Using Analytic Hierarchy Process to Evaluate Software Quality Characteristics of Smartphone

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Abstract

According to IDC's [8] analysis report, there were 82.44 million Smartphone that had been shipped worldwide in 2006. This report also pointed out the shipment of 2007 could reach more than a hundred million. Smartphone has supported various multimedia and wireless technologies such as push e-mail, Bluetooth, wireless LAN (WLAN), camera and GPS. It uses software to integrate and control these wireless and multimedia functions, but most people have indistinct understanding for software quality. Furthermore, there are gaps in cognition of software issues during the development stage and then result in serious problems which can not be solved effectively. Besides, when decision makers need to determine whether the product can reach shipping quality or not, they may encounter difficulties to make the decision or make the wrong decision due to their subjective judgments or one-sided information. Therefore, this research analyzes related literature and collects software issues, to which, Delphi technique has been used to determine software quality factors of Smartphone, and then categorizes them into ISO/IEC 9126 software quality model. Finally, analytic hierarchy process (AHP) method has been conducted to evaluate the importance of each quality factors, and then apply them as the basis of software quality improvement and decision-making.

Keyword: Smartphone, software quality, Delphi, Analytic Hierarchy Process

1. Introduction

1.1. Background and motivation

Embedded System is mostly adopted in mobile phone system. The characteristic of embedded system is difficult for users to correct mistakes via patch code. For most people, they will not actively to update firmware via Internet. Even if users are able to update the firmware by themselves, it is relatively possible to result in damages. Once any fatal mistake of software has been found, consumers may either ask for after-sales service or return their mobile phones. In countries where customers are highly protected, such as Japan and America, customers can ask for compensation from mobile phone producer or carrier if it causes in business loss. However, customers often have weak and vague concepts towards software quality. It is difficult for most people to judge the level of software quality. When mentioning about software quality, most people can only have the sense of usability and applicability. Software developers or decision makers frequently ignore the flaws of software defects or misjudge the severity of bugs such that fatal issues are not effectively improved. In order to truly control Smartphone software quality, manufactures have to use effective software quality management to plan, execute and verify software development process. Additionally, they have to manage software quality during the developing process and detect issues by testing. Furthermore, they shall analyze the impacts of software and apply evaluation criteria to establish efficient software management evolution model. To avoid the above situations and enhance software quality management, understanding the software quality factors and importance are very critical, this research is focusing on this.

1.2. Research purpose

In the software developing cycle, testing is a very important stage. No matter in waterfall model, V- model, prototyping model, spiral model or object-oriented model, testing is defined as an important stage. Due to different cognitions, project manager, product developer and testers often dispute the severity of issues produced from various testing. This will increase development cost and might even result in product return if they neglect the severity of fatal defects. In order to decrease the misjudgment of software quality, this research finds out the weights of software quality factors to provide the basis for decision makers or manager to trade-off software quality improvements or quality issues. Also, this research can assist testers to correctly judge the severity of software defects and help developers understand the priorities of issues during the developing process in order to improve software management efficiency. The main purpose of this research is to analyze factors of Smartphone software quality and evaluate the weights of those factors. It also can help software developers and testers correctly evaluate severity of defects and provide the basis of software quality to decision makers

2. Literature review

2.1. Smartphone definition

Currently mobile phone can be divided into three types based on functionality, including the simplest mobile phone, feature phone and Smartphone [14]. The simplest mobile phone enables voice calls and short messaging (SMS), also includes contacts storage. Feature phone has included simple software operating environment. However, user can only execute one software application at one time such as email sending, receiving, multimedia messaging, camera and game, Smartphone can support multi-thread operation environment so that some applications can be launched at the same time. The architecture of Smartphone can be separated into two main systems, operating system and radio system. Operating system makes it possible for users to download programs in order to extend functions freely and Smartphone equips with mass personal information management and storage.

As a result, Smartphone can be defined as a telephone which contains personal digital assistant function and mobile phone capability. User can freely install applications and store personal data into device. Moreover, Smartphone can perform various applications simultaneously, such as sending/receiving email and playing multimedia files at the same time

2.2. Software quality definition

Most people hold a vague concept towards software quality. General description of software quality is “they are good to use” or “they meet our requirements”. However, it is very difficult for user to provide a concrete answer. According to IEEE 610.12 [9], software quality is (1) The degree to which a system, component, or process meets specified requirements. (2) The degree to which a system, component, or process meets customer or user needs or expectations. Pressman [19] defined software quality as “Conformance to explicitly stated functional and performance requirements, explicitly documented development standards, and implicit characteristics that are expected of all professionally developed software.” Additionally, Hoyer [7] claimed that software quality met the conformance to specification and customer needs. Based on above definitions, IEEE 610.12 and Hoyer defined software quality from user’s point of view while Pressman defined it from professional developers’ viewpoints. From the above points of view, software quality shall conform to the requirement degree of function, efficiency and standard, moreover it has to meet customer and user satisfaction.

2.3. Software quality evaluation model

Software quality evaluation model can be divided into two methodologies [18]. The first one is process management which is to setup software developing process specification and standard operating procedures of requirement analysis, system design, procedure design, coding, testing, verification, operation and maintenance. In order to improve item by item and gradually reach to the optimization. One of the typical models is SW-CMMI. The other is product quality assessment. Mainly, it analyzes software product’s quality first and then establish software quality model. It aims to manage and improve the defects. Examples are ISO/IEC 9126, McCall and Boehm.

McCall’s Quality Model [16] proposed in

1977 that defined software quality as three major perspectives: product operations, product revision and product transition. The three perspectives totally contain eleven factors.

Quality of product operations depends on correctness, reliability, efficiency, integrity and usability.

Product revision includes maintainability, flexibility and testability.

Product transition includes portability, reusability and interoperability.

Each quality factor includes several quality criteria. And every criterion is correlative with quality factors. In fact, the idea behind McCall's quality model used metrics to measure quality criterion. The actual quality metric achieved by answering yes and no questions, and then put in relation to each other. Figure 1 is McCall's FCM (Factors, Criteria and Metrics) hierarchy model.

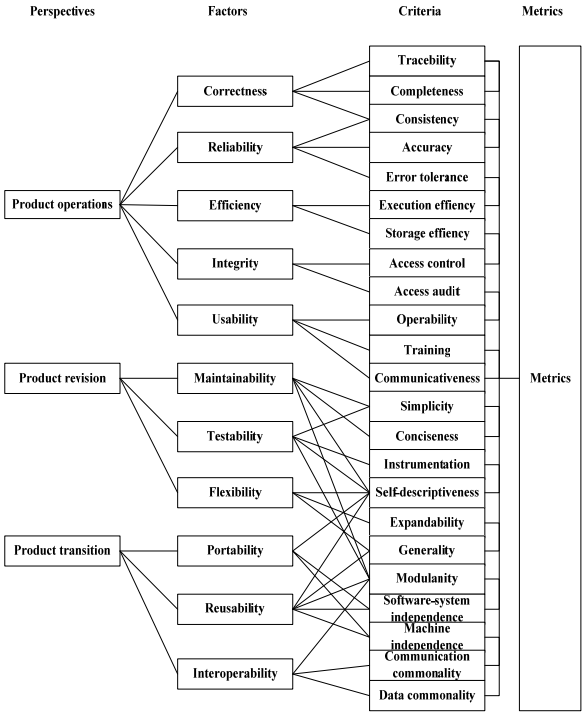

Figure 1. McCall's software quality model [16]

Boehm's Quality Model [2] is similar to McCall Quality Model. It also includes customers' expectations and requirements. However, Boehm's model discussed about hardware performance which was not mentioned in McCall's quality model. It presented a hierarchical quality structure to explain software general utility and separated it into three primitive characteristics: portability, as-is utility and maintainability. Like as McCall's quality model, it also includes quality factors. Factors of As-is utility are reliability, efficiency and human engineering, factors of maintainability are testability, understandability and modifiability. Portability is a special factor which exists both in primitive characteristic and factors. Quality factor is divided into several criteria which can impact quality factors. Figure 2 is the characteristics tree of Boehm's software quality model.

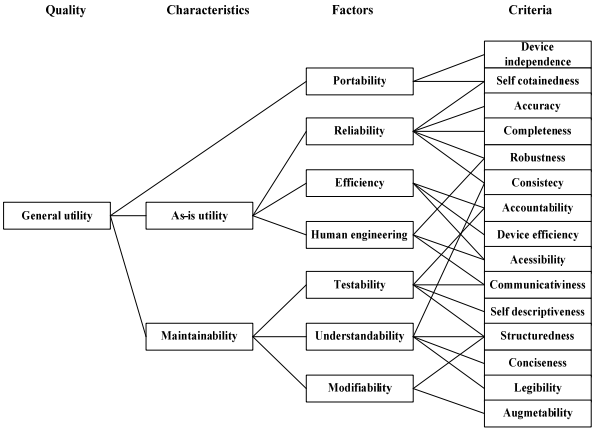

Figure 2. Boehm's software quality model [2]

ISO 9126 is an international standardized model. At the beginning of 1990, software engineering tried to merge all the software quality concepts and factors into one model, expecting to be the worldwide standard of software quality, In June 2001, ISO/IEC revised ISO 9126 by improving software quality model and definition [10]. It put emphasis on the hierarchical process model which described software quality in two parts: (1) external and internal quality (2) quality in use. For the external and internal quality, it includes six main characteristics and several sub-characteristics of each main characteristic. The external and internal characteristics of ISO 9126 are shown in Figure 3.

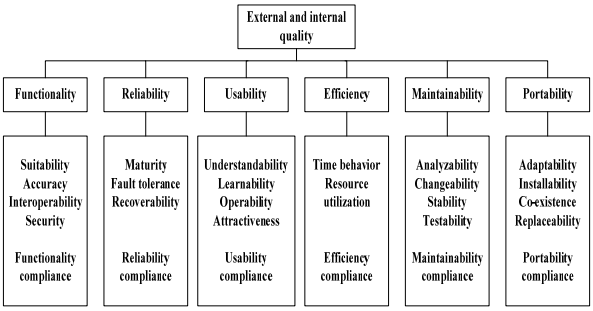

Figure 3. ISO 9126 internal and external software quality characteristics [10]

For quality, there are four main characteristics that are effectiveness, productivity, safety and satisfaction.

Functionality includes suitability, accuracy, security, interoperability and functionality compliance.

Reliability includes maturity, fault tolerance, recoverability and reliability compliance.

Usability includes understandability, learnability, operability, attractiveness and usability compliance.

Efficiency includes time behavior, resource behavior and efficiency compliance.

Maintainability includes analyzability, changeability, testability and maintainability compliance.

Portability includes adaptability, install-ability, co-existence, replaceability and portability compliance.

ISO 9126 suggests measuring the sub-characteristics directly. The difference between ISO 9126, McCall and Boehm is ISO 9126 using a distinctive hierarchy structure. Each sub-characteristic is related to one main characteristic. This implies that every sub-characteristic only impact to one main characteristic. As a result, it is easy to clarify the factors of software quality in complicated software. Moreover, ISO 9126 is user-oriented while McCall and Boehm are model-oriented. This research adopts ISO 9126 to be the software quality evaluation model for the following reasons: It is a restrained structure which is suitable to apply in complicated software. Moreover, it is the international standard and flexible for use.

2.4. Analytic hierarchy process

The Analytic Hierarchy Process (AHP) developed by Thomas L. Saaty in 1970. It is mainly applied to decision-making for uncertain situations and multiple evaluation criteria. The purpose of AHP is to make the hierarchy structure to systemize the complicated problems. Decision factors are divided into different elements and level elements into structure such that large complicated problem can be destructed into several sub-problems. Then integrate again based on AHP steps. As a result, AHP can make complicated problem easier to be analyzed and use them to be the basis of decision-making. The main four steps are as the following [21].

(1) Define the problem and specify the solution desired. Structure the hierarchy from the overall managerial viewpoint.

(2) Define the evaluation attributes, criteria and establish the pairwise comparison matrix.

(3) Calculate the eigenvalue and eigenvector to get the relative weights of attributes and alternatives.

(4) Check the consistency ratio.

3. Research methodology

Software quality is a multi-attribute structure which can be judged from goal, dimension, factor, criteria and metric. From the perspectives of decision-making, multiple decision analysis can be separated into multiple objective decision analysis (MODA) and multiple attribute decision analysis (MADA). The first one does not have a confirmed goal, but it can reach the optimal goal via limiting critical conditions. The second one is based on multi-attribute value theory (MAV) and it is applied when more than one attributes have to be considered under a confirmed situation. It is suitable to apply MADA since software quality itself has the specific goal and multiple attributes. The most frequently applied methods of MADA are simple multi-attribute ranking technique (SMART) [5], analytic hierarchy process (AHP) [20] and data envelopment analysis (DEA) [3].

The purpose of this research is to discuss relative importance between software quality and factors. Software quality model belongs to a hierarchy structure and it consists of multiple factors. The specialty of analytic hierarchy process is hierarchy structure and it is suitable to decide the priority, solve contradictory and controversy, and then to find out expected result. In order to find out the software quality factors and criteria of Smartphone, this research explored documents to list out related theory and software quality factors. Next, it utilized group decision to repeatedly discuss with experts by Delphi method to perfect the software quality and software quality factors. Therefore, this research aimed first to deeply discuss Smartphone software framework, characteristic, sub-characteristic, quality management and evaluation model by documentary analysis. Next, it had a series of interviews with software quality assurance engineers to clarify definitions of factors which impact software quality. Finally, it applied analytic hierarchy process to find out the weight of each factor.

3.1. Research subjects

Most people apply AHP questionnaires to survey product quality from end-users. However, those evaluation methods are post for audit. They are analyzed after using products for a period of time. It would help us to understand the values of product, but this has limited assistance toward improving quality when developing products. Moreover, most users hold great different cognitions of product functions and different depth as well as width of usage. This affects on validity and stability of questionnaires. In fact, software quality is measured by so-called software quality assurance (SQA) engineers [6] in most companies. SQA engineers have to deal with and verify thousands of issues from the product developing cycle. They have to handle customer feedback defects in the meantime. For providing valid definitions and analysis of Smartphone software quality to ensure its validity and reliability, the most suitable method is to use AHP questionnaires to analyze and survey those experts. H Company is a famous company which focuses on Smartphone research, development and manufacture. According to IDC 2007 statistics [8], there were 82.44 million Smartphone that had been shipped worldwide in 2006. H Company produced 11.65%, which was about 9.6 million Smartphone. Its sale area includes North America, South America, European, Asia, Australia, Middle East and etc. This research invited SQA engineers and managers to participate in Delphi and AHP questionnaire.

3.2. Software quality factors of Smartphone

When this research applied multiple attribute decision analysis (MADA), it had to define, understand problem and clarify related decision elements. It had to clarify the related elements of Smartphone software quality. In order to reach this, the first procedure of documentary analysis was used to collect, manage and analyze Smartphone related characteristics, functions and utilizations [4]. Then, this research referred to related software models and ensured the attributes of factors that must contain completeness, operational, decomposable, non-redundancy and minimum size [12]. In the following step, we listed all the Smartphone software quality factors into questionnaire, sent it to four experts with separate E-mail and asked them to review and feedback their comments by Delphi method, as well as urged them to revise the definition, evaluation criteria and explanations back and forth until all of the experts' opinions has been narrowed down. Finally, all the factors and evaluation factors were integrated into ISO 9126 software quality model.

Functionality includes eight criteria (1) Conformability with specifications (2) Accurateness with system settings (3) Interoperability with various platforms (4) Compliance with specified certifications (5) Data survivability and security (6) Accurateness with radio communication (7) Bluetooth and WLAN connectivity (8) System compatibility with accessories.

Reliability includes seven criteria (1) Transmission reliability (2) Operation reliability (3) Radio reliability (4) System fault tolerance (5) Recoverability with system errors (6) Mean time to failure (7) Battery Life.

Usability includes seven criteria (1) Operability and understandability (2) Consistent user interface (3) System auto-configuration (4) Detailed user guide and help files (5) Sound quality (6) Detailed warning message (7) Man-machine interface designing.

Efficiency includes seven criteria (1) System performance (2) Transmission performance (3) Data access performance (4) Display performance (5) Multitasking performance (6) Resource consumption (7) Virtual memory allocation.

Maintainability includes six criteria (1) No side effect after modification (2) Analyzability with exceptions (3) Resolvability with system defects (4) Changeability with new requirement (5) Testability and verifiability (6) Modularization architecture.

Portability includes six criteria (1) Adaptability with specified hardware (2) Replaceability with specified OS (3) Radio portability with specified system (4) Installability with specified environment (5) Conformance with specified standards (6) Program optimization.

Besides above factors and criteria, this research also defined detail definitions and explanations for each criterion.

3.3. Establishing hierarchy structure

Before establishing hierarchy structure, the first procedure was "confirm the decision target in order to produce a root target". Then, it applied

top-to-down division or bottom-up integration to gradually complete the target level by level. The top level represented the final goal, and it was to find out Smartphone software quality. The top-to-down six division of target are functionality, reliability, usability, efficiency, maintainability and portability. The attributes in third level are above listed criteria. Figure 4 is the structure of Smartphone software quality.

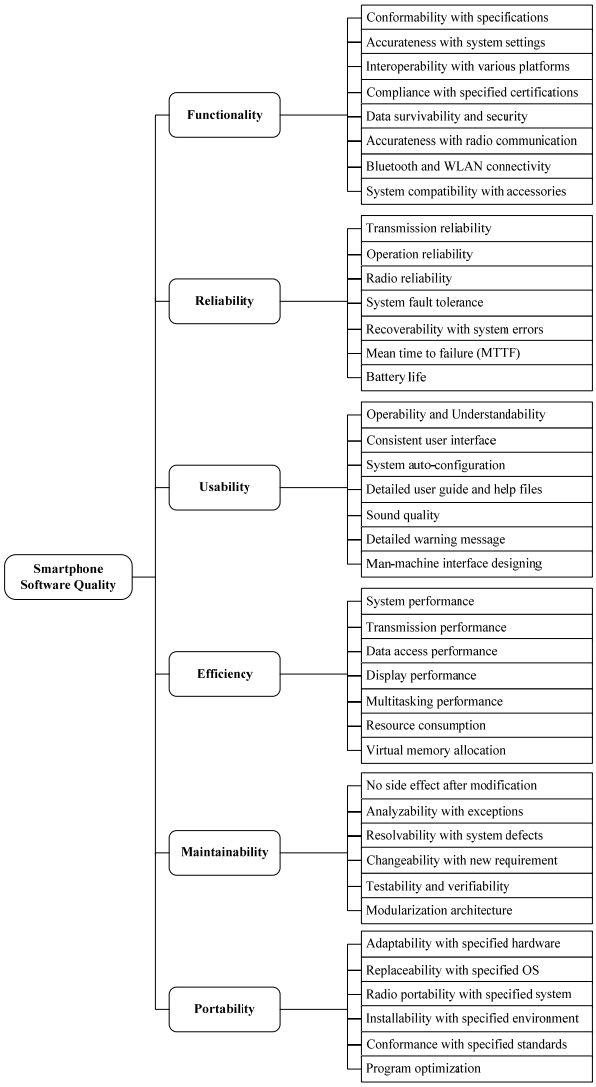

Figure 4. Hierarchy structure of Smartphone software quality

3.4. Designing AHP questionnaire

AHP evaluation was to use attribute in last level to be the basis of evaluation criteria of next level. At the same time, it utilized pairwise comparison to get decision makers' judgments. And it applied relative importance matrix to be the matrix. This questionnaire used relative importance 1-9 to compare with each factors and criteria.

The way to implement questionnaire was to post questions in ASP webpage which was located in IIS and SQL server. Script in the webpage automatically recorded users' names to prevent such situations that users forget to fill in their names. For the purpose of authentically understanding of each question in questionnaire, user could read detail explanation of every evaluation item via hyperlink. Based on above actions, users could clearly understand the operation of questionnaire and cognitions of software quality factors and evaluation criteria. Then the validity of questionnaire could be increased. The AHP questionnaire is shown in Figure 5.

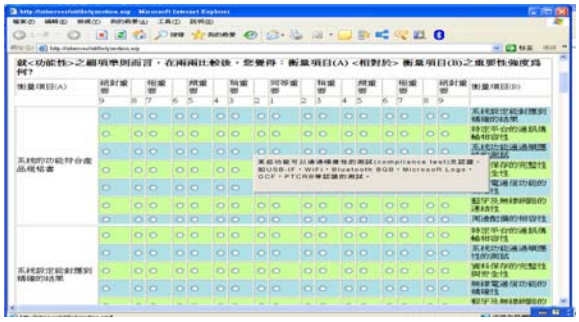

Figure 5. AHP online questionnaire

3.5. Consistency ratio verification

This research had done a questionnaire research in H Company by sending email to product assurance engineers and asking them to fill in the questionnaire. Total 50 mails were sent and 31 questionnaires were received. Recall rate was 62%. This research based on AHP to establish a comparison matrix of software quality factors in each level. Eigenvalue was gotten first from analysis. Hereafter, eigenvector was found out. Finally, the Saaty's consistency Index (C.I.) was used to verify in C.I. and C.R. (Consistency Ratio) for each questionnaire [20]. Some questionnaires were eliminated since their consistency ratio was too high. After the elimination, only 25 questionnaires were considered to be valid and their CR values were smaller than 0.1 which complied with AHP standard. In order to verify the validity of amount of questionnaires, this research had re-computed each weight from three questionnaires randomly picked out. It realized that even if these weights were changed and the ranking of factors were not affected. As a result, it could conclude that both questionnaire amount and value had reached certain degree of validity.

4. Data analysis of AHP

The factors' result of AHP research is tabulated in Table 1. From the weight, the highest two factors are reliability (0.25) and efficiency (0.21) and the lowest one is functionality (0.116). As its result, most users care about stability of system and efficiency of operation, such as no system hang, no drop call and high performance of operation.

Table 1. AHP weight of six factors

Six factors	Weight	Priority
Reliability	0.25	1
Efficiency	0.21	2
Usability	0.17	3
Maintainability	0.129	4
Portability	0.125	5
Functionality	0.116	6

Based on Table 2, data survivability and security (0.235), and accurateness with radio communication (0.211) outweigh other factors. These two functions are most important for functionality development. Conformability with specifications (0.05) is the most neglected in Smartphone. Per discussion with experts, possible reason for this is that product specification is written as a general standard, not for specific function or operation. Therefore, users tend to pay less attention to the described function in product specification. Table 2 is the AHP weight of functionality criteria.

Table 2. AHP weight of functionality criteria

Functionality	Weight	Priority
Data survivability and security	0.235	1
Accurateness with radio communication	0.211	2
Bluetooth and WLAN connectivity	0.13	3
Accurateness with system settings	0.114	4
System compatibility with accessories	0.095	5
Compliance with specified certifications	0.084	6
Interoperability with various platforms	0.08	7
Conformability with specifications	0.05	8

For viewpoint of reliability, the highest two attributes are radio reliability (0.226) and operation reliability (0.194) as shown in Table 3. For that Smartphone is the combination of mobile telecommunication and functions in personal computer, general users care about the reliability of telecommunication and system stability most.

Table 3. AHP weight of reliability criteria

Reliability	Weight	Priority
Radio reliability	0.226	1
Operation reliability	0.194	2
Recoverability with system errors	0.171	3
Mean time to failure (MTTF)	0.118	4
System fault tolerance	0.115	5
Transmission reliability	0.091	6
Battery life	0.085	7

From the perspective of usability, sound quality (0.319) is the highest item. This reflects the basic feature of Smartphone is communication, sound quality of voice call is very important for users. Table 4 is the AHP weight of usability criteria.

Table 4. AHP weight of usability criteria

Usability	Weight	Priority
Sound quality	0.319	1
Operability and Understandability	0.144	2
Detailed warning message	0.12	3
Man-machine interface designing	0.119	4
System auto-configuration	0.117	5
Consistent user interface	0.104	6
Detailed user guide and help files	0.077	7

From efficiency, the highest two factors are virtual memory allocation (0.203) and resource consumption (0.191) as shown in Table 5. Due to the limitation of Smartphone size, structure and battery, it can not extend hardware as generals PC. Therefore, it is extremely important to manage virtual memory and system resources.

Table 5. AHP weight of efficiency criteria

Efficiency	Weight	Priority
Virtual memory allocation	0.203	1
Resource consumption	0.191	2
Multitasking performance	0.175	3
System performance	0.134	4
Display performance	0.117	5
Data access performance	0.099	6
Transmission performance	0.08	7

As for Maintainability, no side effect after modification (0.256) is the highest weight of factor. When developing and maintaining software, software engineers shall not only examined and analyze modified parts but also whole structure in order to reach optimal quality of modification and the lowest risk. Any occurrence of side effects will result in difficulty of decision trade-off and re-evaluation of quality. Table 6 is the AHP weight of maintainability criteria.

Table 6. AHP weight of maintainability criteria

Maintainability	Weight	Priority
No side effect after modification	0.256	1
Testability and verifiability	0.185	2
Modularization architecture	0.161	3
Resolvability with system defects	0.154	4
Analyzability with exceptions	0.129	5
Changeability with new requirement	0.116	6

When talking about portability, program optimization (0.259) is the highest factor and it also complies with basic software engineering requirements. In order to meet this attribute, developers have to plan in the initial step of software design and infrastructure to find out the most suitable development method and software program structure. Software craftsmanship emphasizes the cost of software development and maintenance as well as partial quality that have been decided in the planning and structure on prototype phase [15]. Table 7 is the AHP weight of portability criteria.

Table 7. AHP weight of portability criteria

Portability	Weight	Priority
Program optimization	0.259	1
Installability with specified environment	0.166	2
Conformance with specified standards	0.165	3
Radio portability with specified system	0.151	4
Replaceability with specified OS	0.139	5
Adaptability with specified hardware	0.12	6

5. Conclusions

Quality is the life of product while decision is the core of management. In the times of only paranoid survives, enterprise usually rushes to market to obtain the business opportunity. However, this also will bring troubles in quality control and decision-making and there's no basis of trade-offs in quality. With fast development of telecommunication, mobile devices are massively used and traditional feature phones are gradually replaced by Smartphone whose market share is increasing year by year. Many business units are devoting into this field. This research analyzed the factors and weights of Smartphone software quality to provide the basis for quality management, improvement and decision-making. For the research result, the most important factor of Smartphone quality is reliability. Therefore, mobile company shall focus on quality control of system operation and telecommunication reliability. For all criteria, sound quality is also the significant factor of software quality. Moreover, software infrastructure optimization and alleviation of side effects from program modification are needed to be paid attention to.

In the future, this research will utilize Sugeno fuzzy rule to establish a decision support system and verify the reliability of this system via heuristics. It will implement these obtained AHP weights of factors to the Sugeno fuzzy model. It can provide the score of software quality to decision makers to help them understanding the quality level.

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