Czech University of Life Sciences

Faculty of Economics and Management

Department of Information Technologies

Diploma Thesis

Open Source OS for Mobile Devices

Bc. Jiří OPLETAL

In this place, please insert

the Diploma Thesis Assignment.

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I declare that I have worked on my diploma thesis titled "Open Source OS for Mobile Devices" by myself and I have used only the sources mentioned at the end of the thesis. As the author of the diploma thesis, I declare that the thesis does not break copyrights of any third person.

In Prague, 20.3.2013 _____

Bc. Jiří Opletal

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Operační systém s otevřeným zdrojovým kódem pro mobilní zařízení

Open source OS for mobile devices

Summary

The Android open source operation system is recently the most popular platform for mobile devices. However, it is not deployed only on smartphones and tablets; various devices with this open source OS are appearing recently such as cameras, light bulbs or fridges. On the other hand, Android devices with top HW specification are becoming highly affordable for masses as low-cost OEMs adopted the manufacturing processes of established companies as HTC, Samsung or Sony. In this thesis, the overview of Android historical development is provided together with its competitor's descriptions. In analytical part, it is proposed with a new method for determining the quality of mobile OS, which is later used for comparing Android OS with its competitors. Contrary to traditional estimations of mobile OS quality, this new method is based on the very crucial criterion, which is often omitted – user's feedback weighted by expert's experiences. This user's feedback is divided into seven basic criteria which influence the quality of OS the most. As a result, the quality index is computed for testing OS. According to quality index and brief market study, the recommendations for company releasing an Android device are formulated.

Key words

Android, open source, smartphones, mobile devices, iOS, Google Inc., Java, quality comparison, mobile security

Souhrn

Operační systém Android, založený na otevřeném kódu, je v současné době nejpopulárnější platformou pro mobilní zařízení. Přesto se neomezuje jen na chytré telefony a tablety. Na trhu se v poslední době objevuje široká paleta zařízení s operačním systémem Android, například fotoaparáty, chytré žárovky či dokonce ledničky. Na druhé straně se mobilní zařízení s Androidem a špičkovou hardwarovou specifikací stávají velmi dostupnými pro masovou spotřebu. Důvodem je především fakt, že nízkonákladoví výrobci adaptovali výrobní procesy zavedených hegemonů v oboru jako je HTC, Samsung či Sony. V této práci je dále popsán historický vývoj Androidu spolu s poskytnutím informací o jeho konkurentech. V praktické části práce je navržena nová metoda určování kvality mobilního operačního systému, která je následně použita pro srovnání Androidu s jeho konkurencí. Navzdory tradičním postupům odhadu kvality mobilních operačních systémů je nově navržená metoda založena na zkoumání velmi významného kritéria, které je často opomíjeno – uživatelské zpětné vazby vztažené k názorům expertů na mobilní technologie. Tato uživatelská zpětná vazba je pro účely práce rozdělena do sedmi základních kritérií, které ovlivňují kvalitu operačního systému nejzásadněji. Výsledkem tohoto zkoumání je index kvality sloužící k porovnání mobilních operačních systémů. Na základě tohoto indexu kvality a marketingové studie jsou formulována doporučení pro společnost uvádějící na trh zařízení s operačním systémem Android.

Klíčová slova

Android, otevřený software, chytré telefony, mobilní zařízení, iOS, Google, Java, srovnání kvality, mobilní bezpečnost

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1 Introduction

,,Android is an open source software toolkit for mobile phones that was created by Google and the Open Handset Alliance. It's inside millions of cell phones and other mobile devices, making Android a major platform for application developers." Ed Burnette [3, p. xiii]

The smartphone device has been one of the most significant influences on our social behavior in this ever-changing era. It is embedded into our daily life, and yet was rarely known five years ago; now, it is becoming indispensable. However, it is not mainly the hardware itself which is the crucial attribute. The main reason that makes difference between phones and today's smartphones is simple— its operation system.

Obviously, the Android platform is not the only option for mobile devices. It is not even the first developed mobile OS. It could be seemed as symbolism when the first world smartphone was released exactly 20 years ago, which was called the "IBM Simon". It had mighty 16 MHz processor Vadem and 1MB RAM. Since then, more than 2 billion mobile devices recognized as "smart" had been produced.

Several mobile OSs were developed afterwards; however, their success was quite limited. Palm OS for PDA, Symbian, Maemo and many others had failed. Breaking point came in June 2007 when Apple introduced its revolutionary communication device, iPhone with iOS. In the same year, an Open Handset Alliance (OHA) was formed under patronage of Google Inc. in order to conduct the development of open source OS for mobile devices – Android. As a matter of fact, the step of keeping Android mobile platform an open source and providing it to manufactures for free appeared highly successful.

It has been five years since Android open source OS was released in 2008. Since then, it became the most successful mobile device OS with more than 400 million activations and nearly one million third-party applications developed for its ecosystem. Those facts are revealing a question that what is the reason for such rapid growth, and moreover, if this trend will persist in the future.

2 Thesis objective and methodology

2.1 Objective

The thesis is thematically focused on issue of open source operating system (OS). The main goal is to analyze advantages and disadvantages of open source OS, comparison with competitors and estimation of future trends of development and providing market release study of open source OS run devices. Partial goals of thesis are:

- to specify fundamentals of an open source OS: Android OS,
- to create an index comprising and including set of attributes (security issues, GUI, APP developers support) which can evaluate any mobile device OS,
- to provide future trends of development and forecast of progress and
- to provide recommendations and references for potential releasing company of open source OS device on the market.

2.2 Methodology

Methodology of the thesis is based on study and analysis of specialized information resources. The practical part is focused on analysis of OS's parameters and their comparison. The subjective data for OS quality index are gained from questioner. Release study is supported by related marketing methods focused on 4P analysis and SWOT analysis. Based on a synthesis of theoretical knowledge and results of author's own work, the conclusions of the thesis will be formulated.

3 Overview of open source OS for mobile devices

As mobile technologies experienced an exponential growth in past ten years, the most significant reason for its rapid development is mobile operation systems (OS). Operations systems and its various services crucially influence a change in society lifestyle: Recently nobody is bound to a particular location in order to access his *data*, process his work or enjoy extracurricular activities. In other words, mobile technologies and mobile devices OS make the dependence on *place* strongly irrelevant according to any type of activity. [1]

This process was initiated by evolving laptops and personal computers into complex *smartphones*, tablets, cloud computing services and virtual private networks allowing accessing any data without considering place or time. The smartphones, as an initiators and most important figures of mobile technologies development, are considered as a *smart* according to their complex operation systems allowing processing nearly same actions as with personal computer. This thesis is focused on open source operation systems – mainly Android OS. Because of its intricate composition is Android also referred as full mobile platform or even mobile ecosystem.

3.1 Specification of OS Android

Google's specification of Android as mentioned on its official website refers:

,,Android is the world's most popular mobile platform. With Android you can use all the Google apps you know and love, plus there are more than 600,000 apps and games available on Google Play to keep you entertained, alongside millions of songs and books, and thousands of movies. Android devices are already smart, and will only get smarter, with new features you won't find on any other platform, letting you focus on what's important and putting you in control of your mobile experience." [2]

In other words, Android is a wide open source platform developed mainly for mobile devices (smartphones, PDA, navigations, tablets). It contains operation system based on Linux core, middleware, user interface and applications. It is developed by consortium Open Handset Alliance (OHA), which goal is progressive growth of mobile technologies with less cost for development and distribution along with user friendly interface.

During the development were taken into account restrictions of mobile devices as battery life, less computing power and memory. [2] Furthermore kernel of Android was designed to run various hardware - OS can be used without restrictions for different chipset, size of screen and screen resolution.

3.1.1 Android platform

The power of Android platform is mainly in its complexity. It consists not only of operation system with interface for end users, but also with complete solution for setting up operation system including specification of drivers, tools for mobile operators and manufactures and powerful tool for application development – Software Development Kit.

3.1.2 Application development - SDK

Tools for application development for android operation system are included in Software Development Kit (SDK). Set of SDK is divided for three types: basic, recommended and full installation of the kit.

Basic installation

Basic installation of SDK includes only necessary tools for application development.

- SDK tools
    - Includes tools for debugging, application testing, managing of AVD (Android Virtual Devices), Android emulator, tool for analysis of graphical layout, etc.
- SDK Platform tool
    - Includes various enhancing tools for application development. Tools in SDK Platform tool are dependence on platform version and are always updated in new SDK version. One of the most significant tools is Android Debug Bridge, which enable uploading of files into device
- Android SDK platforms
    - It's necessary for developing an Android app to must install at least one Android platform against which application is compiled. Often, any given version of the Android will be revised with bug fixes or other changes, as denoted by the revision number. Each platform is consisting of library, system image, sample code, emulator skin and other codes. [4]

Recommended installation

Recommended installation of SDK contains mainly only supportive documents for SDK as sample codes and documentation. Also USB driver is included; the tool necessary for debugging and testing of applications installed on the device.

Full installation

- Google API
    - o libraries, enabling interface of Google Maps as they can be used in applications
- Other SDK platforms
    - o Most significant is Market Licensing package, tool that includes library verifying if application is a legal copy [4]

3.1.3 Operation system layers

Architecture of OS Android is divided into five layers. Each layer has its purpose and is not necessarily separated from other layers. [5]

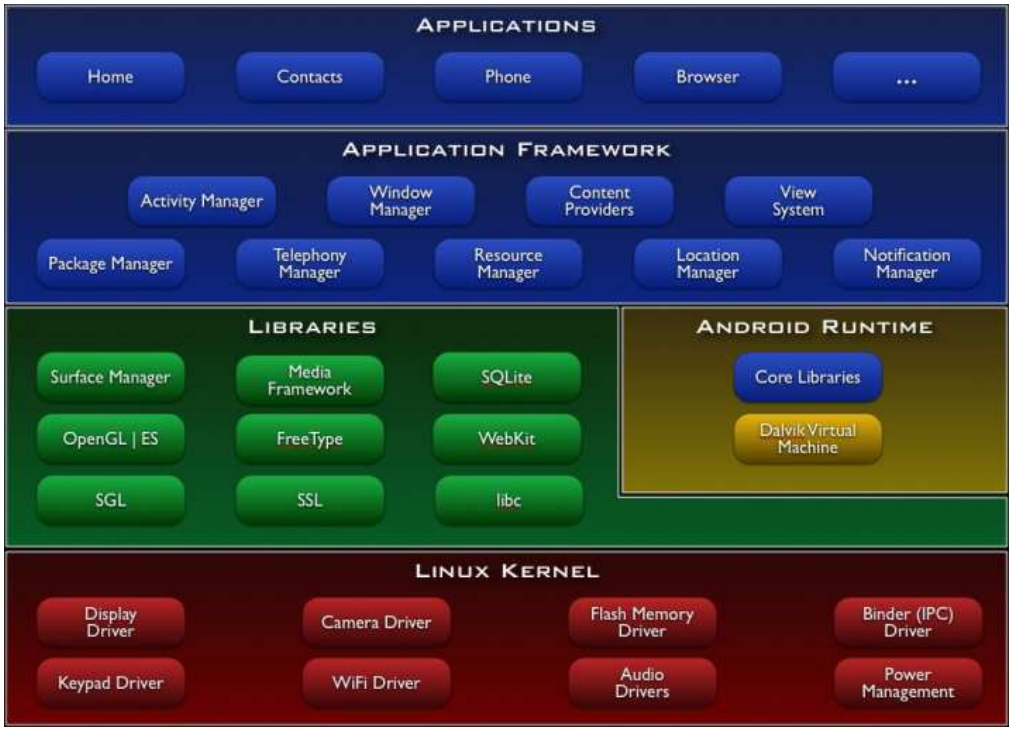

Figure 1: Android system architecture [6]

Linux Kernel

Linux Kernel is the lowest layer. It is based on Linux 2.6 kernel. Android uses Linux kernel as a hardware abstraction layer.

For example an OEM (Original Equipment Manufacturer), trying to bring up Android on a new device, has to bring Linux and gets all drivers in place first. The reason of using Linux is because it provides proven driver model together with many existing drivers. It also provides memory management, process management, a security model, networking and a core operating system infrastructure that is robust and has been proven over time. [7]

Libraries

Libraries, the second lowest level, run on the top of the kernel and contain all the code that provides the main features of an Android OS. The most significant libraries are:

- Surface Manager
    - Surface Manager is used for compositing window manager with off-screen buffering. Off-screen buffering is process allowing developers directly draw into the screen, but drawings is moved to the off-screen buffer. It is combined with other drawings and form the final screen the user will see. This off screen buffer is also the main reason behind the transparency of windows. [8]
- Graphics Libraries
    - Basically the Open GL|ES, SGL are two core graphics libraries. The Open GL|ES is a 3D graphics library while SGL is 2D graphics library.
- Multimedia Framework
    - The multimedia framework supports playback and recording of various audio, video and picture formats. It is provided by PacketVideo, one of the

members of OHA (Open handset Alliance). The multimedia framework contains all of the codecs that are required for multimedia experience.

- FreeType - used for fonts rendering.
- SSL – Secure Socet Layar responsible for security of data connection
- SQLite – tool providing database support.
- WebKit
    - WebiKit is a name of rendering core of open source browser engine. It provides tools for browsing the web. [9]

Android Runtime

This layer includes virtual machine DVM (Dalvik Virtual Machine) and basic Java libraries. Virtual machine Dalvik was developed in 2005 especially for Android by Dan Bornstein team. [10] DVM has registry oriented architecture and uses all basic properties of Linux core as:

- coordination of running processes,
- memory management or
- work with threads.

This new virtual machine was created because programmers, who were creating application for OS Android, were developing in Java language and its libraries are licensed as an open source, however virtual machine, made for program compilation does not belong under open source license. Another reason for creating DVM was the need of optimization virtual machine for needs of mobile devices, where the focus is on power as well as on energy saving. Ujbányai [11, p.19]

Application for Android are programmed in Java language, compiled into Java byte code and afterwards compiled into “bytecode” using Dalvik compilation. Final code is run by

DVM. Each application is independent process with own installation of DVM

Application framework

Application framework is the most significant layer for developers. Thanks to open platform of Android OS, developers can take advantage of productive environment for developing innovative applications. Application framework enable access various services, which can developer use in his application as access to graphics-user interface. [12]

The most significant services of application framework are:

- View System – includes graphic-user interface into applications
- Notification Manager – access status bar with custom notification for applications
- Content Providers – access to native applications as People and Calendar
- Activity Manager – Control life cycle of applications

Application

Last layer represents particular applications used by users. Those applications can be native (preinstalled) or download from online catalogue (Google Play).

3.2 Evolution process

Software platform Android was unveiled on 5th November 2007 by official introduction together with forming and Open handset Alliance (OHA). It had 34 members and was given a responsibility for ongoing Android development as it started evolution of open source OS Android.

3.2.1 Android introduction

Company Android Inc. was established in California in October 2003 by Andy Rubin, Rich Miner, Nick Searsand and Chris White. In August 2005 Google Inc. acquired this not well known startup Android Inc. Experts started to speculate about Google entering the *smartphone* market by developing its own phone. [14] ,,We're hoping thousands of different mobile phones will be powered by Android." Eric Schmidt [13]

,,Google has developed a prototype cell phone that could reach markets within a year, and plans to offer consumers free subscriptions by bundling advertisements with its search engine, e-mail and Web browser software applications, according to a story published today in The Wall Street Journal" [16]

After acquisition of Android Inc. a Linux based platform was developed under lead of Andy Rubin and in September 2007 Google successfully claimed few mobile technology patents. [17]

3.2.2 Open Handset Alliance

As mentioned above, OHA was formed in November 2007 with 34 members. Today there are 84 members, including mobile handset makers, application developers, mobile carriers and chip makers. Members of OHA are not allowed to produce phones that run incompatible versions of Android. [19]

However there were issues about contradictions between keeping Android as *open* software OS and Google's intent for keeping all versions of Android OS compatible. Last controversy was caused by Alibaba, Chinese company, which tried by cooperation with Taiwanese Acer to release a smartphone with incompatible version of Android called Aliyun. [18] The release was stopped by Google and OHA only a few hours before start.

3.2.3 First Android device

First version of Android 1.0 was introduced on 23rd September 2008, mainly for developer's purposes and to get familiar with new mobile platform and embark on applications creation. A month later, on 22nd October, first commercial Android OS running phone was released: T-mobile G1, which was also known as HTC Dream. On the same date was also released application Android Market with 30 applications for download. Furthermore operation system was released with complete source code for developers use. This was part of the reason why many OEM decide to equip their devices with open source OS Android. [20] [21]

Recently there is over 800000 applications in Google Play , Android is running on more than 600 type of devices and have 61% - 75% market share according to various analysis. [22] [23] [24] [58]

3.2.4 Market share

Open source operation system Android is the fastest growing OS in the market. Since its release in 2008, it got 3% market share in 2009 (3% of all mobile devices considered as smartphones). In 2010 market share grows to 7%. Turning point came in 2011 when Android reached almost 50% market share. During 2012 Android open source OS reached 61% - 75% of market share, according to various analysis. [25]

According to Google's statistics, until 2012 were activated more than 400 million Android devices. The most significant date according to new activations was 25th December 2012 when 17 million of Android devices were activated. Comparing with 25th December 2011, *only* 6.8 million devices were activated. In other words in 2012 were 2.5x more activations. Also comparing to regular day of December 2012 it is 330% increase as

average number of activations since 1st December to 20th December was 4 million. [25] [27]

3.2.5 Google Play

Google Play (GP) is main part of open source OS Android. It is preinstalled application developed by Google and serving as an application online catalogue. Previously GP was called Android Market as it was renamed in March 2012 together with adding services as purchasing e-books, music, movies and other multimedia content.

In beginning of 2012, Android market reached 400 000 unique applications, in beginning of 2013 number of unique applications doubled to 800 000 and is expected to reach 1 million in mid-2013. [28] The most applications are programmed in Java as Google SDK strongly encourages for using this language.

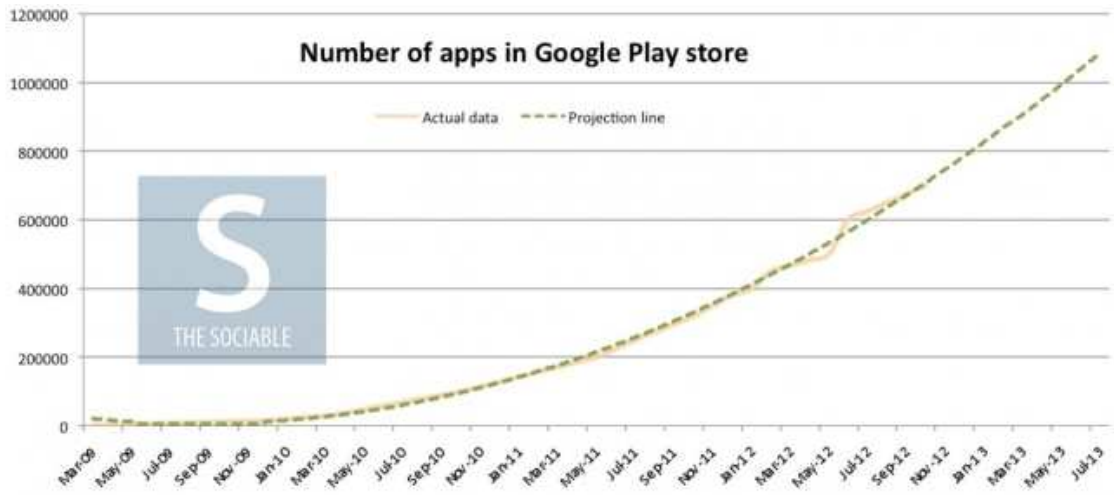

Figure 2: Number of Applications in Google Play store [15]

3.3 Android version history

As mentioned above, first released version of Android 1.0 was introduced on September 2008. Later was updated to Android 1.1 with no new features, only fixing particular system issues. Not to mention, all updates are accessible through OTA (over the air) system, which automatically notice users about new system version update.

Despite Android 1.0 had no codename and Android 1.1 was called Petit Four, all ongoing versions starting with Android 1.5 are recognized by codenames sorted as alphabetical *snacks*.

3.3.1 Cupcake 1.5

First real update of Android was released on 30th April 2009 as 1.5 Cupcake with new Linux core 2.6.27. This update brings new functions as video recording with camera, uploading videos to server Youtube or uploading pictures to server Picasa (booth Google services). New widgets were added to support efficiency of the OS coupled with enhancing software keyboard with automatic prediction of words. Native internet browser was updated by search option and function copy and paste. Additionally Bluetooth function was improved in its communication with hands free devices. [29]

3.3.2 Donut 1.6

Next version Android 1.6, codename Donut, was released on 15th September 2009. Linux core was updated from 2.6.27 to version 2.6.29. The most significant update was search engine integrated in Peoples application, bookmarks, history of web browser and internet itself. Also camera application was improved video recording option and picture gallery. Users can now comfortably switch between camera and video recorder. Picture gallery supports marking, deleting or using more files at the same time. Moreover enhanced

battery indicator was implemented. User can now recognize applications which consume and decrease a battery life the most critically and manage them. In addition Android Market was improved by sorting applications by their purpose (office, games, paid apps, free apps).

Crucial upgrade was adaptation of screen rendering for screen of any size and any resolution. Marginal upgrades were support of VPN, CDMA, 802.1x technologies, gestures and synthesis of voice. [30]

3.3.3 Eclaire 2.0

Android version 2.0, codename Eclaire, was released on 26th October 2009. It came with speed optimization, upgrading user interface and enhancing web browser which was added a support of HTML 5. Furthermore for users was added option of synchronization of contacts with Microsoft Exchange. Users are now able to browse several email accounts, in one window. Also saved SMS and MMS can be searched according to content. Coupled with possibility of setting maximum life time of SMS before deleting, the message manager was significantly improved.

Crucial update received also camera, as it was given option for focus on macro images, digital zoom, white balance, LED flash and various color modes. Application People received quick action button as it makes it more comfortable for users (quick call, SMS send, email send). This new option can be also used as a widget on user screen. Not to mention software keyboard was improved for quicker and comfortable writing.

Two more updates of Eclaire version were released on 3th December 2009 (SDK version 2.0.1) and 12th January 2010 (SDK version 2.1). Those two updates didn't bring any improvements directly to users, but offered a new API for developers. [31]

3.3.4 Froyo 2.2

Next version was released on 20th August 2010 as Android 2.2, codename Froyo. Linux core was updated to 2.6.32. Android 2.2 brought desired option of moving application from internal storage to external storage, e.g. microSD card. It was appreciated by users because of mobile devices common restrictions was a limited memory. According to this, installation of third party applications usually caused the problem that operation system had no memory left for system application and it started lagging of the whole system. Additionally new function of Wi-Fi hotspot was implemented. In other words, any Android device can by turn into Wi-Fi hotspot, also up to 8 devices can be connecting to internet through it. Implicit requirement is active mobile data connection or USB connection with computer with access to internet.

To say nothing of this version Android 2.2 integrated flash support, system keyboard received small updates, camera, gallery and user interface were improved. On the top of that was added function JIT (Just In Time) compilation which speed up system responses 2x – 5x. Coupled with enhanced RAM management, Froyo update was a turning point both for users and developers and open source OS Android became a powerful system for mobile devices. [32]

3.3.5 Gingerbread 2.3

On 6th December 2010 was released Android version 2.3 with codename Gingerbread. Linux core was updated from version 2.6.32 to version 2.6.35.

Gingerbread updated user interface to be more responsive, quicker and intuitive. Moreover text editing was enhanced as users are able to choose a single word or paragraph by long touch on screen. Additionally new telecommunication functions were added as VOIP (Voice Over IP) calls with SIP account and support for NFC (Near Field Communication - wireless communication between devices for distance 0 - 20cm). NFC

technology is widely used for contactless payment (known also as a *touch and go* or *wave and pay*), buying tickets or data transfer. NFC is not only a software function, but also need a particular hardware to run. [33]

As a matter of fact, NFC technology started to be widely used by launch of Samsung Nexus S, the first Android phone commercially supporting NFC and also first smartphone running Android 2.3. [34]

3.3.6 Honeycomb 3.0

Android 3.0 with codename Honeycomb was released on 22nd February 2011. This version was developed only for tablets. In early 2011, Google chose to temporarily withhold the Android source code to the 3.0 Honeycomb release. The reason, according to Andy Rubin in an official Android blog post, was because Honeycomb was rushed for production of the Motorola Xoom [35].

Notable change is the way how applications are controlled, which is enriched by various 3D effects. Keyboard was adjusted to larger screen. Furthermore new function for *drag and drop* was added for easy moving of objects. Additionally a support of multiple-core processors was added. Those improvements made Android 3.0 to step into became a full game console. [36]

Customizable Home screens

The user interface is slightly different from previous Android versions. ,,Five customizable Home screens give users instant access to all parts of the system from any context. Each screen offers a large grid that maintains spatial arrangement in all orientations. Users can select and manipulate Home screen widgets, app shortcuts, and wallpapers using a dedicated visual layout mode. Visual cues and drop shadows improve visibility when adjusting the layout of shortcuts and widgets. Each Home screen also offers a familiar

launcher for access to all installed applications, as well as a Search box for universal search of apps, contacts, media files, web content, and more."[36]

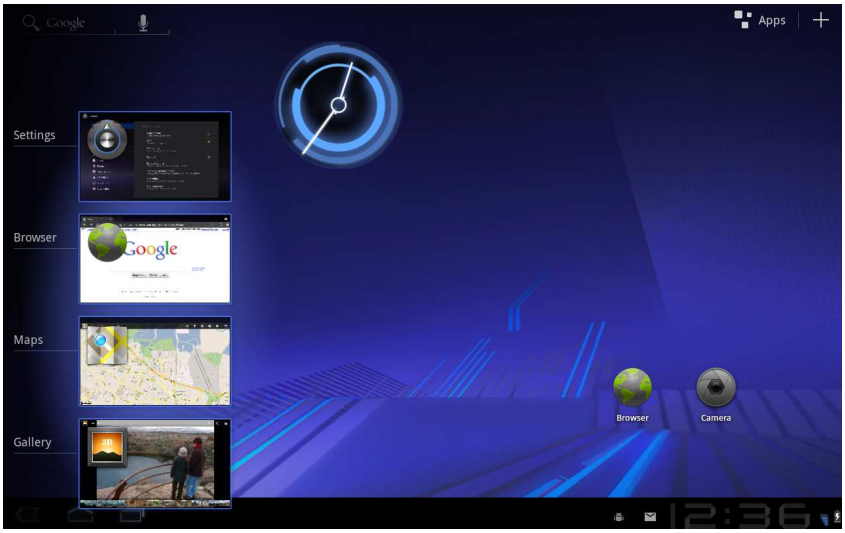

Figure 3: User interface of Android 3.0 Honeycomb [36]

Today Android 3.0 idea is not supported anymore, for the reason there is a trend to unify Android OS for smartphones and tablets. [37]

3.3.7 Ice Cream Sandwich 4.0/4.0.3

Android version 4.0 Ice Cream Sandwich (ICS) was unveiled on May 2011, but it was released on 19th September 2011 inside Galaxy Nexus smartphone. Open source platform ICS is dedicated for both smartphones and tablets. ICS is referred as the most crucial update among all Android versions and as a huge leap ahead.

ICS comes with new user interface supporting efficiency and user-friendliness. Moreover it brings better support of multitasking as a key strength of Android. Other upgrades were focused on visualization, e.g. Recent Apps button lets users jump instantly from one task to another using the list in the System Bar. The list pops up to show thumbnail images of

apps used recently — tapping a thumbnail switches to the app. [38]

Google's intention and hard work to make Android a user-friendly open source operation system is even more obvious when experiencing Android 4.0 ICS. For example new feature Face Unlock was added as well as Android 4.0 introduces a completely new approach to securing a device, making each person's device even more personal. ,,Face Unlock is a new screen-lock option that lets users unlock their devices with their faces. It takes advantage of the device front-facing camera and state-of-the-art facial recognition technology to register a face during setup and then to recognize it again when unlocking the device. Users just hold their devices in front of their faces to unlock, or use a backup PIN or pattern." [39]

3.3.8 Jelly Bean 4.1/4.2

Android update with codename Jelly Bean (JB) was unveiled and released on conference Google I/O on 9th July 2012.

JB's most significant upgrade was function called Project Butter, dedicated to solve frequent problems with device lag. ,,It ensures that CPU and graphics run in parallel, rather than crash into each other and has a big impact on both real and perceived speed: the entire interface runs at 60 frames per second on sufficiently fast hardware. Graphics are now triple-buffered to keep scrolling and transitions humming along, and the processor will swing into full gear the moment you touch the screen to keep input lag to a minimum." [40]

Equally important is new support of offline voice recognition, improved notification bar, added Google Now and support of more user accounts.

Focusing on update of Google Now – it is an intelligent personal assistant available for Android open source operating system. "An extension of Android's native Google Search

application, Google Now uses a natural language user interface to answer questions, make recommendations, and perform actions by delegating requests to a set of web services." [41]

JB update introduces an improved camera with HDR and pipeline for enhanced performance. On supported devices, apps can use a new HDR camera scene mode to capture an image using high dynamic range imaging techniques.

3.3.9 Key Lime Pie 5.0

Android version 5.0 with codename Key Lime Pie will be next generation of Android open source OS. It's released is doubted to happen on conference Google I/O in San Francisco on 14th May. Developers argue new functions which will Android 5.0 bring however there are some highly credibly expected features.

Voice assistant

Despite expected since Android version 4.0, there was no integration of competitor to Siri from Apple. Voice assistant should be able to process orders in common talk, instead of exact orders. Also voice assistant interface could be provided to third party developers, which can be an advantage against Apple's Siri.

Not to mention a few alternative voice assistants are already available on Google Play. [43]

Full backup

Android already offers native application of backup of user data. However native applications only backup some user data and not all applications and their data. Thus third party applications as Titanium backup or advanced NAND are frequently used. Android 5.0 could support feature of complete system backup as user is no longer tied to

particular device, and can turn any device into his personal workstation with all his personal data.

Developers and authorities also mention enhanced PC connection feature, improved multitasking, system maintenance and synchronization with multiple devices as a significant update of Android 5.0.

3.4 Versions distribution

One of the important issues about open source OS Android is its fragmentation. Android was developed as mobile platform and came with the promise that it could power almost any device. ,,That's created a proverbial cornucopia of mobile devices that consumers have to choose from, but it's also led to the issue of fragmentation — there are so many devices running different versions of Android with different capabilities that can alter experience.” [42]

In May 2012 open source OS Android was deployed on 3,997 devices, which makes it most popular mobile OS in the world, however it also brings several problems mentioned above. Samsung’s devices make up 40% of all Android devices, followed by HTC, Sony-Ericsson, Motorola and LG. [45]

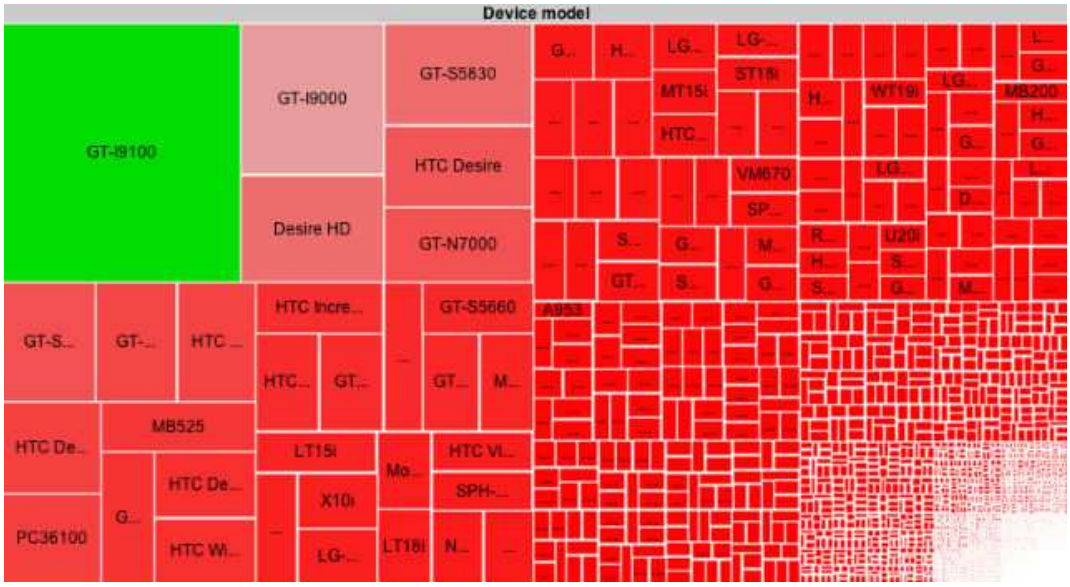

Figure 4: Open source OS Android devices fragmentation. [44]

Despite Android device fragmentation is significant; it is not a crucial problem to Android OS. The most important issue is fragmentation of Android versions. The table below shows Android version distribution among all Android running devices.

Version	Codename	API	Distribution
1.6	Donut	4	0.2%
2.1	Eclair	7	2.2%
2.2	Froyo	8	8.1%
2.3 - 2.3.2	Gingerbread	9	0.2%
2.3.3 - 2.3.7		10	45.4%
3.1	Honeycomb	12	0.3%
3.2		13	1.0%
4.0.3 - 4.0.4	Ice Cream Sandwich	15	29.0%
4.1	Jelly Bean	16	12.2%
4.2		17	1.4%

Figure 5: Version distribution February 1st 2013 Source: [48]

The output is obvious, the most Android devices don't run the newest Android version - it is less than 15%. Almost half of the users are using Android 2.3 Gingerbread (GB). As a matter of fact it is very disturbing for Android developers, as Android 2.3 GB was released on 2010 and is considered as outdated.

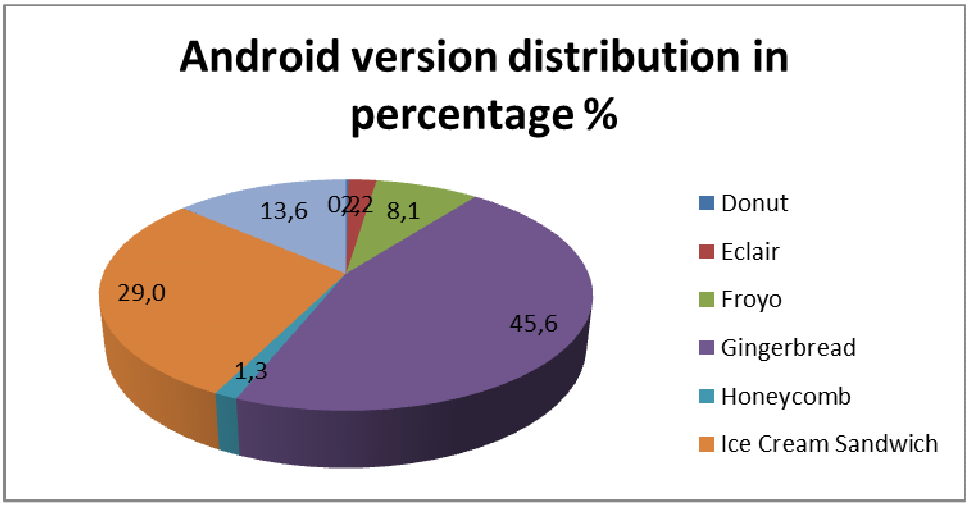

Figure 6: Version distribution February 1st 2013 Source: [48]

As [Figure 6] shows, most users with Android phones never get to take advantage of the latest features because of Android fragmentation. However, the crucial reason why fragmentation matters is application reliability and compatibility. [47]

Developers can't focus on the newest version of the system and use all its benefits. In the first place, they still have to take into account more than half of the users are using outdated version of the system, thus it can cause an application incompatibility.

As [Figure 7] demonstrate, the trend of system version migration is very slow. As a matter of fact, fragmentation will always stay one of the most notable issues of open source OS Android with no working solution proposed.

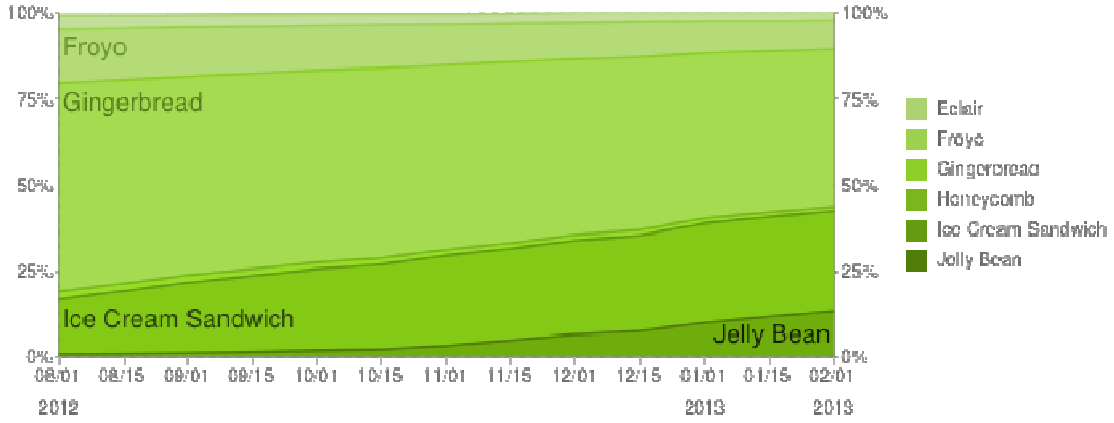

Figure 7: Open source OS Android version history [48]

3.5 Security

As mentioned above Android is a mobile platform designed to be open both to developers and users. ,,Android applications make use of advanced hardware and software, as well as local and served data, exposed through the platform to bring innovation and value to consumers. To protect that value, the platform must offer an application environment that ensures the security of users, data, applications, the device, and the network.” [49]

In 2012 mobile operation systems experienced growing trend of security threads. According to Symantec report, in 2010 appeared 160 new mobile security vulnerabilities, but in 2011 it was already 315 security problems which continue growing during 2012. In 2011 also occurred 5000 new security threads. Such a trend is proving that harmful code is starting to focus on mobile devices.

3.5.1 Android as a security thread

Not all mobile platforms are in the same level of danger. For example Windows phone has minority market share and thus is not as tempting for possible attackers. The 95% of today malware is developed for Android operation system. [50]

The main reason for Android OS being in the center of malware attention is its openness. Through Google Play can be easily downloaded any malware or a potentially dangerous third party application. In 2012 very frequent way to infect a mobile Android device was to modify a popular, well known application and distribute it as an original but with dangerous code included. [51]

During years 2010 and 2011 were infected more 10.8 million Android devices with malware. Key findings of growing security issues can be specified as

- ,,malware threats to Android devices increased 1880 percent from January to December 2011,
- the top countries with infected Android devices were China, India, the United States of America, Russia and the United Kingdom.” [52]

3.5.2 Malware rise

As mentioned in chapter 3.5.1, despite new versions of Android with better security solutions are available, most Android devices still run outdated Android version 2.3. As a matter of fact it is a significant security threat. Since no central system update is possible, there is no option to protect all users from critical weaknesses of the system. On the other side Android OS separate rights so applications cannot access network and OS’s resources without previous approval. In the light of this fact, the most crucial problem for Android security is user himself as he usually gives application rights that can be abused.

By the same token analysis of Kaspersky labs describes several warnings about Android security. The most significant one is continuing trend of rise of malware installed. As we can see, in second quarter of 2012 a number of malware detected on Android devices almost tripled comparing to first quarter of 2012.

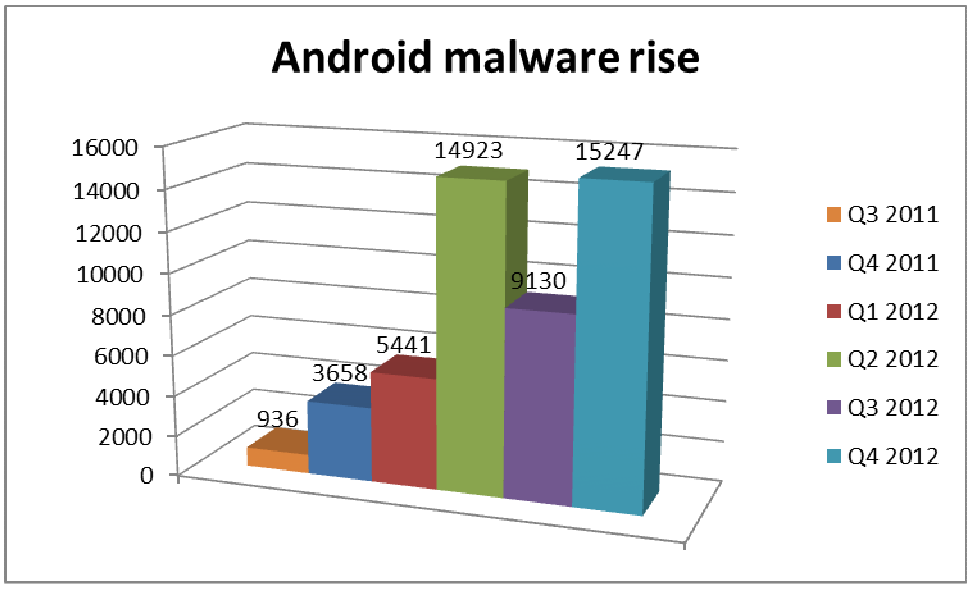

Figure 8: Android Malware rise during 2011 - 2012 [53] [54]

Furthermore analysis of mobile malware for Android OS proceed by Kaspersky Lab in Q3 2012 revealed that the most popular targets among cybercriminals were Android versions 2.3.6 and Android 4.0.4. However fragmentation of Android version is a serious issue, according to this analysis we can presume, that not only outdated Android versions are target of malicious software, but also the newest version are having similar security problems.

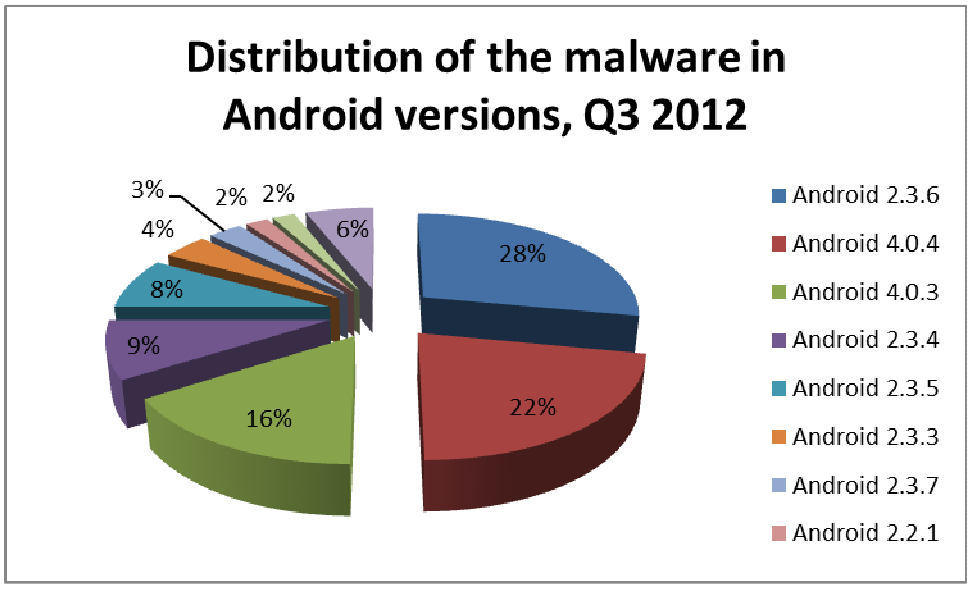

Figure 9: Distribution of the malware in Android versions, Q3 2012 [55]

3.5.3 Corporate adoption

Android operation system is mostly not suitable for corporate use. In the light of this fact many companies deny to use Android in their business environment. The reason is that Android is missing many features for enterprise-business adoption; mainly security functions. The most significant issue is lack of data encryption support, micro SD card encryption and better malware protection. Additionally Android OS needs option of remote data deletion by administrators and better tracking in case of loss of steal.

Furthermore security scandals related to Android also doesn't encourage companies to deploy this open source OS for company communication. Not to mention issue revealed in May 2011 when server The Register informed that 99% of Android platform running phones are vulnerable against privacy data and passwords stealing. It was as simple as when user accesses a web service, he receives a *token,* which is used for further user verification. Password is not needed during token is valid (next two weeks). However this token is send with no encryption so anybody who obtains it can convince a web service that he is allowed to access particular user's account. This security threat was partially

fixed in Android 2.3.4, however some services are still vulnerable. Android OS still can be used in corporate sphere, but only marginally and for work with non-sensitive data.

3.6 Trends of Android OS

In 2008 Android open source operation system was launched as a platform for mobile phones in the first place. In the light of future changes android deployed also on tablets and *phablets* (a term used in literature for smartphone with screen size around 6”). Despite Android OS was developed mainly for phones and later for tablets, many other devices start to use this open source platform recently. In the future, Android will probably occupy many devices of our daily use.

3.6.1 Samsung Galaxy Camera

Samsung Galaxy Camera (SGC) is not first Android powered camera in the world (it is Nikon S800c), but first camera with concept fully connected with Android platform as it offers 4G cellular connection and a rear control panel that is indistinguishable from a smartphone screen.

It offers quad core processor Exynos 4412, 21x zoom and optical stabilization of pictures. Version of Android is 4.1.1 (Jelly Bean) with Samsung TouchWiz interface 4.0. It supports data connection through HSUPA network with frequencies 850 / 900 / 1900 / 2100 MHz, using a micro SIM card. SGC is prove, that Android OS is as complex, it can be usefully deployed in other devices than phones. [56]

3.7 LIFX Android bulb

,,LIFX is a WiFi enabled, multi-color, energy efficient LED light bulb that user control with mobile Android device (supports iOS also).” [57] LIFX is as simple as user only installs a special bulb into a lamp and downloads an application from Google Play. With application interface he can control the bulb from anywhere and also choose brightness for each particular bulb.

Figure 10: LIFX Android controlled bulb [57]

Moreover bulb is hence to Android controlled consumption environment friendly as it reduces energy consumption. To say nothing of LIFX project is the most successful project based on model the internet of things, focusing on home automation and overall concept of smart home. [57]

3.8 Android controlled devices

There are certainly significant amount of devices powered by Android which are far away to be recognized as smartphones. For example in the 1Q of 2013 first Android fridge T9000 was unveiled and as a matter of fact, Eric Schmid, executive chairman of Google, said he wants every house to run an Android fridge in the future. Likewise there is a trend of rising Android remote controlled gadgets as helicopters, cars etc. The principle is same as in case of LIFX – connection with helicopter is managed by WiFi and smartphone with installed application serve as a remote control. Those projects prove that Android is complex OS that will be used for various types of device in the future.

3.9 Competitors

Regardless Android OS deployment success, many competitors occur. This paper will briefly describe four significantly competing operation systems. On the contrary, there exists much more operation systems for mobile devices; however they are not important recently due to their marginal representation. As example can be used Nokia's Symbian OS or Samsung Bada OS, which experienced a steep fall in market share. On the other hand appears several new mobile OS as Ubuntu OS of Firefox OS, however due to their marginality their description is only brief.

Competition is expected to grow continuously. According to IDC analysis, it is especially Windows Mobile OS which will take over Android users. „During the five-year period from 2012 through 2016, Android's share of the global smartphone market will dip from 61% to 52.9% according to IDC, Apple's iOS will slide gradually from 20.5% to 19%, and Microsoft's share of the market will balloon from 5.2% in 2012 (Windows Phone and Windows Mobile combined) to 19.2% in 2016, passing iOS to become the No.2 smartphone platform in the world." [58]

In the table below is described market share of significant mobile devices OS's and their estimated market share in 2016.

Smartphone OS	2012 Market Share	Estimated 2016 Market Share
Android	61.0%	52.9%
Microsoft	5.2%	19.2%
iOS	20.5%	19.0%
BlackBerry OS	6.0%	5.9%
Others	7.2%	3.0%
Total	**100.0%**	**100.0%**

Figure 11: Worldwide Smartphone Operating System 2012 and Estimated 2016 Market Share [58]

3.9.1 Apple iOS

iOS was originally developed for mobile phones iPhone, later it was used also in other devices as iPod Touch, iPad and also Apple TV. The release was together with iPhone on 29th June 2007. ,,Apple has radically changed the world's views on mobile security, moving it from a world where all policies were dictated by the IT department (regardless of how that impacted the actual users) to a model where the IT department has to now balance the needs of both the workplace and the workforce." [46] Today in Apple store is downloadable more than half million of application for iOS.

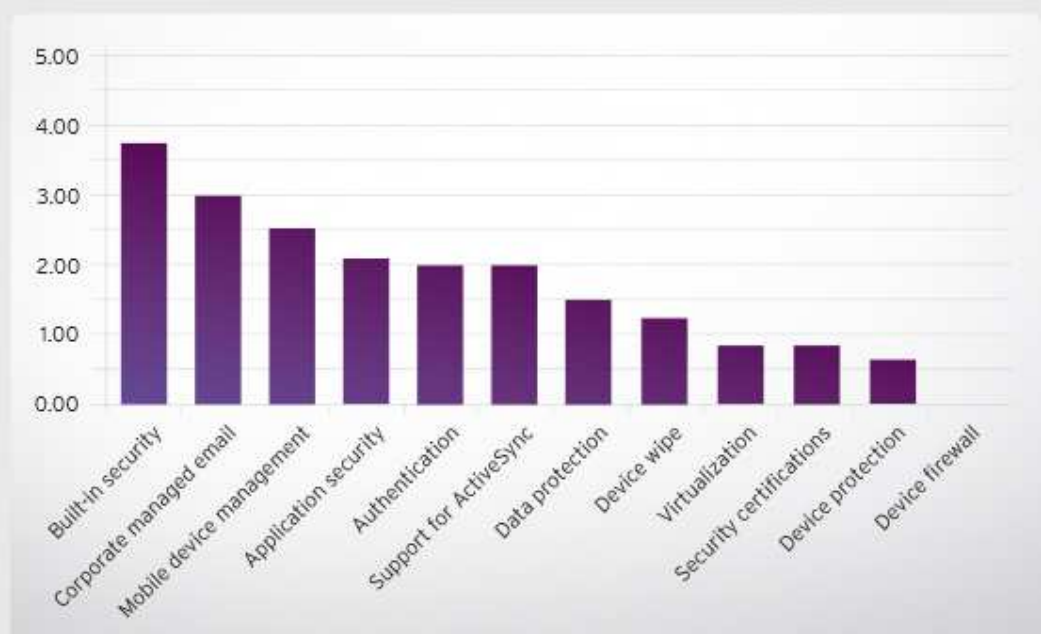

Figure 12: iOS security balance [46]

In summary, main difference between Android OS and Apple's iOS is the level of openness which influences the security. Since Android is having serious number of security issues, iOS is due to its close ecosystem more secure mobile OS. As a last iOS users are widely recognized as platform "loyal" users. [59]

3.9.2 Microsoft

Microsoft mobile operation system Windows Phone (WP), released on 20th October 2010, is a successor of Windows Mobile, which was developed mainly for PDA devices and early smartphones. Windows Phone is not compatible with Windows Mobile. Recently there are two versions Windows Phone 7 and Windows Phone 8 with also doesn't have mutual compatibility.

There are already more than 150 thousand applications in Windows Phone marketplace, which in other words means it doubled number of application during year 2012. As number of application is recognized as important characteristic of operation system

user popularity, WP is about to gain back Microsoft market share, which is losing since 2010. According to IDC study [58] it is going to overtake mainly Android users.

3.9.3 BlackBerry OS

Blackberry is an operation system developed by Canadian company Research in Motion (RIM). System supports multitasking and multiple input devices. Blackberry platform is mostly known for its corporate communication excellent support and its advanced security function. It supports wireless activations and synchronization of contact list, calendar, tasks and emails trough Microsoft Exchange, IBM Lotus Domino or Novell GroupWise. It must be used parallel with BlackBerry Enterprise Server. Developers can create their own applications for Blackberry OS using proprietary BlackBerry API.

Blackberry is also known as a victim of its success. Its security standards provide all communication with BlackBerry phone highly encrypted so it is slightly difficult to monitor it's a communication. In contrast, many governments see this fact as a national threat and banned BlackBerry (e.g.: Saudi Arabia, UAE). [60]

Comparing to Android, BlackBerry is more focused on corporate clients, despite recently is losing this market against its competition due to inability to match needs of today smartphone users.

3.9.4 Other OS

Omitting *"dead"* operation systems as Symbian and Bada, many new mobile operation systems occur in 2012. As a most influence are considered two of them – Firefox operation system and Ubuntu OS. Both operation systems are open source.

Firefox OS is built by non-profit company Mozilla and it provides the complexity of an operating system to the basic web browser. ,,It is also optimized for touch and it negates the need for an app store through core HTML5 integration which allows any HTML5 application to directly access the device hardware. At once this creates millions of 'apps' from existing webpages and utilities.“ [61]

Ubuntu built by Canonical doesn’t focus on developing a mobile version of Ubuntu OS for desktop computers. It is rather trying to develop a system automatically optimize itself for different screen sizes. ,,As such it is a single operating system that can switch user interface (UI) depending on the screen size to which it connects. Consequently developers only need build a single app with different UIs and Ubuntu uses open standards for their construction.“ [61]

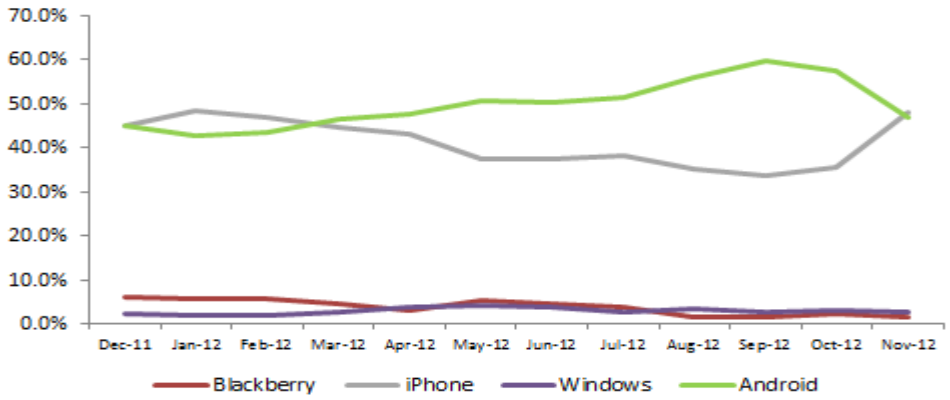

Figure 13: US smartphone market share [62]

4 Quality index for comparing and evaluating OS

A crucial goal of this thesis is to develop a new method for comparing and evaluating mobile devices operation systems. This method will be based on combination of users and experts perspective and presented by QEE Index (Quality of Experience Enhanced Index).

Traditional comparisons analysis of mobile OS consider as criteria only particular (and isolated) properties of system [63] or on other hand only suggestions of developers [64]. Both examples above have one characteristic in common. Their comparing analysis doesn't include the most important criterion – user's subjective opinion and experiences, in other words, user's feedback. Not only in general, but user's opinion and experiences for every aspect of operation system, are omitted. However operation system quality comparison is supposed to be based mainly on user's experiences.

An analysis based only on comparison of declared OS functions can hide and omit very important data. For example, in January 2013 both iOS and Android application catalogues (App store and Google Play) had same number of unique applications – 800 000. Furthermore Google Play is going to take over App Store in June when it will, according to estimations, reach 1 million of applications.

If analysis of quality considers those data as only criteria, Android and iOS would have same value of quality index. In June, when Android would reach more applications then iOS, it would correspondingly become an operation system, with higher quality index value. Using criteria "quantity of application in catalogue" for comparison would cause Android to be better OS than Apple's iOS.

However, according to study of ReadWrite Mobile, iOS users are more satisfied with quality of their applications compared to Android users. [42] In this case, pure data

(quantity of applications in catalogue) are a misleading criterion omitting user's feedback and real experiences.

For this reason, the new method for evaluating and comparing mobile devices OS is proposed. This method considers users subjective opinion and experiences with their OS as a main criterion. Those users' data are obtained by questionnaire and processed by multi-criteria decision analysis with weights gained by expert's questionnaire.

4.1 Basic analysis

219 smartphone users participated in questionnaire. The questionnaire consists of two kinds of questions – yes or no questions and rating questions. Rating questions were answered on a scale 1 to 5, as 1 mean strongly agree and 5 strongly disagree. Moreover each question was thematically related with one of seven criterions for further analysis.

As a brief result of questionnaire, the gender distribution was almost ideal. 47% of respondent were men and 53% women. The most frequent OS was Android as 64% of respondent mark it. Some of the variants (e.g.: BlackBerry OS) have marginal representation in questionnaire (which quite well corresponds with representation on the world market), thus those data would be inconclusive if it would be statistically analyzed.

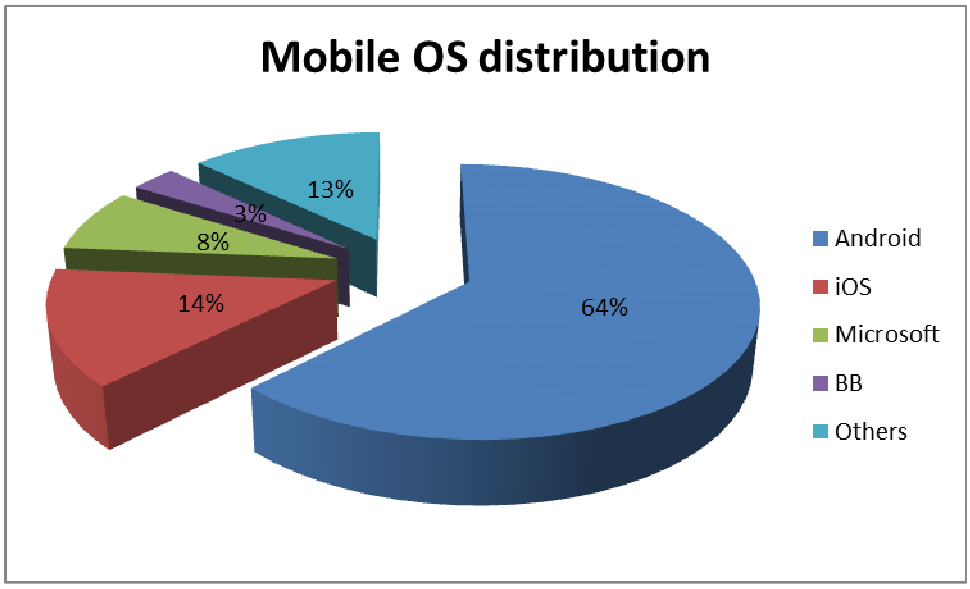

Figure 14: Mobile OS distribution Source: own

4.1.1 QEE Index Criterions

In the table [Figure 15] are presented questions separated by colors into logically corresponding groups. It is seven groups together and they are used as seven basic criterions for OS QEE Index evaluation.

The seven criterions are:

- User loyalty
- Security
- User interface
- OS performance
- OS support (community/official)
- Data portability
- General satisfaction with OS

Question	Android	iOS	Microsoft	BB
1) Which OS is running your smart mobile device?	64%	14%	8%	3%
2) Have you ever change an OS on your mobile device?	30%	42%	53%	43%
3) Have your device ever been infected by virus?	2%	3%	0%	0%
4) Do you use antivirus?	44%	10%	12%	43%
5) Have your device ever been threatened by potentially unwanted application abusing it's permissions?	14%	0%	0%	14%
6) Do you feel, your device is well protected?	2,46	1,74	1,94	2,00
7) Is user interface of your device user friendly?	1,85	1,32	1,76	2,43
8) Is your OS interface intuitive to use and control?	1,87	1,48	1,71	2,00
9) Is performance of your OS "smooth", e.g. there is no "lagging" and "freezing"?	1,94	1,55	1,76	2,14
10) How difficult is to find a proper solution for problem (official channels/ community channels)	2,48	1,90	2,24	2,14
11) How difficult is to migrate your data into another device?	1,81	2,74	2,59	2,14
12) Would you recommend your OS to a friend?	1,51	1,42	1,71	1,86
13) In general, are you satisfied with your OS?	1,64	1,29	1,94	1,86

Figure 15: User's questionnaire results [percentage or MIN 1-5] Source: own

4.1.2 Users *loyalty* for OS

Several criterions will be analyzed individually, loyalty is one of them. According respondent's behavior related to changing their operation systems (e.g.: respondent bought an iOS device, but wasn't satisfied enough and changed for device with different OS when purchasing a new mobile device) was created a graph describing user's *loyalty* for particular OS. In graph [Figure 16], average value is computed from all responses.

Only OS with higher value then average are Android and OS labeled as "Others". Other OS refers to out dated OS as Symbian, Badu etc. The result can be interpreted as users running old operation systems are comfortable with no change of their interface and also they don't require any updates.

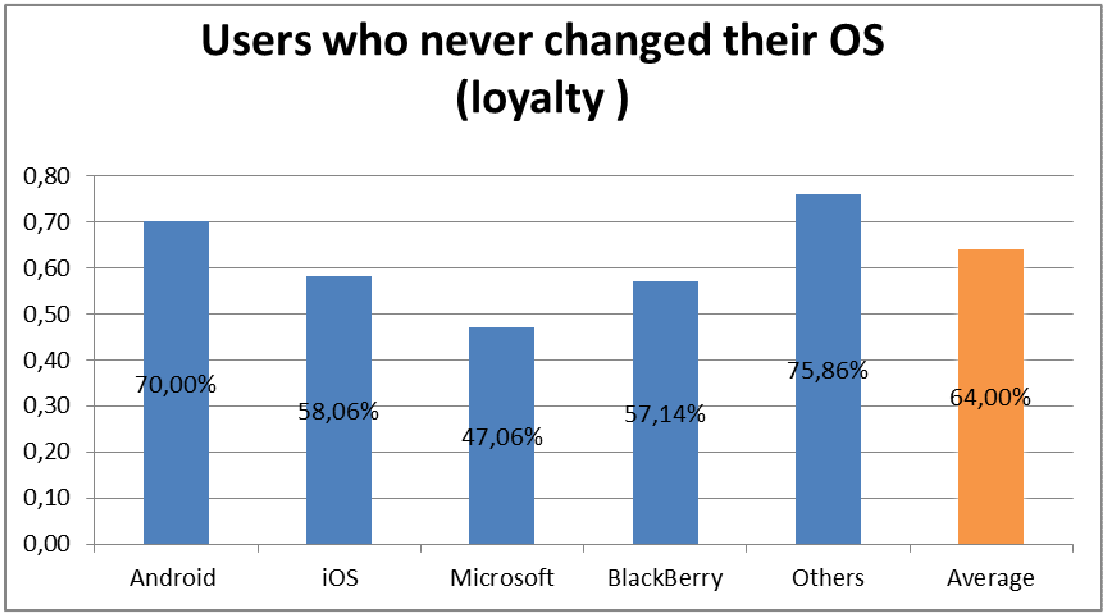

Figure 16: Users who never changed their OS (Loyalty) Source: own

4.2 Partial Indexes

As some criterions for QEE Index were not given by a single value, but by a set of data, they were computed into a partial index. Those partial indexes were determined by a simple multi-criteria decision analysis.

4.2.1 Security Index (SI)

Questions 3-6 of questionnaire [Figure 16] were related to security; however for creating a QEE Index is needed to have only one security criteria - Security Index, thus it is significant indicator of OS quality. In [Figure 17] are recorded adjusted data from questionnaire.

Security Index	Virus infection	Malware infection	Antivirus in use	User protection - subjective
Android	0,02	0,14	0,56	2,46
iOS	0,03	0,00	0,90	1,74
Microsoft	0,00	0,00	0,88	1,94
BB	0,00	0,14	0,57	2,00
Others	0,00	0,07	0,86	2,54
Min/max	min	min	min	min

Figure 17: Criteria matrix for Security Index (SI). Source: own

As all criteria are described as minimization model, grades are given to each variant according to its criteria. Grade 1 is the best, grade 5 the worst. Weights are set according to own experiences with security issues on mobile devices.

	Virus infection	Malware infection	Antivirus in use	User protection - subjective	SI
Android	4	4	1	4	**3,94**
iOS	5	1	5	1	**2,68**
Microsoft	1	1	4	2	**1,34**
BB	1	5	2	3	**2,78**
Others	1	3	3	5	**2,76**
Min/max	min	min	min	min	
Weights	0,4	0,3	0,02	0,28	

Figure 18: Security Index (SI) with weights and counted. Source: own

After all for each variant is computed it's Security Index [Figure 18]. The ideal variant would have SI equal to 1. In conclusion as a best variant was recognized Microsoft operation systems (WP7, WP8) with SI = 1.34. Android OS was recognized as a worst OS according to security; IS = 3.94. Interpretation is, Microsoft OS is the top security device, however it used only by minority of users. Thus there is no wide intention or purpose to create a malware, virus or any kind of security threat for it. On the other hand, Android is using more than half of smartphone users (more than 400 million devices); it is open platform and for this reason it is a top target for malicious application developers. This result was highly expected.

4.2.2 User Interface Index (UII)

UII is one of the most important criterions. It shows us a user satisfaction with OS interface. It significantly influences the overall OS quality. It is important to take into account the fact that data about these criteria are always subjective. Thus there is nothing like an "ideal" UI.

	User friendly UI	Intuitive control of UI	UII
Android	1,85	1,87	**1,86**
iOS	1,32	1,48	**1,40**
Microsoft	1,76	1,71	**1,74**
BB	2,43	2,00	**2,21**
Others	2,33	2,25	**2,29**

Figure 19: User Interface Index (UII) table. Source: own

UII index is composed of two elements – user friendliness of interface and intuitiveness of interface. Result is computed as an average as both criteria have the same importance. UII has minimization characteristic, thus UII = 1 describes an ideal user interface. Best variant according to [Figure 19] is iOS with UII = 1.40, followed with Microsoft, which is surprisingly beating Android.

4.2.3 General Satisfaction Index (GSI)

Last partial index [Figure 20] is evaluating user's convenience with OS in general and their will to recommend to a friend. It is strongly subjective criterion composed of two elements – user's will to recommend OS to a friend and rate of convenience of OS using.

	Will to recommend	Rate of convenience	GSI
Android	1,51	1,64	**1,58**
iOS	1,42	1,29	**1,35**
Microsoft	1,71	1,94	**1,82**
BB	1,86	1,86	**1,86**
Others	3,13	2,79	**2,96**

Figure 20: General Satisfaction Index (GSI) table. Source: own

The GSI is computed as average of both criteria, thus their weights are the same. As it is minimization model, the top variant is iOS with GSI = 1.35, followed by Android with GSI = 1.58. "Others" OS (outdated systems) are on the last place as it was expected.

4.3 Quality of Experience Enhanced Index (QEE)

Thereafter gaining values of all seven criterions for all five variables, the multi-criteria analysis can be processed to compute a QEE Index and demonstrate quality of particular operation systems for mobile devices. Quality of Experience Index is enhanced by weights created with experts in next step.

4.3.1 Experts questionnaire

For accurate QEE Index computation proper weights have to be chosen. With this in mind, a questionnaire for smartphone experts was created. Questionnaire included questions about rate of importance for each of all seven criterions. For this reason, QEE Index becomes significantly accurate as it combines users feedback for OS (criterions) with experts evaluation of each of this particular feedbacks (weights).

Experts respondents were recruited from two channels – IT media focused on mobile devices and companies developing application of mobile devices. Altogether 58 responses were gathered.

According to your opinion a CUSTOMER LOYALTY influences for mobile OS overall quality	2,74
According to your opinion, how strongly attribute of SECURITY influence mobile OS overall quality	3,14
According to your opinion, how strongly attribute of USER FRIENDLINESS influence mobile OS overall quality	4,12
According to your opinion, how strongly attribute of "SMOOTH"PERFORMANCE (NO "LAGGING", "FREEZING" etc.) influence mobile OS overall quality?	4,22
According to your opinion, how attribute of STRONG COMMUNITY influence mobile OS overall quality?	2,02
According to your opinion, how strongly attribute of DATA PORTABILITY influence mobile OS overall quality	3,36
According to your opinion, how strongly attribute of GENERAL USER SATISFACTION influence mobile OS overall quality	3,26
	[Max 1-5]

Figure 21: Expert's answers related to criteria weight. Source: own

[Figure 21] shows maximized result of expert's questionnaire. Those data are transformed into weights as shows in [Figure 22].

Criterion	Weight
Loyalty	0,12
Security Index (SI)	0,14
User Interface Index (UII)	0,18
OS performance	0,18
OS support (community/official)	0,09
Portability	0,15
General Satisfaction Index (GSI)	0,14

Figure 22: Counted weights for seven criterions based on expert's answers

[Figure 22] can be interpreted as UII and OS performance are the most affective criterions; on the other hand OS community/official support is the least affective.

4.3.2 Multi-criteria decision analysis

In the final analysis is created a criteria matrix for all five variants of OS. Criteria contains seven factors introduced chapter 4.1.1 including three partial indexes (SI, UII, GSI) and four criterions based on direct answers (loyalty, performance, support, portability).

	Loyalty	Security Index (SI)	User Interface Index (UII)	OS performance	OS support (community/ official)	Portability	General Satisfaction Index (GSI)
Android	0,70	3,94	1,86	1,94	2,48	1,81	1,58
iOS	0,58	2,68	1,40	1,55	1,90	2,74	1,35
Microsoft	0,47	1,34	1,74	1,76	2,24	2,59	1,82
BlackBerry	0,57	2,78	2,21	2,14	2,14	2,14	1,86
Others	0,76	2,76	2,29	2,75	2,54	1,92	2,96
Min/Max	max	min	min	min	min	min	min

Figure 23: Criteria matrix of users experiences with mobile OS

Omitting the factor of loyalty all criteria has minimizing characteristic. For better convenience of further analysis all data are transformed to maximized model as seen in [Figure 24]

	Loyalty	Security Index (SI)	User Interface Index (UII)	OS performance	OS support (community/ official)	Portability	General Satisfaction Index (GSI)
Android	0,70	0,00	0,43	0,81	0,06	0,93	1,38
iOS	0,58	1,26	0,89	1,20	0,64	0,00	1,60
Microsoft	0,47	2,60	0,56	0,99	0,31	0,15	1,13
BlackBerry	0,57	1,16	0,08	0,61	0,40	0,60	1,10
Others	0,76	1,18	0,00	0,00	0,00	0,83	0,00
Ideal (H)	0,76	2,60	0,89	1,20	0,64	0,93	1,60
Basal (D)	0,47	0,00	0,00	0,00	0,00	0,00	0,00
Hj-Dj	0,29	2,60	0,89	1,20	0,64	0,93	1,60
Min/Max	max	max	max	max	max	max	max

Figure 24: Maximized criteria matrix with ideal and basal variant

Therefor normalized criteria matrix is created by standard approach of using formula Rij= (Yij – Dj) / (Hj-Dj). Also weights obtained in chapter 4.3.1 are included.

	Loyalty	SI	UII	OS performance	OS support (community/ official)	Portability	GSI	Distributed sum-utility
Android	0,80	0,00	0,49	0,67	0,10	1,00	0,86	**0,59**
iOS	0,38	0,48	1,00	1,00	1,00	0,00	1,00	**0,71**
Microsoft	0,00	1,00	0,63	0,82	0,48	0,17	0,71	**0,57**
BlackBerry	0,35	0,45	0,09	0,51	0,62	0,65	0,69	**0,46**
Others	1,00	0,45	0,00	0,00	0,00	0,89	0,00	**0,31**
Weights	**0,12**	**0,14**	**0,18**	**0,18**	**0,09**	**0,15**	**0,14**	

Figure 25: Normalized criteria matrix with counted utility. Source: own

Finally, normalized criteria decision matrix is processed by weighted sum approach to count a distributed sum-utility**.** Mentioned process provides final values of QEE index, which are multiplied by ten for clearly arranged interpretation. Thus ideal value of QEE Index is 10.

OS	QEE Index	Rank
iOS	7,08	1
Android	5,86	2
Microsoft	5,69	3
BlackBerry	4,60	4
Others	3,13	5

Figure 26: QEE Index ranking. Source: own

In [Figure 26] a final conclusion is seen as QEE index is computed for all variants which are sorted according its rating. With QEE Index 7.08/10 has iOS operation system highest ranking. It is followed by Android operation system with 5.86/10 points. The last place is occupied by group of OS labeled as others (Bada, Symbian, etc.)

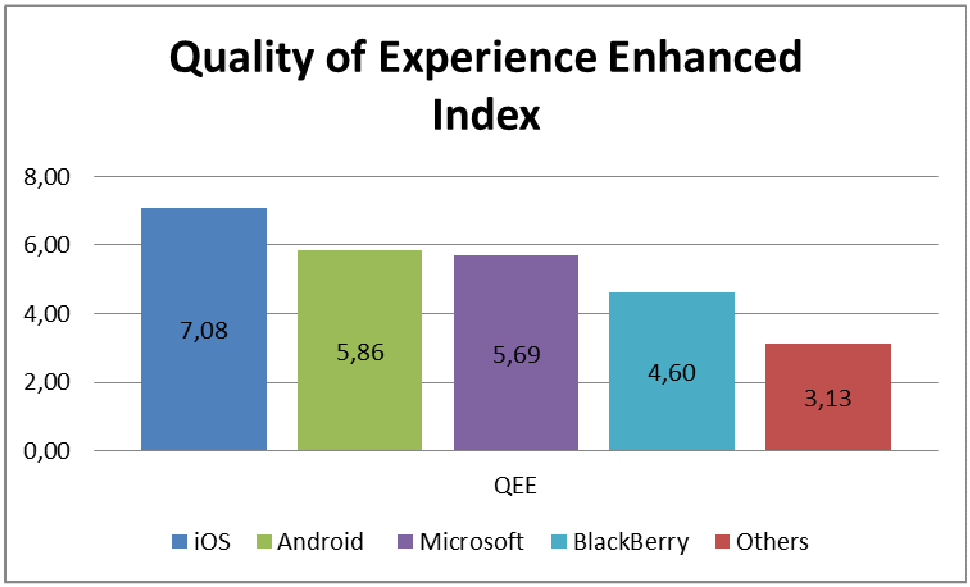

Figure 27: QEE Index outcome sorted

[Figure 27] is concluding the interpretation of QEE Index. User's feedback, behavior and experiences with mobile operating systems, sorted into seven thematic criterions, are represented by QEE with iOS as winner.

It can be interpreted as iOS users are the most satisfied with the significant properties of their operations systems. The level of significances was derived from expert's questionnaire, where developers and IT journalist were evaluating the importance of all seven criterions. As a result was given users Quality of Experience Index, which was enhanced by expert's weights for each criterion.

The Android operation system ended on second place with QEE equal to 5.86/10 points. Despite it defeated iOS in data portability and customer loyalty, which was very surprising, it lose in the field of security, which was well expected, and UII (User Interface Index) as users consider using iOS interface more convenient. Despite those facts, second place is still satisfying for Android operation system and is better than expectations.

4.3.3 OS minimum QEE requirements

As an illustration and better data understanding was created a radar chart describing OS evaluation in each of seven criterions compared with minimum requirements for OS derived from QEE Index. For graph creation was used summarized data from questionnaire with minimizing characteristic. Minimum requirements were set as two most important criterions according to weights (UII and performance) obtained an average value of all variants and rest obtained a worst value of criterion of all variants.

As a matter of fact, those requirements are the basic minimum required from mobile operation system.

	Loyalty	Security Index (SI)	User Interface Index (UII)	OS performance	OS support (community/ official)	Portability	General Satisfaction Index (GSI)
Android	1,50	3,94	1,86	1,94	2,48	1,81	1,58
iOS	2,10	2,68	1,40	1,55	1,90	2,74	1,35
Microsoft	2,65	1,34	1,74	1,76	2,24	2,59	1,82
BlackBerry	2,14	2,78	2,21	2,14	2,14	2,14	1,86
Others	1,21	2,76	2,29	2,75	2,54	1,92	2,96
Min. QEE requirements	2,65	3,94	1,90	2,03	2,54	2,74	2,41

Figure 28: Minimized multi-criteria decision matrix with minimum OS requirements variant

As seen in [Figure 29] below, minimum QEE requirements for mobile operation systems are represented by green line and lines that are not *inside* this hypothetical polygon are infringing minimum QEE requirements. In other words, two operation systems doesn't meet requirements, despite QEE minimum is significantly low. It is BlackBerry OS and group of operation systems labeled as "others", in other words *obsolate* operation systems as Symbian, Bada etc.

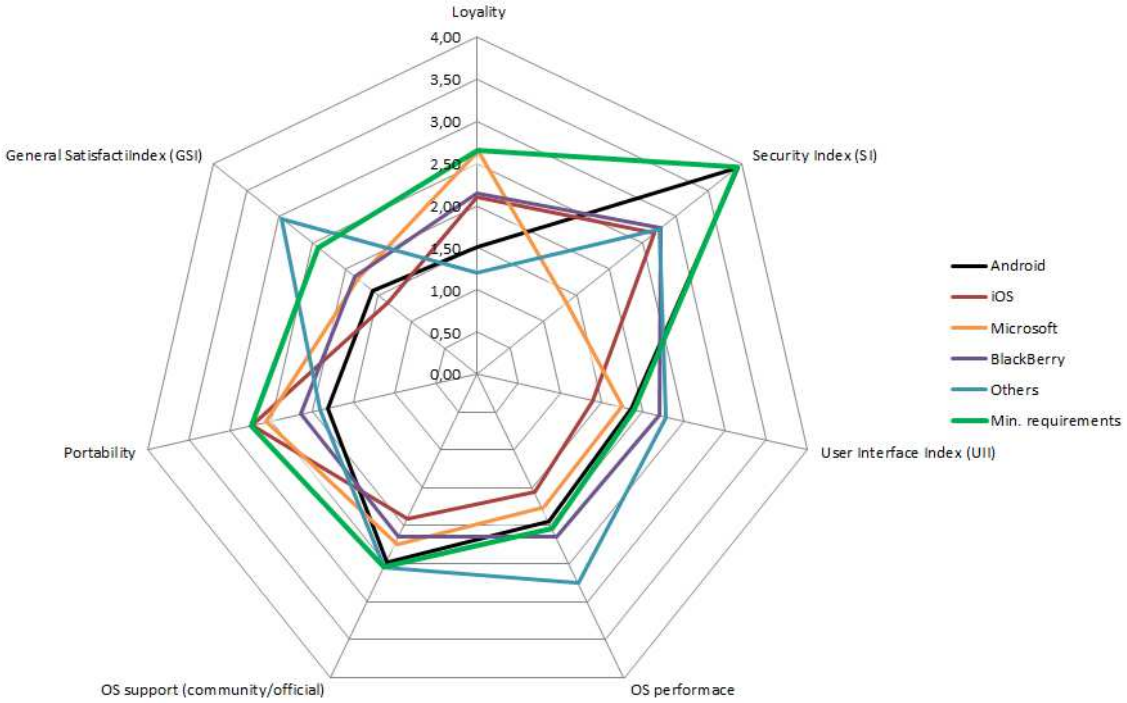

Figure 29: Radar chart of evaluated variants compared to minimum requirements [minimizing]. Source: own

5 Market release study

An important goal of this thesis is to provide a market release study for company introducing a new mobile device running OS Android. For market release study several assumptions are taken. A target market is Central Europe region. As this region is highly competitive for mobile devices manufactures, especially smartphones, Android advantages has to be used to its best.

The most significant advantage is its openness, which is crucial for proposed release strategy. Openness in other words means that any manufacturer can deploy Android into its device. As a result many new low-cost manufactures appear, mainly in PRC (Peoples Republic of China). Those mobile devices are recognized by excellent HW parameters, newest version of Android OS and low-cost price.

According to literature *,,marketing deals with identifying and meeting human and social needs. One of the shortest definitions of marketing is "meeting needs profitably."* Kotler & Keller [65, p. 5] Thus provided market release study is intend for company releasing a low-cost Android smartphone (social needs) manufactured by company with no experiences with EU market, however with low cost expense (profitability).

5.1 Marketing mix analysis

Important step of marketing release study of low cost Android device is a marketing mix analysis or in other words a 4P analysis, additionally enhanced to 7P analysis.

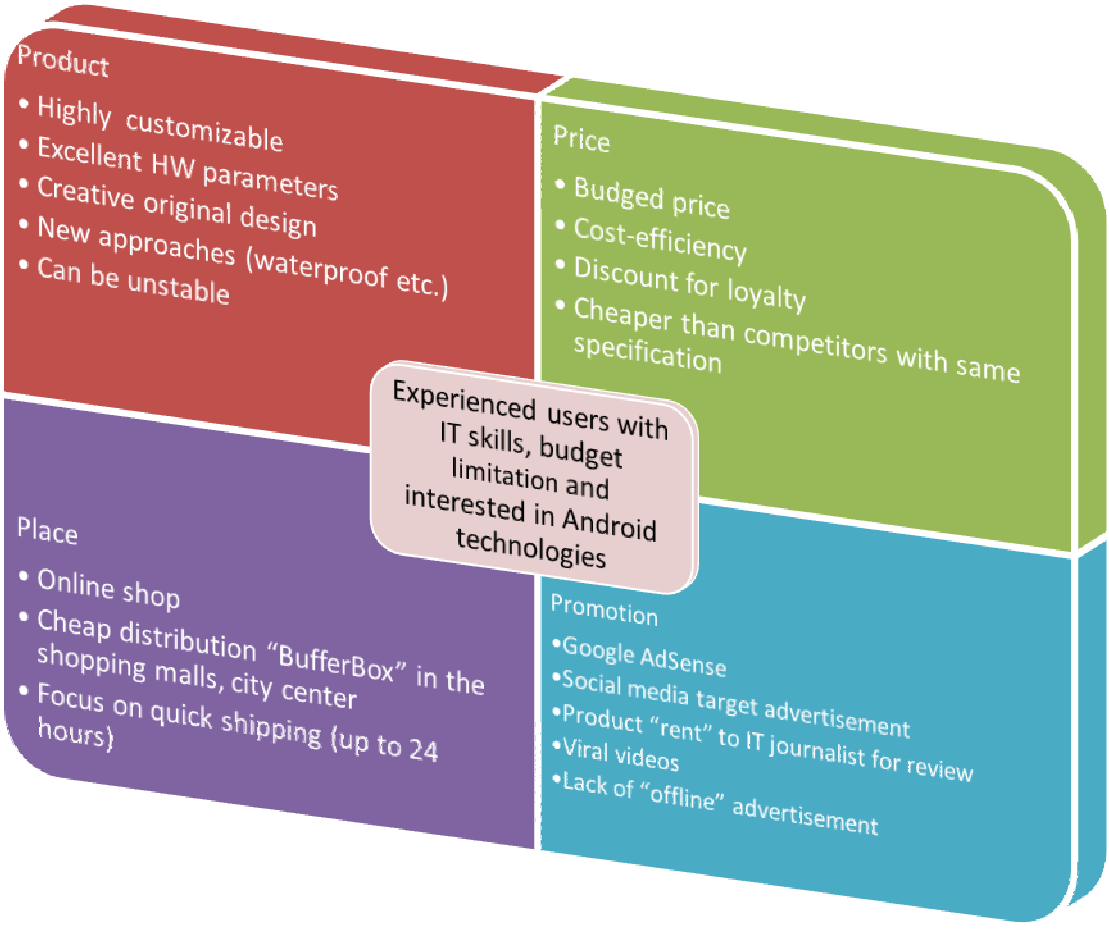

Figure 30: 4P analysis of releasing a low-cost Android device. Source: own

The 4P analysis can be in this case enhanced to 7P, which provides another business tools for determining product offering.

Physical evidence

The elements within the online store are mainly consisting of graphical elements referring to the online presence and “physical” evidence of online shop on the internet. Since there are no “physical” stores, all effort is put into making design as comfortable and remarkable as possible.

People

Since store has only online presence, the customers came into contact with staff only through web chat or voice call. As a matter of fact, with no being in touch in person, online customer care is even more sensitive for experienced staff with great communication skills. Thus various tools for serving customers online are implemented as hotline, ZOPIM chat, “hot mail” etc.

Process

Marketing process is mainly focused on work with IT and Android professionals and providing device for free testing and review. According to this a fear from unknown brands will be deducted.

5.2 SWOT analysis

To describe the key points of market release study was chosen a SWOT (Strength, Weakness, Opportunity, and Threats) analysis. Each criterion is evaluated by ten questions which were chosen by method of brainstorming. The answers are always ranked on a scale 1-3 – answers agree receives 3 points, answers disagree 1 point. Finally a radar chart visualizing answers is provided.

5.2.1 Strengths

Question	Response	Strength Rating	Category
Strength of OS QEE Index	Agree	**3**	QEE OS quality
Strength of OS competitiveness	Neither Agree or Disagree	**2**	OS Competitiveness
Strength of OS user loyalty	Agree	**3**	User Loyalty
Strength of various line of devices	Neither Agree or Disagree	**2**	Various Line
Strength of good reputation with buyers	Disagree	**1**	Reputation
Strength of being market leader	Neither Agree or Disagree	**2**	Market Leadership
Strength of cost/quality advantage	Agree	**3**	Cost/quality
Strength of superior /technological/technical skills	Agree	**3**	Dynamics Technology
Strength of being isolated from strong competitive pressures	Neither Agree or Disagree	**2**	Competitive Pressure
Strength of being good at creating new products	Agree	**3**	New products
Total		**24**	

Figure 31: Strengths of company releasing a low-cost Android device in Central Europe region [scale 1-3]. Source: own

As seen in [Figure 30], main strength of company releasing a low cost Android device is Android itself as it has good QEE Index rating, including excellent user's loyalty index, which can bring many new customers.

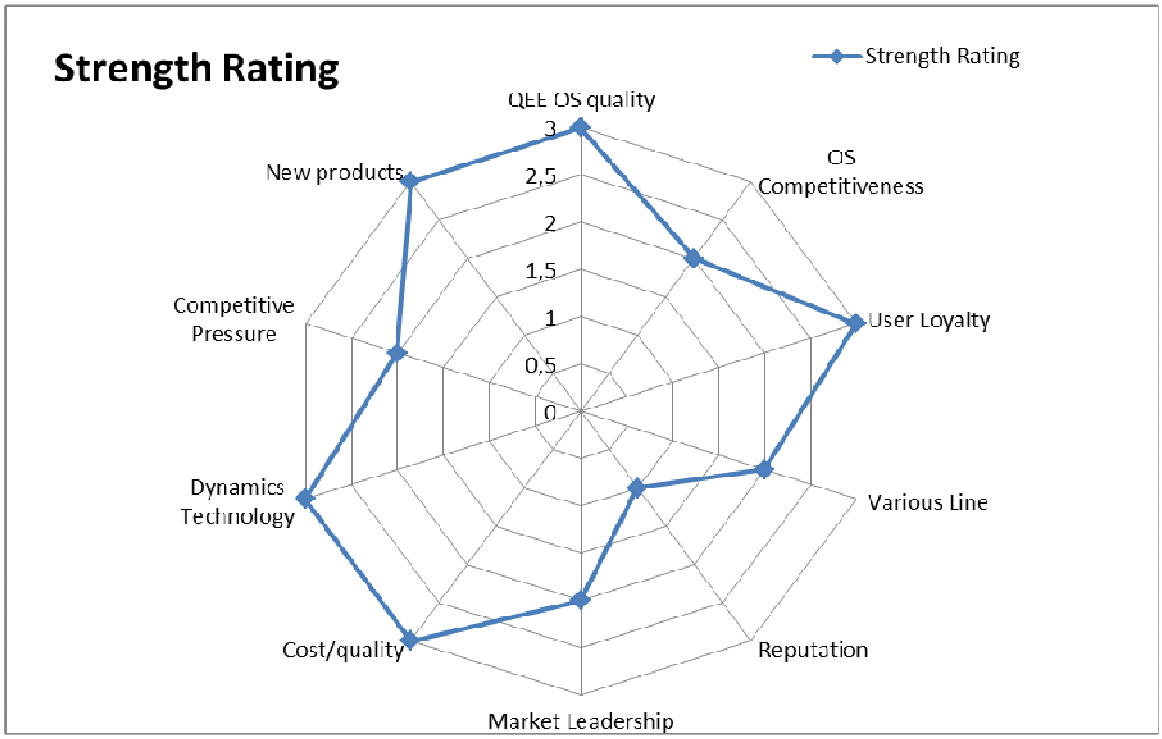

Figure 32: Strength rating radar chart

5.2.2 Weaknesses

Question	Response	Weakness Rating	Category
Weakness of device certification	Neither	2	Certification
Weakness of device quality	Agree	3	HW Quality
Weakness of custom ROM reliability	Agree	3	ROM quality
Weakness of ROM translation quality	Agree	3	ROM translation
Weakness of having no clear strategic direction	Neither	2	Strategy Implementation
Weakness of being plagued with internal operating problems	Agree	3	Internal Operations
Weakness of falling behind on Research & Development	Neither	2	R&D
Weakness of having a narrow product line	Disagree	1	Product Line
Weakness of having a weak market image	Agree	3	Market Image
Weakness of having below average marketing skills	Disagree	1	Marketing Skills
Total		**23**	

Figure 33: Weaknesses of company releasing a low-cost Android device in Central Europe region [scale 1-3]. Source: own

As shows [Figure 32] main weakness for company releasing a low cost Android smartphone is its HW quality and ROM quality together with market image of low cost (mainly Chinese) brands. To say nothing about certification issues, since European regulators are extremely strict.

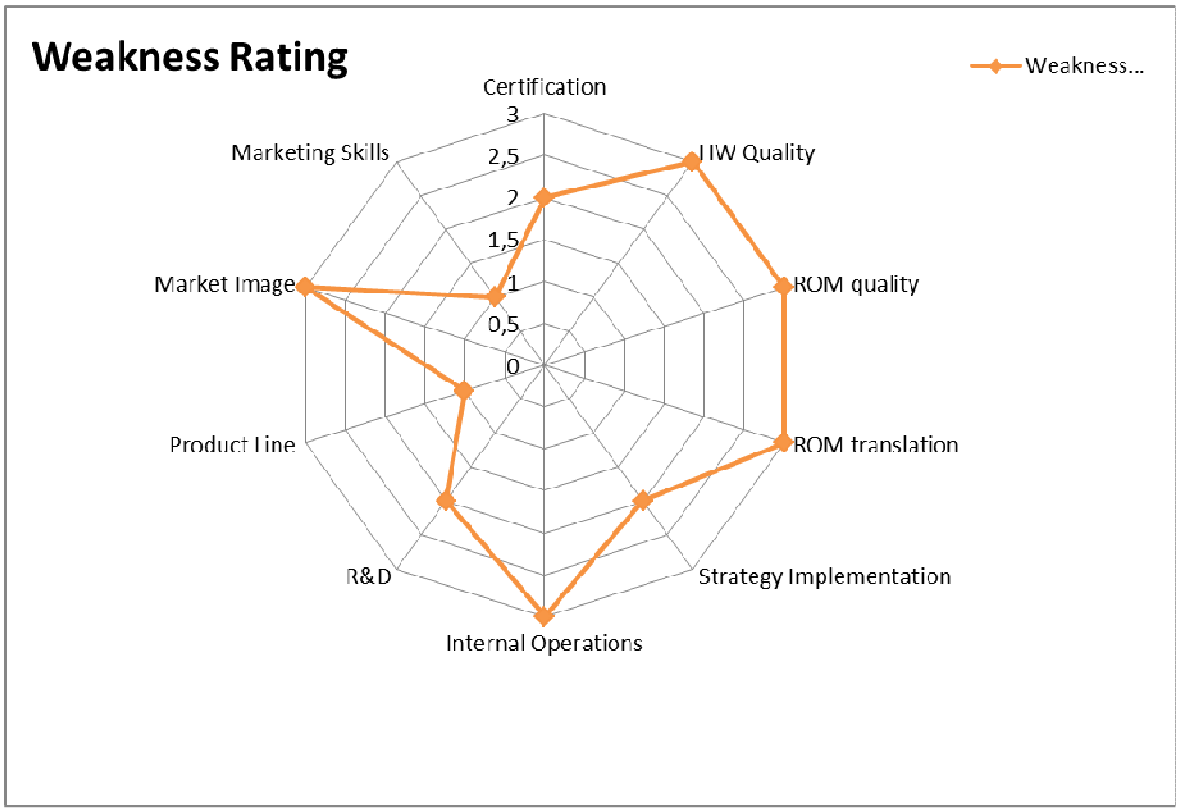

Figure 34: Weakness rating radar chart

5.2.3 Opportunities

Question	Response	Opportunity Rating	Category
Opportunity of OS openness	Yes	3	OS Openness
Opportunity of improving reputation of low-cost brand	Maybe	2	Improving Reputation
Opportunity of expansion Android devices to meet customer needs	Yes	3	Product Enhancement
Opportunity of new markets or market segments to enter	Yes	3	New Markets
Opportunity of becoming exclusive distributor for region	Yes	3	Exclusive Distribution
Opportunity of falling trade barriers	No	1	Foreign Trade
Opportunity of improving UII	Yes	3	UII Improving
Opportunity of market growing faster than in the past	Yes	3	Market Growth
Opportunity of adding SW improvements	Yes	3	SW Improvements
Opportunity of fewer regulatory requirements	No	1	Regulatory Overhead
Total		**25**	

Figure 35: Opportunities for company releasing a low-cost Android device in Central Europe region [scale 1-3]. Source: own

As described in [Figure 34] important opportunities for company releasing a mobile phone with OS Android in Central European region is to expand to other EU markets together with obtaining an exclusive distribution rights. Not to mention opportunity to improve a User Interface Index (UII) by adding own SW.

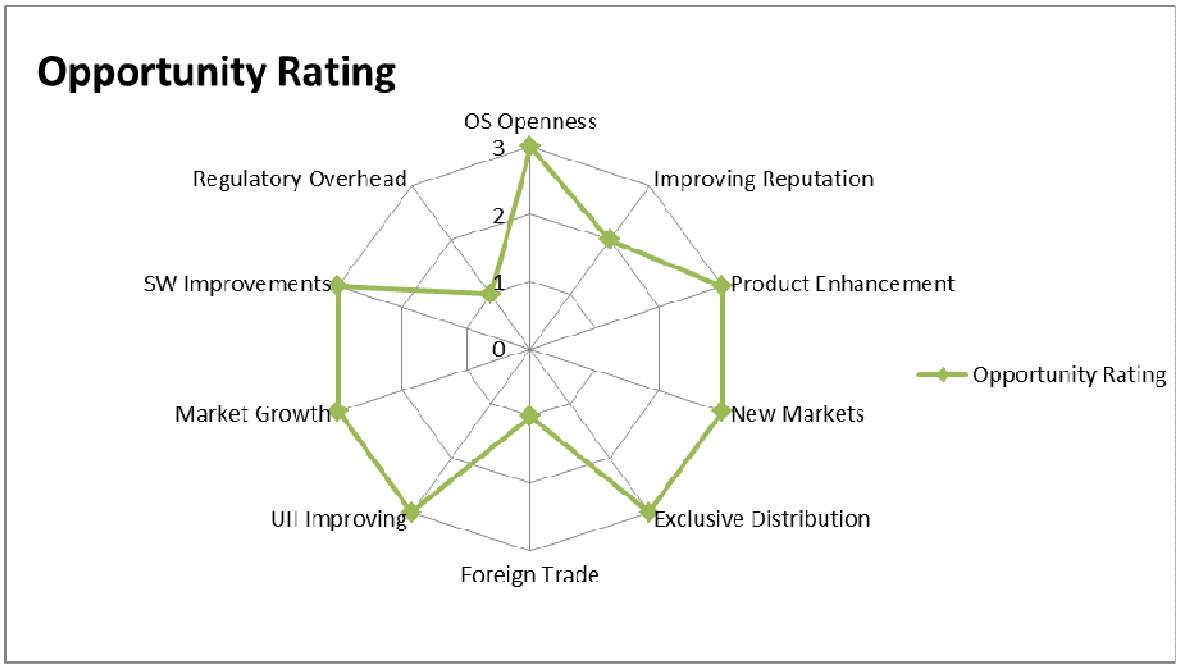

Figure 36: Opportunity rating radar chart. Source: own

5.2.4 Threats

Question	Response	Threat Rating	Category
Threat of poor quality control HW/SW	Yes	3	Quality HW/SW
Threat that customers will fear of low-cost brand	Maybe	2	Fear of Low-cost
Threat that market grows more slowly than expected	No	1	Market Growth
Threat that adverse shifts in **Yuan** exchange rate	Yes	3	Foreign Trade Environment
Threat that regulatory requirements become onerous	Yes	3	Regulatory Overhead
Threat of being vulnerable to changes in the business cycle	No	1	Business Cycle
Threat that customers will use growing bargaining power	Yes	3	Buyer's Power
Threat that sales of substitute product rise	Maybe	2	Market Requirements
Threat of demographic changes are having a negative impact on business	No	1	Demographics
Threat of low barriers to entry the industry	Yes	3	Entry Barriers
Threat of security issues	Yes	3	Security issues
Total		**25**	

Figure 37: Threats for company releasing a low-cost Android device in Central Europe region [scale 1-3]. Source: own

The threats for company launching low cost Android OS mobile device are mainly its unstable quality, regulators and raising competitors. Demographics surprisingly weren't considered as a threat as smartphones with smart OS are getting popular among all population.

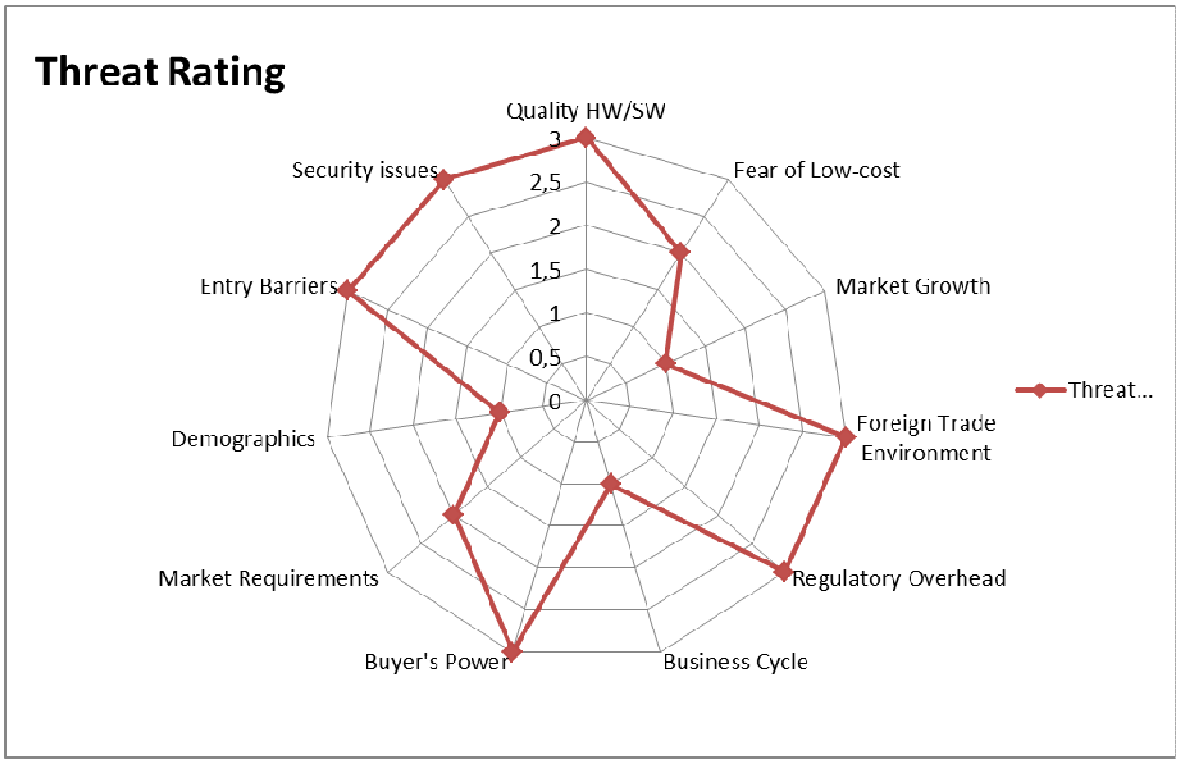

Figure 38: Threat rating radar chart. Source: own

5.2.5 Conclusion

Total Strengths	24	Total Weaknesses	23
Total Opportunities	25	Total Threats	25
Total Strength and Opportunity	**49**	**Total Weaknesses and Threats**	**48**

Figure 39: Conclusion of SWOT analysis. Source: own

As smartphones are becoming devices of people daily life, there will although be a demand for cheap and cost effective mobile devices. A SWOT analysis for release of such a low cost smartphone with Android OS was provided. As seen in [Figure 38] the strength and opportunities received 49 points and Weaknesses and threats 48 points. Thus conclusion is the release of low cost Android phone is recommended however attention to many certain issues must be taken into account.

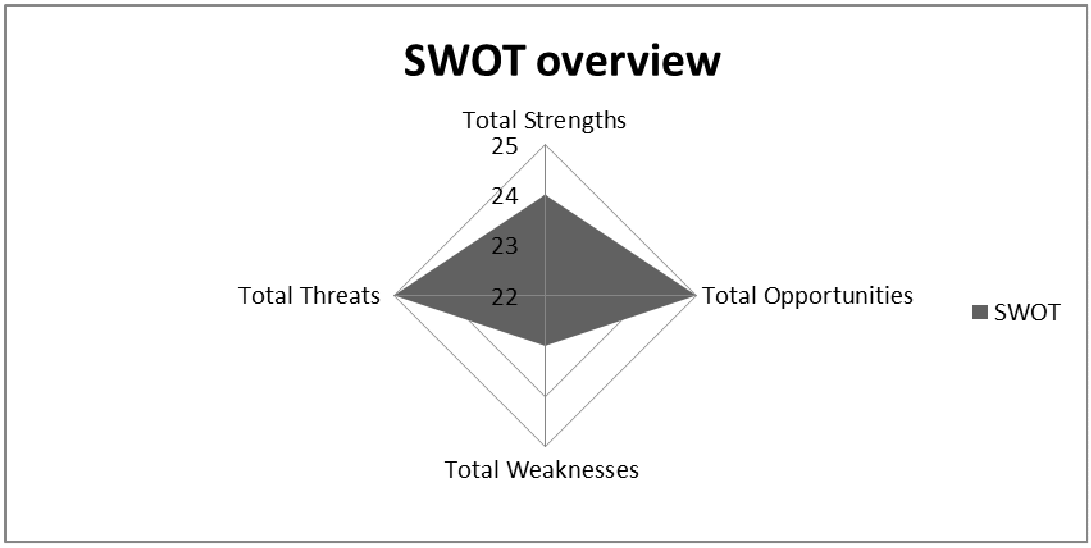

Figure 40: SWOT overview. Source: own

5.3 Android activations forecast

To obtain a basic knowledge about future development of Android growth, a forecast of Android devices daily activations was made. Data were collected since January 2010. Source of the data is Google dashboard, as it is only authority, which has right to release it. However the data are given out in irregular intervals (2 – 6 months) and despite information between those intervals can be obtained from various sources; there is a suspicion that *non-Google* data are only estimated, not observed. Thus despite trend of time series is valid, observed data can be questioned.

An Activations line describes an average number of daily activations during a month. Full table of data is provided in Supplement 1. As forecasting method was chosen a linear trend. Its function is y = 33428x.

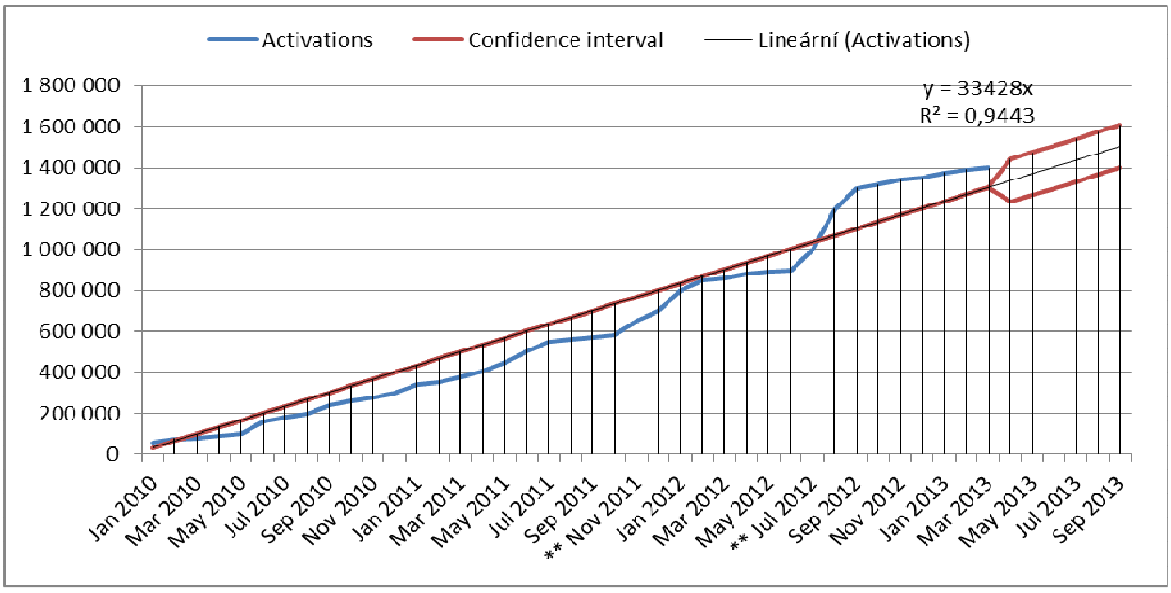

Figure 41: Forecast of Android daily activations. Source: own

According to trend function the coefficient of determination is R^2 =0.94. It can be interpreted as trend function fits observed data in 94%, which is satisfying result. In other words, trend function explains real data in 94%, furthermore forecast is likely to be well predicted.

As another key point confidence intervals for forecast were counted with α=0.05. In this case an interval prognosis was proceed, as it is more suitable than forecast of single value. Thus 95% of estimated values are meant to be in interval as shown in [Figure 41].

For example according to trend function, in June 2013 is estimated activation of 1 403 976 devices. With 95% probability number of activated devices will vary in interval <1 299 941; 1 5018 001>.

Furthermore a few deviations can be seen in observed dataset. Those are probably caused by external factors of releasing a highly expected Android device which significantly raised number of activated (purchased) Android devices and with its power influence whole market. For example the deviation [Figure 41 (**)] starting in November 2011 was apparently caused by releasing a highly expected table Amazon Kindle Fire in this month and deviation starting in July 2012 by releasing a desirable Samsung Galaxy SIII.

6 Evaluation of results and recommendations

Outcomes of literature review are compared with results of the analytical work in second part of the thesis. Furthermore recommendations for company launching an Android device are provided.

According to literature part, the main weaknesses of Android OS are its security issues [50]. It was confirmed in analytical part, where Security Index (SI) of Android was evaluated as the worst among all researched OS, with SI = 3.94. The best SI obtained mobile operation OS from Microsoft; it's SI was approaching 1 the best, with value SI = 1.34.

Moreover particular findings from literature were disputed. As described in chapter 3.9.1, Apple's iOS is supposed to be platform with the most stable and loyalty user base. However according to findings of this thesis, Android has the most loyal user base as 70% of questionnaire respondents never tried device with different mobile OS than Android. iOS surprisingly ended on third place with 54%, which is below average level of loyalty - 64%. Thus a stereotype [59] related to Apple iOS user's loyalty can be denied.

Additionally the Android device [47] and version [48] fragmentation was pointed out as serious problem. Mainly because of developers can't focus to create applications and comfortable user interface only for particular device, but they have to take into account more than 600 different devices with more than 6 version of Android OS. As a matter of fact in practical part was confirmed the insufficient quality of Android user interface. UI Index was third worst among tested OS with UII = 1.86. On the contrary, the worst UII obtained group labeled as "others", including obsolete OS as Symbian and Bada. It only proves the trend that users interface comfort is one of the most significant criterions for quality estimation and no OS can compete on the market without excellent UII.

This thesis furthermore provides recommendation for the company launching an Android device in Central Europe region. As most significant advantages of Android was pointed its openness, affordability and adjustability. Thus a low-cost device with excellent HW specification manufactured in PRC was chosen.

The reason is as simple as smartphones are becoming the casual part of people's lifestyle and in near future mobile devices with smart OS will become obligatory accessories for our society. Since smartphone lose its position of expensive specialized devices for experts and become another common device of daily life, we can expect a high price pressure. As a matter of fact launching low-cost Android device is a reasonable marketing strategy. Of course company has to be aware of threats according to provided SWOT analysis, e.g. bad reputation of low-cost PRC manufactures and level of quality control, however Android openness, high Quality of Experience Enhanced Index, general users satisfaction, loyalty and linearly increasing trend of future growth make it the best option both for users and device releasing company.

7 Conclusion

This thesis accomplished its specified goals. Conduction of multi-criteria decision analysis of user's feedback created a Quality of Experienced Enhanced (QEE) Index for determining OS quality. Its accuracy was improved by results of experts' questionnaire, which provided weights for each of seven basic criteria used for computing QEE.

The outputs of partial indexes of QEE describe the advantages and disadvantages of Android OS. The main disadvantages are poor security protection functions, as its Security Index is lowest among all tested OS. Graphical user interface (GUI) is second crucial problem of Android as it has third worst rating, way behind its main competitor's iOS and OS from Microsoft. Comfortable user interface and malicious SW protection are one of the most significant criteria; thus, as a matter of fact, Android poor performance in those disciplines is highly reflected in final QEE Index. On the other hand, the advantages are surprisingly its user platform loyalty, where Android is the top among all OS and users satisfaction with OS in general.

The research has proven that Android is the second best mobile operation system with QEE equal to 5.84/10 points. It is exceeded only by iOS with QEE = 7.08/10 and followed closely by mobile OS from Microsoft with QEE = 5.69/10 points. The favored BlackBerry OS fails with only 4.6/10 points, keeping last but one place. In secondary research, there were set minimum requirements for mobile OS based on QEE Index, which were fulfilled only by Android, iOS and Microsoft.

In final research recommendations for the company launching an Android device in Central Europe region are provided. According to SWOT analysis, the strengths and opportunities of launching Android device are its openness, affordability and adjustability. Thus, a mobile device with excellent HW specification, but manufactured by low-cost OEM was chosen. Last reason for choosing Android is its current market share of 61% and forecasted linearly growing trend of daily activations. According to prediction, there will be approximately 1.3 – 1.5 million of daily activation of Android devices in June 2013.

In conclusion, Android is certainly a high quality OS whose assets are influenced by several issues as security and UI.

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Supplements

Date	Activations	Linear function
Jan 2010	60 000	33 428
Feb 2010	75 000	66 856
Mar 2010	82 000	100 284
Apr 2010	90 000	133 712
May 2010	100 000	167 140
Jun 2010	160 000	200 568
Jul 2010	180 000	233 996
Aug 2010	200 000	267 424
Sep 2010	240 000	300 852
Oct 2010	260 000	334 280
Nov 2010	280 000	367 708
Dec 2010	300 000	401 136
Jan 2011	340 000	434 564
Feb 2011	350 000	467 992
Mar 2011	380 000	501 420
Apr 2011	405 000	534 848
May 2011	450 000	568 276
Jun 2011	500 000	601 704
Jul 2011	550 000	635 132
Aug 2011	560 000	668 560
Sep 2011	570 000	701 988
Oct 2011	580 000	735 416
** Nov 2011	650 000	768 844
Dec 2011	700 000	802 272
Jan 2012	800 000	835 700
Feb 2012	850 000	869 128
Mar 2012	860 000	902 556
Apr 2012	880 000	935 984
May 2012	890 000	969 412
Jun 2012	900 000	1 002 840
** Jul 2012	1 000 000	1 036 268
Aug 2012	1 200 000	1 069 696
Sep 2012	1 300 000	1 103 124
Oct 2012	1 320 000	1 136 552
Nov 2012	1 340 000	1 169 980

Dec 2012	1 350 000	1 203 408
Jan 2013	1 375 000	1 236 836
Feb 2013	1 390 000	1 270 264
Mar 2013	1 400 000	1 303 692
Apr 2013		1 337 120
May 2013		1 370 548
Jun 2013		1 403 976
Jul 2013		1 437 404
Aug 2013		1 470 832
Sep 2013		1 504 260

Confidence intervals:

Upper	**Lower**
1 233 169	1 441 071
1 266 565	1 474 531
1 299 941	1 508 011
1 333 295	1 541 513
1 366 629	1 575 035
1 399 941	1 608 579