration of customer requirement information. This knowledge about user preferences is usually incorporated in the testing phase at the end of the system design process (Eliashberg, Lilien, & Rao, 1997). Typically, the user is asked to evaluate the product in user tests or – in the end – on the shop floor, when the user decides to buy a product (or not). However, in these late stages of the system design cycle, the design process of the product is usually finished and only marginal changes are made in the product when it fails in user tests. Contrary to that, the inclusion of user preferences in early stages of system design, i.e. in the analysis or design phase, could provide a valuable contribution to design trade-offs and lead to different design decisions.

Therefore, the focus of this work is to present a methodology to include user preferences into early stages of the system design cy-cle. More specifically, we aim for an extension of the engineering trade-off analysis by integrating user preference information in the analysis and design phase of system development.

2.2. Technology acceptance

The integration of user preferences into the system design process leads to another important aspect with regard to system development: user acceptance. The ongoing technical improvements of mobile or smartphones do not automatically guarantee user acceptance. Especially in early stages of system design, user preferences and demands are not adequately considered so far, which might have negative impact on acceptance issues.

There are many examples of failed market launches of technical innovations due to a lack of user acceptance. One example is "Interactive TV" (iTV), which was predicted to be a technical revolution (Stipp, 2001), has not achieved a breakthrough so far. A review of acceptance studies of iTV revealed that user acceptance was only integrated in terms of usability tests of the final product (Bernhaupt, Obrist, & Tscheligi, 2007).

In order to explain and predict the adoption of technologies by end-users and to avoid market failures, several theoretical models were developed. The most influential and best-established theoretical approach is the Technology acceptance model (TAM (Davis, 1989)). The TAM is based on the Theory of Reasoned Action (TRA (Fishbein & Ajzen, 1975)), which originates from social psychology and seeks to explain behavior. The TRA assumes that a person's behavior is influenced by the specific intention to perform a behavior. Further influential factors on this behavioral intention are an individuals' attitude towards the behavior and individual norms. The Technology acceptance model broadened and transferred the TRA assumptions to the area of technical systems. The TAM assumes that the decision to use a new technical system or device is determined by a behavioral intention, which is influenced by the perceived ease of use and the perceived usefulness of the system. The ease of use describes "the degree to which a person believes that using a particular system would be free from effort", the perceived ease of use is "the degree to which a person believes that using a particular system would enhance his or her job performance" (Davis, 1989). In the extended version of the TAM (Venkatesh & Davis, 2000) the model was complemented by external variables, which were assumed to influence the behavioral intention to use a system, e.g. social and cognitive processes (subjective norm, system image and relevance, quality of output). The TAM received considerable attention and was intensively researched and validated (e.g. Davis, 1989; Taylor & Todd, 1995). It was empirically tested using different models or incorporated model constructs (Davis, Bagozzi, & Warshaw, 1989; Gefen, 2004; Taylor & Todd, 1995), user groups (Arning & Ziefle, 2007; Straub, Keil, & Brenner, 1997), and technologies (Featherman & Pavlou, 2003; Hu, Chau, Shen, & Yan Tam, 1999). Summarizing the findings, the TAM was proven as a valid, robust and powerful theoretical model (Davis, 1989; King & He, 2006).

However, the transfer of these acceptance models to the system development process causes some problems:

(1) Acceptance models such as the TAM aim for an evaluation of *complete* technical systems or applications (e.g. online banking, mail systems, WAP services). They do not provide information about the evaluation of single technical characteristics of a product (e.g. display size or battery life time of a mobile device).

(2) Methodologically, the TAM and its model extensions use a structural equation modeling approach to investigate relationships among the proposed determinants of acceptance. The determinants of acceptance models – such as "perceived

ease of use" of the TAM – are operationalized on a high level of abstractness, summarizing multiple item responses of participants in one construct score. One item example for the TAM construct "perceived ease of use" is "learning to use the system was easy for me". If a user experiences difficulties using the technical system, and responds with a low rating, the item does not provide information about the sources of difficulties (e.g. problems with the menu design, the design of the GUI or with the manual). Thus, the aforementioned acceptance models and their constructs do not provide decision criteria or concrete practical guidelines for system designers.

In order to integrate user preferences into early stages of the system design process, it is important to apply user-oriented empirical methods, which allow for a more detailed evaluation of system characteristics.

2.3. Conjoint analysis

Conjoint analyses, which are widely used in market research, overcome the aforementioned shortcomings of acceptance models and methodologies and contribute decision criteria, which could extend the engineering trade-off analysis in the system design process.

Conjoint analysis is a decompositional method to investigate preferences for products or services. Within conjoint analysis respondents rate a product or a service consisting of multiple attributes. Thus, in conjoint measurement, a respondent considers all factors concurrently for each attribute combination. Using this analysis, the user evaluations can be decomposed into separate utilities, or part-worths (Backhaus, Erichson, Plinke, & Weiber, 2011). Data collection is, therefore more holistic and more ecologically valid, because complete situations or products rather than single features are considered.

In this term, conjoint analyses provide an additional value to acceptance research since it is possible to obtain an accurate estimation of user trade-offs between single device characteristics. Furthermore, it is possible to determine a valid model of consumer judgments. With this model predictions can be made about consumers' acceptance of any combination of attributes (Backhaus et al., 2011).

Despite its widespread use in other disciplines, especially in market research, only few studies used conjoint analysis to investigate technology acceptance in general (Keen, Wetzels, de Ruyter, & Feinberg, 2004) or acceptance of mobile phones, infrastructure or services (Dohle, Keller, & Siegrist, 2010; Pagani, 2004). Keen et al. (2004) investigated the structure for consumer preferences to make product purchases through three available retail formats – store, catalogue, and the Internet. Pagani (2004) formulated a model to explain adoption of mobile multimedia services and tested it empirically on the Italian market. Among other methods she used conjoint analysis to investigate the importance of service features. Dohle et al. (2010) used conjoint analysis to evaluate participants' preference for various attributes of base stations.

Literature analysis revealed that, as far as we know, no study used empirical methods such as conjoint analysis to transfer knowledge from technology acceptance research to system design processes.

2.4. Research questions

What if technical possibilities in the system design process exceed the reasonable frame of technical and financial aspects? The most reasonable and economical solution is the involvement of user preferences into early stages of system development. In order

to support a user-oriented research, the aim of this research was the identification of relevant technical features that enhance users' acceptance. More specifically, we aimed for

1. An identification of device characteristics, which are relevant in the purchase decision of smartphone users.
2. The determination of the relative importance of these characteristics from the user perspective, e.g. Do users prefer a higher degree of information throughput or a higher degree of energy efficiency (battery capacity)?
3. An investigation of trade-offs between specific device characteristics, e.g. How much battery life time is the user willing to lose for an improvement of one or more of the described features e.g. speech-quality?
4. An evaluation of user-oriented research methods: Does a conjoint analysis yield additional insights into acceptance issues and provide added methodological value and practical guidelines for system developers?

3. Prestudy: identification and selection of user-relevant attributes

A pre-study was conducted in order to identify and select the most relevant hardware characteristics of mobile devices from the users' perspective. This study was necessary because (a) the number of possible attributes and levels in conjoint analyses is restricted and we needed to filter the most relevant device characteristics, and (b) we had to strike a balance between device characteristics which are deemed important by the user and those which are relevant to system designers and developers.

3.1. Questionnaire

A questionnaire was developed, which assessed demographics (age, gender, education), usage frequency and preference ratings of device characteristics. Participants were asked, "Imagine you would like to buy a new mobile device. How important are the following features for you?" For hardware preference ratings a six-leveled Likert-Scale was used, where participants were asked to specify their level of agreement or disagreement on a symmetric agree-disagree scale (1 = "this hardware feature is extremely unimportant" to 6 = "this hardware feature is extremely important"). The following hardware characteristics of mobile and smartphones had to be rated: battery life, display resolution, synchronization with PC, data rate, design, energy saving mode, weight, display size, device size, internet access, camera, latency (until the first data package arrives), brand, speech quality, signal quality, memory capacity, robustness, connection stability, standby time, SAR/radiation, and touch screen.

3.2. Participants

A total of n = 48 mobile phone and smartphone users between 23 and 62 years (M = 34.0, SD = 11.22, 52% female) took part in the pre-study. Regarding educational level, 12% had "Abitur" (German qualification for university admission), and 86% held a university degree. The majority of participants (82%) possessed a mobile phone and 46% reported to own a smartphone. More than half (55%) reported to mainly use the mobile phone and 45% reported to mainly use the smartphone. Asked for their usage behavior, participants reported the following usage frequencies of specific functions and applications (Table 1). The majority of participants used their mobile devices for phone calls and text messages at least once a day. Almost 50% used the mobile device several times a day for phone calls and over 50% reported to surf the internet at least 1x per week with their mobile device. All in all, the usage of Internet,

Table 1
Usage frequencies of mobile devices ($n = 481$).

Frequencies in %	Phone calls	Text messages	Internet	Games	Navigation
2–3x/day	49.0	36.7	27.7	0.0	0.0
2–3x/week	24.5	26.5	2.1	14.9	6.4
1x/day	22.4	22.4	14.9	2.1	0.0
Less than 1x/week	2.0	6.1	4.3	23.4	25.5
1x/week	2.0	6.1	2.1	2.1	17.0
Never	0	2.0	48.9	57.4	51.1

gaming or navigation apps was less frequent in comparison to the "standard" functions of phone calls and text messages.

Looking at the usage frequencies of their mobile devices, we can conclude that a technology-experienced sample was under study, which was able to give valid statements in the following hardware preference ratings.

3.3. Results

The most important hardware features in the purchase decision of a mobile device were battery life, speech quality and connection stability (all $M = 5.5$), followed by connection quality ($M = 5.4$). The least important features were latency ($M = 3.8$), camera ($M = 3.7$), radiation and brand (both $M = 3.6$, Fig. 3).

In order to find out if users of mobile phones and smartphones preferred different hardware features, the sample was divided into two groups according to the mainly used device type: mobile phone users ($n = 27$, 55%) and smartphone users ($n = 21$, 45%). A MANOVA with the factor "device type" yielded significant differences in hardware feature preference ratings (Table 2). The following criteria were significantly more important for smartphone users: Internet access, data rate, display size and resolution, syn-
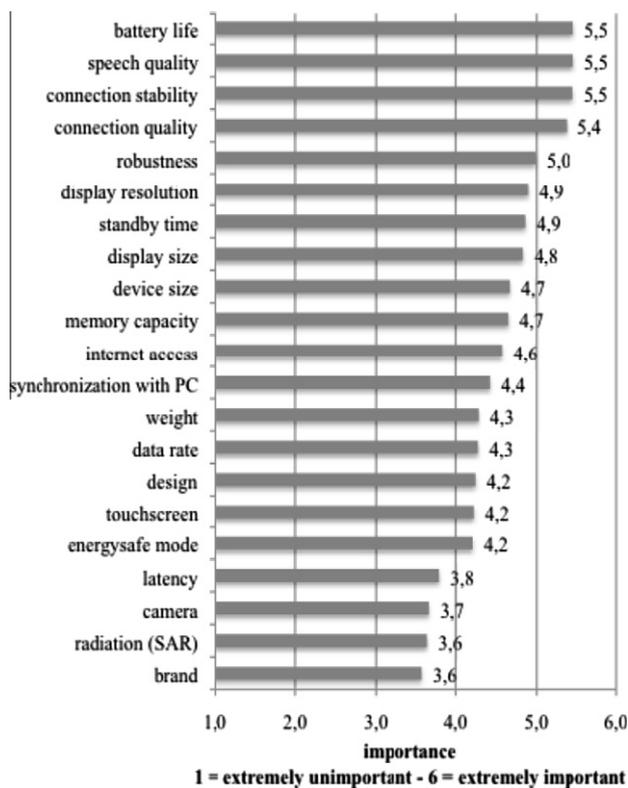
Table 2
User ratings of mobile device hardware criteria ($n = 48$).

	Mobile phone users ($n = 27$)		Smartphone users ($n = 21$)		
	M	SD	M	SD	p
Internet access	3.6	1.6	5.6	0.9	$p < 0.01$
Connection stability	5.4	0.8	5.5	0.6	n.s.
Connection quality	5.3	0.8	5.4	0.6	n.s.
Battery life	5.5	0.6	5.4	0.6	n.s.
Speech quality	5.5	0.6	5.4	0.6	n.s.
Data rate	3.2	1.3	5.3	0.7	$p < 0.01$
Display size	4.3	1.1	5.3	0.7	$p < 0.05$
Display resolution	4.6	1.1	5.2	0.8	$p < 0.01$
Synchronization with PC	3.7	1.5	5.1	0.8	$p < 0.01$
Memory capacity	4.3	1.4	5.0	0.9	$p < 0.05$
Standby time	4.8	0.8	4.9	1.1	n.s.
Robustness	5.2	0.9	4.8	1.0	n.s.
Device size	4.5	1.2	4.8	1.0	n.s.
Touchscreen	3.7	1.5	4.7	1.3	$p < 0.05$
Latency	3.0	1.4	4.5	1.4	$p < 0.01$
Design	4.2	1.4	4.2	1.4	n.s.
Weight	4.3	1.2	4.2	0.9	n.s.
Energy safe mode	4.3	1.2	4.0	1.2	n.s.
Camera	3.5	1.5	3.8	1.3	n.s.
Brand	3.5	1.5	3.6	1.1	n.s.
Radiation (SAR)	3.9	1.3	3.2	1.5	n.s.

chronization with PC, memory capacity, touchscreen, and latency. Moreover, smartphone users reported to have different priorities in purchase criteria. The "top" purchase criteria of smartphone users were Internet access, connection stability and quality, battery life, speech quality and data rate. For mobile phone users the ranking was as follows: battery life, speech quality, connection stability and quality, and robustness.

Although some preference overlaps exist in the two user groups (battery life, connection stability and quality, speech quality), smartphone users more strongly prefer criteria related to mobile Internet usage such as Internet access and data rate.

3.4. Conclusions

According to the findings of our pre-study, users in fact have specific device criteria in mind, when they decide to purchase a new mobile device. According to these preference findings, the following criteria were chosen as attributes for conjoint analyses: *battery life*, *connection stability* and *quality* as well as *speech quality*. The user-group specific analysis of preference ratings showed that smartphone users have higher demands regarding the performance of their mobile device. Smartphone users access the Internet via their mobile device more often and use it for data-oriented functions. Consequently, system designers should also consider criteria such as Internet access and data rate.

4. Study II: conjoint study

According to the results of the pre-study four attributes were chosen for the conjoint study: *battery life*, *connection stability* and *quality* and *speech quality*. The attributes were selected for two reasons. First, results from the pre-study revealed that they are important for the user regarding his decision for or against a device. Secondly, they are relevant for engineers because they are competitive in a way that they cannot all be implemented into one chip due to standardization restrictions. In order to get insights into the relative importance of device criteria and/or trade-offs of potential users between specific device criteria, a conjoint analysis was conducted.

Fig. 3. Preference ratings for device criteria ($n = 48$).

4.1. Participants

Data were collected in an online survey conducted in Western Germany between May and June 2011. Participants were asked via e-mail to take part in the study and were forwarded to the questionnaire. It took about 20 min to complete the questionnaire.

In complete, 178 participants took part in the study. As the questionnaire had to be fully completed for further statistical analyses (no missing answers), only 100 data sets were used.

The mean age of participants was 28.2 (SD = 6 years), 50% of the respondents (N = 50) were men and 50% were women. Nearly half of the participants (44%) reported to be smartphone users. The mean number of years using a mobile device was 9.9 years (SD = 2.8 years).

4.2. Design of the study

Choice-Based-Conjoint (CBC) analysis was used as method for the current study. CBC interviews closely mimic the purchase process for products because a set of products is shown on the screen to the respondents and it is then asked which one they would choose (Orme, 2009). In this study participants were shown 3 sets of product configurations plus a "none option".

4.3. Questionnaire

SSI Web Software was used for the construction of the questionnaire (Sawtooth Software). Table 3 shows the four attributes used in the conjoint analysis and their corresponding levels.

In the beginning of the questionnaire, participants received a detailed description of the four attributes, their levels and their technical interaction. Table 3 gives an overview of the attributes and their levels. The attribute "battery life" had four levels, which varied from 3 h talk time to 15 h talk time. The attribute "speech quality" was combined with an additional charging fee and participants could listen to audio examples of each level of speech quality (normal, good and excellent). The attribute "signal quality in dead spots" (former "connection stability") consisted of three levels, i.e. "no signal", a "signal with partially bad quality" and "good signal" in every "dead spot". The former criterion "connection quality" was operationalized as attribute "data-transmission rate" with five levels, which varied from a rate sufficient for making phone calls to a rate for downloading HD Videos. In order to enhance comprehensibility for the user, a data rate in terms of numbers (Mb/s) was added.

Given that all attributes and their corresponding levels would have yielded 225 (5 × 3 × 3 × 5) possible combinations, it was necessary to reduce the number of stimuli. The SSI Web Software offers the possibility to reduce the number of combinations – in our study to 13 random tasks and 2 fixed tasks for each respondent. Due to a lack of technical feasibility of combining some attributes' levels, a few prohibitions were included into the design.

Prohibition means that some levels of attributes might not appear together in one set (e.g. 15 h of battery combined with good signal in dead spots). Whenever prohibitions are included, a test of design efficiency is necessary, which examines whether the design is comparable to the hypothetical orthogonal design (Orme, 2009). The module for testing the design efficiency included in the SSI Web Software confirms the assumption that although containing some prohibitions, the design regarding a total of 100 respondents is sufficient.

In addition to the three choice tasks, participants could also choose the option "No, I would not choose any of these options because I'd rather like to configure all these aspects manually".

After completing the CBC exercises participants had to fill-in demographic questions regarding age and gender and also some questions concerning their usage behavior with mobile phones (mobile phone type, frequency, years of usage).

4.4. Results

In order to gain deeper and valid insights, participants were divided into two groups according to their preferred mobile device, i.e. mobile phone users and smartphone users. Results were analyzed using the SMRT Software (Sawtooth). First, part-worth utilities were calculated on basis of Hierarchical Bayes (HB) estimation and based on these part-worth utilities importance scores were derived.

The HB procedure of estimation has the advantage that all part-worth utilities are computed for respondents individually rather than computing importances from average part-worth utilities over the whole sample. The relative importance of an attribute is calculated by taking the part-worth utility range for each factor and dividing it by the sum of the utility ranges for all factors. Thus, they provide a measure of how important the attribute is relative to all other attributes.

4.4.1. Relative importance of attributes and part-worth utilities

The *relative importance* of all four attributes is presented in Fig. 4 separated for smartphone and mobile phone users. Signal quality (32.07%) followed by speech quality (23.75%) were the attributes of greatest importance for smartphone users. Data-transmission rate (22.32%) and battery life (21.85%) seemed to be of lower importance in this group for the choice of one of the presented options. Mobile phone users in contrast valued speech quality (33.97%) followed by signal quality (27.74%) as most relevant attributes in their choice task. Battery life (22.40%) was the third important criterion whereas data-transmission rate (15.98%), in contrast to smartphone users, was the least important attribute.

Although *speech quality* was perceived as one of the most important attributes, the *part-worth utilities* in Fig. 5 reveal that respondents in both groups clearly emphasized to prefer normal speech quality without any additional costs (65.73 mobile phone; 40.15 smartphone) in comparison to good or excellent speech quality, where additional fees were charged. The fact that this attribute has one of the greatest differentials between its highest and lowest level (125.7 mobile phone; 85.32 smartphone) indicates that there is a high preference for no additional costs rather than for better speech quality itself.

For *signal quality*, the differentials between good signal and no signal were higher for smartphone users (124.93) than for mobile phone users (102.89), although, both groups revealed an explicit preference for good signal.

So far we can conclude that depending on the level of the respective attribute, speech quality as well as signal quality were the driving indicators of whether participants opted for the combination or not. This means that excellent speech quality paired with additional costs was the decisive point *not* to choose this attribute
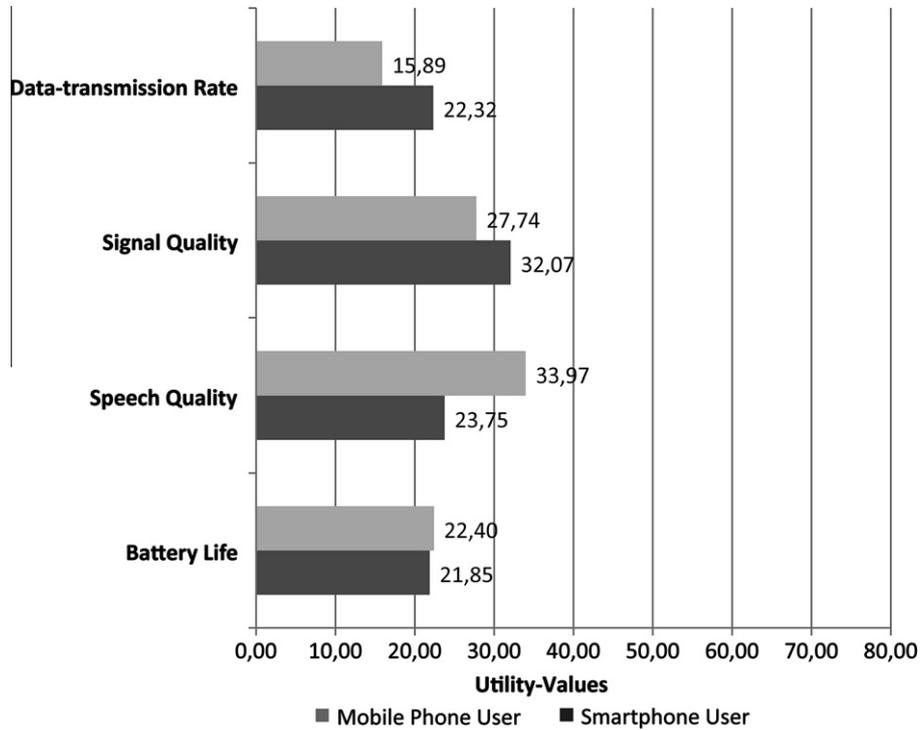
Table 3
Attributes and levels used in the Conjoint Analysis.

Battery life (h)	Speech quality	Signal quality in "dead spots"	Data transmission rate
3	Normal (no add. charge)	No signal	Phone calls & SMS 0.1 Mb/s
6	Good (+2.50€ add. charge)	Signal (partially bad quality)	e-mails 0.5 Mb/s
9	Excellent (+5€ add.charge)	Good signal	Internet surfing 10 Mb/s
12			Videos 25 Mb/s
15			HD videos 50 Mb/s

Fig. 4. Relative importance of attributes measured in utility values for both user groups.

combination regardless of whether the presented combination contained any other favored levels or aspects. In contrast to this, a good signal quality in "dead spots" was the most positively connotated preferred aspect for most participants in both groups.

Looking at the part-worth-utilities for the attribute *battery life*, the greater preference for 12 h battery life (although 15 h might be more preferable) in both groups (26.51 mobile phone; 24.47 smartphone) can be explained by the prohibition that a good signal quality in "dead spots" did not appear with more than 6 h of bat-tery, due to the fact that the algorithm to calculate the signal in dead spot zones leads to a higher energy dissipation.

The greatest differences between the both groups were to be found within levels of the attribute *data-transmission rate*. Smartphone users clearly prefer a data transmission rate for loading videos (16.51), whereas mobile phone users comply with a data rate that suffices just for internet surfing (14.57).

Summarizing so far, the results indicate that whenever participants had to choose whether they prefer at least 9 h of battery life
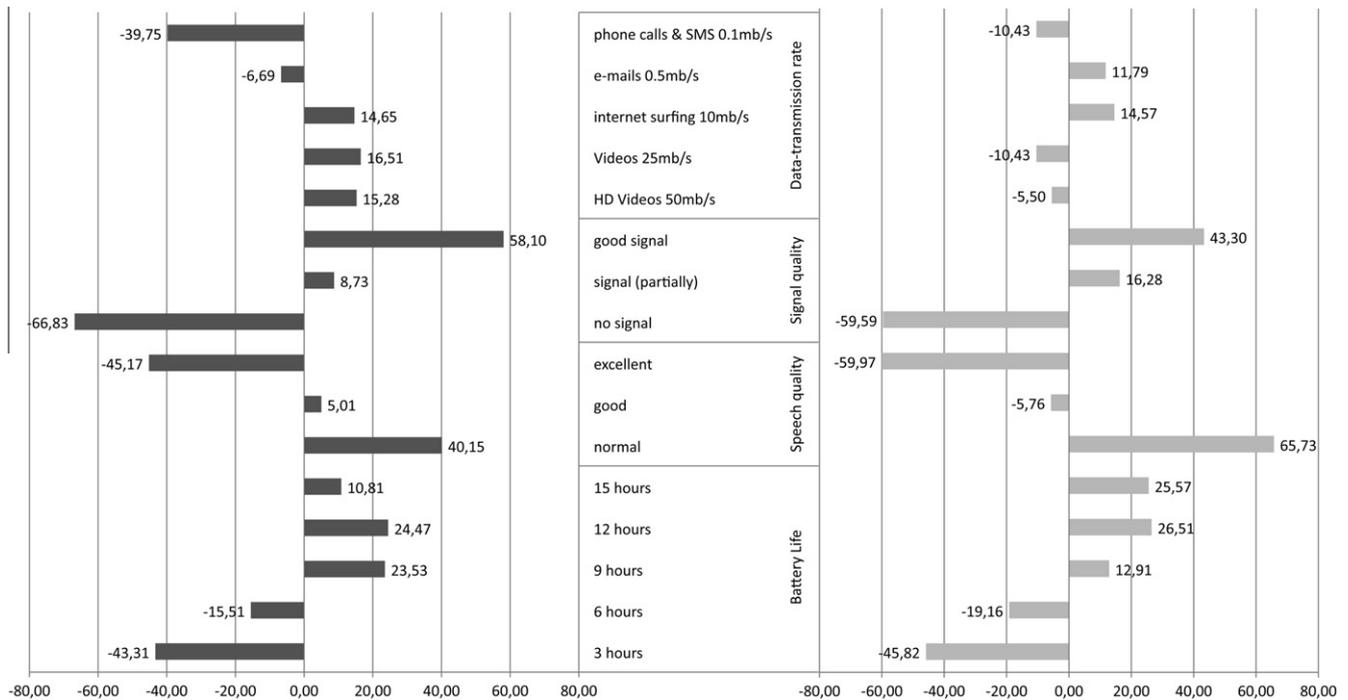

Fig. 5. Part-worth utilities of attributes for both user groups: Smartphone users on the left, mobile phone users on the right.

or a good signal quality in dead spots, the majority of participants would choose the latter.

4.4.2. Analysis of trade-offs

After it became clear that some hardware characteristics are more relevant in the decision process of the users than others and that mobile phone users even differ from smartphone users, the question arose: How do users weigh one hardware characteristic in relation to another e.g. how much of the energy efficiency is the user willing to lose for an improvement in signal quality in dead spots?

The analysis of trade-offs between these attribute levels was conducted by using SMRT Sawtooth market simulator. The simulator is used to convert part-worth utilities into simulated market choices. In a first step, several product concepts are defined in terms of the attributes and levels used in the study. Second, the shares of preference of each product concept are compared against each other. Based on the assumption that users would definitely have chosen one concept the sum of the share of preference is always 100%. The proportional share of preference of each product concept then indicates how many percent of users would have chosen this specific concept.

Results of prior part-worth utilities analysis revealed that most respondents prefer normal speech quality with no increase in preference when changing one level. Thus, we decided to keep the level for this attribute constant in all product configurations. All products were configured based on technical feasibility. An example for a non-feasible product alternative, which was not considered in our analysis, was the combination of 12 h of battery life with good signal in dead spots (see "Prohibtions").

4.4.2.1. Battery life vs. data-transmission rate.
In contrast to other attributes (hardware characteristics) data-transmission rate was the least important attribute in the decision of mobile phone users. Thus, the trade-off between these two attributes was only conducted for smartphone users.

Two product concepts were configured: 9 h *battery life and 25 Mb/s* (*Videos*) *vs.* 12 h *battery life and 10 Mb/s* (*internet surfing*).
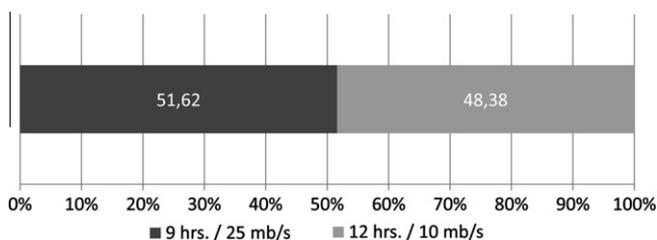
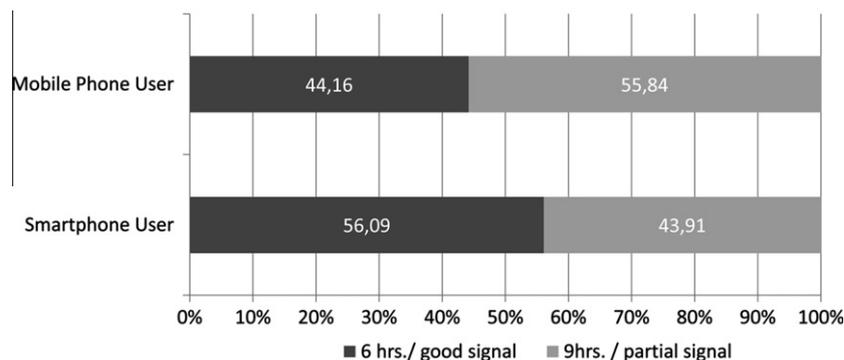**Fig. 6.** Trade-off battery-life vs. data-transmission rate.

Both levels of battery life and data-transmission rate revealed the highest share of preference in the prior part-worth analysis. Fig. 6 shows the share of preference for each of these two product concepts in the group of smartphone users. It becomes obvious that whenever users had to decide between one of the two concepts, slightly more than half of the users would prefer a higher data-transmission rate with lower battery capacity over more battery capacity paired with a lower data-transmission rate.

4.4.2.2. Battery-life vs. signal quality.
Signal quality was the most important attribute for a decision in the smartphone user group and the second important aspect for mobile phone users. Furthermore, results of the part-worth analysis revealed that for both groups a good signal in an area with dead spots is the most preferable level. Due to technical feasibility this characteristic is contradicting a high battery capacity. For example, a battery capacity of 9 h talk time was maximally combinable with a partial signal in dead spots. Hence, 12 h battery capacity would result/implicate no signal in dead spots. Thus, to find a trade-off between these two contradicting aspects, two products were configured: 6 h *battery life and good signal vs.* 9 h *battery life and partial signal*. Results of the trade-off analysis for both user groups are presented in Fig. 7.

The figure clearly points out that mobile phone users would chose the alternative with a higher battery capacity and worse signal whereas smartphone user strongly prefer a good signal over a higher battery capacity. We can conclude that smartphone user are willing to dispense with 3 h battery life for always having a signal of their mobile device in areas that normally have dead spots.

5. General discussion

The system design process for mobile device innovations typically focuses on an optimization of technical parameters. Due to feasibility reasons and growing financial pressure in R&D, the selection of these optimization targets is primarily based on technical and economical considerations. The inclusion of user preferences usually happens at the end of the design process, when the user is asked to evaluate the product in user-tests or – in the end – on the shop floor, when the user decides to buy a product or not. However, in these late stages of product development, the design process is usually finished or only marginal changes are made to the product.

As purchase decisions by the user are strongly determined by specific mobile device characteristics, the inclusion of user-oriented input into early stages of the design process might lead to improved design decisions. Therefore, the aim of this study was the implementation of a quantified understanding of user needs in terms of values into the system design process. Moreover, we aimed for an extension of the engineering's trade-off analysis by

Fig. 7. Trade-off battery-life vs. signal quality for both user groups.

using conjoint analysis in order to investigate trade-offs between specific device characteristics, e.g. "How much energy efficiency in terms of battery life is the user willing to lose for an improvement of device features e.g. signal-quality?" Finally, our aim was the evaluation of empirically based user-oriented research methods. We focused on the question whether conjoint analyses yield additional insights into acceptance issues in early stages of the system design cycle and whether its results provide improved practical guidelines for system developers in comparison to conventional approaches in system engineering.

Therefore, in this study two empirically based user-centered methods were applied (user survey and conjoint analysis), which were supposed to provide valuable information in supporting decisions regarding optimization targets in system design. The first study was a user preference survey, which focused on the identification of relevant mobile device characteristics. In the second study, these device characteristics were used for a trade-off analysis by conducting a conjoint analysis.

First, the results and their practical implications for mobile device system design are discussed in detail. Secondly, the additional value of conducting conjoint analysis for this purpose in comparison to conventional surveys will be evaluated. Finally, managerial implications of these results are discussed.

5.1. Contributions to system development

The findings of the user survey (study I) showed that users have in fact clear preferences in mind regarding mobile device characteristics. The most important characteristics, which affect purchase intentions, were battery life, speech quality, connection stability and connection quality. Taking different user groups into account (mobile phone vs. smartphone users), we found that smartphone users more strongly prefer device features which are related to mobile internet usage such as internet access and data rate. Although current mobile device design already strongly focuses on the development of smartphones for Internet usage, the finding confirms the market potential of devices suitable for the demands of the mobile internet. Based on the findings of the user survey we derived four hardware characteristics to be further evaluated by conjoint analysis: Battery life, speech quality, signal quality and data-transmission rate.

Results indicated that speech quality and signal quality are the most important features in the decision for one of the queried 'service packages' for both user groups. Speech quality, however, was important insofar as users do not want to pay for an additional service. The more detailed analysis of part-worth utilities gives an overview of which attribute features are only just acceptable for users of smartphones or mobile phones. Results indicated that both user groups would accept a minimum of 9 h of battery life and for signal quality at least a partial good signal in dead spots, whereas a good signal was preferred more strongly. Due to technical feasibility respondents had to choose whether they would opt for 9 h battery life or a good signal in dead spots. This interesting question was answered with a sensitivity analysis that revealed that a device which is constant in all other characteristics (speech quality and data-transmission rate) would be more valuable to smartphone users when it provides good signal in dead spots, even if it has only 6 h of battery life. The opposite was shown for mobile phone users. The same trade-off revealed a clear preference for a longer battery life in this user group.

Today's smartphones provide battery runtime for a talk time between 7 and 12 h, which is less than conventional mobile phones offer. The design of a new phone typically has to target this battery runtime as well, because it is already limited due to a greater variety of different task within a smartphone. The system designer therefore has to trade-off the reception quality versus energy dis-

sipation carefully. In the presented study we brought this trade-off decision to the users. The results show that the smartphone users could live with far less runtime in exchange for a better reception.

It has to be assumed that smartphone users have a greater tolerance towards less battery runtime in contrast to mobile phone users because they are used to it and the benefit of the multifunctionality of a device outweighs this aspect. Therefore, smartphone users are the more interesting user group in this study because it is essential to ascertain the minimum acceptable amount of battery runtime in contrast to other optimization targets on the basis of a sample that is used to current technical standards.

5.2. Contributions to technology acceptance research

The present research work demonstrated that technology acceptance research benefits considerably from an interdisciplinary and multi-method approach. The combination of research questions from system engineering, i.e. the specification of optimization targets in system design, with technology acceptance research methods provided a novel research framework regarding the investigation of acceptance-relevant trade-offs for users. Moreover, the application of a multi-method-approach, i.e. the combination of two empirical methods, allowed (a) to identify acceptance-relevant hardware features of mobile devices (in the user survey), and (b) to get concrete information about the specification or configuration of these features for the design of a novel product (in the conjoint analysis). In most acceptance and usability studies the potential of a multi-method-approach regarding a holistic and productive investigation of acceptance issues is disregarded as only single methods are applied (e.g. Gefen & Straub, 1997; Venkatesh & Davis, 2000).

As a further contribution to acceptance research, this work was a first step to overcome criticism on established acceptance models such as the TAM (Bagozzi, 2007; Benbasat & Barki, 2007). These acceptance models neither provide information about the evaluation of single product characteristics nor do they deliver decision criteria or concrete practical guidelines for system designers. In our study, user preferences regarding single device features were uncovered and concrete product configurations were specified which were attractive for potential users. Moreover, technology acceptance models are primarily job-related, which implies a mandatory system interaction by the user. As today's mobile devices are also widely privately used on a "voluntary" basis, user preferences referring to private usage should be included in acceptance research. This also requires a differentiated view on specific user groups (e.g. mobile phone vs. smartphone users), which significantly differed according to their usage profiles and preferences.

The successful integration of acceptance research methods and knowledge into early stages of system design showed that acceptance research should not start at the end of the system development process. As present acceptance approaches mainly have a static view (Benbasat & Barki, 2007), an early and iterative inclusion of acceptance issues throughout the system development process will also contribute to a more valid, dynamic perspective on technology acceptance.

5.3. Managerial Implications

Our findings have managerial implications, particularly in terms of R&D management. Implementing the users' preferences into early stages of the product development process offers several advantages concerning effectiveness as well as economic aspects of development. R&D managers should consider the users' input not only in late stages of system design lifecycles but also for decision processes in the early design phase.

This study demonstrated how the design phase could be enriched: A user survey focused on the question which features are relevant for the user. In a second user study we demonstrated that conjoint analysis is an adequate tool for finding the minimum requirements users have regarding technical specifications as well as answering the question "which features are more important to the user". Furthermore, applying conjoint analysis demonstrated how the engineers' trade-off analysis can be facilitated and delimited by taking the users' perspective into account since the engineer does not have to decide between all technical possibilities but now has a framework that tells him e.g. "how much battery life the user is willing to lose for a better signal quality in dead spots".

By applying user preferences to early development stages the product development process could be more efficient and, as a consequence, more economic due to reduced potential misspecifications that otherwise will be detected in later stages when conducting user tests with prototypes or, the worst case, on the shop floor. Especially with regard to growing market pressure and the increasing demand for fast and customer tailored solutions the integration of user values into the development process could be crucial for a successful market launch of new products.

Differences in results between potential (mobile phone user) and current users (smartphone users) suggest that a differentiated view of the individual user groups is indispensible.

Although this study demonstrates a successful implementation of user input into the development of mobile device architecture, managers should consider that the procedure depends on several aspects. For example it might be a difference whether it is about the development of a new or an already existing (or established) technology (Callahan & Lasry, 2004). In the case of conjoint analysis it has to be assured that potential users have sufficient knowledge of the attributes in order to make a valid decision. The question of which method should be applied also depends on the kind of question the engineer needs to answer, as we discussed earlier.

5.4. Limitations and future research

First of all, a sample size of 100 may be appropriate, but having a larger sample size may provide more fruitful results.

Secondly, the focus of this study was to show the added value of integrating the user into the product development process on the basis of an example. Future researches should always consider the specific user group they want to address (Arning, Gaul, & Ziefle, 2010).

The low preference for the attribute "speech quality" could also have been evoked by methodology. Due to its connection to price this attribute was considered to be less important as long as it did not cost the user anything. We can conclude that price should always be handled with care in a conjoint analysis.

In order to prove and validate the additional value of the extension of the engineering trade-off analysis by integrating user preferences in early stages of system design, further research should investigate the effect on purchase intentions or sales figures in comparison to "conventionally" developed products.

Acknowledgment

References

Arning, K., Gaul, S., & Ziefle, M. (2010). Same same but different. How service contexts of mobile technologies shape usage motives and barriers. In G. Leitner, M. Hitz, & A. Holzinger (Eds.), *HCI in work & learning, life & leisure, 6th symposium of the WG HCI&UE of the Austrian computer society (USAB 2010). Lecture notes in computer science* (Vol. 6389, pp. 34–54). Berlin, Heidelberg: Springer.

Arning, K., & Ziefle, M. (2007). Understanding differences in PDA acceptance and performance. *Computers in Human Behaviour, 23*(6), 2904–2927.

Backhaus, K., Erichson, B., Plinke, W., & Weiber, R. (2011). *Multivariate Analysemethoden – Eine anwendungsorientierte Einführung* (13). Auflage. Heidelberg: Springer.

Bagozzi, R. P. (2007). The legacy of the technology acceptance model and a proposal for a paradigm shift. *Journal of the Association for Information Systems, 8*(4), 244–254.

Benbasat, I., & Barki, H. (2007). Quo Vadis, TAM? *Journal of the Association for Information Systems, 8*(4), 211–218.

Bernhaupt, R., Obrist, M., & Tscheligi, M. (2007). Usability and usage of iTV services: Lessons learned in an Austrian field trial. *ACM Computers in Entertainment, 5*(2) (Article 6).

Blanchard, B. S., & Fabrycky, W. J. (2006). *Systems Engineering and Analysis* (fourth ed.). New Jersey: Prentice Hall.

Callahan, J., & Lasry, E. (2004). The importance of customer input in the development of very new products. *R&D Management, 34*(2), 107–120.

Chattopadhyay, A., Kammler, D., Witte, E. M., Schliebusch, O., Ishebabi, H., Geukes, B., Leupers, R., Ascheid, G., & Meyr, H. (2006). Automatic low power optimizations during ADL-driven ASIP design. In *Proceedings of the international symposium on VLSI design, automation & test (VLSI-DAT)* (pp. 123–126). Hsinchu, Taiwan.

Cisco visual networking index (2012): Global mobile data traffic forecast update, 2010-2015, <http://www.cisco.com/en/US/solutions/collateral/ns341/ns525/ns537/ns705/ns827/white_paper_c11-520862.html>, retrieved 05.01.2012.

Davis, F. D. (1989). Perceived usefulness, perceived ease of use, and user acceptance of information technology. *MIS Quarterly, 13*(3), 319–340.

Davis, F. D., Bagozzi, R. P., & Warshaw, P. R. (1989). User acceptance of computer technology: A comparison of two theoretical models. *Management Science, 35*(4), 982–1003.

Dohle, S., Keller, C., & Siegrist, M. (2010). Conjoint measurement of base station siting preferences. *Human and Ecological Risk Assessment: An International Journal, 16*(4), 825–836.

Eliashberg, J., Lilien, G. L., & Rao, V. R. (1997). Minimizing technological oversights: A marketing research perspective. In R. Garud, P. R. Nayyar, & Z. B. Shapira (Eds.), *Technological Innovation: Oversights and Foresights* (pp. 214–230). Cambridge: Cambridge University Press.

Featherman, M. S., & Pavlou, P. A. (2003). Predicting E-services adoption: A perceived risk facets perspective. *International Journal of Human-Computer Studies, 59*(4), 451–474.

Fishbein, M., & Ajzen, I. (1975). *Belief, attitude, intention and behavior: An introduction to theory and research.* California: Addison-Wesley.

Gefen, D. (2004). What makes an ERP implementation relationship worthwhile: Linking trust mechanisms and ERP usefulness. *Journal of Management Information Systems, 21*(1), 263–288.

Gefen, D., & Straub, D. W. (1997). Gender differences in the perception and use of e-mail: An extension to the technology acceptance model. *MIS Quarterly, 21*(4), 389–400.

Hu, P. J., Chau, P. Y. K., Shen, O. R. L., & Yan Tam, K. (1999). Examining the technology acceptance model using physician acceptance of telemedicine technology. *Journal of Management Information Systems, 16*(2), 91–112.

Keen, C., Wetzels, M., de Ruyter, K., & Feinberg, R. (2004). E-tailers versus retailers: Which factors determine consumer preferences. *Journal of Business Research, 57*(7), 685–695.

King, W. R., & He, J. (2006). A meta-analysis of the technology acceptance model. *Information & Management, 43*(6), 740–755.

Orme, B.K. (2009). Which conjoint method should i use? Technical working paper. Sequim, Wash., Sawtooth Software.

Pagani, M. (2004). Determinants of adoption of third generation mobile multimedia services. *Journal of Interactive Marketing, 18*(3), 46–59.

Stipp, H. (2001). Der Konsument und die Zukunft des interaktiven Fernsehens. *Media Perspektiven, 4*(7), 369–377.

Straub, D., Keil, M., & Brenner, W. (1997). Testing the technology acceptance model across cultures: A three country study. *Information & Management, 33*(1), 1–11.

Taylor, S., & Todd, P. (1995). Understanding information technology usage—a test of competing models. *Information Systems Research, 6*(2), 144–176.

Venkatesh, V., & Davis, F. D. (2000). A theoretical extension of the technology acceptance model: Four longitudinal field studies. *Management Science, 46,* 186–204.