OPERATOR ACCEPTANCE OF MOBILE DATA COLLECTION TECHNOLOGY

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ABSTRACT

We employed the Technology Acceptance Model to identify the determinants of operator Intention to Use a mobile device introduced in a mature research reactor facility to aid in data collection rounds. In the model, Intention to Use is determined by beliefs about the Perceived Usefulness and Perceived Ease of Use of a technology. These beliefs are formed through determinants such as Job Relevance that may be more or less predictive for a given context of use.

We interviewed and surveyed 26 operators and subjected the data to quantitative and qualitative analysis. The qualitative analysis revealed that operator concerns about both Perceived Usefulness and Perceived Ease of Use influenced their Intention to Use the handheld system. A linear regression model found Perceived Usefulness and Voluntariness to be significant determinants of Intention to Use. A second regression model on Perceived Usefulness yielded a complex model dominated by Result Demonstrability.

Taken together, the results support the conclusion that operators were more inclined to use the mobile data collection tool when its use was perceived to be voluntary; when its results were readily understood to be relevant to the work, and when the level of effort was reasonable. The highlighting of both utility and usability determinants encouraged a balanced approach to re-design of the system. Design recommendations included communicating the benefits of system use for the operators and other stakeholders; increasing the salience of adverse indicator readings or trends; and allowing for greater flexibility in the execution of the data collection rounds.

Key Words: technology acceptance, mobile devices, operator rounds, usefulness, usability

1 INTRODUCTION

Information systems can be deemed to have failed if the intended users do not adopt them. One mitigation against this risk is to identify the factors that predict whether target users will form an *intention to use* a given system in a defined use context. If such factors can be identified for new technology applications in a specific work context, system designers can add them to design requirements.

The introduction of mobile technologies in nuclear facilities offers a case study of technology introduction into established work contexts. Mobile devices offer opportunities to improve the effectiveness and efficiency of facility operations and maintenance. However, some workers are not accustomed to mobile devices and may be reluctant to accept them in the workplace.

Such was the concern when a mobile device was introduced to aid in data collection rounds in a mature research reactor facility. A handheld scanner replaced paper-based logs, allowing operators to scan equipment tags and record parameter readings. The data were downloaded into a SCADA system when the device was docked following the rounds.

Initial operator resistance to the device was attributed variously to gaps in system knowledge, general discomfort with technology, and intransigence. These attributions led some stakeholders to call for system training and mandated use interventions. However, other stakeholders asked whether targeted design changes could lead to increased adoption through operator "pull" as opposed to management "push".

We undertook an analysis and redesign effort with the objective of identifying the determinants of technology acceptance and subsequently enhancements to the system to increase its adoption by operators. This paper reports on the modeling of the factors that predict use of the mobile device for operator data collection rounds. These factors then informed redesign priorities.

1.1 Technology Acceptance Models

A literature review identified the Technology Acceptance Model (TAM) as the most widely used family of models for determining acceptance of new technology. Other models of technology acceptance have been developed and modified based on the context of their use. The TAM family of models was chosen for this project on the basis of its successful application in other industries. However, no studies to date have been found that use TAM (or any other technology acceptance model) in the nuclear industry. We therefore considered different variations of this model to adjust for use in this field.

1.1.1 TAM

Davis et al. [1] introduced TAM as a descriptive model of user acceptance for information systems (Figure 1). TAM hypothesizes that Behavioral Intention determines new technology use. Two factors that directly influence a person's Behavioral Intention are Perceived Ease of Use (PEU) and Perceived Usefulness (PU). PU is specified to have an independent and direct effect on Behavioral Intention, whereas PEU has an effect on Behavioral Intention both directly and mediated through PU.

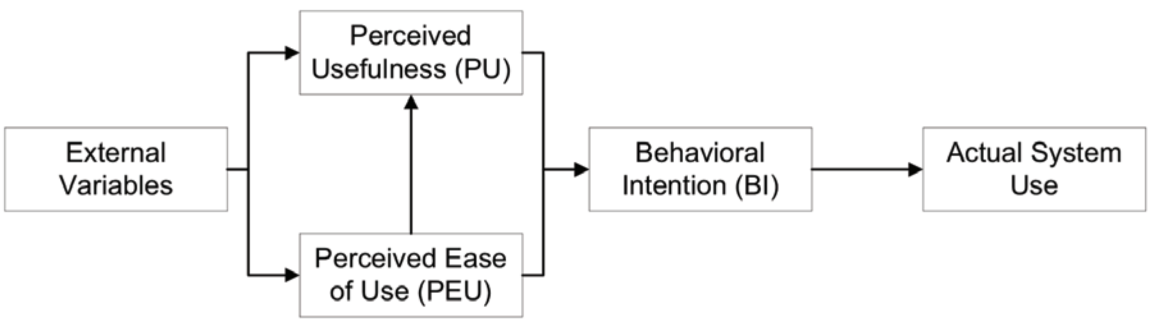

Figure 1: Technology Acceptance Model [1]

TAM defines PEU as a person's perception that a technology will be free of effort. PU is defined as a person's perception that using the technology will lead to enhanced personal job performance [2]. Davis and Venkatesh hypothesized that PU was a more important determinant of BI compared to PEU because workplaces typically emphasizes productivity, which is a factor in performance outcome [3]. Two decades of empirical empirical work on TAM suggest that the model consistently explains about 40% of the variance in individuals' intention to use a new technology and actual usage [4].

1.1.2 TAM2

In 2000, Venkatesh and Davis proposed an extension of TAM, called TAM2 (see Figure 2) [5]. Since initial TAM research found PU to be a fundamental driver of usage intention, TAM2 decomposes the key determinants of PU:

- Subjective Norm: The degree to which an individual perceives that most people who are important to him think he should or should not use the system.
- Image: The degree to which use is perceived to enhance one's status in one's social system.
- Job Relevance: The degree to which an individual believes that the system is applicable to his job.
- Output Quality: The degree to which an individual believes that the system performs his job tasks well.
- Result Demonstrability: The degree to which an individual believes that the results of using a system are tangible, observable and communicable.

TAM2 also include two moderators:

- Experience: The individual's previous experience with the system or a similar system.
- Voluntariness: The degree to which use of the system is voluntary.

TAM2 been shown to account for 40%-60% of the variance in PU and 34%-52% in PEU [5].

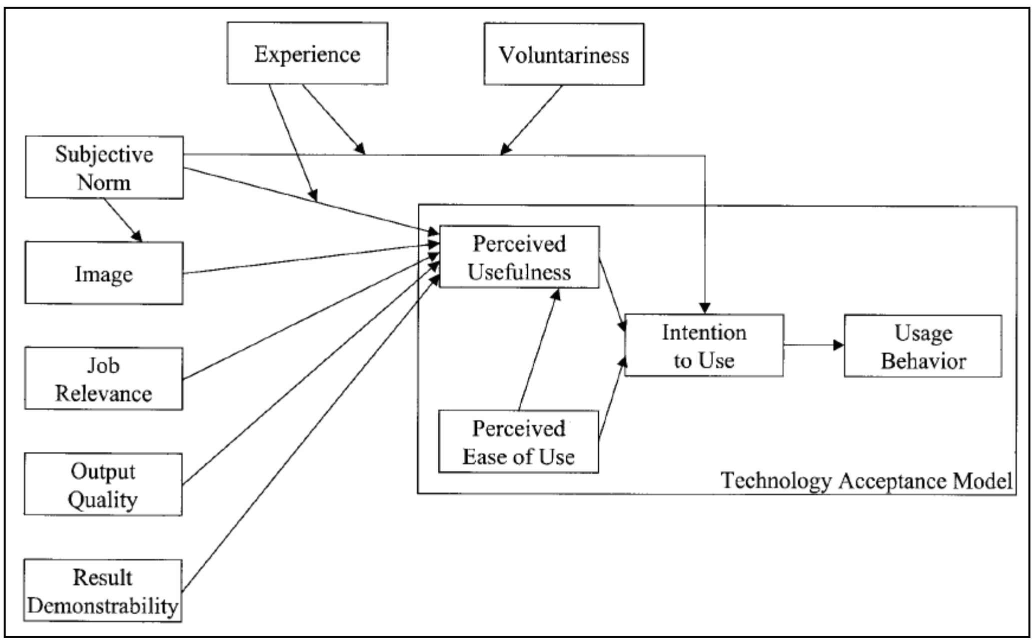

Figure 2: TAM2

1.1.3 TAM3

TAM3 extends TAM2 by adding determinants for Perceived Ease of Use, including Computer Self-Efficacy, Perception of External Control, Computer Anxiety, and Objective Usability [4]. Tests conducted by Venkatesh and Davis, showed that TAM3 was able to explain 53% of the variance in Intention to Use. However, TAM3 is more complex and not as well established as TAM or TAM2 [6].

1.2 Selecting an Appropriate Technology Acceptance Model

The following criteria were used to select the most appropriate TAM model for our study: 1) Length of the questionnaire, 2) Ability to predict Intention to Use, 3) Suitability for the work context, and 4) Prior use of the model in related work contexts and with similar technologies. Table I shows a score (1-5) for each model against each criterion. Out of a total score of twenty, TAM, TAM2 and TAM3 scored 16, 17 and 12 points, respectively. Although the total scores for TAM and TAM2 were nearly the same, TAM2 was chosen because it would provide more design guidance given its inclusion of determinants of PU.

Table I. Selection of Technology Acceptance Model Version							
Model	**Advantages**	**Disadvantages**	**Survey Length**	**Predictive Power**	**Suited to Context**	**Related Use**	**Total**
TAM	Well accepted, simple, widely researched	Neglects antecedent factors	5	4	4	3	16
TAM2	Includes PU determinants	More up to date models exist	4	4	5	4	17
TAM3	Includes PU and PEU determinants	Many factors to asses	3	4	3	2	12

1.3 Modification of the TAM2 model for application context

To assess the investigators' selection of the TAM2 model, key stakeholders were given a list of the determinants in TAM3 (since it contains all of the determinants from all of the Technology Acceptance Models) and asked to rate the determinants with respect to how important they are for predicting use of the data collection system. These stakeholders confirmed that the determinants included in TAM2 were appropriate for the context, with two modifications. First, the Image determinant was deemed not applicable in the context. Second, Computer Anxiety was cited from the TAM3 PEU determinants as possibly relevant for the target user population. We therefore excluded Image and included the Computer Anxiety questions in the questionnaire.

2 METHOD

Twenty-six nuclear operators participated in the study after giving their informed consent. Operators were released from their regular work duties to enable their participation, but were not compensated.

A questionnaire was used to gather operator perceptions of each determinant. The questions and scales were taken from previous TAM2 studies to increase validity. Semi-structured interviews conducted following the completion of the questionnaires provided additional feedback on operator perceptions of the new system.

Two of the authors administered the questionnaires at the facility. The interviewer first introduced the goal of the study, which was to assess the new mobile data collection tool. The interviewer then explained the procedure for completing the questionnaire and ensuring anonymity of the participants. Once the operator had completed the questionnaire, the interviewer conducted a semi-structured interview to solicit operator input on aspects of the new tool that they liked or disliked (and why).

3 RESULTS

3.1 Qualitative Analysis

We first discuss analysis of the qualitative data obtained through the semi-structured interviews. The object of analyzing these data is to determine the categories, relationships and assumptions that inform the respondents' view of the topic of interest [8]. The qualitative analysis followed two parallel analysis methods; conventional and directed content approaches [9]. Each operator comment was first divided into single units of data based on the ideas presented, where a comment that represented a unique idea was deemed as a single unit of data.

3.1.1 Conventional Approach

The conventional approach is an inductive method that creates codes or categories based on the data collected. The suggested steps to complete this analysis are as follows [7]:

1. Read the entire set of data to capture key thoughts or concepts;
2. Make notes of the first impressions of the data (such as main ideas being presented by the data);
3. Code each data point with labels that are reflective of the key thoughts, and;
4. Categorize each code into clusters to create categories.

The assigned categories are shown in Table II, along with their corresponding frequency.

Table II. Conventional Content Analysis of Qualitative Feedback

Category	Frequency	Percent
Workload	51	27%
Interface design	30	16%
System integration	23	12%
Design process and Implementation	18	10%
System accuracy	12	6%
Barcode	11	6%
Acceptance	11	6%
Usefulness	8	4%
Computer anxiety	7	4%
Voluntariness	5	3%
Flexibility	5	3%
Ergonomics	5	3%
Safety	2	1%

3.1.2 Directed Content Approach

The directed content approach is a deductive method that uses prior research to categorize the data. In this case, the determinants of technology acceptance identified in the TAM2 model were used to organize and group the data. This approach used codes from the conventional approach and assigned each code to a category pertaining to the TAM2 determinants. Table III presents the results.

Table III. Directed Content Analysis of Qualitative Feedback

Category	Frequency	Percent
Perceived Ease of Use	111	65%
Perceived Usefulness	46	27%
Experience	9	5%
Voluntariness	5	3%

3.1.3 Interpretation

Over 50% of the comments organized using the conventional approach pertained to workload, interface design and system integration. Specifically, operators perceived that the new technology imposed additional workload and more time was required to complete the tasks as compared to the paper logging method. The directed content analysis suggests that Perceived Ease of Use and Perceived Usefulness are the determinants that are most important to the operators, with Perceived Ease of Use being more important than Perceived Usefulness. Sub-determinants such as Experience and Voluntariness were less well represented

Comments categorized as addressing Perceived Usefulness suggested that operators did not understand the purpose of the new data collection system (i.e., what the data were being used for). Further, the limits and alarm messages used to communicate the allowable ranges were often incorrect and therefore considered not useful.

3.2 Descriptive Statistical Analysis

Table 3 presents the mean, median, mode and standard deviation values for each TAM2 determinant.

Table IV. Descriptive Statistical Analysis Results

Determinant	Mean	Median	Mode	Std. Dev.	Interpretation of Value of 7 (high anchor)
Intention to Use	5.7	6.0	7.0	1.5	I intend to use it
Subjective Norm	5.3	5.5	7.0	1.5	People who are important to me think I should use it
Perceived Usefulness	2.9	3.0	1.0	1.6	It is useful
Perceived Ease of Use	4.6	5.0	6.0	1.7	It is easy to use
Voluntariness	2.1	1.0	1.0	1.6	It is voluntary
Job Relevance	4.7	5.0	4.0	1.8	In my job, the usage is important/relevant
Output Quality	3.6	4.0	4.0	1.6	Good quality output
Result Demonstrability	4.7	5.0	4.0	1.5	I understand the results from the system
Computer Anxiety	2.5	1.0	1.0	1.9	I'm not comfortable with computers

The results indicate that operators' Intention to Use the data collection system was generally high. This could be attributed to the mandatory nature of system implementation, which is consistent with the low Voluntariness scores. Also consistent with high Intention to use are the high scores for Subjective Norm, which suggest that operators generally held a perception that the people who are important to them think they should use the system. Operators also reported fairly high Perceived Ease of Use for the system, which seems to contradict the balance of comments from the semi-structured interviews. Computer anxiety was rated low. Perceived Usefulness was rated poorly, indicating that Operators do not perceive the system to be useful for their job. This is consistent with mid-range scores for determinants moderating Perceived Usefulness, which include Job Relevance, Output Quality, and Result Demonstrability.

3.3 Regression Analysis

Following the TAM2 framework [5], we carried out stepwise linear regressions to identify the significant determinants and sub-determinants of Intention to Use. We started by looking at how the determinants directly affect Intention to Use. The regression model included the following determinants: Voluntariness, Subjective Norm, Perceived Usefulness and Perceived Ease of Use.

Table V shows the final step of the first regression. The model indicates that Voluntariness and Perceived Usefulness are the two significant predictors of Intention to Use. The model accounted for 55.1% of the variance in Intention to Use, which is statistically significant and consistent with other representative TAM2 studies reporting R Square values between 34% and 52% [5].

Table V: Regression on Intention to Use					
Determinants	**Unstandardized Coefficients**	**Standardized Coefficients**	**t (standard error)**	**Sig. (Beta)**	**P-value**
(Constant)	5.731	0.200		28.691	0.000
Perceived Usefulness	0.686	0.149	0.642	4.594	0.000
Voluntariness	0.514	0.181	0.398	2.846	0.009

The identification of Perceived Usefulness as important to determining Intention to Use warrants a closer investigation of the determinants of Perceived Usefulness. (Voluntariness does not have determinants in the model, so no further analysis is possible.) A second linear regression was performed to identify determinants that predict Perceived Usefulness. The regression included the following determinants: Subjective Norm, Job Relevance, Output Quality and Result Demonstrability. The final step of the resulting model is shown in Table VI. There are six determinants, with two significant main effects and four significant interactions. The results suggest that Result Demonstrability will have the greatest impact on Perceived Usefulness.

Table VI: Regression of Perceived Usefulness					
Determinants	**Unstandardized Coefficients**	**Standardized Coefficients**	**t (standard error)**	**Sig. (Beta)**	**P-value**
(Constant)	3.245	0.226		14.362	0.000
Result Demonstrability	0.716	0.211	0.650	3.391	0.003
Subjective Norm * Job Relevance	0.400	0.138	0.734	2.903	0.009
Subjective Norm * Result Demonstrability	-0.508	0.158	-0.784	-3.218	0.005
Job Relevance * Output Quality	-0.0352	0.109	-0.775	-3.218	0.005
Output Quality * Result Demonstrability	0.528	0.134	1.016	3.953	0.001
Perceived Ease of Use	0.257	0.124	0.307	2.074	0.052

3.4 Summary

The four analysis methods yield what initially appear to be conflicting results. Both the conventional and directed content approaches to the qualitative analysis of operator comments point to Perceived Ease of Use as the source of operator attitudes toward the data collection system. However, the qualitative and inferential statistical analyses suggest that operators had a moderate-to-strong intention to use the system, despite generally disagreeing that it was useful for their work. In particular, operators did not agree that the system helped them to perform their job tasks well. Ratings of Ease of Use were mid-range, offering some confirmation of the qualitative analyses, but also moderating the severity of that finding. Finally, the regression analyses revealed the complexity of the Intention to Use picture, particularly with respect to Perceived Usefulness.

4 RECOMMENDATIONS

This analysis identified a number of design features of the mobile data collection system that can be modified to increase user acceptance of the new technology. Table VII lists the recommended enhancements to the data collection system, identified over the course of the analysis. These enhancements have near-term implications for increasing operator acceptance of the new data collection technology. The rationale for each enhancement is listed, along with the TAM determinants that the enhancement is anticipated to impact. Where more than one TAM determinant is listed, the determinants are listed in order of relevance to the recommendation.

Table VII. Selected Recommended System Enhancements

Recommendation	Rationale	Impacted TAM Determinants
Communicate the benefits of using the data collection system to the operators	Operators perceived the new system to increase workload without added benefits. Designers should communicate the net benefits of system adoption.	Perceived Usefulness, Result Demonstrability
Create a map or database of barcode locations	Operators reported difficulty in identifying the location of some barcodes.	Perceived Ease of Use
The data collection system should mirror the station and system operating states	The system did not recognize the states of the reactor, requiring operators to enter data for non-operational equipment.	Perceived Ease of Use
Implement error correction functionality	Operators were frustrated that the system did not allow input error correction	Perceived Ease of Use
Implement a search capability	A search function would allow operator to identify adverse system health trends.	Perceived Ease of Use, Result Demonstrability
Implement volume adjustment for the unit	Operators indicated they could not always hear the data input acknowledgement.	Perceived Ease of Use
Match current parameter limits or acceptance criteria to current trend levels	Acceptability limits for the operating parameters did not match the current operating values/trends. Operators had to acknowledge notifications for parameters within the normal operating range.	Perceived Usefulness, Perceived Ease of Use
Enable a larger font option in the handheld unit.	Operators reported difficulty viewing the current font size on the handheld device.	Perceived Ease of Use
Ensure that barcodes are sufficiently spaced to avoid incorrect scanning	Barcodes were frequently located in close proximity to one other. This led to operators scanning incorrect barcodes.	Perceived Ease of Use
Increase salience of adverse parameter trends	Adverse system trends were easier to identify using the paper recording sheets, as the values were closer together.	Perceived Use-fulness, Perceived Ease of Use
Allow customization of the sequence of data collection for each set of rounds	Operators reported that the order in which they completed rounds varied by individual and round.	Perceived Ease of Use, Perceived Usefulness
Populate the data input field with the last reading.	Requiring the re-entry of values that rarely change is an ineffective use of effort.	Perceived Ease of Use

5 CONCLUSIONS

When operators initially resisted the introduction of the mobile data collection technology, management and system developers considered implementing either mandatory use policies or training to overcome the perceived intransigence or suspected lack of competency. However, by modeling the determinants of use intention among the operator population, system designers became aware of a complex set of usability and usefulness factors (and interactions) predicting use. None of these factors would have been addressed by either policies mandating use or system training, suggesting that either intervention would have met with further operator resistance.

Instead, the TAM modeling effort revealed opportunities for design interventions that target the factors more likely to have a positive impact on use intention. The analyses supported the conclusion that these interventions should balance usability improvements and near-term additions to functionality. Usability improvements focused on interface design and system integration modifications to decrease operator workload. New functionality focused on improving utility by communicating to operators how the collected data are used downstream, and correcting the prevalence of false alarms.

Given the relative ease and minimal expense with which the survey and data analysis were conducted – and the depth of insight obtained – TAM showed promise as an iterative system development tool for mobile applications in nuclear facilities. Although the case study related in the paper was undertaken in response to expressed reluctance to use a particular mobile system, the TAM process could be used to anticipate use intention of a new technology application. The insights could then be included in an initial design effort, further increasing the utility and cost advantage of such an effort.

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