

An Information Systems Model of the Determinants of Electronic Health Record Use

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Keywords

Electronic health records, health information technology, EHR evaluation, provider assessment of EHR quality

Summary

Objectives: The prominence given to universal implementation of electronic health record (EHR) systems in U.S. health care reform, underscores the importance of devising reliable measures of factors that predict medical care providers' use of EHRs. This paper presents an easily administered provider survey instrument that includes measures corresponding to core dimensions of DeLone and McClean's (D & M) model of information system success.

Methods: Study data came from self-administered surveys completed by 460 primary care providers, who had recently begun using an EHR.

Results: Based upon assessment of psychometric properties of survey items, a revised D&M causal model was formulated that included four measures of the determinants of EHR use (system quality, IT support, ease of use, user satisfaction) and five indicators of provider beliefs about the impact on an individual's clinical practice. A structural equation model was estimated that demonstrated a high level of inter-correlation between the four scales measuring determinants of EHR use. All four variables had positive association with each of the five individual impact measures. Consistent with our revised D&M model, the association of system quality and IT support with the individual impact measures was entirely mediated by ease of use and user satisfaction.

Conclusions: Survey research provides important insights into provider experiences with EHR. Additional studies are in progress to investigate how the variables constructed for this study are related to direct measures of EHR use.

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1. Introduction

Electronic health records (EHR) are widely heralded as a key component of health care reform in the U.S. [1, 2]. Proponents claim that EHRs can both reduce costs [3] and improve the quality of medical care [4, 5]. To date, the empirical basis for these claims is somewhat mixed [6, 7], although there is evidence that specific EHR functions, such as clinical decision support and computerized physician order entry, can improve quality [6], eliminate medication errors [8, 9] and reduce unnecessary tests [10].

Whatever their potential benefits, EHR adoption and use have been generally sluggish, with variation across specialties and geographical locations [11]. Recent data suggest that approximately 40 percent of US physicians and 27 percent of hospitals are using at least a “basic” electronic health record [12, 13]. There is also a marked disparity in uptake between small and large physician groups, and location. EHR use ranged from 22% in District of Columbia to 71% in Wisconsin [13]. To promote the adoption and meaningful use of certified EHR technology, the U.S. congress included the Health Information Technology for Economic and Clinical Health (HITECH) Act, as part of the American Recovery and Reinvestment Act of 2009 (Recovery Act) [14]. Since 2011 the Medicare and Medicaid EHR programs [15] have provided incentive payments for both hospitals and health care professionals, who demonstrate meaningful use of certified EHR technology and meet other program requirements established by the Centers for Medicare & Medicaid Services (CMS). Besides implementation costs, both user and organizational factors may further influence the optimal use of EHR systems [11]. However a comprehensive set of validated measures applicable for health information systems is absent for investigation of user and organizational determinants of EHR use. This study describes a survey instrument designed to measure multiple dimensions of medical care providers’ perceptions and beliefs about the quality of their clinic’s EHR system and its impact on patient care.

2. Objectives

We constructed a questionnaire for medical care users of EHRs that was guided by DeLone and McLean’s (D&M) seminal review of measures of Information Systems (IS) success [16, 17]. The survey included a battery of 35 questions that formed nine scales covering three D&M domains of information system success. Study data were obtained from a post-implementation survey administered to a sample of EHR users working in a large number of primary care settings. We describe the construction and psychometric properties of the scales. To explore the theoretical and empirical coherence of the nine scales, we estimated a structural equation model of the hypothesized causal links among the scales based upon a revised version of the D&M IS model.

3. Background

3.1 Elements of the DeLone and McClean Information Systems Model

More than two decades after its original publication, D&M remains an influential research synthesis, distilling measures devised in hundreds of empirical studies into six constructs. Construct labels and succinct definitions are taken directly from D&M’s 1992 article[16]:

- **System Quality:** measures of the information processing system itself (p. 64)
- **Information Quality:** measures of information system output (p. 64)
- **Information System Use:** recipient consumption of the output of an information system (p. 66)
- **User Satisfaction:** recipient response to the use of the output of an information system (p. 68)
- **Individual Impact:** the effect of information on the behavior of the recipient (p. 69)
- **Organizational Impact:** the effect of information on organizational performance (p. 74).

Within each of these constructs further dimensions may be specified for empirical study. Within user satisfaction we separate out ease of use and we measure five separate dimensions of individual impact. D&M further proposed (► Fig. 1) a causal interdependence between these six constructs.

The model specifies that system quality and information quality jointly affect both system use and user satisfaction. Information system use and user satisfaction can each affect the other. Both are also antecedents of individual impact, which in turn leads to organizational impact.

3.2 Prior Efforts to Measure D&M constructs

The D&M seminal article has stimulated a substantial body of research to validate measures for each of the six constructs and the model has been tested and validated in hundreds of studies in the management IS domain over the last 20 years [17]. A much smaller body of research has attempted to assess whether individual empirical measures of the D&M constructs fit the proposed causal model [18]. There are even fewer studies that have specifically adapted D&M for clinical information system (CIS) evaluation. Van der Meijden and colleagues used this model to categorize the different measures of success used in 33 inpatient CIS evaluation studies [19]. They concluded that the D&M model is applicable to understanding success of CIS and found evidence supporting all constructs of the D&M model. Hayrinen and colleagues applied the D&M constructs to classify EHR evaluation studies and found that outcomes related to the information quality construct were most frequently measured [20]. Otieno and colleagues developed a survey to measure nurses' views regarding EHR, focusing on the constructs of use, information quality, and impact on clinical care [21].

Although the survey instrument for this study was devised to measure D&M constructs, the survey questions and scales also measure related constructs specified in other theoretical models of the adoption and use of information technology. For example, perceived ease of use is a common measure across theories because of the large amount of research relating to the Technology Acceptance Model [22]. However, as noted by Petter and colleagues [23], perceived ease of use as used in TAM does not capture the external constructs of D&M, such as system quality. A number of researchers have incorporated D&M constructs with TAM noting that D&M constructs are needed to capture external factors not measured in TAM [24-26].

Despite the previous work using D&M described above, there is no single instrument that brings together measures of multiple D&M constructs that has been validated in the context of EHRs in primary care settings. Our work addresses this gap. For this study, we limit the empirical range of measures of the D&M constructs to system quality, information quality, user satisfaction, and individual impact as perceived by the user. Direct measures of EHR use and impact are conspicuously absent in the study's model. As reviewed in the discussion section below, the methodological challenges and caveats in measuring those two constructs directly from EHR records merit a separate article.

4. METHODS

4.1 Project Setting: Primary Care Information Project (PCIP)

Study participants were primary care providers, physicians, nurses and physicians assistants, who practice at medical care organizations assisted by PCIP, a Bureau of the New York City Department of Health and Mental Hygiene (DOHMH) to foster EHR use [27]. Through a competitive call for proposals, PCIP selected ClinicalWorks (eCW) as the EHR software vendor for its initiative to foster EHR adoption and use among NYC primary care organizations located in medically underserved communities. Practices were recruited by PCIP to participate in the EHR adoption and use initiative, and all participating providers received a standard software package, training, and technical support after going 'live' on the eCW EHR. Over 500 solo or small group practices, federally qualified community health centers and hospital outpatient departments, with over 2,500 primary care providers, have adopted eCW through PCIP.

4.2 Questionnaire Development

Study data came from a post implementation survey (“Provider survey”) administered by PCIP staff as part of its program evaluation. The original pool of items for possible inclusion in the study’s survey instrument was assembled through a literature search that yielded 23 articles presenting validated survey measures of IS implementation. Based upon this review, we prepared a table that grouped validated scales and their constituent items by D&M construct. A panel of informatics experts with social science, nursing and medical care expertise drawn from members of our research team and senior leaders of the PCIP project (including the Assistant Commissioner and Director of PCIP) reviewed this table and recommended specific questions for inclusion in a pilot survey. The expert panel selected an initial pool of 69 questions grouped into four D&M constructs:

- a) system quality (14 items),
- b) information quality (10 items),
- c) three dimensions of user satisfaction-user satisfaction (9 items), perceived value (3 items), ease of use (9 items) and
- d) five dimensions of provider beliefs about the impact of EHR use on their clinical practice (individual impact).

The latter included items to measure change following EHR implementation in provider’s productivity (2 items), decision making (3 items), documentation (6 items), workflow (9 items) and prevention practices (4 items). Items were reworded to apply to EHR use. A small number of new questions were written specifically for this study.

A pilot study was undertaken between May and August of 2008. Participants eligible for the pilot survey were medical providers who have begun using the eCW EHR system, did not complete a pre-implementation survey (to avoid survey fatigue); and who had at least six months access to the EHR. Self-administered surveys were distributed to 149 practitioners working at 42 different practice organizations. We received 96 completed pilot surveys from 38 different practices.

Because the number of information system questions included in the pilot study, 69, was considered far too many to be retained in a self-administered survey to be completed during the work day, we applied a data driven method, principal component analysis (PCA) to the pilot data. The original set of D&M related items was reduced to 35 included in the revised version of the post-implementation provider survey (available as online appendix to this article). Small factor loadings derived from the PCA, lead us to drop three items that measured the DM construct, perceived value. Otherwise, multiple items were retained for all other constructs. ▶Table 1 and ▶Table 2 list the questions included in the revised provider survey grouped by D&M construct, their response categories and the sources of the questions. The revised provider survey also included questions on provider demographics and communications with other providers.

Approximately six months after the EHR was installed in a practice, the revised post-implementation survey was distributed to all providers authorized to use their agency’s EHR. Respondents had the option to complete an online or paper-and-pencil version of the survey. By May 2010, the pilot and revised surveys had been distributed to 893 eligible providers working at approximately 450 medical care organizations.

4.3 Scale Validation

To assess the psychometric properties of operational scales formed from questionnaire items, we began by inspecting correlations among the provisional sets of items forming each scale. We used Cronbach alpha reliability coefficient to measure internal consistency of each scale. We checked to see if items from the original pool of questions that were minimally correlated with other items selected for each scale could be dropped without diminishing the psychometric properties of study scales. In a few instances we retained multi-item scales despite questionable psychometric properties (alpha <0.7), when we judged that content validity outweighed inter-item reliability. For scales with four or more items, we performed a principal factor analysis to assess each scale’s dimensionality and construct validity. We inspected the eigenvalues a measure of each factor’s variance, to determine if the initial pool of items for each scaled might form more than one interpretable dimension. As de-

scribed in the results section, scale values were derived from either factor scores or summation of raw item values.

4.4 Statistical Modeling of Revised D&M Causal Model

We next formulated a revised version of the D&M causal model to further investigate the conceptual coherence among scales measuring different constructs of the D&M model (► Fig. 2). Structural parameters for the linear equations specified by this model were estimated using multiple regression methods. Estimates of regression coefficients for variables of theoretical interests were adjusted for possible confounding influences: length of time in practice, gender and number of months using the system. Standard errors of regression coefficients were adjusted for unmeasured dependencies among multiple providers in the same practice using the population average model variant of generalized estimating equations (GEE) [28].

Although missing information was minimal for any single variable, the number of missing values on one or more variables in the regression equations was substantial. For some regression equations, complete data were available for only 77% of respondents. To make optimal use of available information, we applied the chained equation method of multiple imputation of missing values [29]. We generated 20 complete data sets of sample size equal to 460. Rubin's formulae was used to combine estimates of regression coefficients and standard errors from the multiple complete data sets [30]. All statistical analyses were performed using Stata 11.

5. Results

5.1 Sample Characteristics

The post implementation provider survey was completed by 460 primary care providers for a 52% response rate; 79% were medical doctors, 8% were nurse practitioners, 7% were physician assistants, and 5% were doctors of osteopathy. Survey respondents were employed at 211 different practices. The practices included 178 small office based practices, 20 community health center locations, and 13 units of large medical centers. The number of completed surveys by practice ranged between one from 138 practices to 19 from one practice. Equal numbers of males and females completed the survey. The median length of time practicing medicine was 11 years (mean = 13.5, standard deviation [SD] = 9.3) and ranged up to 40 or more years. Almost all respondents, 96%, reported formal training on the PCIP implementation of eCW; two-thirds reported 10 or more hours of instruction. Although the surveys were scheduled for administration approximately six months after a provider first gained access to the system, 10% of the respondents reported using the system for less than six months and 40% for nine or more months (primarily because of logistical issues of when surveys were mailed and received).

5.2 Scale Properties and Final Scale Specification

Assessment of the psychometric properties for scales measuring system and information quality constructs (► Table 1) resulted in a substantial revision between the original grouping of items and the composition of the final scales. The initial group of five system quality items had a marginal Cronbach alpha of 0.56, and the factor analysis retained two factors with positive eigenvalues of 1.23 and 0.34. The two items measuring information quality had a modest 0.15 correlation.

We next investigated the properties of combining the seven items measuring system and information quality constructs into a single scale. The Cronbach alpha for the pooled items was .65 and the factor analysis resulted in a two-factor solution (eigenvalues of 1.68 and 0.52 respectively). One item from the original pool of information quality, IQ2, and two items from the system quality pool, SQ1 and SQ2 had the highest loadings (0.49, 0.56 and 0.64) on the first factor (see ► Table 1 for the wording of these and subsequent items. IQ and SQ prefixes refer to information and system quality questions). These items formed the revised three-item system quality scale with a Cronbach alpha scale reliability of 0.64.

We created a second scale from the two items that loaded on a second factor SQ4, “I receive prompt service when I require technical support”, and SQ5, “technical support can be relied on to fix my problem”. Based upon the related content of the two items, we labeled this scale as measuring a new construct, the level of agency IT support. This scale we believe is of policy interest, but does not correspond to any of the original D&M constructs. It is notable that these two items were written specifically for the project survey, rather than from a previously published D&M scale.

We dropped IQ1 and SQ3. We judged that they did not contribute useful information for improving scale reliability. These latter items had weak factor loadings (less than 0.3), their inclusion in both system quality and IT support reduced Cronbach alphas and their marginal distributions exhibited limited variation.

► Table 2 summarizes the psychometric properties of the scales measuring the D&M user satisfaction and individual impact constructs. All but one of the preliminary items were retained in scales measuring distinct dimensions underlying these two construct. In contrast to the system quality items, there was no evidence for further subdivision of the two user satisfaction scales and the five individual impact scales.

The three items measuring user satisfaction had a Cronbach alpha equal to 0.77. The three items measuring ease of use showed weak inter-correlations. We dropped item EU3, “the EHR has made it easier for me to access patient information from outside the office” as its content was judged not relevant to the EHR functionality, which was intended exclusively for in-office use. Despite a poor Cronbach reliability alpha of .18, we decided to combine the two items to measure ease of use because of their strong content validity.

We retained all items that measured the respondents’ perceptions of the positive or negative impact of the electronic health record on various dimensions of clinical practice, which corresponded to D&M’s individual impact construct. With the exception of productivity (Cronbach alpha = 0.35), the individual impact scales had Cronbach alphas of 0.8 and higher. A single factor accounted for a substantial percentage of the common variance for items forming each individual impact scale with four or more items (documentation, workflow, and prevention). The eigenvalue for the first factor was 3.06 for the six-item documentation scale, 3.65 for the 8-item workflow scale and 2.25 for 4-item prevention scale. Eigenvalues for subsequent factors were substantially smaller, all below 0.47. Factor loadings on the first factors ranged between 0.65 and 0.8. By contrast, factor loadings never exceeded 0.45 for higher order factors.

Values for the final scales with three or more items were computed from factor scores which have means of 0 and standard deviations of 1. Values for the four two-item scales were obtained by averaging the items. The means and standard deviations for these variables were: ease of use (mean = 3.3, SD = 0.87), productivity (mean = 3.1, SD = 1.1), and decision making (mean = 3.2, SD = 1.1). The IT support items were centered on their means and then summed to create this scale.

5.4 Estimation of a Revised D&M Model.

To assess the conceptual coherence and criterion validity of the D&M scales, we next estimated the structural parameters measuring associations between the variables forming a revised D&M model depicted in ► Fig. 2. This model, includes nine variables of theoretical interest: a scale combining items measuring system and information quality, agency IT support, two user satisfaction measures, and five individual impact measures. The model specifies that user satisfaction is a function of perceived system quality, IT support and ease of use. It further specifies that influence of system quality and IT support on individual impact is mediated through the two user satisfaction variables.

► Table 3 presents the estimated unstandardized regression coefficients for the revised D&M model. The results are consistent with the hypothesized causal relationships specified in ► Fig. 2. System quality and IT support were positively associated with respondent rating of the EHR’s ease of use (column 1). In turn, these three variables were each positively associated with user satisfaction (column 2).

Columns 3, 5, 7, 9 and 11 in ► Table 3 present the estimates of the effects of the system quality and IT support, on the individual impact variables, before adjusting for the hypothesized mediating effects of ease of use and satisfaction. System quality had the expected positive and significant associations with all of the individual impact variables. A one standard deviation change in a respon-

dent's perception of system quality was associated with between 0.4 to 0.5 standard deviation increases in each of the five measures of a respondent's assessment of the positive impact of EHR on the individual's clinical practice. IT support exhibited a positive but weaker effect on the individual impact variables. This variable only achieved levels of conventional statistical significance ($p < 0.05$) for its association with prevention and decision.

When we add ease of use and user satisfaction to the structural equations (columns 4, 6, 8, 10 and 12 in ► Table 3), they exhibited independent and positive associations with favorable respondent ratings on all five measures of individual impact (all coefficients were significant at the $p < 0.05$ level or better). Moreover, consistent with the hypothesized mediator roles of ease of use and user satisfaction, the independent associations between system quality and IT support were substantially reduced in the fully specified model. After adjustment for ease of use and user satisfaction, the size of coefficients for system quality were reduced by 50% or more when compared to their corresponding unadjusted values. System quality's effect was completely mediated for productivity, documentation and decision-making. Its coefficients in columns 8, 10 and 12 in ► Table 3 were statistically insignificant ($p > 0.1$). Statistical tests of mediation in ► Table 4, confirm that presence of significant indirect effects of system quality for all five individual impact variables [37].

IT support's pattern of association with the individual impact variables, albeit weaker than those for system quality, was also consistent with complete mediation through ease of use and satisfaction. As shown in ► Table 3, none of the coefficients directly linking IT support to the individual impact variables were statistically significant ($p < 0.05$) after controlling for the mediator variables. In particular, the evidence that IT support's effect on individual impact operated through ease of use and satisfaction was strongest for prevention, productivity and documentation (► Table 4).

6. Discussion

Although this study built upon development of measures in many earlier studies, to our knowledge, this is the first study that presents a comprehensive set of measures for the D&M model adapted for primary care providers' use of an EHR system. Study findings demonstrate that survey research is a feasible method to obtain reliable information about provider perception and beliefs that may influence EHR use. Nine scales were constructed from 32 items on a self-administered post-implementation provider survey used to evaluate the implementation of the EHR at over 211 primary medical care practices participating in the Primary Care Information Project. Many of the items used to measure study constructs indicated substantial variability in user perceptions and assessment of a common EHR system. Study scales measured dimensions of D&M constructs for system quality, user satisfaction and individual impact. One scale measuring agency IT support emerged in addition to constructs in the original D&M schema. With the exception of ease of use and productivity, all scales had moderate to high reliability.

The results of regression analysis offered strong evidence that the nine scales result in an empirical model that conforms to a revised D&M causal model. The four "determinants" of EHR impact on individual clinical practice (system quality, IT support, ease of use, satisfaction) were highly inter-correlated as predicted by the D&M model. Higher satisfaction and perceived ease of use were independently associated with a more positive assessment of EHR on each of the five individual impact variables. Consistent with our model, system quality and IT support's influence on individual impact was largely indirect (i.e. mediated through their association with ease of use and user satisfaction). It should be emphasized that our purpose was to investigate the strength of association among the putative indicators of D&M model. The cross sectional design does not permit a causal interpretation of study results.

It is important to distinguish the study measure of system quality, which is based on individual perception rather than an objective assessment of inherent qualities of a system. The inherent variable nature of the personal assessment underscores that providers working with the same EHR may come to very different assessment of the quality of the system. We should also add that the items selected for this study did not discriminate between the D & M model's distinction between "system quality" to measure technical success and "information quality" to measure semantic success [17]. This raises questions for further research as to whether there is an empirically measurable distinc-

tion between these two constructs that was missed in this study or whether the typical user does not discern the more abstract distinctions implied by these two constructs.

Our model includes one construct, IT support that was not part of the original D&M formulation. We do note this variable has some resonance with a construct called “service quality”, which was added by D&M in their revision of the classical model [17]. Although our variable was constructed from items specifically added to the user survey, it appears, as we might expect, an important factor in determining EHR use. Ready access to IT support, along with system quality, was strongly associated with ease of use and user satisfaction. It appears that the level of IT support, whether provided by agency staff or an outside contractor may be an important factor in shaping user satisfaction and perception of ease of use. Similar to system quality, IT support’s influence on the individual impact variable was largely mediated through user satisfaction and ease of use. However, IT support’s total effect on the individual impact variables was generally weaker than that for system quality. This suggests a more detailed investigation of the properties of IT support might yield more reliable scales that contain complete information about the role of IT support in promoting EHR use.

A limitation of the current model is the absence of direct measures of EHR use and impact. Individual impact variables are best interpreted as a separate dimension of information systems success and not surrogates for EHR use. We have access to PCIP EHR activity data in the form of monthly counts of how often providers use different EHR functions. However, we have learned that working with EHR data is complicated. We have encountered multiple challenges in the conceptualization of EHR use, in devising reliable and valid measures of EHR use from EHR activity data, and merging survey data with the EHR data. The cumulative effect of these challenges substantially reduced the number of surveys that could be linked to informative EHR use variables, and undercut valid interpretation of models estimating the association between the EHR use and other D&M variables.

A companion paper is currently under preparation that outlines the conceptual and methodological challenges that stand in the way of expanding empirical studies that seek to combine measures of the determinants of EHR use obtained through surveys with EHR use metrics. In addition to measuring EHR use, our model may be expanded in two directions. First the model can be expanded to include patient health outcomes so that we can assess the link between EHR use and its impact on individual provider practice and improvement in the effectiveness of care. Second, the IT support construct is but one of a larger set of possible contextual variables that might influence individual EHR use. As possible dimensions of contextual influences on individual EHR use, we are considering both practice characteristics as well as properties of agency networks in which individual practices are embedded. This is consistent with other recent work that suggests expansion of the D&M model to include more organizational and contextual factors [38, 39].

7. Conclusion

Survey research is a promising approach for gathering program evaluation and research information to assess use of an EHR, and ultimately, its impact on clinical practice. To our knowledge this is the first study to apply survey research methods to measure key D&M constructs in the context of EHR research. Our findings show that providers using the same EHR often have quite different perceptions about the quality of the system, and consequently, their satisfaction and assessment of ease of use and the EHR’s impact on their individual clinical practices. We also show that IT support plays a role in user satisfaction and perceived ease of use. Decision-makers responsible for EHR implementation can apply findings from self-administered questionnaires to assess need for improved system design. Survey findings can also identify providers who are relatively negative in their assessment of system quality and thus may benefit from targeted technical support and training to boost their comfort with the EHR and consequently, perceived usefulness and actual use of the EHR.

Clinical Relevance Statement

The post implementation provider survey described in this paper is a useful tool for evaluating EHR implementation. Practices that have recently installed or modified an EHR may consider incorporating the questions presented in this article as part of an in-person or online user survey. It

has been successfully administered in a larger number of both freestanding and hospital-based primary care practices in New York City. These scales have good psychometric properties for diagnosing user perceptions of the strengths and weaknesses of an EHR for clinical practice that prior research has identified as important determinants of system use.

Conflict Of Interest Statement

The Authors have no conflict of interest regarding this study.

Protection Of Human Ssubjects

The study was approved for human subjects by the Institutional Review Boards of Columbia University Medical Center and was deemed exempt for review by the NYC DOHMH review board.

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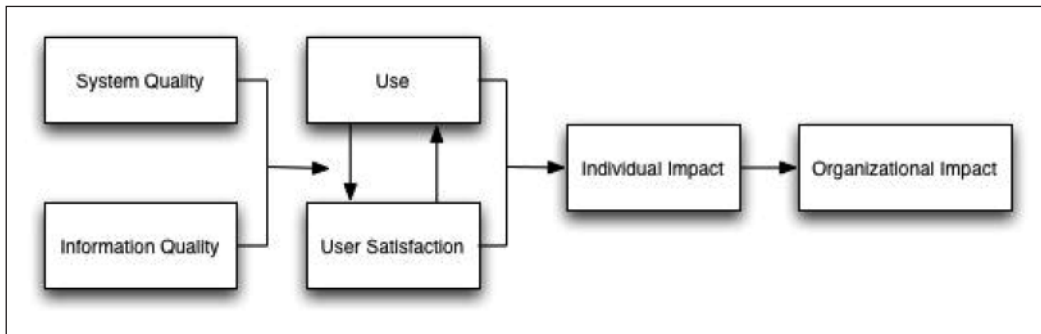


Fig. 1 DeLone and McLean Model

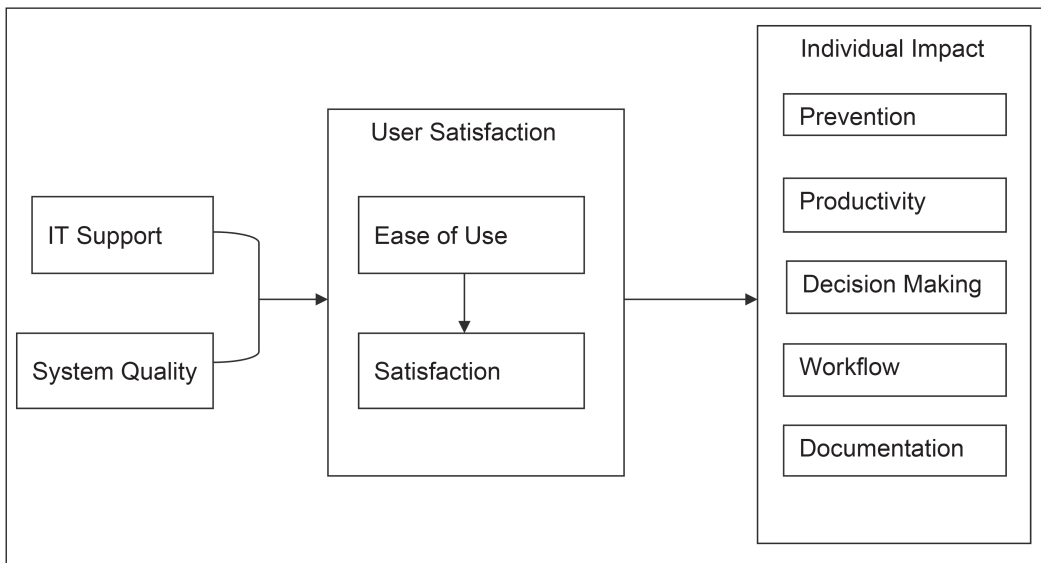


Fig. 2 Revised DeLone & Mclean Model

Table 1 Properties of Scales Measuring D&M System and Information Quality Constructs

Original Construct	Preliminary Grouping of Scale Items	Final Construct	Final Scale Items and Cronbach Alpha
Information Quality ¹	<ul style="list-style-type: none"> ● IQ1. * There is inaccurate information in the EHR [18, 21]. ● IQ2. The EHR provides me with all the information I need to take care of the patient [ibid]. 	System Quality (includes information quality item)	<ul style="list-style-type: none"> ● SQ1'(IQ2). The EHR provides me with all the information I need to take care of the patient. ● SQ2'(SQ1). It is relatively easy to move from one part of a patient record to another. ● SQ3'(SQ2). How often can you count on the EHR to be up and available? <p>Cronbach alpha = 0.64</p>
System Quality	<ul style="list-style-type: none"> ● SQ1. It is relatively easy to move from one part of a patient record to another¹ [31]. ● SQ2. How often can you count on the [EHR to be up and available¹ [21]? ● *SQ3. I have to look for assistance most of the time when I use the EHR¹ [31]. ● SQ4. I receive prompt service when I require technical support⁺². ● SQ5. Technical support can be relied on to fix my problem⁺². 	IT Support	<ul style="list-style-type: none"> ● IT1(SQ4). I receive prompt service when I require technical support⁺². ● IT2(SQ5). Technical support can be relied on to fix my problem⁺². <p>Cronbach alpha = 0.74</p>

*dropped question

+Not in original inventory, no source cited

Response categories

1 "never/almost never/some of the time/about half of the time/most of the time/always/almost always"

2 "never/sometimes/always"

3 " Yes/No"

4 "completely disagree/generally disagree/neutral/generally agree/complete agree"

5 " much more difficult/slightly more difficult/no change/slightly easier/much easier"

Table 2 Properties of Scales Measuring User Satisfaction and Individual Impact D&M Constructs

Construct	Items	Cronbach alpha
User Satisfaction		
User Satisfaction	<ul style="list-style-type: none"> ● US1. How often are you satisfied with the EHR system [32]¹? ● US2. Would you recommend your current EHR...⁺³? ● US3. How often is the system successful [ibid]¹? 	0.77
Ease of Use ⁴	<ul style="list-style-type: none"> ● EU1. I have become skilled at using the EHR's advanced features [22, 33]. ● EU2. There are too many alerts and reminders [ibid]. ● *EU3. The EHR has made it easier for me to access patient information from outside the office [ibid]. 	0.18
Individual Impact		
Beliefs about EHR use on Productivity ⁴	<ul style="list-style-type: none"> ● P1. Using an EHR has decreased the amount of time I spend talking to my patients [34, 35]. ● P2. I have to work longer hours to see the same number of patients with the EHR [ibid]. 	0.35
Beliefs about EHR use Decision Making ⁴	<i>Using an EHR has improved my ability to...</i> <ul style="list-style-type: none"> ● DM1. Provide preventive care⁺. ● DM2. Make decisions about patient care [ibid] 	0.80
Beliefs about EHR use Documentation ⁵	<i>How has the EHR changed your performance</i> <ul style="list-style-type: none"> ● DOC1. Documenting physical exams ?[36] ● DOC2. Documenting histories [ibid]? ● DOC3. Documenting allergies [ibid]? ● DOC4. Documenting CPT and ICD-9 codes for billing [ibid]? ● DOC5. Keeping problem lists updated [ibid]? ● DOC6. Keeping medication lists updated [ibid]? 	0.86
Beliefs about EHR use on Workflow ⁵	<i>How has the EHR changed your performance</i> <ul style="list-style-type: none"> ● WF1. Ordering laboratory and radiology tests [ibid]? ● WF2. Reviewing laboratory and radiology tests [ibid]? ● WF3. Writing prescriptions [ibid]? ● WF4. Renewing prescriptions [ibid]? ● WF5. Monitoring medication safety at the point of prescribing [ibid]? ● WF6. Monitoring patient medication adherence [ibid]? ● WF7. Communicating referral information to sub-specialists [ibid] ● WF8. Reviewing referral information from sub-specialists [ibid] 	0.86
Prevention/ Performance Impact ⁵	<i>How has the EHR changed your performance</i> <ul style="list-style-type: none"> ● PREV1. Ordering appropriate preventive care services during the visit [ibid]? ● PREV2. Making a list of patients based on diagnosis or history [ibid]? ● PREV3. Contacting patients to remind them of care for which they are due [ibid]? ● PREV4. Assisting patients in self-management activities [ibid]? 	0.84

*item dropped from final scale

+Not in original inventory, No source cited

Response categories:

¹ "never/almost never/some of the time/about half of the time/most of the time/always/almost always"

² "never/sometimes/always"

³ "Yes/No"

⁴ "completely disagree/generally disagree/neutral/generally agree/complete agree"

⁵ "much more difficult/slightly more difficult/no change/slightly easier/much easier"

Table 3 Full Structural Equation Model for the Revised D&M Model (N = 460)

	Ease Use		UserSatisfaction		Workflow		Prevention		Productivity		Documentation		Decision Making	
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(11)	(12)
System Quality	0.20** (0.06)	0.75*** (0.045)	0.50*** (0.069)	0.20* (0.079)	0.39*** (0.060)	0.16* (0.06)	0.38*** (0.078)	0.00 (0.086)	0.54*** (.061)	0.11 (0.071)	0.48*** (0.071)	0.10 (0.093)	0.48*** (0.071)	0.10 (0.093)
IT Support	0.21*** (0.05)	0.09* (0.046)	0.061 (0.057)	-0.02 (0.053)	0.14** (0.051)	0.08 (0.05)	0.091 (0.067)	0.00 (0.069)	0.086 (.054)	-0.002 (0.048)	0.21** (0.069)	0.12+ (0.069)	0.21** (0.069)	0.12+ (0.069)
Ease Use		0.14** (0.043)		0.20*** (0.048)		0.13** (0.047)		0.17** (0.059)		0.11* (0.043)	3.3*** (0.17)	0.17** (0.064)	3.3*** (0.17)	0.17** (0.064)
User Satisfaction				0.35*** (0.060)		0.27*** (0.057)		0.47*** (0.072)		0.54*** (0.058)		0.46*** (0.079)		0.46*** (0.079)
Constant	3.45** (0.12)	-0.49** (0.17)	0.12 (0.13)	-0.49 (0.17)	0.17 (0.12)	-0.29 (0.20)	3.5*** (0.18)	-2.88** (0.29)	0.11 (0.12)	-0.31+ (0.18)	3.3*** (0.17)	2.68*** (0.36)	3.3*** (0.17)	2.68*** (0.36)

+ p<0.1 * p<0.05 **p<0.01 ***p<0.001

Note: Unstandardized coefficients are reported. Standard errors are in parentheses below parameter estimates. Covariates included, but not reported here, were years practicing, gender, months used eCW at time of survey.

Dimensions of Individual Impact	System Quality		Indirect effects of IT Support through	
	Direct	Indirecta	Direct	Indirect
Workflow	0.20* (0.079) ^b	0.30* (0.080)	-0.02 (0.054)	0.063 (0.079)
Prevention	0.16* (0.06)	0.23* (0.049)	0.08 (0.050)	0.06* (0.024)
Productivity	0 (0.086)	0.38* (0.076)	0 (0.069)	0.091* (0.046)
Documentation	0.11 (0.071)	0.43* (0.069)	-0.002 (0.048)	0.088* (0.039)
Decision Making	0.10 (0.093)	0.38* (0.080)	0.12+ (0.069)	0.09 (0.052)

Table 4
Direct and Indirect Effects of System Quality and IT Support on Individual Impact Variables

^a Indirect effect is difference in estimates of system quality coefficients in ► Table 3 with and without controls on ease of use and user satisfaction.

^b Standard errors are in parentheses below estimates. Standard errors and test of significant for indirect effects are based upon MacKinnon [37].

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