Framework for Quality Metrics in Mobile-Wireless Information Systems[1]

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Abstract

Mobile and wireless devices and networks enable "any place, any time" use of information systems, providing advantages, such as productivity enhancement, flexibility, service improvements and information accuracy. These benefits can be nullified by using systems of insufficient quality. Mobile-wireless information systems face new kinds of problems: narrow bands, small devices, tiny screens, and diversity of users and devices. Information systems quality cannot be measured only by software faults absence; it must be broader, including characteristics to cover all aspects, life-cycle phases, and viewpoints. This research develops a methodology to define and quantify the quality components of such systems, merging two fields together: mobile-wireless applications and standards for product quality assurance. The research has developed a list of questions from which new quality metrics were defined and empirically validated, extending the ISO/IEC 9126 quality standard for mobile-wireless information systems. The paper describes the metrics development process and presents examples of metrics.

Keywords: information systems, mobile, wireless, quality, software engineering.

[1] This article is based on the author's PhD dissertation conducted in the Business Administration School at Bar-Ilan University, Israel, supervised by Dr. Moshe Mor and Dr. David Schwartz.

Introduction

Technology improvements enable the building of information systems which can be used "any place, any time", through mobile and wireless devices and networks. Mobile-wireless information systems can create benefits for organizations; e.g., productivity enhancement, processes and procedures flexibility, customer services improvement and information accuracy for decision makers, which together emphasize competitive strategy, lower operation costs, and improved processes. However, these benefits can be nullified by using non quality information systems. In order to use these systems successfully, they need to be of good quality (Terho, 2002). Quality is a multi-dimension concept which includes a multitude of characteristics. Several attempts have been made to examine the information systems quality nature, to define quality components and to find systematic ways to measure them (ISO/IEC 9126-1, 2001; Kan, 2002; Pandian, 2004). Many information systems fail due to poor quality. Research has been focused on traditional (Kan, 2002) and internet information systems (Calero, Ruiz, & Piattini, 2004; Covella & Olsina, 2006). However, mobile-wireless information systems face new kinds of problems, such as narrow bands, lack of coverage, devices with

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small memory and screens which cannot display large amount of data, and diversity of users and devices. The special mobile-wireless information systems characteristics require a different quality definition.

This research uses software engineering to define the mobile-wireless information systems quality components and develops a methodology to quantify these components, in order to enable the evaluation, comparison, and analysis of mobile-wireless information systems quality.

The research process, as shown in Figure 1, consists of several phases: (1) mobile-wireless information systems examination to detect special quality problems and risks that result from the architectures and protocols of such systems; (2) choice of ISO/IEC 9126 quality characteristics affected by mobility and wirelessness; (3) definition of objects and metrics to allow objective measurement of mobile-wireless information systems quality; (4) metrics theoretical and empirical validation.

This paper focuses on the effects of mobile-wireless information systems on quality characteristics and introduces a list of questions from which new metrics are defined and mapped according to different viewpoints. In addition, two of the new metrics are described.

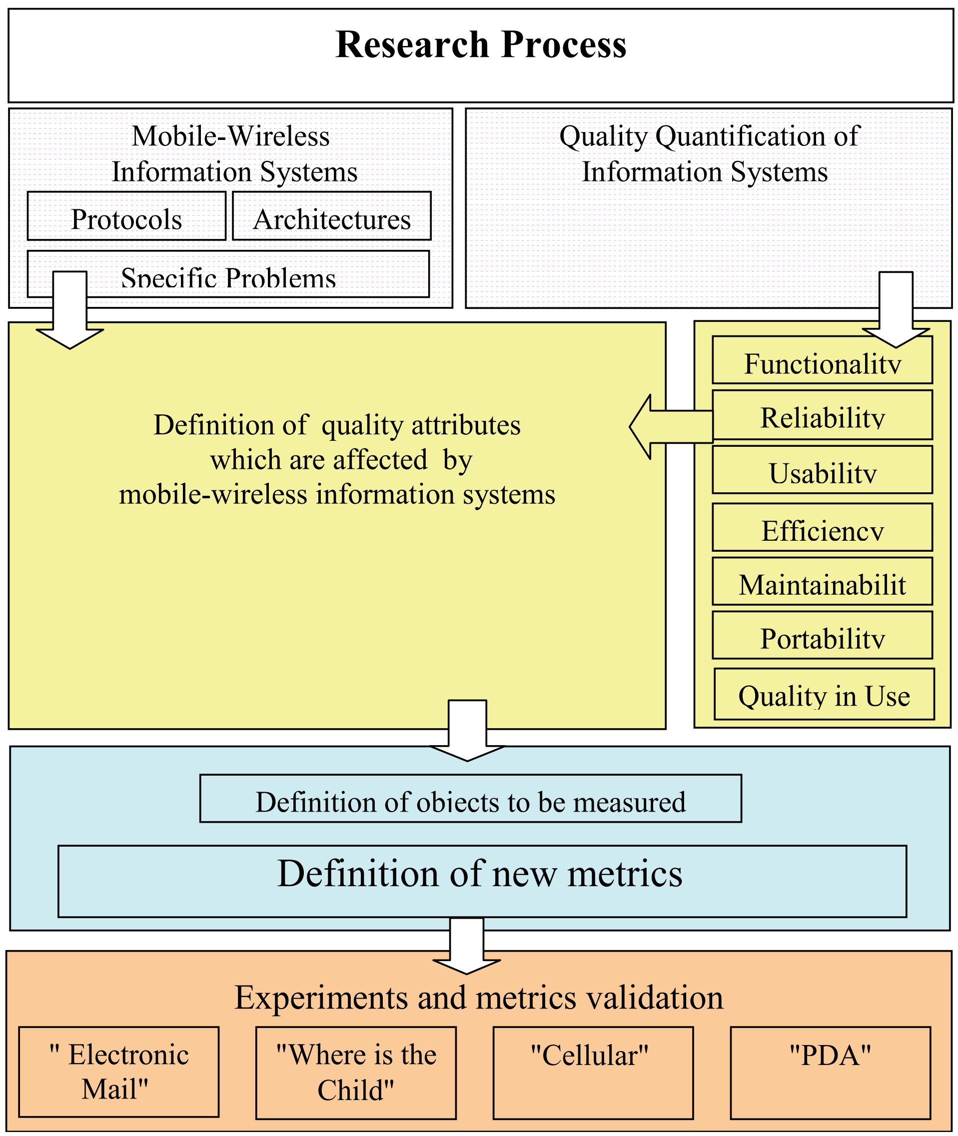


Figure 1 - The research process

Mobile-Wireless Information Systems

Schiller (2000) describes two mobility dimensions: user mobility, which allows connection to the system from different geographical sites, and device mobility, which enables mobility of both user and system, such as laptops, personal digital assistants (PDA), or cellular phones. This research focuses on mobile-wireless information systems, which allow users to be connected any time at any place.

There were unsuccessful attempts to develop mobile-wireless information systems at the beginning of the millennium, since technology, devices and infrastructures were immature. This situation changed during 2003, and analysts agreed that these kinds of systems will grow and their market share will expand (Lau, 2006; Lee, 2003). The major reasons are emergence of third generation wireless networks (UMTS - Universal Mobile Telecommunications System, CDMA2000 1x - Code division multiple access, and GPRS - General Packet Radio Service), their coverage expansion, and development of smart mobile devices.

Applications Based on Mobile-Wireless Information Systems

There are two classifications of mobile-wireless information systems: horizontal and vertical (Stafford & Gillenson, 2003). Horizontal applications are general, adaptable to a wide range of users and organizations, e.g.: e-mail, browsers, and file transfer applications. Vertical applications are specific to a type of users or organizations, for example: financial applications, such as money transfer, stock exchange and information inquiry; marketing and advertising applications according to the actual user position, i.e., pushing coupons to stores and information about sales nearby; emergency applications to check real-time information from government and medical databases and utility companies applications used by technicians and meter readers.

There are several advantages of using these systems in the place and time of the event occurrence, in particular, productivity enhancement, resource allocation flexibility, competitive advantages, service improvements, and information accuracy (Malladi & Agrawal, 2002).

Problems in Mobile-Wireless Information Systems

Mobile-wireless information systems face some unique problems originating from the mobile devices. First, these devices have small memories, short battery life, and limited calculation and computation capabilities. Second, there is a wide variety of devices, possessing different characteristics, and the application must be adaptable to all of them. Third, the use of the devices is uncomfortable because of their size, tiny screens, low resolution, and small keyboards that are difficult to operate. Fourth, security problems can arise when devices are lost, due to possible unauthorized access to sensitive data.

The network causes other problems, including: limited bandwidth, inconsistent connection stability, transfer delays, and varied standards and protocols, some with high overhead, decreasing the performance level. Moreover, when users operate the system during mobility, the connection point to the network can change, obstacles can disturb, causing temporary disconnections, interruptions, or disturbances. Besides, security, privacy, and confidentiality are very important issues (Di Pietro & Mancini, 2003; Herzberg, 2003).

These problems intensify when the information system is targeted for a wide audience, where the users are faceless and there is neither user training nor implementation, but they are significant also in closed organizational information systems.

Information Systems Quality Measuring

Measuring creates a quantitative description of processes and products which allows behavior comprehension. This knowledge enables the selection of tools and techniques to control and improve processes, products, and resources. People at dissimilar tasks: developers, managers, users, etc. have different viewpoints on quality. Information systems quality cannot be measured only by the absence of software faults; it must be broader, including characteristics to cover all aspects, life-cycle phases, and viewpoints.

Several standards and frames have been defined for information systems development process measuring. The most recognized are CMMI (Capability Maturity Model Integration) (Chrissis, Konrad, & Shrum, 2006), ISO9000:2000 (ISO9000, 2000) with its ISO90003 (ISO90003, 2004) guidelines for software and ISO/IEC 15504 (ISO/IEC 15504, 2004, 2006), formerly known as SPICE (Software Process Improvement and Capability Determination) which integrates CMMI and ISO90003.

Product quality measuring is complicated, since there is no consensus on quality meaning. The most recent model, defined by the International Organization for Standardization and the International Electrotechnical Commission, is ISO/IEC 9126 (ISO/IEC 9126-1, 2001) standard that decomposes quality into several characteristics, further divided into sub-characteristics. This standard defines internal metrics to be measured without having to operate the system, external metrics to be measured while testing or executing the system, and quality in use, which is the system quality from the user's viewpoint.

What Do We Need To Measure?

Mobile-wireless information systems must be measured on the basis of traditional systems metrics, e.g. ease of maintainability, minimum complexity, lack of faults, mean time between failures (MTBF), etc., which are the fundamental metrics for all information systems. Furthermore, they must be measured according to internet systems metrics, e.g. no broken links, ease of navigation, etc. In addition, they need to be measured with special targeted mobile-wireless metrics (Spriestersbach & Springer, 2004).

In this research, an additional questions list, specific for mobile-wireless information systems, was developed using Goal-Question-Metric approach (Basili & Rombach, 1988), which constituted the basis for quantitative metrics definition. The mobility and wireless influence on ISO/IEC 9126 quality characteristics are described below, followed by the relevant questions.

Functionality

Functionality (ISO/IEC 9126-1, 2001) includes four sub-characteristics: suitability, accuracy, interoperability, and security. In location aware applications, using the automatic user location can alleviate the input operation, improving suitability. However, the user location can change during the transaction performance, causing incorrect output and affecting the accuracy. The application may need to access data at different servers and interact with one or more specified systems. The application must use standard protocols in order to perform this correctly and support interoperability. Security is affected in different ways, for example: loss or theft of the mobile device, exposure of the messages in the network to unauthorized access, and privacy loss because of location aware functions. The mobile-wireless information systems quality questions that need to be quantified are:

- Does the application use location aware functions where applicable?
- Is the location aware functions output updated according to the user's position change during the transaction operation?
- Does the application apply user profile in order to adapt the output to user and device?
- Does the application use standard protocols and interfaces?
- Does the application include mechanisms of authentication, encryption, authorization, and confidence?

Reliability

Reliability (ISO/IEC 9126-1, 2001) includes the following sub-characteristics: maturity, fault tolerance, and recoverability. During mobility, network problems, hiding obstacles, and hopping between antennas may disturb and interrupt communication. Thus, the system must be fault tolerant to maintain a specified level of performance, and, when connection is suspended, the system needs to re-establish the communication and recover the data directly affected, supporting recoverability.

- To what degree does the mobility cause interruptions?
- Does the application use cache memory efficiently to avoid loss of data?
- Does the transaction interruption damage data?

Usability

Usability (ISO/IEC 9126-1, 2001) includes the following sub-characteristics: understandability, learnability, operability, and attractiveness. Usability is one of the most important characteristics when targeting systems to wide audiences, which need to operate an intuitive system without direct training and support. Mobile users may not be able to concentrate on the system use, so the application should not be complicated, the input must be easy to insert, intuitive, and simplified by using location aware functions (Terrenghi, Kronen, & Valle, 2005). The operability sub-characteristic is affected mainly by the mobile device attributes: screen size, keyboard or numeric pad, etc., which restrict input and output interaction possibilities. Moreover, the noisy surroundings (when operating the system while on a street or public environments) may distract the user and cause input errors, inaccuracy, and slowness. The ability to reach the relevant data "any place any time" enlarges the system attractiveness.

- To what degree is the screen over-loaded and diminishes the application understandability?
- Are there specific menus for each possible operation?
- Are the buttons which operate each option clear enough?
- Is the help function for tasks easy to find?
- Is the application configurable according to user and device?
- Do the input fields have default values or choices instead of textual input in order to minimize errors?
- Does the system use location aware functions in order to minimize inputs?
- Is the length and format of the outputs optimized to screen size?

Efficiency

Efficiency (ISO/IEC 9126-1, 2001) includes the time behavior and resource utilization sub-characteristics. Time behavior sub-characteristic is very important in the wireless environment because the price of each minute of data transferring is very high, and the users will avoid expensive systems. Moreover, users are accustomed to speedy systems, so slowness will not be accepted. Mobile devices include small memory and low processing resources, so applications must be aware of these restrictions and optimize resource utilization.

- Is the transaction execution time minimal?
- Does the application utilize the cache memory?
- Is the size of the application stored in the device proportional to the memory size?
- Is the size of the help system stored in the device proportional to the memory size and the application size?

Maintainability

Maintainability (ISO/IEC 9126-1, 2001) includes the analyzability, changeability, stability, and testability sub-characteristics. This set of characteristics reflects mainly the technical stakeholders' viewpoint, such as the developers and maintenance people (Hordijk & Wieringa, 2005). Thus, the mobile-wireless features do not have significant influence upon them.

Portability

Portability (ISO/IEC 9126-1, 2001) includes the adaptability, installability, co-existence, and replaceability sub-characteristics. Portability is very important when the system is targeted to wide audience because of the large diversity of devices held by users and the lack of control over these devices, e.g. configuration devices and applications run by them. The application must adapt itself to the device features, both during installation and operation, and according to the user's preferences. The application installation on the device must be invisible to laypersons. The application operation in the mobile device needs to exist harmonically, sharing common resources, with other applications installed in the same device, especially co-existing with the telephone facilities.

- Does the application adapt to different devices?
- Does the application utilize middleware to adapt outputs to users and devices according to the user profile?
- Is the application easy to install in all required devices?
- Does the application interfere with other applications/services installed in the same device?

Quality in Use

Quality in use is the user's view of quality: "The capability of the software product to enable specified users to achieve specified goals with effectiveness, productivity, safety and satisfaction in specified contexts of use" (ISO/IEC 9126-4, 2004). Since mobile applications may be used while driving or walking, tasks which need the user attention, the application manipulation must be simple and intuitive, enforcing safety.

- Does the application prevent unnecessary paging for input or output?
- Does input operation require minimum typing?

Definition of the New Metrics

In order to define the new metrics, the architecture and protocols of the mobile-wireless information systems were analyzed (Asunmaa et al., 2002; Green, 2003; Huber, 2004; Tarasewich, 2003; Varshney & Vetter, 2002; Vaughan-Nichols, 2004) and the objects which affect the characteristics and sub-characteristics of quality were detected. As described in Figure 2, the method used to define the metrics is as following. Each identified object was decomposed into measurable attributes (ISO/IEC 15939, 2002). Each feature was assigned a unit measure and a scale, according to its meaning. This was done based on Kitchenham, Pfleeger, and Fenton methodology (1995). Using the objects identified and their attributes with corresponding units and scales, metrics (ISO/IEC 15939, 2002) were defined. The metrics are methods for the measuring process with specific formulas.

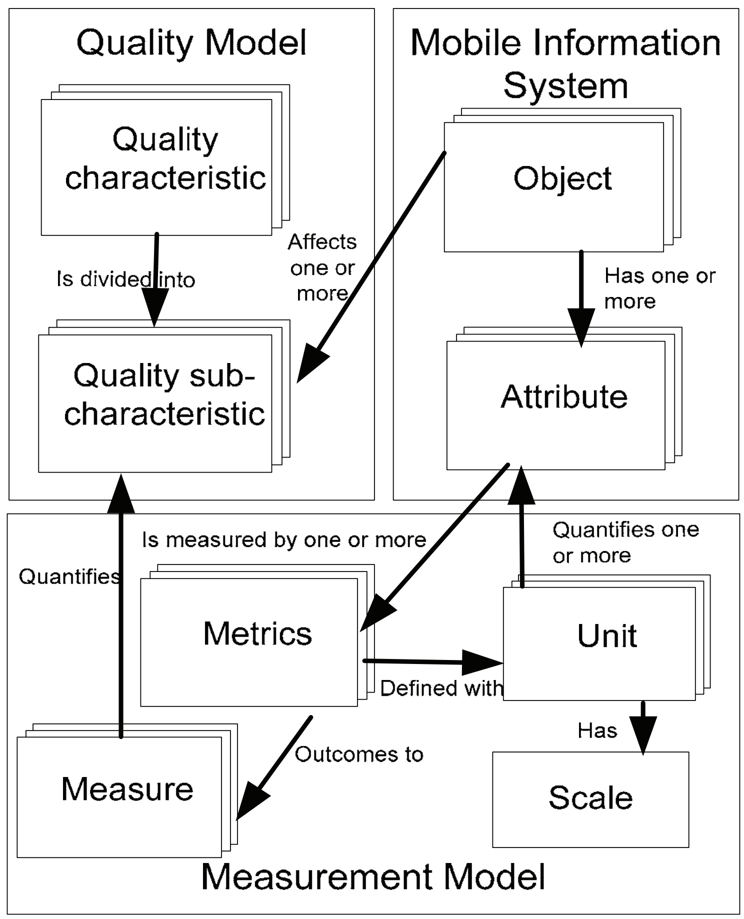


Figure 2 - Definition of metrics

The new defined metrics can be mapped in two different viewpoints:

- As a matrix which displays the metrics according to the specific problems in mobile-wireless information systems. Table 1 presents this viewpoint mapping.
- As a hierarchy starting from the quality characteristics, describing which metrics quantify the degree of quality for each characteristic and sub-characteristic. This is shown in Figure 3.

Table 1 - Metrics mapped to mobile-wireless problems

Source of problems:	Network					Device						Mobility				
Type of problem / Metrics	Narrow band	Connection stability	Security	Diverse standards	High costs	Variety of devices	Low memory	Tiny screens	Limited computational abilities	Small keyboard	Loss and information security	User adapted information	User location change	Security and privacy	Disturbances and disconnections	Users trust
Response time to get information from server	X	X			X										X	X
Response time to get information from cache	X		X		X		X		X						X	X
Size of application in mobile device							X									
Size of help in mobile device							X									
Device memory cleanup after transaction							X									
Network throughput	X	X		X												
Display load								X								
Clarity of operation possibilities								X								
Operation menu existence								X								
Completeness of operation menu										X						
Display self-adjustment possibilities								X				X				X
Messages conciseness	X				X		X	X								
Ease of input entering										X						
Ease of output use					X			X								
Parameters self-adjustment possibilities	X				X					X		X				
Ease of use - displays per output	X	X	X		X										X	X
Ease of use - displays per task	X	X			X			X	X						X	X
Tasks based on user location								X				X	X			
Update of user location based tasks												X	X			
Speed of user location update													X			X
Loss of accuracy on user location tasks																X
Secure messages and information on device											X	X		X		X
Message time on air														X		
Use of user profile	X				X	X						X				
Use of middleware					X	X						X		X		X
Installations success						X										
Ease of installation						X										
Co-existence with phone activities							X		X							
Use of standard protocols				X												
Use of cache		X													X	
Resume of transaction after disconnections															X	

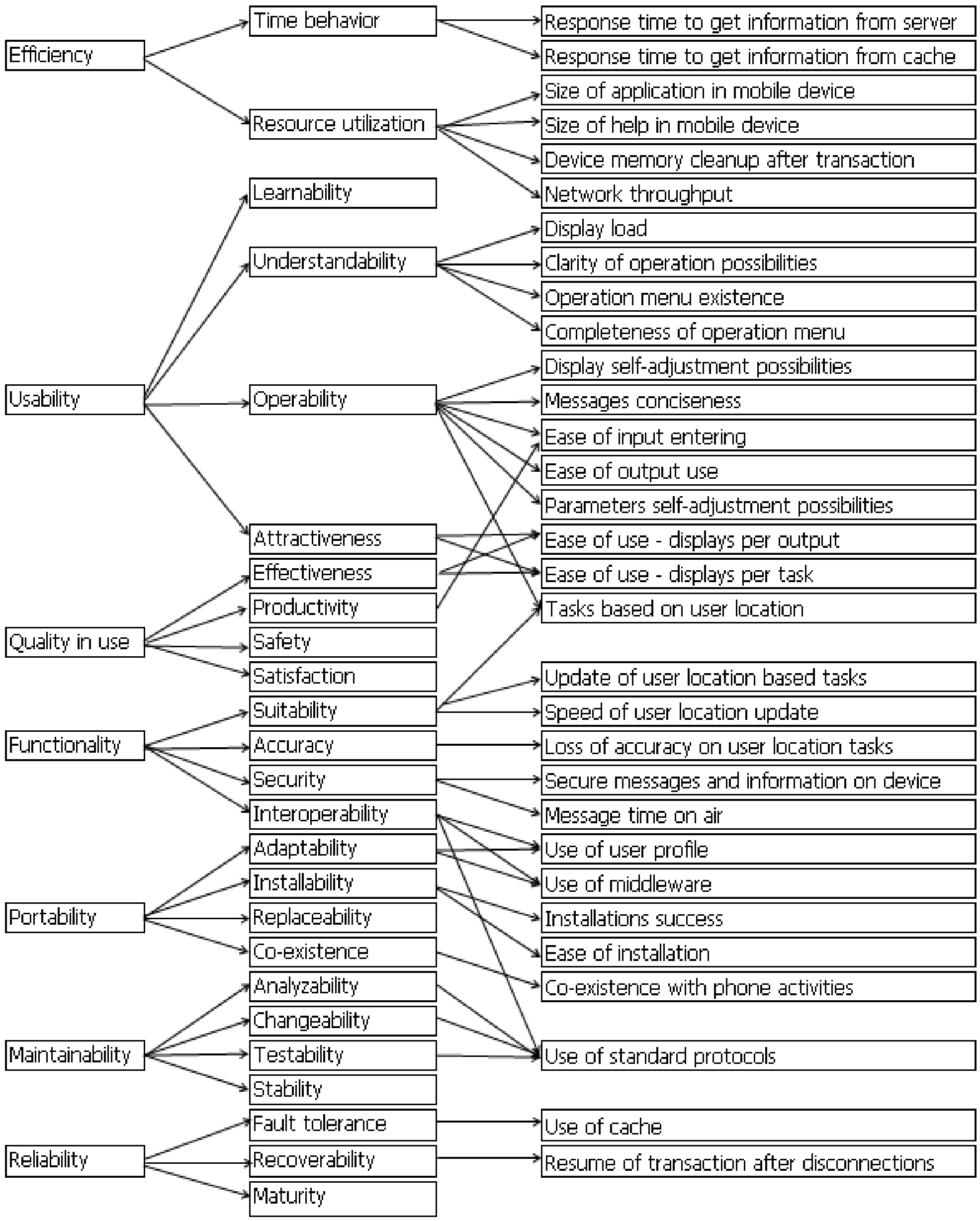


Figure 3 - Metrics mapped to quality characteristics

Tables 2 and 3 present examples of two new metrics developed in the research: “Display load” metric and “Memory cleanup” metric.

Table 2 - Definition of "Display load" metric

Metric Name	Display load
Quality sub-characteristic	Usability – Understandability
Purpose of the metric	To what degree are the displays loaded? The screen of the devices is small, and the understandability is lower when the display is overloaded.
Method of application	Check the ratio between display size (information displayed) and screen size. The ratios are categorized and given a score, in inverse relationship to the display size, thus smaller displays categories receive greater scores. Then a weighted average is calculated.
Metric type	Internal
Attributes measured	ScrS – Device screen size PgS – Display size DisNum – Number of displays in the system i – Display number (1..DisNum)
Computation	Definition of categories and scores: $X_i = \begin{cases} 1 & \text{if } 0 < \frac{PgS_i}{ScrS} \le 1/4 \\ 2/3 & \text{if } 1/4 < \frac{PgS_i}{ScrS} \le 1/2 \\ 1/3 & \text{if } 1/2 < \frac{PgS_i}{ScrS} \le 3/4 \\ 0 & \text{if } 3/4 < \frac{PgS_i}{ScrS} \le 1 \end{cases}$ $X = \frac{\sum_{i=1}^{DisNum} X_i}{DisNum}$ Where $DisNum \ge 1$, $ScrS \ge 1$ and $PgS_i \le DisS$ for all i. If the size of the display is greater than the size of device screen, the display will be partitioned according to the number of pages to be displayed, and the calculation will be performed for each one of these pages.
Expected output	$0 \le X \le 1$
Interpretation of measured value	The higher the better
Metric scale type	Ordinal
Measure type	Count/Count
Input to measurement	Requirements Specification Design Product Description (from device manufacturer)
ISO/IEC12207 reference	Software Design
Target audience	Developer Maintainer Human Interface Designer

Table 3 - Definition of "Memory cleanup" metric

Metric Name	**Memory cleanup**
Quality sub-characteristic	Efficiency – Resource Utilization
Purpose of the metrics	To what degree the memory is cleaned-up after completing a task? The devices have small memory, so any "garbage" left after completing a task may decrease the subsequent work performance.
Method of application	Check the size of free memory before starting the test, and afterwards.
Metric type	External
Attributes measured	$MmET_t$ – free memory size at end of task i ApS – Application Size MmS – Memory Size TNum - Number of Tasks in System
Computation	$X = \frac{\sum_{t=1}^{TNum} \frac{MmET_t}{(MmS - ApS)}}{TNum}$ where $MmS - ApS > 0$ and $TNum \geq 1$
Expected output	$0 \leq X \leq 1$
Interpretation of measured value	The higher the better
Metric scale type	Ratio
Measure type	Size
Input to measurement	User Monitoring Record Test Report
ISO/IEC12207 reference	System Testing Operational testing
Target audience	Requirer Developer Maintainer

The Experiments

Each metric defined by this research was validated theoretically and empirically at least by one of four different experiments performed in diverse technologies and devices, such as cellular phones and Personal Digital Assistants devices (examples of different displays can be seen in Figure 4):

1. The "PDA" experiment was performed on a system developed by Dooblo, a commercial company. The system allows conducting surveys on a PDA infrastructure. This system contains five different surveys, each including several displays.

2. The "Cellular" experiment was performed via a simulation developed specifically for this research. The system simulates a cellular phone application. This application allows technicians to service customers at home, per customers' complaints, that they generated via the cellular phone. This system was implemented twice, a "high quality" system and a "low quality" system, which enables comparisons.

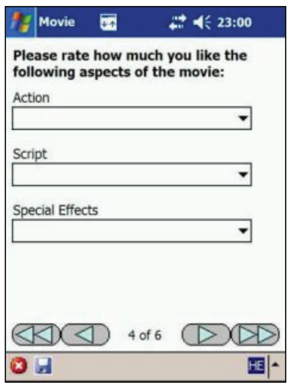
3. The "Where is the Child" experiment was performed using a service provided by a major mobile phone company, which enables parents to receive information about the location of their child over the cellular phone using GPS and cellular infrastructure.

4. The "Electronic Mail" experiment was performed in parallel in two different environments, in order to compare them, and on a third environment, not wireless and not mobile, as a reference point.

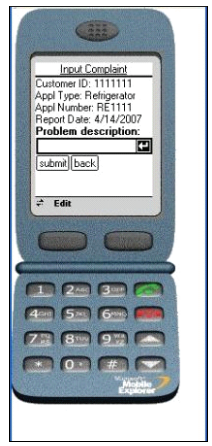
   a. Electronic Mail on a PDA environment, based on Microsoft Outlook.

   b. Electronic Mail on a cell phone, based on a service supplied by a major mobile phone company, which was developed based on Microsoft Outlook Express.

   c. Electronic Mail on a desktop computer, based on Microsoft Outlook Express.

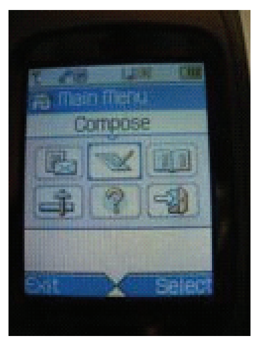


(1) "PDA"



(2) "Cellular"

(3) "Where is the child?"



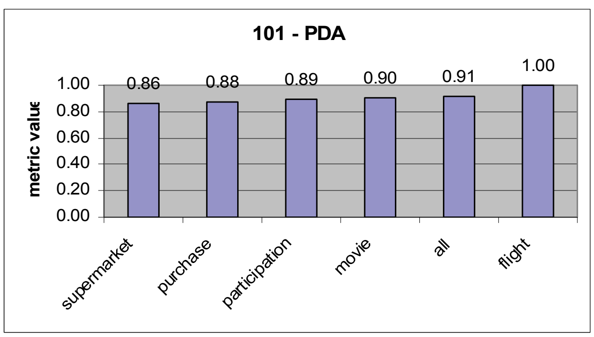
(4-b) "Electronic Mail"

Figure 4 – Examples of displays of the experiments

The aim of the validation was to prove that the metrics behave in a consistent and logical mode; thus, we can rely on them to quantify the quality of these systems, for example, by showing that the value of the metric grows when quality increases and vice versa..

The theoretical proof and the empirical experiments successfully validated the new metrics defined in this research. This paper focuses on the metrics development process, therefore the validation results are detailed only for the above example metrics.

The "Display Load" metric was validated in two different experiments, "PDA" and "Cellular". First, it was validated by the "PDA" experiment (Figure 5) which contains five different surveys, each including several displays. Therefore this experiment was further divided into six cases, one for each survey as it was an independent system and one for all together. For less loaded displays the metric value received was higher, i.e., the displays of the "Flight" survey which are the less loaded, got a metric value of 1, the highest possible. Second, the metric was validated using the "Cellular" experiment, once with the "High quality" system, and once with the "Low quality system", each was performed with empty and full displays (Figure 6).



ScrS	DisNum	Avg(PgSi)	X
630	38	119.13	0.91

	TaskID	i	PgSi	PgS/ScrS	xi	DisNum	Avg(PgSi)	X
Flight	1	1	105	0.167	1	10	73.6	1
	1	2	42	0.067	1			
	1	3	99	0.157	1			
	1	4	61	0.097	1			
	1	5	88	0.140	1			
	1	6	61	0.097	1			
	1	7	73	0.116	1			
	1	8	82	0.130	1			
	1	9	62	0.098	1			
	1	10	63	0.1	1			
Purchase	2	11	112	0.178	1	8	137.38	0.875
	2	12	150	0.238	1			
	2	13	66	0.105	1			
	2	14	160	0.254	0.667			
	2	15	115	0.183	1.000			
	2	16	231	0.367	0.667			
	2	17	67	0.106	1.000			
	2	18	198	0.314	0.667			
Movie	3	19	108	0.171	1.000	7	129.43	0.905
	3	20	130	0.206	1.000			
	3	21	75	0.119	1.000			
	3	22	83	0.132	1.000			
	3	23	203	0.322	0.667			
	3	24	149	0.237	1.000			
	3	25	158	0.251	0.667			
Supermarket	4	26	105	0.167	1.000	7	143.57	0.857
	4	27	183	0.290	0.667			
	4	28	149	0.237	1.000			
	4	29	79	0.125	1.000			
	4	30	92	0.146	1.000			
	4	31	321	0.510	0.333			
	4	32	76	0.121	1.000			
Participation	5	33	102	0.162	1.000	6	130.1667	0.889
	5	34	50	0.079	1.000			
	5	35	217	0.344	0.667			
	5	36	127	0.202	1.000			
	5	37	175	0.278	0.667			
	5	38	110	0.175	1			

Figure 5 – Validation of "Display load" metric in "PDA" experiment

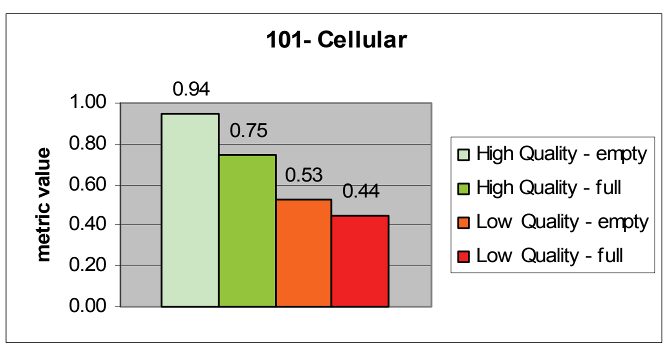
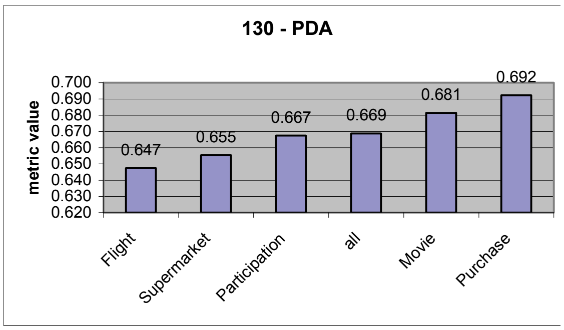


Figure 6 – Validation of "Display load" metric in "Cellular" experiment

The "Memory Cleanup" metric was validated with the "PDA" experiment, for each survey, as it was an independent system and for all together. In the cases where the memory was better cleaned after completing the task, the metric value was higher, as shown in Figure 7.



Tnum	Aps	MmS	
150	5.75	35.49	

	case	∑MmETi		x
all	all	2983.45	100.318	0.669
Flight	1	577.64	19.423	0.647
Purchase	2	617.62	20.767	0.692
Movie	3	608.00	20.444	0.681
Supermarket	4	584.76	19.662	0.655
Participation	5	595.43	20.021	0.667

Figure 7 – Validation "Memory Cleanup" metric in "PDA" experiment

Conclusion

This paper introduced two subjects and bound them together. First, it described mobile-wireless information systems and stated the new quality problems and challenges faced by these systems; second, it introduced the field of quality frames and standards for process and product quality assurance. Mobile-wireless information systems raise unique problems which affect quality. Therefore a set of questions was defined, which were developed methodologically to a list of metrics. These metrics enable objective quality evaluation and comparison of mobile-wireless information systems. The metrics were mapped in two different viewpoints, covering the quality characteristics on one hand, and the system problems on the other hand. A sample of two metrics was exhibited. The metrics listed above were developed according to the defined methodology and validated theoretically and empirically. Therefore, it confirms that these metrics enable objective quality evaluation and comparison of mobile-wireless information systems.

These metrics are useful when the quality of a mobile-wireless information system must be analyzed and quantified, for example when comparing two proposed systems, or when a system has to be developed or bought. When the metrics are used to compare systems, the higher the metric value, the higher the system's quality. However, when only one system has to be measured, the metrics need an external value to compare to. These values can be defined in advance according to the requirements of the system.

This research focused in mobile-wireless information systems which are activated through end devices which include a screen with displays, such as cellular phones and Personal Digital Assistance devices. The research can be expanded to new kinds of mobile-wireless information systems, emerging because of the rapid development of the technology and the wireless networks, such as wearable information systems and information systems based on RFID technology.

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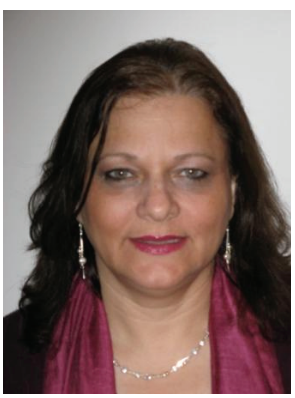
Biography



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