UNIVERSITY OF Southampton

An Industrial Study of Effort Estimation in Mobile App Development using Agile Processes

Thesis for the degree of Doctor of Philosophy in Computer Science

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Abstract

Faculty of Engineering and Physical Sciences

School of Electronics and Computer Science

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By

Abdullah Altaleb

Estimates of software effort, size and cost are essential to a project manager, in order to plan and manage a project to prevent it from failing. The planning and development of mobile apps are unlike traditional software applications due to the characteristics of the mobile environment, including high autonomy requirements, market competition and many other constraints. The aim of this study is to investigate the current state of practice relating to the essential factors and optimal techniques for effort estimation that help and support an Agile team to give reliable estimates for developing a mobile app task. The results of a Systematic Literature Review (SLR) of effort estimation models in mobile app development are presented; this is followed by a summary of estimation techniques used across mobile apps. In particular, the focus in the SLR is on the software estimation models applicable to the Agile Software Development (ASD) process. From the SLR, some research gaps are suggested, along with possible future work on mobile effort estimation techniques in ASD. Following this, the research aim and objectives are provided for this study, as well as appropriate research methods, strategies, plans and designs.

In this study 20 interviews were conducted in 18 different organisations, consisting of both structured and non-structured questions. The result revealed that Expert Judgment and Planning Poker were the most used estimation techniques in the organisations. Some challenges and issues were raised and discussed around these techniques. The results, in addition, revealed 68 comprehensive factors and appropriate techniques that could be used in effort estimation for development of a mobile app. A proposed effort estimation technique has been constructed from the interviews. Moreover, the study presents case studies in three companies that examined and evaluated their current estimation techniques. It proposes and has validated an estimation technique to enhance the accuracy of existing techniques. The study presents the effectiveness of the estimation factors/predictors in supporting a development team to manage, estimate and create subtasks for their user stories.

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Research Thesis: Declaration of Authorship

Print name:	Abdullah Rashed Altaleb
Title of thesis:	An Industrial Study of Effort Estimation in Mobile App Development using Agile Processes.

I declare that this thesis and the work presented in it are my own and has been generated by me as the result of my own original research.

I confirm that:

1. This work was done wholly or mainly while in candidature for a research degree at this University;
2. Where any part of this thesis has previously been submitted for a degree or any other qualification at this University or any other institution, this has been clearly stated;
3. Where I have consulted the published work of others, this is always clearly attributed;
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Altaleb, A., Al Hashimi, H., & Gravell, A. (2020). A Case Study Validation of the Pair-estimation Technique in Effort Estimation of Mobile App Development using Agile processes. In 10th IEEE International Conference on Advanced Computer Information Technologies (ACIT 2020). IEEE Germany Section, Deggendorf Institute of Technologies, Germany. (Accepted Paper)

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Altaleb, A., & Gravell, A. (2019b). An Empirical Investigation of Effort Estimation in Mobile Apps Using Agile Development Process. Journal of Software, 14(8), 356–369. https://doi.org/10.17706/jsw.14.8.356-369 (Extended Paper).

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Glossary of Terms and Abbreviations

Agile SD	Agile Software Development
API	Application Programming interface
App	Application
ASD	Agile Software Development
BA	Business Analyst
Dev	Developer
EJ	Expert Judgement
FP	Function Point
IH	Ideal Hour
IT	Information Technology
MASAM	Mobile Application Software development based on the Agile Methodology
NDA	Non-Disclosure Agreement
OS	Operating System
P/H	Person per Hour
PM	Project Manager
PMO	Project Management Office
PP	Planning Poker
QA	Quality Assurance
RQ	Research Question
SA	System Analyst
SDP	Software Development Process
SLR	Systematic Literature Review
SP	Story Point
UAT	User Acceptance Testing
UCP	Use-Case Point
UI	User Interface
UX	User Experience
XP	eXtreme Programming

Chapter 1: Introduction

Effort estimation plays an important and critical role in any software project. To generate contracts, both project managers and clients use effort estimation models to measure the effort, size, cost and duration involved in designing and implementing a software project. Good estimation is one of the success factors for companies, as bidding at a good price could mean that they win a contract bid. Incorrect estimations can negatively affect companies' marketing and sales, also leading to monetary losses.

In the past, mobile devices were used only for receiving and sending messages and calls; today, however, they are becoming essential to modern life. Among the many examples of smartphone usage are making flight bookings, GPS navigation, banking transactions, gaming and communicating with others on social media. Mobile applications represent a new trend in the software industry, and the demand for such apps is set to increase significantly with mobile technology developments. In fact, there were approximately two billion smartphone users around the world in 2016, and this figure is expected to reach 2.8 billion by 2018. The revenue from application stores is predicted to reach $189 billion by 2020, up from $88.3 billion in 2016, according to statista.com. Planning and developing a mobile app is unlike that of traditional software systems in many aspects. Mobile devices are becoming increasingly complex, and designing their apps presents some special requirements and constraints that are less commonly found in traditional software.

The main goal of this study is to identify, investigate and validate the effort estimation factors and techniques for developing mobile apps using the Agile process. This study aims to present and evaluate a current state of practice for the effort estimation techniques for mobile app development in Agile processes. Its objectives are to investigate the efficiency of current estimation techniques in the industrial fields and evaluate their effectiveness in terms of Agile processes for mobile app development. It also aims to provide propose an effort estimation technique drawn from multiple Agile professionals across several organisations to improve the accuracy of existing estimation techniques.

This research study primarily examines the state-of-the-art techniques used in the field of effort estimation for mobile apps in ASD by means of a Systematic Literature Review (SLR). The guidelines proposed by Kitchenham and Charters (2007) have been used to construct this SLR, and no previous literature or studies were found to have empirically validated and examined effort estimation model for mobile apps. This study identifies, critically evaluates and integrates the findings of all studies relevant to the topics addressed by the research questions. This thesis details the SLR and points to some research gaps and future directions in the field of effort estimation with mobile app developments in ASD.

In addition, this research applied a survey method which collected data from 20 experts to investigate the current state of practice of effort estimation techniques and factors across 18 companies in various business fields. The collected data have been analysed quantitatively and qualitatively, and it was found that the Expert Judgment (EJ) and Planning Poker (PP) techniques are most commonly used for mobile app development in the Agile process. Moreover, 48 effort estimation factors from previous studies have been evaluated and 20 further factors obtained that could affect the accuracy of the effort estimation value. This study details the analysis methods and techniques used, and provides further results related to mobile app development.

Finally, the researcher applied a case study method which proposed and validated estimation technique in order to enhance the performance of the existing estimation techniques from the industry. Three case studies have been applied in three companies, involving in total around 15 professionals, and examined the efficiency of the comprehensive estimation factors and predictors collected previously by survey.

1.1. Research Structure

This thesis is organised as follows: Chapter 2 presents a brief background to ASD, the characteristics of mobile apps and the effort estimation models. The research methodology is described in Chapter 3, including the research aims, objectives, strategy, design and approach. The steps in the SLR are detailed in Chapter 4; following this, its results are discussed, and research gaps, research questions and possible directions for future work are identified in Chapter 5. In Chapter 6, the details of the data collection preparation and strategy of the interview method are presented, followed in Chapter 7 by the data collection analysis and discussion of the interviews. In Chapter 8, the details of the data collection preparation and strategy of the case study method are presented, followed in Chapter 9 by the data collection analysis and discussion for the case study. Finally, the conclusions and future work are presented in Chapter 10.

1.2. Peer-reviewed and Published Work

During the study, the researcher was working on several publications to obtain further feedback, recommendations and comments from experts related to this research area. Some of the thesis results and analysis works have been already published in the following peer-reviewed conferences and journals:

- Altaleb, A., Al Hashimi, H., & Gravell, A. (2020). A Case Study Validation of the Pair-estimation Technique in Effort Estimation of Mobile App Development using Agile processes. In 10th IEEE International Conference on Advanced Computer Information

Technologies (ACIT 2020). IEEE Germany Section, Deggendorf Institute of Technologies, Germany. (Accepted Paper)

- Altaleb, A., Altherwi, M., & Gravell, A. (2020). An Industrial Investigation into Effort Estimation Predictors for Mobile App Development in Agile Processes. In 9th IEEE International Conference on Industrial Technology and Management (ICITM 2020). IEEE, University of Oxford, United Kingdom.

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- Altaleb, A. R., & Gravell, A. (2018). Effort Estimation across Mobile App Platforms using Agile Processes: A Systematic Literature Review. Journal of Software, 13(4), 242–259. https://doi.org/10.17706/jsw.13.4.242-259.

- Altherwi, M., Altaleb, A., &Gravell, A. (2020). Programming Language Popularity and Trends in OSS based on Mining Software Repositories. In 2020 ACM SIGPLAN conference on Systems, Programming, Languages, and Applications: Software for Humanity (SPLASH 2020). Chicago, USA (Submitted).

Chapter 2: Background

This chapter gives an overview of effort estimation through ASD and its relationship to developing mobile apps. In section 2.1, the Agile process and methodologies are discussed. The characteristics of the mobile app environment and platforms are detailed in section 2.2, comparing mobile app development with traditional software development. Finally, in section 2.3, an overview of several estimation techniques in software development is presented, and the most common Agile development techniques are discussed.

2.1. Agile Software Development Process

Before starting to discuss the characteristics of ASD, we need to understand the definition itself. What does 'agile' mean? According to the Cambridge.org dictionary, it means 'being able to move quickly and easily' (Cohen et al., 2003). The definition from the software engineering point of view is the ability to move quickly and easily to help the software development process to become more efficient (Pekka Abrahamsson et al., 2002). Software development is an organised process that involves managing a project so that it is delivered in an economical, rapid and efficient manner (Rao et al., 2011). Thus, the goal of ASD is to develop solutions efficiently and deliver projects quickly, with any changes that are necessary being made rapidly.

Compared with traditional software development, ASD places less emphasis on up-front plans and strict plan control and more on the flexible mechanisms to facilitate any changes to the management plan during the project cycle (Rao et al., 2011). There are many ASD methods (Scrum, Extreme Programming XP, Crystal, Feature Driven Development, Lean Development, and Dynamic Systems Development Methodology); however, common characteristics include iterative development to allow the team to adapt to the changes in the requirements and to interact deeply. Indeed, doing so encourages the development team to work closely to make decisions immediately and reduce any involvement with intermediate artefacts.

Agile is an iterative and incremental means of development that promotes frequent delivery of a product's features (Hoda et al., 2010). The Agile principle increases communication so that customers, business people and developers work together (Pikkarainen et al., 2008). In addition, to achieve the project needs, the emphasis is firmly on accepting changes to the project requirements and on holding open discussions with customers, with less reliance on documentation.

In 2001, 17 software practitioners and consultants gathered to compile the Agile Manifesto (Beck et al., n.d.). This outlines the four core values of ASD upon which all Agile methods rely on in various ways, favouring:

1) Individuals and Interaction, over Processes and Tools. This encourages and places emphasis on teamwork and communication.
2) Working Software, over Comprehensive Documentation. An Agile design requires a user story that is sufficient for a developer to build the function. The Manifesto values documentation, yet values operational software even more.
3) Customer Collaboration, over Contract Negotiation.
4) Responding to Change, over Following a Plan.

These four fundamentals are supported by 12 principles that guide the various Agile methodologies (‘Principles for Agile Manifesto,’ n.d.):

1) Customer satisfaction through early and continuous software delivery.
2) Accommodate changing requirements throughout the development process.
3) Frequent delivery of working software.
4) Collaboration between the business stakeholders and developers throughout the project.
5) Support, trust, and motivation of the people involved.
6) Enabling face-to-face interactions.
7) Working software is the primary measure of progress.
8) Agile processes to support a consistent development pace.
9) Attention to technical details and a design that enhances agility.
10) Simplicity – develop just enough to get the job done right now.
11) Self-organising teams encourage great architectures, requirements, and designs.
12) Regular reflections on how to become more effective.

There are several Agile development practices; however, Scrum and eXtreme Programming (XP) are the most popular and commonly adopted methods in companies (Pikkarainen et al., 2008). Recently, the 13th annual State of Agile survey in 2019 announced that 72% of the 1,319 respondents reported that Scrum methodology is the most widely practised (36% of respondents from organisations of less than a thousand people and 46% of those of more than 5 thousand) (‘13th Annual State of Agile Report’, 2019).

Scrum methodology is a framework to manage and develop a complex product, and various process and techniques can be employed. Scrum takes an iterative and incremental approach to control risk and accept change (Schwaber & Sutherland, 2017). The Scrum team consists of (Schwaber & Sutherland, 2017):

- Product owner: responsible for managing, expressing and ordering the product backlog items.
- Development team: small number of professionals to undertake the development work and deliver an increment of the product.

- Scrum master: individual to promote and support Scrum team, to make sure everyone understands the Scrum practice and theory.

2.2. Mobile Application Development

Mobile app development differs from traditional software systems development in many aspects. The traditional methodologies to develop desktop applications are inapplicable to mobile app development (Ajit Kumar et al., 2016), which faces exceptional constraints and requirements compared to other software systems (Kaur & Kaur, 2018). It is necessary to apply appropriate methods that are able to address the challenges. One of the notable challenges is the multiple platform issue that is encountered. Developers always plan for and are concerned about the compatibility of their app with all mobile operating systems, such as IOS, Android, Microsoft Windows Mobile and BlackBerry.

There are three major types of mobile apps, namely mobile web, native and hybrid (A.I. Wasserman, 2010; Xanthopoulos & Xinogalos, 2013). Mobile web apps are usually based on common internet technologies, such as HTML and JavaScript, and can be browsed on a mobile device without the need for an installation process. However, this kind of application has limited access to the underlying device's hardware and data, such as GPS, sensors, camera and memory. A native mobile app is usually developed for a particular mobile operating system and must be installed on a mobile device via an application store, such as Google Play or Apple Store, and can access all of a device's features, such as hardware components and API. An IDE, supported by special tools, must be used to develop a native app. This kind of app requires special skills and a high level of experience, in contrast to mobile web apps, as the source code is not reusable for any other platform. A hybrid app is a combination of a mobile web and a native app, meaning that the HTML5 app is embedded inside the native container. In other word, a hybrid app is basically a small website that runs in a browser shell inside an native app, and that can access the platform layer ('Ionic Framework', n.d.).

When developing a mobile app that works on several platforms by means of native development, for each of the platforms it is necessary to repeat the development process cycle, including the coding phase (Dalmasso et al., 2013; Ottka, 2015). Web applications suffer from limited access to a device's hardware and have no direct access to the lower level of the API (Lassoff & Stachowitz, 2015). Cross-platform tools, such as PhoneGap, Xamarin and JQuery-Mobile, are solutions that can create an app for multiple platforms from a common code base. The design and implementation of the app are undertaken just once, then it can be deployed to any specific platform after customisation by the tool. The app will be installed on the mobile device as a native application (Xanthopoulos & Xinogalos, 2013).

Additional challenges that differentiate mobile app development from traditional application systems (Dalmasso et al., 2013; Kaur & Kaur, 2018; Rahimian & Ramsin, 2008; Rosen & Shihab, 2016) include the wireless communication issue, portability, many standards, protocols and network technologies, strict time-to-market requirements, and the mobility issue (autonomy and localisation). Moreover, the limitations of power supply (battery), processor efficiency, a small sized user interface and memory performance are other challenges that do not arise with desktop computers (Ajit Kumar et al., 2016; Hammershoj et al., 2010), and Kumar has presented a detailed analysis of around 12 major challenges that confront mobile app development.

Further challenges are identified by Rosen and Shihab (2016), whose study analysed and examined 13 million posts to the popular online forum Stack Overflow and its Q&A site regarding mobile developers' challenges and questions. The results revealed that the challenges and questions fall into the following categories: frequent changes to the stores' requirements, difficulties with compliance testing, changes to mobile APIs, dealing with data on mobile devices, sensor handling, UI issues, and screen size and resolutions. Moreover, a survey was conducted with 12 senior developers to list the challenges facing the developing of a mobile app (Joorabchi et al., 2013). The study revealed that the most challenging issues for developers are the multiple mobile platforms, the analysis and testing tools, and the emulators.

Since this study concentrates on cross-platform mobile app development, there are multiple frameworks, and developers have their own preferences (Wasserman, 2010), as shown by a study comparing current cross-platforms (Latif et al., 2016). The preferred platforms that developers usually rely on for mobile app development are listed in the Appendix A. Moreover, another study presents the criteria used to select the appropriate platforms and tools for mobile development (Dalmasso et al., 2013). A developer could select a specific framework and tools based on five elements: 1. native user experience and feeling; 2. offline/online usage; 3. compatibility with mobile devices; 4. access to built-in features; and 5. security (Dalmasso et al., 2013) (see Appendix A for the most common frameworks and tools). It concludes that the PhoneGap framework involves less memory, CPU and power consumption, yet has some limitations regarding UI.

2.3. Software Effort Estimation

2.3.1. Software estimation in general

For all software projects, accurate software estimation of any of its aspects is both interesting and desirable. Predicting the project's timescale, scheduling the budget and assessing the necessary resources will help the software project to succeed and avoid overrun (Nasir, 2006). There are four types of software estimation:

- Effort estimation: amount of effort to complete a project. It is usually measured by person/hour or person/month.
- Size estimation: usually measured by number of lines of code (LOC) to implement the software.
- Cost estimation: funds required to develop the project.
- Schedule estimation: amount of time (duration) required to complete the project.

There are several types of estimation models and techniques that can be used for software estimation. There is no best approach; indeed, each of them has its pros and cons. The techniques can be classified into two major types, namely algorithmic and non-algorithmic (Shekhar & Kumar, 2016). The former is based on equations and mathematics, which are used to process the software estimation; in contrast, the latter is based on analogy and deduction. The list below includes some well-known techniques used in the industrial field (Moløkken & Jørgensen, 2003). The software estimation methods and techniques are as follows (Nasir, 2006); (Shekhar & Kumar, 2016):

- Analogy-based method: compares a project to a similar project that has already been completed. This approach relies on historical data from previously completed projects.
- Top-down method: concerned with the overall characteristics of the software development, requiring few details about the system. This is the kind of method used during the early stages of software development.
- Bottom-up method: gauges each software component and combines them to estimate the overall project.
- Expert Judgment (EJ): one of the most common techniques used in the industries, it relies on the knowledge of experts.
- Function Point Metrics (FP): more commonly used than LOC, it is a measurement unit used to compute the amount of software functionality, such as the number of external inputs, interface files and external enquiries. There are several standards, such as COSMIC and FiSMA, which have been adapted and have improved the FP concept.
- Price to Win Estimation: estimations are determined on the basis of the project's budget. This technique focuses more on the customer budget than on software functionalities.
- Artificial Neural Network: this artificial intelligence model is based on training from historical data.
- Line of Code (LOC): one of the oldest techniques in estimation studies, it is highly dependent on the source code of the completed software.

- COCOMO: a constructive cost model developed by (Boehm, 1984). COCOMO is considered a procedural cost and effort estimation model, and its parameters are obtained from a previously completed software project.
- Use-case Point method: used when (use-case) UML diagrams are employed in the design of a software project. It relies on the interactions between user and system to measure the size and effort of the project.

Britto, Freitas, Mendes and Usman (2014) presented a SLR of effort estimation in the context of Global Software Development (GSD), and selected five studies from 24 (Björndal et al., 2010; Muhairat et al., 2010; Narendra et al., 2012; Peixoto et al., 2010; Ramasubbu & Balan, 2012). It concluded that the EJ approach, including Planning Poker (PP), Delphi and Expert Review, was the most used in effort estimation for GSD. Furthermore, this study identified a wide range of cost drivers; those of culture, language and time zone were the most used in estimating effort in GSD projects.

2.3.2. Software estimation in Agile SD

Mike Cohn's book in Agile estimating and planning answered questions relating to a project's size, project scheduling and planning (Cohn, 2005), finding that the story point and ideal hours/days are the two most common units to express the size measurement of a user story features or a task. The story point is basically the difficulty level of the user story, for example: 1, 2, 3, 5 or 8. These number signifies how difficult and complex the user story is (Cohn, 2005). Another way to measure it is by means of ideal hours. This refers to the time that could take a developer to complete a certain task without interruptions, unplanned issues or challenges (Pekka Abrahamsson et al., 2002).

Using a prior SLR (M. Usman, Mendes, Weidt, & Britto, 2014) allows a detailed overview of the effort and size estimation techniques used in the ASD process. A total of 25 primary studies were examined, all of which satisfied the inclusion criteria and passed the quality assessments of this literature review. PP and EJ were the most frequently used techniques in the ASD process, while story point, use-case point and function point were the most usual size metrics employed. Of the estimation techniques, 12% studied the estimation effort during the implementation phase, around 30% in the testing phase and 12% in the implementation & testing phase; however, none of the primary studies has estimated the effort in the design or analysis phase of the development process. In what follows, I present the most important research in terms of relevance to my study:

- **Expert Judgement and story point**

  (Pekka Abrahamsson et al., 2011) proposed a prediction effort model based on user stories; to achieve this, they employed the eXtreme Programming (XP) method. Using this model, certain predictors were extracted from the user story (number of characters, presence of keywords and priority) for use in the training model.

- **Planning Poker and story point**

  PP is a consensus-based estimation technique used in Agile. It starts by a product owner reading an Agile user story and describing the necessary features to the estimators. The estimators, including the development team members, hold up a playing card to convey an appropriate quantified estimation of the resources required for the user story (Cohn, 2005).

  Haugen (2006) conducted an empirical study to examine the PP process undertaken by a development team to estimate the effort required for a user story. One development team followed the eXtreme Programming (XP) method and its resulting estimation was compared to that of the unstructured group. Performance and accuracy using PP were better than the unstructured group estimation process. Subsequently, Mahnič and Hovelja (2012) carried out an empirical and detailed study of PP to estimate the user story during the early stages of the ASD process, to define the release plan. The authors found that the estimation's accuracy under PP was greater than that of the individual experts' estimates.

- **Use-case point**

  Parvez (2013) designed a new layer to improve two essential factors: efficiency; and risks involved in estimating the effort needed under the use-case point method. Six points relate to the implementation of the new model; all increase the performance and efficiency of the use-case point estimation method.

- **COSMIC Functional Size**

  Hussain, Kosseim and Ormandjieva (2013) addressed certain challenges surrounding the application of COSMIC in the Agile development process. COSMIC FS is an international standard based on ISO/IEC for measuring the software functional size of the user requirement. In their study, COSMIC was found not to be compatible with Agile, because of the formality level of its user requirement. It needs to be formalised at a certain level of granularity, where the user communicates with the system, and be visible to the measurer. However, a preliminary experiment obtained a reasonable result for an approach that approximates COSMIC FS, based on the informal text user requirements.

Bilgaiyan, Sagnika, Mishra and Das presented a SLR of software cost estimation in ASD (Bilgaiyan et al., 2017). The estimation mechanisms examined were Neural Network, EJ, PP and Use-case point. It was found that EJ was one of the most common among conventional estimation techniques in ASD (Gandomani et al., 2014; Grimstad & Jørgensen, 2007; Jørgensen, 2004b, 2004a; Jørgensen & Grimstad, 2010).

2.4. Summary

This chapter provided an overview of Agile values, principles and methodologies. Scrum is the Agile methodology most widely used in the industrial fields, according to the annual State of Agile report. In addition, it gave a background to the various mobile app development frameworks and gave the main reasons why mobile development is different from other software development. Finally, it described the various effort estimation methods used in Agile processes.

Chapter 3: Research Methodology

A research project is usually thought of as a series of linked activities that must be followed in order to undertake and complete the project. These activities vary from one research project to another. This study it is structured as follows: formulating and clarifying the research topic, undertaking a critical literature review, devising a research approach, formulating the research design, research strategy and data collection plan, and analysing the data (Saunders, Lewis, & Thornhill, 2009; Dudovskiy, 2018).

The first section of this chapter defines the research aim and objectives of this study. Following this, an overview of the systematic literature review SLR will be provided in section 2. The research approach and design are stated in sections 3 and 4, respectively. Lastly, the data collection method and strategies are stated in section 5.

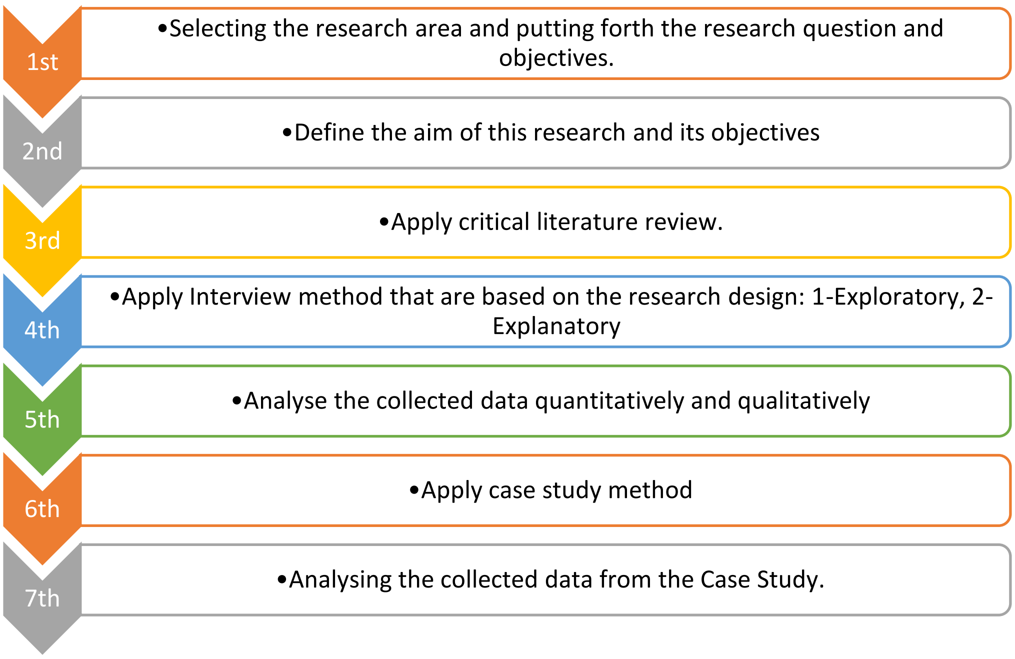


Figure 1: Research methodology activity

3.1. Research Aim and Objectives

The research aim is to identify the effort estimation factors in the development of mobile apps and to investigate effort estimation techniques using the Agile process in mobile apps in the industrial fields. Having a research aim helps to design the research questions, while the research objectives help to divide the aim into parts. This makes it easy to address each part individually (Dudovskiy, 2018). The research questions will be stated in Chapter 4 in order to apply the SLR to answer on these questions.

The research objective comprises steps that explain how the research aim is to be achieved:

- Identify and analyse the factors in the effort estimation techniques and analyse the Agile process adapted for mobile apps.
- Analyse the existing effort estimation techniques for traditional software development in ASD and the most frequently used method.
- Identify and explore the relationship between existing Agile effort estimation techniques for a traditional software and the factors/cost drivers of mobile effort estimation techniques.
- Validate the efficiency of effort estimation factors for mobile app development.
- Study and assess the impact of the adapted ASD process in mobile apps, alongside the cost drivers of mobile effort estimation techniques.

3.2. Conducting the Literature Review

A critical literature review provides a strong base for any research project. A Systematic Literature Review SLR will be used in this study to have a narrative review of the current state of art and practice of effort estimation techniques for mobile app development in Agile processes. The critical review, in addition, helps to provide an overview of the current knowledge to identify relevant methods and gaps in this research project. The SLR will be presented in Chapter 4.

3.3. Research Approach

Adopting the right approach helps to design a study in an appropriate way; this, in turn, makes it possible to identify the correct and most suitable approach with which to collect data. The right approach is concerned with the way in which data are collected to answer the research question. There are three types of research approach, namely inductive, deductive and abductive (Dudovskiy, 2018). In this study, the plan is to apply only two approaches, deductive and inductive. The deductive approach is used when we have a hypothesis – 'a statement that can be tested' – concepts or proposed methods, and design a research strategy to test, evaluate and confirm it. This study has multiple hypotheses and concepts regarding the adaptation of effort estimation techniques of Agile process to mobile apps that need to be tested and evaluated. This will be carried out alongside the existing mobile effort estimation techniques.

Figure 2, below, illustrates the progress of the deductive research. There are multiple estimation methodologies from the literature review and a need to examine and explore their suitability to developing mobile apps, in the Agile context.

Figure 2: Deductive research progress

The inductive approach starts by observing the collected data and then formulating a theory based on the results of data analysis. Many mobile effort estimation techniques have been discussed previously, and these have been used to develop a new estimation model. In this research, this approach explores the estimation techniques used in the development of mobile app and analyses the collected data to find the most suitable model for mobile app effort estimation.

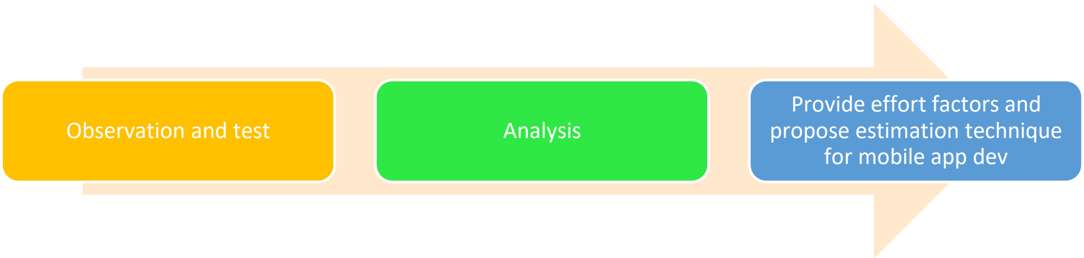


Figure 3: Inductive research progress

3.4. Research Design

The research design is a general plan of the steps to be taken to answer the research questions and achieve the objectives. A research design is usually divided into three groups: exploratory, descriptive, explanatory (Creswell & Creswell, 2018; Saunders et al., 2009). For this research, the focus is on exploratory and explanatory design.

Exploratory research aims to investigate the research questions with a view to finding new insights. It is not necessary to find an answer to these questions; indeed, the aim is more to clarify the understanding of the problem. Certain issues have arisen from the SLR that showed that no previous study has investigated the adaptation of the Agile process to mobile apps, regarding mobile effort estimation techniques. As such, the research design will be based on the exploratory concept. Also, there is a need to explore the essential factors for effort estimation in mobile app development and identify suitable estimation techniques for mobile app development in the industrial fields.

Explanatory research studies the relationship between variables by analysing the situation surrounding a problem. From the literature review, a couple of mobile estimation techniques were identified that rely on certain factors/cost drivers to predict the effort involved in a mobile app development. Moreover, there were techniques proposed to estimate the effort in the Agile process, such as the PP technique. This study needs to look into the relationship between the variables of those techniques in order to find answers to the research questions and to study how the current effort estimation techniques for Agile process could be employed in the development of mobile apps.

3.5. Research Strategies and Data Collection Method

There are many research strategies, such as survey, experiment, case study, action reaction and grounded research. The strategy choice is guided by the research aim, questions and objectives, available resources and time.

Survey is one of the most frequently used strategies across research projects (Kothari, 2004; Saunders et al., 2009). The strategy is usually applied as part of the deductive research approach, as discussed previously. The survey approach will answer the 'who', 'what', 'where' and 'how many' questions. Moreover, using the survey technique provides quantitative data that can be analysed statistically in order to identify the relationship between the collected variables, which subsequently makes it possible to produce a model.

Interview is considered as one of the data collection techniques that belongs to the survey strategy. Using the interview approach makes it possible to gather and obtain reliable data that are relevant to the research question and objectives; it also helps to maintain and structure the research objectives. There are many types of interview: structured (questionnaires), semi-structured and in-depth interviews. Since the purpose of the research study design is both exploratory and explanatory in nature, the most suitable approaches with which to collect data for this study are both standardised and non-standardised techniques.

- Standardised technique: Structured interviews are based on questionnaires that rely on predetermined questions. The study will use this method to evaluate and assess current effort estimation factors and find out their applicability to the mobile app development. This method will enable the collection of quantifiable data and help to discover the most suitable estimation technique for mobile app development.
- Non-standardised technique: this includes:
    - Semi-structured method: using a list of the areas to be covered in all interviews. The questions may differ from one interview to another, and this depends on the conversation flow. Semi-structured interview questions are helpful when it

comes to understanding the relationship between variables in an explanatory study.

- In-depth method: these are informal, and the questions are not defined or predetermined. The purpose of using this technique in the present research is to give interviewees the opportunity to speak freely about the topic area. This method is suitable for an exploratory research design and makes it possible to seek out new insights and discover what is happening.

In this study, both structured and non-structured interview methods are used for the effort estimation factors and Agile process adopted in mobile app development. This approach will help to achieve the research objectives by:

1. Evaluating the current effort estimation factors to find their applicability to mobile app development in the IT sector.
2. Finding further effort estimation factors for mobile app development that are based on Expert Judgement in the IT sector.
3. Exploring further the estimation techniques and processes used in the IT sector and validating their efficiency.
4. Exploring the processes to employ the effort estimation factors for mobile apps in the Agile process.
5. Examining the applicability of the Agile process in mobile app development and evaluating the Agile process adopted for mobile apps.

In general, semi-structured and in-depth interviews give the opportunity to probe the answers provided and let the interviewees explain their responses. Moreover, discussion with interviewees might lead to new considerations and ideas that have not yet been thought of or addressed in the research questions and objectives. The interviews will use a mixed-method approach to collect quantitative and qualitative data at the same time, 'in parallel', as shown in Figure 4.

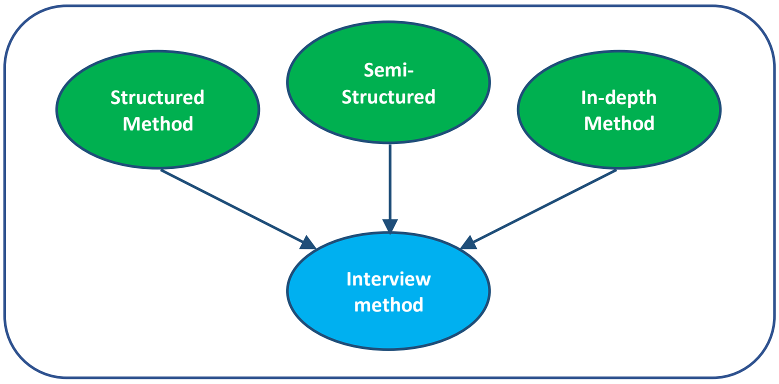


Figure 4: Interview approach

The survey techniques will give confidence in validating the proposed estimation model and testing this model in a case-study method. As part of the method, it is planned to conduct an empirical investigation into the effort estimation techniques proposed in multiple organisations when designing and implementing a mobile app. In this project, there will be an effort estimation measurement before starting the project; then a comparison of the actual effort value and the estimated value after finishing the sprint of a project, to assess the accuracy of the estimation model; and then analysis of the result for its implications and observations of its effectiveness.

The case study method will help to capture the complexity of the real-life situation by doing an empirical investigation of the Agile process in mobile app development and the influential effort estimation factors for the apps as well. Action research method, in addition, will be applied in this study that encourage the participants in an organisation to collaborate in diagnosing and solving the problems. More detail of the case study method, plan and design is found in Chapters 9.

This research uses multiple data collection and analysis techniques to answer the research questions and objectives. Using multiple methods is useful as allow key issues to be obtained from the unstructured interviews at the exploratory stage, and to address and employ these issues in the structured interview 'questionnaires' to collect explanatory data. The triangulation method is a multiple methods concept that refers to the use of multiple data collection techniques in a study to corroborate its research findings and increase the validity of the results.

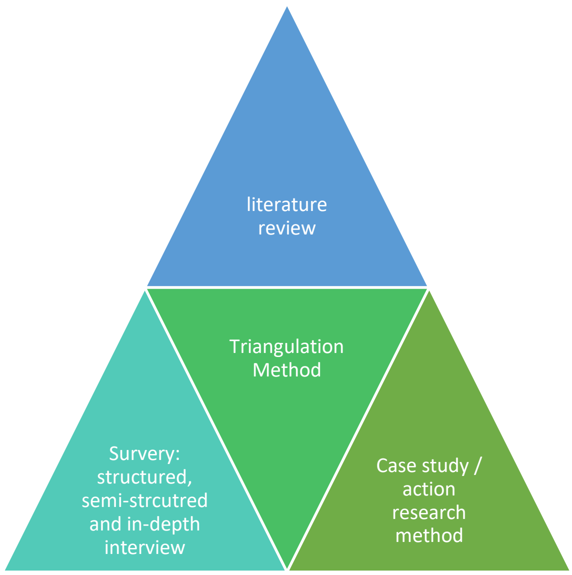


Figure 5: Multi-methods (triangulation)

For the case study, multiple focus group discussions and observations were held in three companies in the Kingdom of Saudi Arabia. The case-study methodology and reporting was conducted following the guidelines and standards for software engineering studies provided and validated by Runeson and Höst (2009) and Runeson, Höst, Rainer and Regnell (2012). The first is case study organisation is Company A, which provides mobile app solutions to clients. This company is in Alkubar, Saudi Arabia. The other two, Company B and Company C, are in Riyadh.

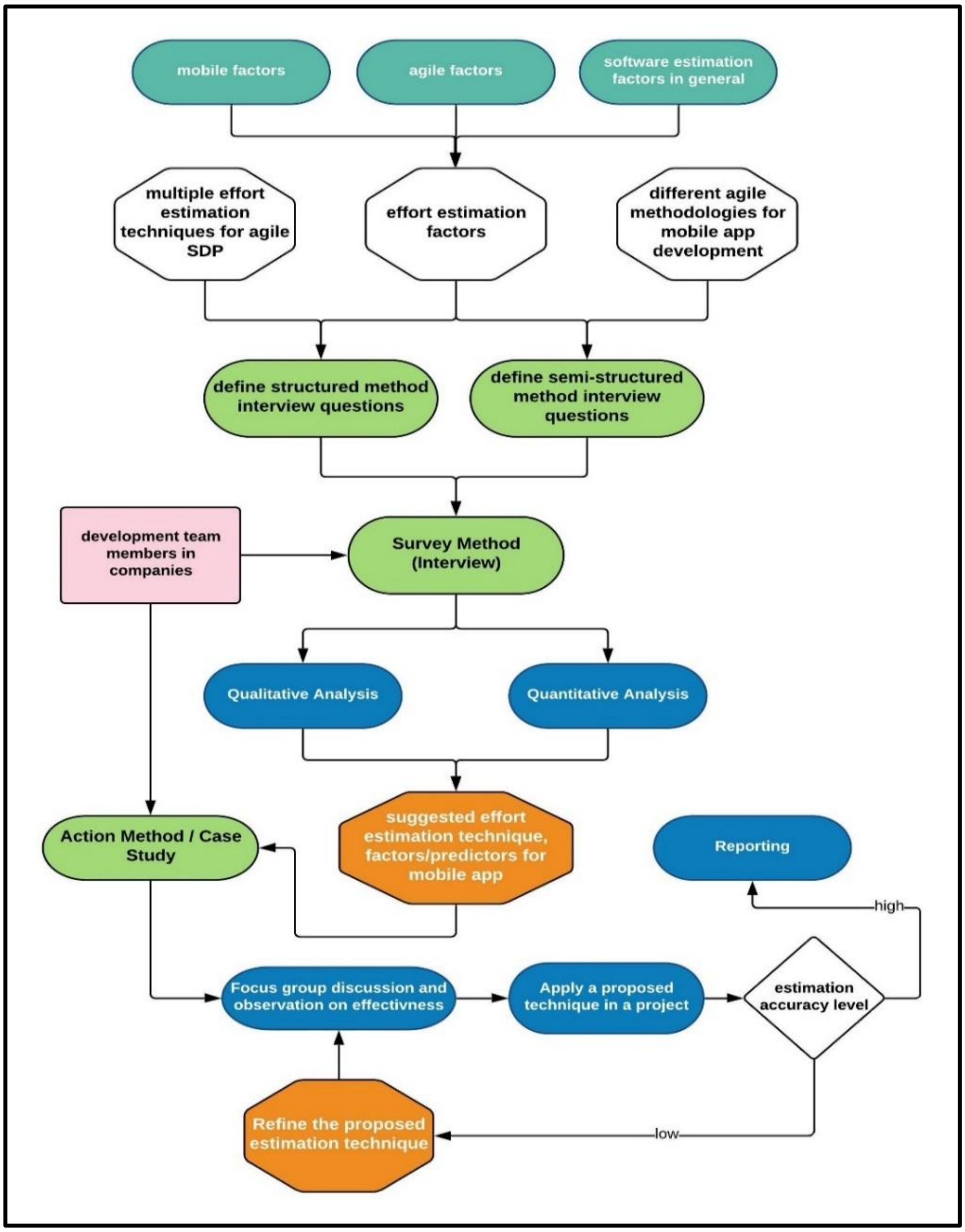


Figure 6: Research method overview

To sum up, Figure 6 illustrates the research method to be followed in the study. In-depth and semi-structured methods are used as an exploratory research design to discover what is happening, to seek new insights and to understand the relationship between the effort estimation factors in ASD for mobile app and across Agile methodologies for mobile development process. By contrast, structured methods will be used to identify and examine the effort estimation factors and Agile process in developing mobile apps.

3.6. Time Horizon

Two designs of research methodology can be used to plan a research time horizon (an investigation that could be taken at a single point in time). One is cross-sectional and, when the research is noted in a diary or recorded through a series of snapshots, it is longitudinal (Saunders et al., 2009). The cross-sectional design is applicable to a study to investigate a particular phenomenon at a particular time, namely the effort estimation factors on mobile apps that use the ASD process. In addition, a longitudinal design and measurement will be applied to investigate the estimation effort in each process and iteration of the Agile method 'sprint'.

3.7. Summary

This chapter provided a full detailed plan, design, strategy and approach of this research study. The aim of this study and objectives was set out at the beginning of the chapter. From the discussion of SLR result from chapter 4, exploratory and explanatory research designs will be used in this study. The interview method is planned, and the results from the interview will be validated and confirmed by case study.

Chapter 4: Systematic Literature Review

The design of the literature review in this study was inspired by the Evidence-based Software Engineering (EBSE) model; its guidelines were followed (Kitchenham et al., 2009) to synthesise the best-quality scientific studies. A mixture of assessment criteria were used in this SLR, including the AMSAR (A Measurement Tool to Assess Systematic Review) standard (Shea et al., 2009) and assessment guidelines from Kitchenham and Charters (2007). These were employed to assess the reliability, validity and feasibility of the measurement tools in these studies. In the first part of this chapter, the scope of the research and the research questions are laid out. The second section details the search strategies and inclusion and exclusion criteria. This literature review will end with a presentation of the studies' assessment criteria.

4.1. Scope and Research Questions

4.1.1. Research scope

Before starting the research review, I had to ask myself an important question: is a systematic review really needed? I had to guard against asking general research questions, as it would have been difficult to determine the usefulness of the answers obtained. Before determining the final research questions, it was helpful to break them down into sub-questions to make them more precise. For the following questions, I used the PICOC model (Petticrew & Roberts, 2006). This model is very effective when it comes to framing and considering the components of questions.

Population: Agile Software Development process and mobile app platform projects.

Intervention: Effort/size estimation methodologies/model for mobile apps.

Comparison: Various effort estimation techniques in mobile apps.

Outcome: The precision and accuracy of studies that have focused on effort estimation in mobile apps.

Context: All studies (empirical, hypotheses) related to Agile SD in effort estimation.

4.1.2. The research questions

RQ1. What methods or techniques have been used to estimate effort in mobile application development using Agile methods?

RQ2. What are the effort factors and predictors that have been used in software estimation technique in Agile SD?

RQ3. What are the characteristics of the dataset/knowledge that have been used in studies to estimate effort in mobile applications?

a. What is the type of project (educational/economical, etc.)?
b. What type of framework has been used on the mobile app (mobile web/native/hybrid application)?
c. What type of operating system has been used on the mobile app (Android/IOS/Windows OS)?

RQ4. What is the accuracy level and efficiency of using Agile SD to estimate the effort of mobile application software projects?

4.2. Primary and Secondary Search Strategy

4.2.1. Search criteria

After stating the research questions, I broke them down into terms that I could use to find relevant articles. I was concerned with a wide range terms to address the questions. Within the search terms, it was important to include all synonymous words, singular/plural words and words with alternative spellings. Identifying the major terms from the questions and obtaining their synonyms and alternatives is one advantage of using the PICOC model. AND/OR operators were used to link the terms.

It is important to understand how to design the query and state the search criteria. Before starting, I had to consider which format I wanted to follow. Each library's database has a specific format when it comes to building a query to fetch and reiterate data from its database engine. In this literature review, I was interested in the title, abstract and the article's keywords in constructing the search query.

I designed this query using the Google DBSE (Database Searching Engine) and other DB sources that address using advanced search on search engines. I chose to focus my research on the following database libraries: IEEE Explore, ACM Digital Library, Scopus, Compendex and Inspec. This was because they are specialist libraries in the field of computer science and engineering. Since the Compendex and Scopus libraries have an almost total overlap (elsevier.com, n.d.), I chose to combine their results. Moreover, I combine the results of Inspec and WebOfScience, since they have the same query format and the same website location (http://apps.webofknowledge.com). In the search scope section, I describe in detail the selected libraries and databases.

4.2.2. Search scope

This literature review encompasses both published and unpublished studies relevant to my study. Based on the research topic and field (Kitchenham et al., 2009; Siddaway, 2014), it covers all databases of high-quality and reputable primary published studies related to my topic questions, as listed in Table 1: Search scope of the database. The unpublished studies are from other databases that specialise in technical reports, the most common of which is the Directory of Open-Access Repository; this gathers together literature from thousands of universities across the world. In addition, Google Scholar is one of the most popular search engines with which to find unpublished studies.

4.2.3. Search query

(effort OR efforts OR cost OR size OR performance) ***AND*** *(estimation OR estimating OR estimate OR prediction OR predicting OR predict OR assess OR assessment OR calculate Or calculation OR measure OR measuring)* ***AND*** *(mobile OR smartphone OR screen touch OR phone OR apple OR android OR IOS)* ***AND*** *(app OR apps OR application OR applications OR software OR program OR programs)* ***AND*** *(agile OR "software development" OR scrum OR XP OR "extreme programming" OR Crystal OR DSDM OR "dynamic system development method" OR lean).*

For each of the database libraries, I followed tips on how to use their database engines to obtain highly accurate results for articles. As seen in Table 1, I produced a schema of database queries and their results. Each of the queries generated different results. I categorised their value and importance into three:

- **Very Important Query (VIQ):** contains all or most of the terms/ideas of my research topic. These kinds of research results were usually very close to my topic and were very relevant; as such, I need to read these papers/articles in more detail. It was rare to have a large number of results for this query.
- **Normal Query (NQ):** contains some of the terms/ideas of my research topic. Results were not close to my topic yet were still relevant. I usually read the abstract and summary of these articles and assessed whether they were related to my topic. I designed this query to collect background knowledge on related topics.
- **Not Important Query (NIQ):** I designed this query to pinpoint all topics that were being discussed in my research field/area. This helped me to expand my search scope and acquire more knowledge of what kinds of research have been published in this field (mobile app software development).

Table 1: Search scope of the database

Database name/search engine	Search results
IEEE explore	126
ACM Digital	308
Inspec	134
Web Science Core Collection	
Scopus	124
Compendex	
OpenDOAR	9
Google Scholar (for unpublished works)	

The queries in Table 65: Query schema from Appendix B, found 701 articles. Table 2: Query result in detail, shows the distribution of the queries' results and their importance.

Table 2: Query result in detail

Query ID	Query Importance	Result
SQ1	NQ	23
SQ2	VIQ	0
SQ3	VIQ	6
SQ4	VIQ	17
SQ5	NQ	48
SQ6	NQ	7
SQ7	NIQ	293
SQ8	VIQ	8
SQ9	NQ	123
SQ10	NQ	11
SQ11	VIQ	0
SQ12	NIQ	76
SQ13	VIQ	17
SQ14	NQ	32
SQ15	NQ	9
SQ16	VIQ	31
Total result		**701**

Table 3: Query summary

Query category	Number of query results
Very Important	79
Normal	253
Less Important	369

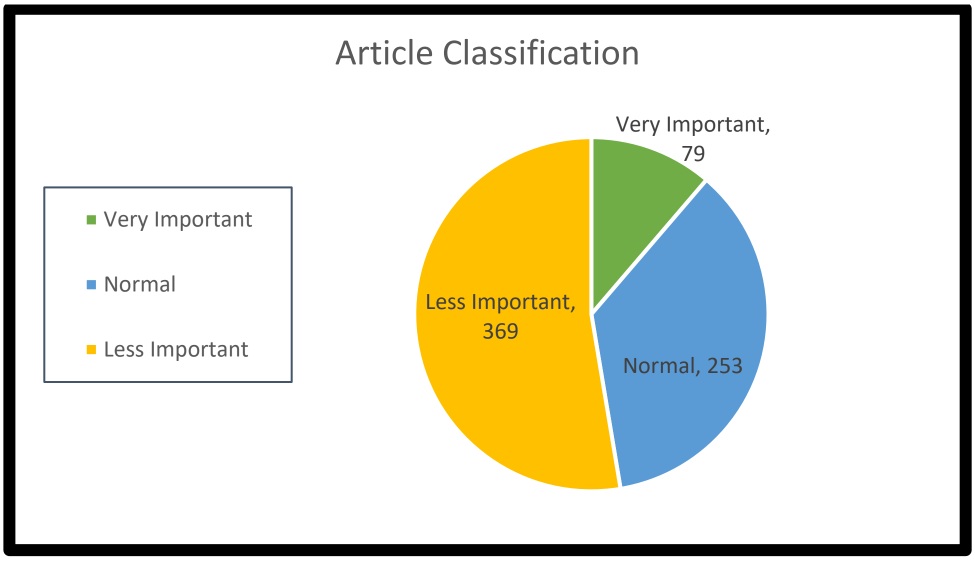


Figure 7: Article distribution

4.2.4. Inclusion and exclusion criteria

Defining inclusion and exclusion criteria helps to clarify the boundaries of a study. In this section, I define an assessment criterion to include articles and studies relevant to the research questions and objectives and to exclude unrelated work.

Inclusion:

- All studies related to the effort or size estimation models for mobile apps.
- All studies that applied the Agile Software Development process.
- All empirical studies (evidence-based studies).
- All peer-reviewed studies reported or presented in workshops, conferences or journals.
- All works presented in one of the highly reputable databases in the above table, and most of the trending unpublished databases that were sourced.
- The first ever smartphone was announced in 1993 (Rajput, 2015) by IBM; it was released with certain apps, such as a calendar, contact book and clock. In 2002, Blackberry released its first smartphone. The smartphone tended to be very limited and could handle only very small apps, such as calendar and so on (Tracy, 2012). In 2008, touchscreen phones (e.g. iPhone, Android) became the revolution of the century. They are based on the app concept (Tracy, 2012), and thus I included **all studies published since 2008 and ignored anything earlier.**
- I included all studies that have been presented and published in the English language.

Exclusion:

- Any study that did not discuss the effort estimation in mobile app development.
- Any study that did not use ASD methods to undertake the estimation.
- Any study that did not validate its work empirically.
- Any study not published in one of the listed databases.
- Any study not published in the English language.

4.3. Study Selection Process

Data gathered by systematic searches should be documented and organised in an appropriate format. Due to the large number of results, all the data (701 articles) were exported to Microsoft Excel for ease of management. The worksheet tabulates their vital details, such as: 1. Paper name; 2. Publishing year; 3. Author's name; 4. Abstract; 5. Article URL; and 6. Search_Query ID(SQ1_SQ16). By managing and grouping the information in one location, the duplicated articles could be eliminated.

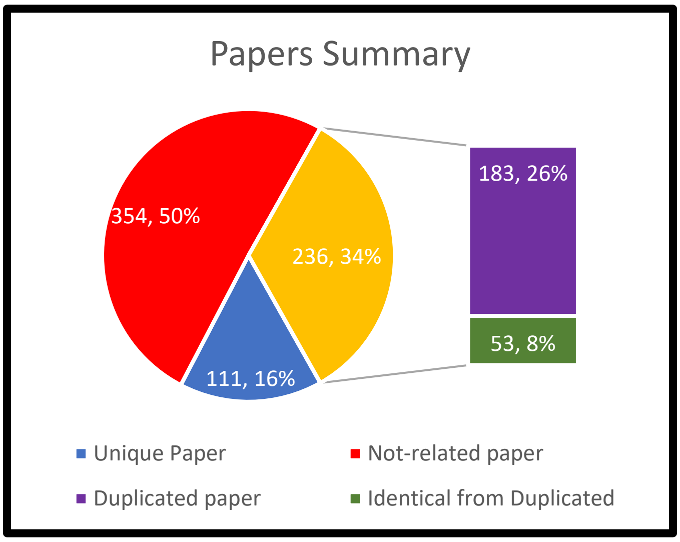
To start screening and filtering the articles, I categorised the process into three phases, as follows.

4.3.1. Screening the less-important search queries

The less-important queries were found by Search_Query 7 and 12. These queries' results were classified as less important, as mentioned in the search query section, and there were 369 articles needing to be filtered. Most were far removed from my own research area, from a quick skim through their abstracts, such as: mobile network, GPS, mobile signals and radio, mobile security, mobile energy of phones and consumption, telescope, health field 'heart pulses', and so on. I excluded all unrelated studies (354 papers) using the inclusion and exclusion criteria and moved the relevant ones to the second phase of the search category.

4.3.2. Screening the normal and highly important search queries

This phase included all studies found by Search_Query 1-6,8-11,13-16, and included all those that had been passed on from the previous phase. There were 111 unique articles and 53 duplicated papers (from 236 recorded). Their titles, abstracts and summaries were read carefully, and the inclusion and exclusion criteria were applied, leaving 35 that satisfied the inclusion criteria.



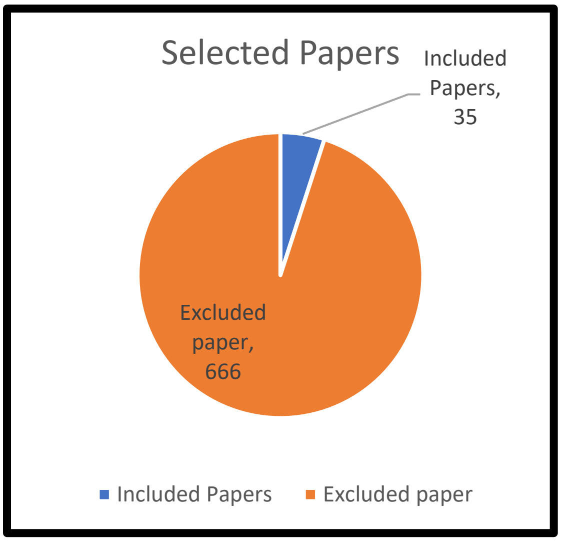


Figure 9: Selected article summary

Figure 8: Article summary

4.3.3. Full text screening

During this phase, the inclusion and exclusion criteria were applied to all the text in the 35 articles, and 21 that related to the literature review were selected, as shown in Table 4. Quality assessment criteria were applied to evaluate and establish the quality of their study.

Table 4: Information on selected articles

Study ID	Article topic	Year	Author(s)
S1	Software cost estimation for user-centered mobile app development in large enterprises	2018	Maria Lusky, Christoph Powilat, Stephan Böhm
S2	A parametric effort estimation model for mobile apps	2017	Syed Ahmad Shahwaiz, Ali Afzal Malik, Nosheen Sabahat
S3	A set of metrics for the effort estimation of mobile apps	2017	Gemma Catolino, Pasquale Salza, Carmine Gravino, Filomena Ferrucci
S4	An empirical validation of mobile application effort estimation models	2017	Tharwon Arnuphaptrairong and Wachira Suksawasd
S5	Investigating the adoption of Agile practices in mobile application development	2016	Alan Santos, Josiane Kroll, Afonso Sales, Paulo Fernandes and Daniel Wildt
S6	COSMIC functional measurement of mobile applications and code size estimation	2015	Loris D’Avanzo, Filomena Ferrucci, Carmine Gravino, Pasquale Salza

S7	Investigating functional and code size measures for mobile applications	2015	Filomena Ferrucci, Carmine Gravino, Pasquale Salza, and Federica Sarro
S8	On the use of requirements measures to predict software project and product measures in the context of Android mobile apps: a preliminary study	2015	Rita Francese, Carmine Gravino, Michele Risi, Giuseppe Scanniello, and Genoveffa Tortora
S9	Reviews on Agile methods in mobile application development process	2015	Dewi Mariati Mahmud, and Nur Atiqah Sia Abdullah
S10	Reviews on functional size measurement in mobile application and UML Model	2015	Nur Atiqah Sia Abdullah, and Nur Ida Aniza Rusli
S11	An analogy-based effort estimation approach for mobile application development Projects	2014	André Nitze, Andreas Schmietendorf, Reiner Dumke
S12	Measure the functional size of a mobile app: Using the cosmic functional size measurement method	2014	Harold van Heeringen , and Edwin van Gorp
S13	Mobile application development: How to estimate the effort	2014	Laudson Silva de Souza and Gibeon Soares de Aquino
S14	Mobile game size estimation: COSMIC FSM rules, UML mapping model and Unity3D game engine	2014	Nur Atiqah Sia Abdullah, Nur Ida Aniza Rusli, Mohd Faisal Ibrahim
S15	Agile Software Development processes for mobile systems accomplishment evidence and evolution	2013	Luis Corral, Alberto Sillitti, Giancarlo Succi
S16	Software development processes for mobile systems: Is Agile really taking over the business?	2013	Luis Corral, Alberto Sillitti, Giancarlo Succi
S17	Measuring mobile application size using COSMIC FP	2013	André Nitze
S18	Agile development methods for mobile applications	2010	Andrei Cristian Spataru
S19	Designing an Agile methodology for mobile software development: A hybrid method engineering approach	2008	Vahid Rahimian, and Raman Ramsin
S20	Development process of mobile application SW based on Agile methodology	2008	Yang-Jae Jeong, Ji-Hyeon Lee, Gyu-Sang Shin
S21	Mobile-D: An Agile approach for mobile application development	2004	Pekka Abrahamsson, Antti Hanhineva, Hanna Hulkko, Tuomas Ihme, Juho Jäälinoja, Mikko Korkala, Juha Koskela, Pekka Kyllönen, and Outi Salo

4.4. Studies Quality Assessment

The guideline criteria by Kitchenham et al. (2009) and Kitchenham and Charters (2007) made it possible to assess those studies based on questionnaires. It was important to assess them to establish which should be focused on and which were of less importance and, in some cases, could be ignored. The quality assessment criteria supported and provided further details on the inclusion and exclusion criteria. The checklist was customised by the suggestions provided by Kitchenham and Charters (2007) and by M. Usman et al. (2014). Below are the questions used to evaluate the selected studies:

1. Are the research aims clearly specified?
2. Was the study designed to achieve these aims?
3. Are the estimation methods used for mobile apps clearly described and their selection justified?
4. Are the variables used in the study adequately measured?
5. Are the data collection methods adequately described?
6. Are the statistical techniques used to analyse data adequately described?
7. Does the researcher discuss any problems with the validity/reliability of their results?
8. Are the measures in the study fully defined?
9. Are the study participants or observational units adequately described?
10. Are all the research's questions answered adequately?

In terms of the answers to these questions, there were three possible options:

- Y: Yes, the answer was explicitly defined in the study = 1 point.
- P: Partially answered by the study = 0.5 point.
- N: No, the answer was not defined = 0 point.

Each study was awarded a score ranging from 0 to 10 points, and any study below 3 was eliminated from the review. The final scores for the quality assessment for the selected articles are seen in Table 5. Some were excluded for failing to satisfy the inclusion criteria (Preuss, 2013), for reporting a study included in another published article (Francese, Gravino, Risi, Tortora, & Scanniello, 2016; De Souza & De Aquino Jr, 2014) or for a low assessment score (Balasupramanian et al., 2013).

Table 5: Assessment of selected studies

Study ID	Score	Study ID	Score	Study ID	Score
S1	8	S2	8.5	S3	7
S4	8	S5	5.5	S6	8
S7	8	S8	8.5	S9	5
S10	4.5	S11	6	S12	5
S13	5	S14	5.5	S15	5
S16	5	S17	4.5	S18	4.5
S19	5	S20	5	S21	5

4.5. Limitations of the Research

The major danger is that the queries may have failed to find all the studies relevant to the SLR. However, to mitigate against this risk, a very deep search strategy was implemented that used Kitchenham's standards for software engineering studies (Kitchenham et al., 2009) and guidelines (Kitchenham & Charters, 2007) to perform the SLR. It resulted in a good query that contained most of the key words of relevant works concerning Agile processes, effort estimation and mobile apps. Some aspects of the SLR are subjective. To mitigate against this effect, the researcher discussed widely and agreed on the findings presented here.

Chapter 5: Literature Review Discussion

The last chapter described the SLR process and strategy for this study, while the research scope, query, questions, results and analysis were given in detail in the previous. At this point, we can return to the research questions. For example, RQ1 asked: What methods or techniques have been used to estimate effort in mobile application development using Agile methods?

The results revealed that various software estimation techniques and models have been used to estimate the effort and size of mobile app projects; however, none has yet employed any Agile methodology.

In light of the previous chapter, Table 6 shows the distribution of the selected studies and their categories. There were 13 studies out of the total of 21 that discussed estimation techniques in mobile apps, whereas eight pertained to Agile SD in mobile apps.

Table 6: Categories of selected studies

Related topic	Study ID
Effort estimation with mobile application	S1, S2, S3, S4, S6, S7, S8, S10, S11, S12, S13, S14, S17
Agile SD with mobile application	S5, S9, S15, S16, S18, S19, S20, S21

This chapter will answer the SLR questions in section 5.1 below, regardless of which software development process was used. Following this, all studies that used Agile SD in mobile app development are discussed in section 5.2, and in section 5.3, the effort estimation factors are discussed. Finally, the research gaps are discussed in section 5.4.

5.1. Effort Estimation in Developing Mobile Apps

After extracting the data from 13 studies on software estimation techniques in mobile apps, the extracted data were consolidated into eight tables to make them readable. This also meant that it was easy to see the relationship between the data and the research questions. The details of the 13 studies are explained more rigorously below in subsections 5.1.1 and 5.1.2.

Table 7 answers RQ1 by listing the estimation techniques that have been used in mobile apps. The Function Size Measurement and EJ techniques were the most usual across mobile apps. To answer RQ2, Table 8 presents the size metrics and cost drivers that were used by the studies. The number of screens and the type of supported platform for the smartphones were the most common factors to measure the estimation prediction. Table 9, Table 10 and Table 11 answer RQ3 by listing the operating systems (OS) supporting smartphones and the types of platforms used to develop mobile apps, the domain of this study. Table 12 investigates the development activity to which the effort estimate is applied. None of the studies estimated the effort involved in the analysis, design and testing. For RQ4, Table 14 lists the various prediction accuracy metrics used in the studies.

The estimation technique is the way of carrying out of the estimation process to obtain the effort value, whereas the size metrics is considered as an effort predictor that has been used to measure the product size (Muhammad Usman et al., 2017). For example, when a specialist uses the Expert Judgment (EJ) technique to estimate the effort of a task, and uses the number of screens metric as a measurement of the complexity of this task; then, the EJ is the estimation technique and the number of screens is the size metric.

Table 7: Estimation techniques

Estimation techniques	Study ID
COSMIC FSM	S6, S7, S11, S12, S14, S17
Function Point Analysis	S4
FiSMA FSM	S13
Expert Judgment	S1, S3, S11
Analogy based	S3, S11
Regression based	S2, S6, S8

Table 8: Size metrics of estimation

Estimation predictor metrics	Study ID
Function point size	S4, S6, S7, S11, S12, S13, S14, S17
UML diagram	S8, S8, S14
Supported Platform type (IOS/Andr./Win./etc.)	S2, S3, S11
Supported device (tablet, smartphone)	S2, S3, S11
User Interface quality and complexity	S2, S3, S4, S11, S13
Backend system availability and Server Config. Flexibility	S2, S3, S11
Dev.Team Skills	S2, S11
App Development flexibility and Complexity	S2, S4, S11
Team Communication, Process complexity and Experience	S2, S11
Push Notification	S1, S2, S3
Landscape and portrait mode	S2, S11
Data Storage and Memory Opt. Complexity	S2, S3
Number of Screens	S2, S3, S4, S13

Number of API party	S2, S3
Support Code reusability	S2, S4a
Technology Maturity	S2, S11
Battery & Power Optimisation	S2, S13
Connection (Wirless,Bluetooth,3G,etc)	S2, S4, S13
Booking and reservation, Calendar and Time, Map and localisation, Social Sharing, Searching contents and Messaging	S1, S3
Deadline date	S3, S4
Number of Functionality/Function Size	S3, S4, S8, S8
Number of files, classes, method, statement and LOC	S8, S8
Registration & login, Chronological list, Hardware access, File upload, Comment feature, navigation	S1
Interrupt handling	S2
Security Analysis Support, Budget for the project, Compatibility with Previous Version, Multi-languages support, Media support, and Paying process user feedback	S3

Table 9: Types of mobile operating system

Type of Mobile app	Study ID
Android based	S6, S7, S8
Apple based	---
Not descried (general smart phone)	S1, S2, S3, S4, S11, S12, S13, S14, S17

Table 10: Type of mobile app development

Development type	Study ID
Native	S8
Web app	--
Hybrid	--
Across platform	S14
Not described (general)	S1, S2, S3, S4, S6, S7, S11, S12, S13, S17

Table 11: Domain of datasets used

Domain and type of dataset used	Study ID
Industrial	S1, S2, S3, S4, S6, S7, S11
Academic	S8
Not defined	S14, S17
No dataset used	S12, S13

Table 12: Development activity

Development Activities	Study ID
Analysis	---
Design	---
Implementation	S6, S7, S8
Testing	---
All	S11
Not Defined	S1, S2, S3, S4, S12, S13, S14, S17

Table 13: Accuracy metrics and evaluation

Estimation Accuracy Technique	Study ID
Mean Magnitude of Relative Error (MMRE)	S2, S4, S6, S7
Median Magnitude of Relative Error (DMRI)	S2, S6, S7
Magnitude of Relative Error (MRE)	S4
Pred	S2, S4, S6, S7
Linear Regression (R2)	S2, S6, S7, S8
Mean Absolute Residuals (MAR)	S8
Median Absolute Residuals (MdAR)	S8
Not Use	S3, S11, S13, S14, S17
Other	S1 (mean)

5.1.1. Techniques using metrics/cost drivers for estimation effort

This section reviews studies that have used metrics/factors/cost drivers to estimate the development effort. The most recent was conducted by Catolino, Salza, Gravino and Ferrucci (2017). Their study identified a set of metrics (e.g. # of static/dynamic pages, develop new/existing app, etc.) to estimate the development effort of mobile apps in the early stages of the process. It would be beneficial to use these metrics in any model estimating the effort involved in developing mobile apps. Catolino's methodology was inspired by Mendes and Counsell (2004) in the context of web app development. The study obtained 41 metrics from 377 quotes that are available online from various companies. The metrics were then validated and analysed by four expert project managers. Since the study is recent, it has not yet been evaluated; however, the researcher plans to establish the validity of these metrics as dependent variables in a prediction model. In another study, Lusky, Powilat and Böhm (2018) proposed an experience-driven approach to estimating the effort by identifying and validating 16 standard features of mobile apps, with a degree of customisation level for those features. This approach was based on the Delphi method.

Shahwaiz, Malik and Sabahat (2016) proposed a parametric model to estimate the effort needed to create mobile apps. They identified 20 effort predictors (e.g. # of screens, application complexity, memory opt. complexity, etc.) and used an online survey that resulted in 169 data points for use in their regression-based model. Earlier, Nitze, Schmietendorf and Dumke (2014) had proposed a conceptual approach using analogy-based and function point-based techniques to estimate the effort needed for mobile app development. The method proposed that certain influential factors may affect the estimation of a project's cost.

Francese, Gravino, Risi, Scanniello and Tortora (2015) built a formal, regression-based estimation model to addressed 23 Android mobile apps. Its purpose was to estimate the effort needed for developing mobile app and the graphical component numbers, based on information from the project's requirements, such as number of use cases, classes and actors. The researcher investigated and the accuracy of this model's prediction – obtained from the requirements – by comparison to the effort needed for mobile app development and the number of graphical components involved. There are four types of Stepwise Linear Regression (SWLR) model in this article:

- S8a: SWLR Model Built around the Requirement Analysis Document (RAD) variables to predict the effort.
- S8b: SWLR Model built around the Source Code(SC) variables to predict the effort.
- S8c: SWLR Model built around RAD to predict the number of XMI files and graphical components.
- S8d: SWLR Model built around SC to predict the number of XMI files and graphical components.

5.1.2. Techniques using functional size measurement

This sub-section focuses on using functional size (FS) measurement to estimate the effort in developing mobile apps. D'Avanzo, Ferrucci, Gravino and Salza (2015) applied the COSMIC FS measurement method to mobile apps, with a particular focus on Android OS. The present study examined how COSMIC FS can be applied successfully in mobile apps and verifies the usage of functional size to predict the code size (memory size kb) of mobile apps. This study was empirically validated by extracting the functional user requirement (FUR) from eight mobile apps from the Google Play Store; next, the data movement (Entry-E, Exit-E, Write-W and Read-R) was obtained from the FUR. It revealed that the prediction model is highly accurate. Other studies, such as that conducted by Heeringen and Gorp (2014), have described guidelines on the application of an approximate method using COSMIC to measure the functional size of mobile apps in a rapid manner. In a similar vein, André Nitze (2013) examined an adapted version of the COSMIC FP approach and assessed its suitability to measure the size of mobile apps from the function user requirements.

In addition, Ferrucci, Gravino, Salza and Sarro (2015) investigated the usage of the COSMIC FS measure to estimate the size (line of code and memory size-byte) of mobile apps. This study included 13 mobile apps from the Google Play Store, applying the same guidance as applied by D'Avanzo et al. (2015). A study by Abdullah, Rusli and Ibrahim (2014) is relevant, which addressed the complexity of game parameters (requirements and characteristics) to accurately estimate the degree of size and effort needed for mobile game apps. This adapted COSMIC FSM to estimate the cost and effort incurred when using the Unity3D game engine; the latter is a multi-platform development tool that allows developers to create and design 3D games and applications for mobiles. The same authors (Abdullah & Rusli, 2015) conducted a review of the functional size measurement (FSM) on a mobile app development using UML modelling methods in terms of the measuring process and rules. Along similar lines, Souza and Aquino (2014) proposed a new method that is adopted in the FiSMA method; however, the study suffered from a lack of empirical evidence and no experts were involved. This approach has not been evaluated, nor has the accuracy of the predication method been measured. Souza constructed a systematic review that covered all characteristics of mobile apps and presented the differences between mobile apps and other traditional software.

An empirical validation study proposed by Arnuphaptrairong and Suksawasd (2017) has validated and compared the effort estimation accuracy of a traditional effort estimation model, Function Point method, (S4a) to a proposed method based on the number of screens of the mobile app (S4b).

5.2. Agile Software Development in Mobile Apps

This section includes all studies that have explored the usage of the ASD process in mobile apps.

Santos, Kroll, Sales, Fernandes and Wildt (2016) investigated the adoption of Agile methods during the process of mobile app development. They identified the challenges and reported the experiences of 20 undergraduate students when adopting mobile practices when developing mobile apps. The current study earlier noted five major challenges of mobile app development; by contrast, the authors identified eight advantages of using the Agile method that their participants benefited from when developing mobile apps.

Corral, Sillitti and Succi (2013b) examined the suitability of the Agile method to meet the needs of the mobile business environment. The authors discussed the actual use of the proposed frameworks that adopt Agile methods for the process of mobile app development. The study revealed that there is a need for evidence-based research to link the proposed frameworks to real project in the IT sector, as it showed a need for actual evidence-based research that declares which software development process is suitable. Similar to the above-mentioned study, Corral, Sillitti and Succi (2013a) presented a detailed review of the Agile-based frameworks currently used in mobile app development, and discussed their limitations.

Mahmud and Abdullah (2015) reviewed and discussed all studies that have adopted ASD methods for the mobile app development process. Below, I examine the most important studies.

5.2.1. Mobile-D approach and an improved Mobile-D approach

P. Abrahamsson et al. (2004) applied a new development process approach that is suitable for mobile app development. Certain challenges and constraints arise when applying the Agile SD process to mobile app development, due to the physical and technical characteristics of the mobile environment (Spataru, 2010; P. Abrahamsson et al., 2004). The Mobile-D approach is suitable for a small team of developers (10 developers or fewer) and a short-term development cycle (10 weeks or less). The approach adopts XP methodology, and is based on the Crystal methodology and Rational Unified Process (RUP). Spataru (2010) has provided an evaluation on using the Agile methods in the mobile app development process and proposed a set of improvements.

5.2.2. Hybrid method approach

Rahimian and Ramsin (2008) stated that, while Agile methods are the most appropriate means of mobile software development through the existing methods, some particular attributes of mobile devices require certain adjustments so that they match existing software development methodologies. This study revealed differences between the development of mobile apps and traditional software development in various aspects: mobile apps involve special requirements and constraints. Their study constructed a new methodology known as the Hybrid Methodology design approach. This is structured as a top-down iterative and incremental process. The framework consists of two major tasks: Prioritisation of the Requirements; and Iterative Design Engine. The framework combines ideas from the Adaptive Software Development to ensure more quality assurance processes and New Product Development (NPD).

5.2.3. Other studies

There are further software development methods proposed for mobile apps, such as Spiral process (Nosseir et al., 2012), based on a usability-driven model. This focuses on risk reduction and support iterations to ensure that the requirements are addressed and validated. Mobile app software development based on the Agile Methodology (MASAM) was adopted in a study proposed by Jeong, Lee, and Shin (2008), closely related to the Mobile-D approach. MASAM comprises four phases, namely development preparation, embodiment (representing the customer's intention), product development, and commercialisation. SLeSS, MASEF and DSDM are other methodologies that have adapted the Scrum, XP and Iteration concepts respectively; indeed, all use the Mobile-D approach as a reference (Mahmud & Abdullah, 2015).

5.3. Effort Estimation Factors in Agile Process

This section investigates studies on the effort estimation factors in the Agile process and presents those that have provided the most influential factors of effort estimation accuracy.

Lenarduzzi (2015) conducted semi-structured interviews to evaluate the considerable social influences on Agile effort estimation. Communication and work pressure are considered as highly important factors in effort estimation during the Agile process. In this study, the technique type used in the estimation process is not specified.

Table 14: Social factors of effort estimation in Agile process

Social factors	Social factors
Communication process	Experience of previous project
Language and culture difference	Technical ability
Work pressure	Working time
Team size	Managerial skills
Work Description	

Tanveer, Guzmán and Engel (2016) used case studies and 11 interviews of up to an hour in SAP, a German company. They assigned them to three Agile development teams to investigate and understand the estimation process in Agile SDP. This study considered the factors relevant to the accuracy of estimates. All three teams undertook their estimation in Scrum at the sprint-planning phase. Teams A and B undertook individual estimations (person/hour) and Team C undertook it by playing an estimation game (story point). The interviewees were asked about the factors that they considered during their estimation in open-ended questions, and some factors were presented for rating by their relevance to the process. The factors most influential to estimates' accuracy are shown in Table 15.

Table 15: Relevant factors in effort estimation and influence on estimation accuracy in Agile

Factor	Factor
Capacity (workload)	Dependencies among BLI
Backlog item complexity	Clarity of requirement
Developer implementation experience	Type of implementation
Developer estimation experience	Priority
developer knowledge of system components of backlog item	

Muhammad Usman, Britto, Damm and Börstler (2018) conducted a case study at Ericsson company to identify how effort estimation is carried out using the Agile process in a large-scale distributed project. This study analysed the accuracy of the estimations and investigated the factors impacting on their accuracy. The Expert Judgment method was the approach used to estimate the development effort. Related to this, another study used several estimation factors in a checklist at three companies and evaluated the results empirically (Muhammad Usman, Petersen, et al., 2018). The accuracy of the effort estimation improved in all three. The following factors are identified as potentially influencing the accuracy of effort estimation:

- Product customisation size: requirement of changes, design and implement the task.
- Customer priority.
- Maturity of the development team: team experience in coding and architecture, and experience in development of complex tasks.
- Multi-site development: Development team in several geographical locations.

5.4. Research Gaps

From the previous discussion and results, we have seen that various software estimation techniques have been applied to the development of mobile apps; however, there are gaps in the research and possible avenues for future work. As seen in Figure 10 in the red plot, the intersection between Agile SD, effort estimation and mobile app contains many omissions and future work opportunities that will be discussed:

1) A possible future study could examine the need to employ and validate existing effort estimation methods using Agile processes, such as Planning Poker, in mobile app development.
2) The relationship between effort estimation techniques in Agile SD and effort estimation in mobile app development.
3) There is a need to provide a comprehensive list of factors/predictors for mobile app developers to help them make accurate estimates.

4) One particular research gap calls for study on the relationship between the cost drivers and effort predictors of effort estimation in Agile SD models and the effort estimation in mobile app models.
5) Another possible future study could employ the prediction factors and cost drivers that have been used to estimate the effort involved in Agile methods during mobile app development.
6) Special attention must be paid to the relationship between the 'Agile software process in mobile apps' AND 'effort estimation in mobile app development'. This could be achieved by conducting:
    a. A study that investigates the newly-adapted Agile development process in mobile software development, such as Mobile-D, alongside existing effort estimation models for mobile apps.
7) Moreover, only one study has applied a cross-platform tool (Unity3D) to estimate the size of the software application (Abdullah et al., 2014); however, this tool is primarily designed for game development and is not suitable for industrial applications (Ottka, 2015). There is a need to conduct more studies on effort estimation for other cross-platform mobile apps.
8) For the native application development, a regression-based technique has been applied to estimate the effort needed to develop a mobile app; however, other estimation models to measure the effort estimation need to be put in place, using other estimation techniques, such as Planning Poker or Expert Judgment.
9) As observed from earlier studies, there are no estimation techniques for analysing, designing and testing the development of mobile apps.

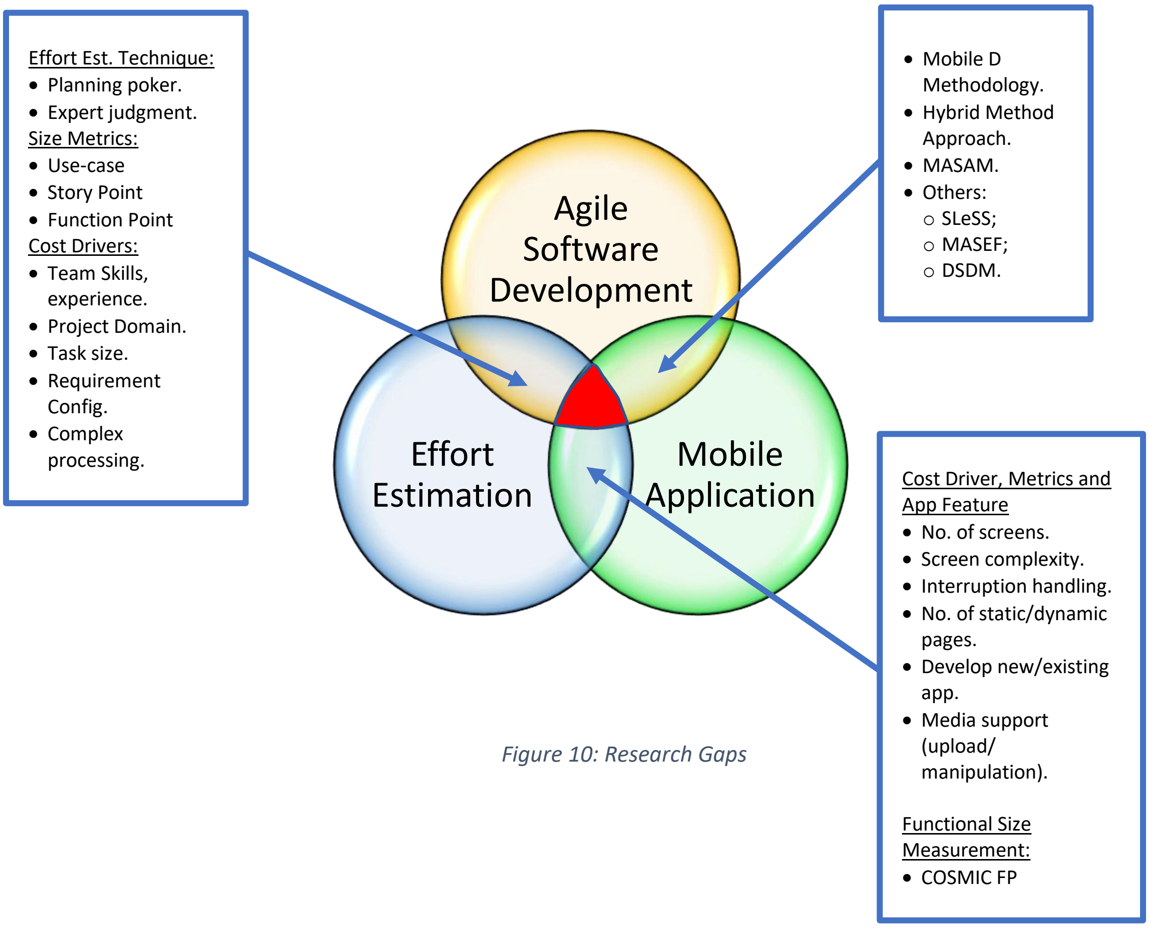


Figure 10: Research Gaps

5.5. Summary

This chapter presented a discussion of the SLR in Chapter 4. The first section discussed the effort estimation techniques used in developing mobile apps. It also discussed studies that covered the Agile process for mobile app development. The discussions revealed that no previous study has implemented, investigated or validated an effort estimation technique for developing mobile apps empirically, in the Agile context. Moreover, a few of the proposed Agile methods designed for mobile app development have not yet been examined and validated empirically, such as Mobile-D and MASAM. This chapter provided effort metrics and factors for the Agile process. Finally, this chapter stated some limitations and gaps in previous studies and indicated the possible directions of future work.

Chapter 6: Data Collection Preparation for the Interviews

In the previous chapter, the overall research methods, process and approaches to be applied in this research study were described. This chapter details the processes followed prior to the data collection survey. It consists of seven sections. Section 6.1 gives an overview of the interview technique used in this study. Section 6.2 explains how the interview questions were constructed, and what data were required for this study. Section 6.3 explains the approach taken for the interviews in this study. Section 6.4 discusses the suitability of the sample size for this research, and section 6.5 presents the details on the pilot test of the interview questions. Section 6.6 explains the ethical considerations for the interviews. Finally, section 6.7 presents the software tools to will be used in the analysis phase.

6.1. Understanding the Interview Technique

In this study, there are two parts to the method used: standardised (questionnaires) and non-standardised (semi-structured and in-depth interview) techniques. The former are designed to identify and describe the variables in organisational practice, whereas the latter (semi-structured and in-depth interviews) are to answer complex or open-ended questions that need further clarification and explanation.

The nature of the questions for the semi-structured interviews makes it suitable to use 'what' and 'how' questions, along with 'why' questions for further exploration. For the in-depth interviews, there is no predetermined list of questions; during the flow of the discussion with the interviewee (experts) they will simply be asked about the areas identified as needing to be explored. The questions for the non-standardised techniques are used to gather data that are normally analysed qualitatively (Saunders et al., 2009). There are two main types of questionnaires:

- Self-administered, which are usually completed by respondents via internet or mail.
- Interview-administered, which are recorded by the interviewer in a structured interview or via telephone.

Interview-administered questionnaires are a more reliable way to ensure that the required data have been collected from the desired respondents, and so this type is used in this study due to the nature of the questions.

6.2. Method Used to Build the Interview Questions

An interview usually offers just one chance to collect the data from respondents, and it is difficult to return to them to ask them for additional information. Therefore, it is necessary to understand of what kind of data that has to be collected. Moreover, it is important to be precise in designing the study's interview questions. They should be based on the research objectives and aim.

For questionnaires, there are three types of variables that can be collected (Dillman, 2000):

- Opinion variables, which rely on a respondent's feeling or beliefs.
- Behavioural variables, which represent what the experts or their organisation did, do or will do about a certain action.
- Attribute variables, which represent the respondent's characteristics.

To build the questionnaire, it was necessary to ensure that the data collection tool was suitable to answer the research questions and achieve the research objectives. To do so, a data requirement table was devised, as this is helpful to pose the correct and necessary questions to obtain the essential data needed for the study (Saunders et al., 2009).

Table 16: Data requirement table for the interviews

Investigative question	Variable required	Detail in which data measured
Research objectives: identify the effort estimation methods in Agile processes for mobile application development and discover the most appropriate approach. Explain and clarify how the estimation technique would be applicable for mobile apps using the Agile process. Moreover, investigate how the Agile process works with mobile app development.		
Type of research: exploratory across different industries that apply an effort estimation technique using an Agile process for mobile development. Also, it explores how organisations apply the estimation technique in the Agile process.		
The effort estimation techniques that have been used in mobile app development	Behavioural variable: What the expert usually does in their organisation to estimate the effort	List of estimation methods and techniques. Ex: Expert Judgment, expression based, etc.
From the previous literature review, several effort estimation factors have been discovered that need to be validated for suitability in mobile apps.	Behavioural variable: What the expert usually does in their organisation to estimate the effort.	Rank the importance level of effort estimation factors list. Ex: push notification, complexity of user story, etc.
Other estimation factors, not mentioned on the previous list, that could affect the estimation.	Behavioural and opinion variables	Any additional estimation factors that experts use or think will help in estimation.
Name and type of framework that has been used in mobile apps.	Behavioural variable	List of mobile app development frameworks. Ex: react-native, PhoneGap, Xamrine, etc.
Type of operating systems that mobile apps work on.	Behavioural variable	List of OS. Ex: IOS, Android, etc.
Accuracy level of the estimation technique.	Opinion and behavioural variable.	Multiple choice: overestimated or underestimated options.
What is the size of mobile app projects?	Opinion	Multiple Choices: small, medium, large
Type of software development process that the expert follows during project.	Behavioural	Choices of multiple SDLC: Agile, waterfall, etc.
The efficiency of the development process in mobile apps.	Opinion	Feeling, excellent, good, neutral, bad, too bad
Years of experience in mobile development.	Attribute	Allow practitioner to enter a number
Years of experience in the Agile process.	Attribute	Allow practitioner to enter a number
Job position, role and type of organisation	Attribute	Manager, programmer, tester, etc
Applicability of the Agile process in mobile app development	Behavioural and opinion	Experience results or feelings (good, neutral, not fit)
Checklist framework for Planning Poker or Expert Judgement technique	Opinion	Feeling what he thinks about this technique

After defining the interview requirements and the type of data to collect, it was possible to build the interview questions. In the Appendix C, Figure 81 gives the interview questions.

6.3. Interview Approach

Both structured and non-structured methods were used within each interview, which is termed mixed methods, to help to validate and verify participants' responses to the questions. The aim of the interview technique is to enable data to be obtained that answer the research questions. In an interview, there are several concerns that should be taken into account (Saunders et al., 2009):

1- Using appropriate language that the interviewee will feel comfortable with.
2- Considering the approach to asking a question, and letting the practitioner talk freely throughout the in-depth questions.
3- Listening carefully and patiently.
4- Testing and summarising the interviewee's understanding.
5- Recording the data in various forms:
    a. Written, for example: forms and checklists.
    b. Audio recorded.

6.4. Sample Size

It is impracticable or impossible to collect data from the entire population, due to the massive population and challenges such as budget and time constraints, data manageability and data accessibility. Thus, it is necessary to select a sample to represent the entire population. There are two main types of sampling: probability sampling and non-probability sampling.

The first technique is used when the sample is gathered in a process whereby all individuals have the same chance of being selected from the entire population. That means the population members are known and they have an equal chance of participating in the study. By contrast, the second technique does not give all the individuals an equal opportunity of being selected. Thus, not every member of the population has a chance to participate. Based on the study's aim, objectives and questions, the most appropriate sample selection technique is non-probability sampling.

A sample group of members are not selected randomly, but by the researcher's criteria. Non-probability or non-random sampling is an appropriate method when the total population in unknown. As it is not possible to conduct in-depth interviews and distribute questionnaires to the entire population, they are conducted with the sample accessible to the researcher, and this is termed convenience sampling.Since the technique used in this research is non-probability sampling, there are certain criteria to choose the practitioners.

They should satisfy the inclusion criteria to make sure that the data collected have been obtained from appropriate sources.

Practitioner criteria:

- The practitioner should have experience of effort estimation in software projects and Agile SDP.
- The practitioner should have practised or been involved in the Agile process on a software project.
- The practitioner could be a software developer, project manager, code tester, code reviewer, code quality assurance, software designer, software architect or have any role relevant to the software development process.

The issue of suitable sample size in non-probability sampling techniques is ambiguous, and there are no rules (Saunders et al., 2009). However, there are considerations of sample size that are dependent on the research questions, objectives, what needs to be discovered and what can be done with the available resources. Based on debates in the literature, it is recommended to continue collecting qualitative data until the point is reached where additional data provides few new insights, which is called data saturation (Dworkin, 2012). It is generally considered that the minimum sample size for interviews is between five and 25 people (Dudovskiy, 2018), while Guest, Bunce and Johnson (2006) offer guidance that 12 in-depth interviews should be sufficient.

6.5. Pilot Testing

Pilot testing of interview questions is a procedure to test the validity of the interview questions before using them in a study. It is necessary to reveal any weaknesses in the interview questions (Kothari, 2004). The aim is to make sure the questions are understandable to the experts and follow a good sequence. The test involved five participants, two of whom were PhD candidates in computer science and three were senior mobile developers in an IT company. The participants confirmed the suitability of the interview questions and their appropriateness.

6.6. Ethical Considerations

Dealing with human participants raises some ethical issues that need to be addressed. The interview questions were formulated to be respectful and appropriate for the participants. An information sheet and a consent form were given to all participants to sign before taking part in the interview to ensure that they were happy to participate and understood what was involved. To ensure the confidentiality of the participants and build trust between the researcher and the participants, they were assured that the stored data would not be linked to their names or their organisation’s name. The data will be stored on secure systems during the research study. Once the research is completed and the results from the data analysis achieved, the data will be destroyed by deleting all data files relating to the participants on laptops, desktops, emails and physical data through shredding paper documents and deleting electronic files, including audio recordings.

Ethical approval was obtained from the Ethics Committee team at the University of Southampton under reference number: 46055 on 19 December 2018. The application included multiple forms: the Data Protection Authorities form, which is responsible for protecting the personal data of the participants; the Participant Information Sheet; the Consent form; and a Risk Assessment form.

6.7. Analysis Tools

To avoid errors and time-consuming calculations, advanced software was used in this study. **IBM SPSS** software offered advanced statistical analysis of the data collected. Also, **Power-BI** software was used for data analysis to provide an interactive visualisation of the data collected and to make them readable and thus facilitate taking decisions quickly. In addition, **NVivo** was used in this research study for qualitative analyses to obtain thematic patterns from the semi-structure interviews. A template was created for the qualitative data analysis to present the codes and categories of the data that represent the themes revealed.

Chapter 7: Analysis and Discussion of the Interview Results

The previous chapter discussed the interview preparation and how to construct the survey. In this chapter, the analysis of the data collected from the survey method is presented. In a survey, there are two types of questions: standardised and non-standardised. This chapter contains three sections, and each will discuss an analysis technique, its process and the findings from its results. In the first section, section 7.1, the structured survey questions will be analysed quantitatively. Following this, in section 7.2, the semi-structured and in-depth interview questions will be analysed qualitatively. In section 7.3, a discussion of the overall analysis of the results and findings will be presented. At the end of this chapter, a proposed model of the estimation technique and discussion will be presented in section 7.4.

7.1. Quantitative Analysis

This section presents a quantitative analysis of the standardised interview questions. This section contains four sub-sections; in each, an interview question is first presented, followed by analysis of the responses. The first sub-section (7.1.1) shows the demographic information on the experts. The second sub-section (7.1.2) shows the types of mobile development platform that have been used by the experts. The third sub-section (7.1.3) describes the effort estimation techniques used by the experts, and the results of the analysis will be presented by using a Chi-square test and Fisher Exact test. In the fourth section (7.1.4), the results from the effort estimation factors will be presented, and then the relationship between the estimation factors and experts' job roles will be analysed using the one-way ANOVA test, the Mann-Whitney test and coefficient correlation. The Table 17 below provides a summary of the statistical tests used in the quantitative analysis.

Table 17: Statistical test used in quantitative analysis

Test Type	Usage	Section
Chi-square test	To see the relationship between the two categorical variables, estimation techniques and measurement types	7.1.3
Fisher's exact test	Designed for small of samples to assess the relationship between the estimation techniques and measurement type of the effort (story point or ideal hour)	7.1.3
Mann-Whitney U test	A Mann-Whitney test is used to compare two sample means of estimation factors and assess whether two groups of participants are different	7.1.4

Independent sample test	The independent sample test is used to compare the differences in the means of the estimation factors between two unrelated job role groups (Developers. QA and PM)	7.1.4
One-way ANOVA test	ANOVA tested whether three or more groups of participants are different in term of their opinion of the estimation factors	7.1.4
Correlation coefficient test	A coefficient correlation enables us to quantify and assess the strength of the linear relationship between each of the effort estimation factors	7.1.4

7.1.1. Experts' demographic information

During the interviews, several demographic questions were asked of the experts, as follows:

Questions	Answer
Work experience countries	
Years of work experience in general	
Current positions/role in your employment	
Previous positions/roles in your employment history	
Name/Nature of organisation you work with (Telecom/IT company/etc.)	

The experts answered all the questions, and details of the answers are presented in the following sections.

Work country and job role

Twenty experts were interviewed for this study, and 17 agreed to being audio recorded, whereas three refused and so notes were taken of their interviews. As shown in Table 18, all the experts had worked in Saudi Arabia, and three of them have also worked in the United States, two in Bahrain and one in India. Figure 11 presents the experts' countries of work experience along with the corresponding frequency. Most of the experts have had multiple roles. From the interviews, Software developer was the most common job role that was mentioned in response to the question on work history, by 12 experts, and that of project manager, quality assurance (QA), freelancer, sales and IT director by 5, 5, 4, 2 and 1 experts, respectively. Figure 13 shows the experts' job roles by their work location.

Table 18: Experts' work experience countries

		Statistic result		Per cent of
		N	Per cent	Cases
Country	Saudi Arabia	20	76.9	100.0
	United States	3	11.5	15.0
	Bahrain	2	7.7	10.0
	India	1	3.8	5.0
Total		26	100.0	130.0

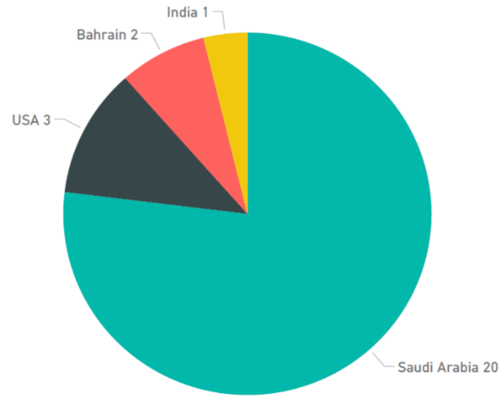


Figure 11: Experts' work country

Table 19: Experts' job roles

		Responses		Per cent of
		N	Per cent	cases
Job Role	Software developer	12	37.5	60.0
	Project manager	5	15.6	25.0
	QA (tester)	5	15.6	25.0
	Freelancer	4	12.5	20.0
	Team leader	3	9.4	15.0
	Sales	2	6.3	10.0
	IT director	1	3.1	5.0
Total		32	100.0	160.0

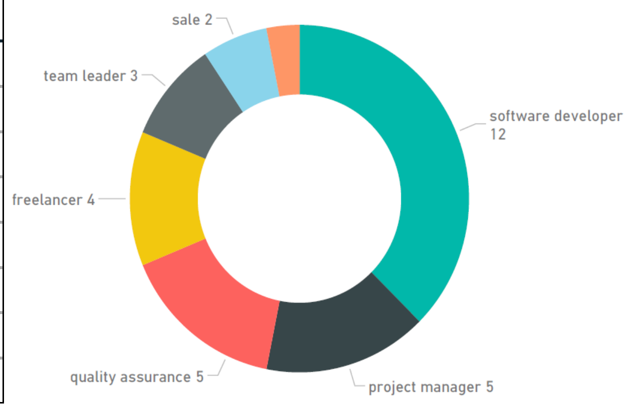


Figure 12: Experts' job roles

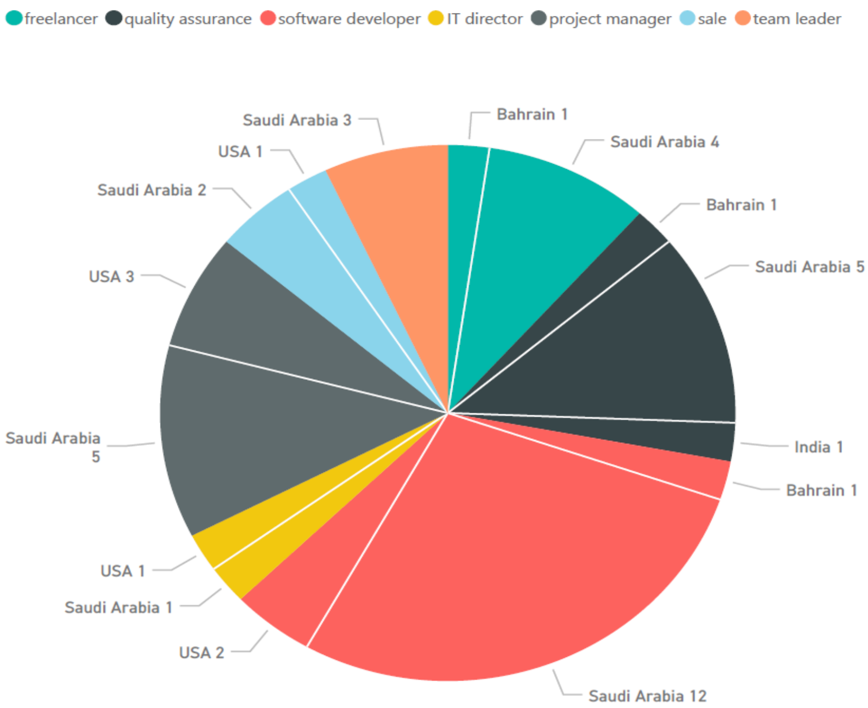


Figure 13: Job roles of the experts by work country

Main job role of the experts

As observed in the responses by the experts, most of them have worked in multiple job roles; however, it is necessary to categorise the experts by assigning them one main job role. The reason is that some statistical analysis is required, and it will ensure there is no interception or overlap between the groups of experts, so each group should be distinct. Therefore, a one-job role has been assigned to each expert, based on their current job. In Figure 14 below, the main job roles of the experts are shown. More detail on the experts' information can be found in Table 66: Expert's information in the Appendix C.

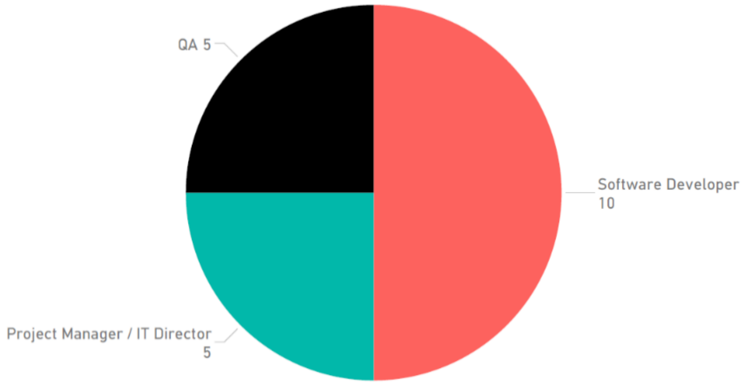


Figure 14: Main job roles of the experts

Years of work experience

The work experience of the all experts ranged from two to nine years. The mean figure for the experts is 5.70 years, and the standard deviation of the years of experience is 1.867. As can be seen in Table 20, most of the software developers' experience ranges from four to six years. Only one IT director took part, and he had worked for roughly four years.

Table 20: Work experience in years

			Years of work experience						
			2 years	4 years	5 years	6 years	7 years	9 years	Total
Job Role	Project manager	Count	0	2	0	1	1	1	5
	Software developer	Count	1	3	2	4	0	2	12
	QA	Count	0	1	1	2	1	0	5
	Freelancer	Count	0	1	1	1	0	1	4
	Team leader	Count	0	0	1	0	1	1	3
	Sales	Count	0	1	0	0	0	1	2
	IT director	Count	0	1	0	0	0	0	1
Total		Count	1	5	3	6	2	3	20

Experts' company type

The experts have worked in 18 organisations, as can be seen in Table 21, which is categorised into seven groups: Telecommunication companies, IT solutions companies, Banking, University, Social and insurance companies, Consultation companies and Government. The majority have worked in IT solutions companies, meaning that seven groups represent 40% of all company types. The details on the companies' information can be found in Table 68 in the Appendix C.

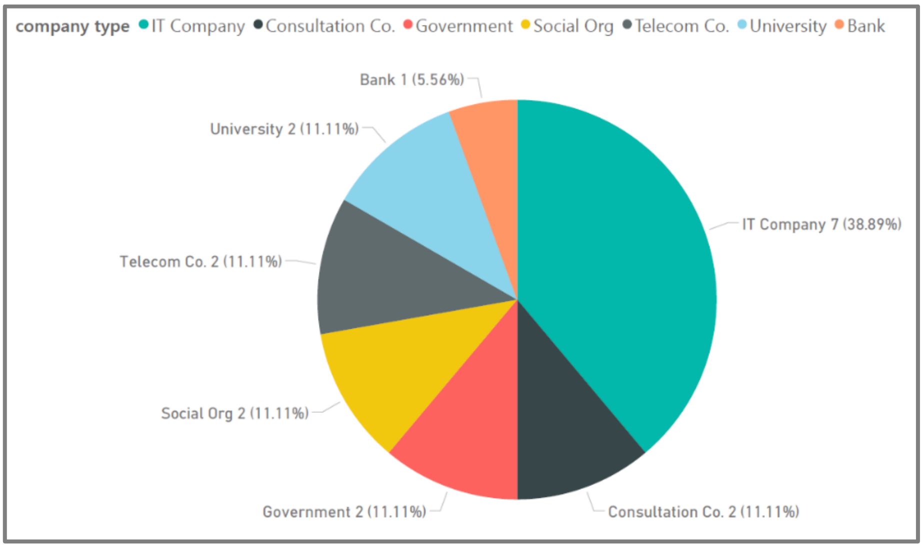


Figure 15: Overview of the company categories

Table 21: Summary of the company types

		No. of company	Per cent %	Cumulative per cent
Category	IT co.	7	38.9	38.9
	Telecom co.	2	11.1	50.0
	Bank	1	5.6	55.6
	Government	2	11.1	66.7
	University	2	11.1	77.8
	Consultation co.	2	11.1	88.9
	Social org	2	11.1	100.0
	Total	18	100.0	

7.1.2. Mobile platform usage

There are three types of mobile app platforms: native, hybrid and mobile web. A native app is developed for a specific platform that uses native APIs. A hybrid app is developed by web technologies, such as HTML, and wrapped in a native container, whereas a mobile web app is developed by web technologies and used in a web browser. There are further details about the mobile platform types in Chapter 2.

In the interview, two questions were put to all the experts regarding the type and name of mobile app platforms and frameworks:

Questions	Answer
Which of the following platform types are used during mobile app development? (native, web-based or hybrid)	
Which of the following frameworks are used during your mobile app development? (Ionic, Android Studio, Swift, etc.)	

As seen in Table 22 and Figure 16, most experts have used a hybrid platform in development, whereas mobile web is less used. Since most usage of platform types is hybrid, the Ionic is the most commonly used framework for developing mobile apps, used by around half of the experts, as shown in Table 23 and Figure 17. Android Studio framework is preferred by the experts for developing native mobile apps. The experts who liked to use a hybrid platform more than native apps claimed that this was to avoid developing two apps for two different platforms.

Since several experts were surveyed, with multiple positions and roles during their work experience, Table 24 shows the distribution of the experts and their preferences for the various mobile frameworks. Android Studio and Ionic frameworks lead the mobile app frameworks.

Table 22: Platform types used by the experts

		Responses		Per cent of Cases
		N	Per cent	
Platform Type	hybrid	12	50.0	60.0
	native	10	41.7	50.0
	web	2	8.3	10.0
Total		24	100.0	120.0

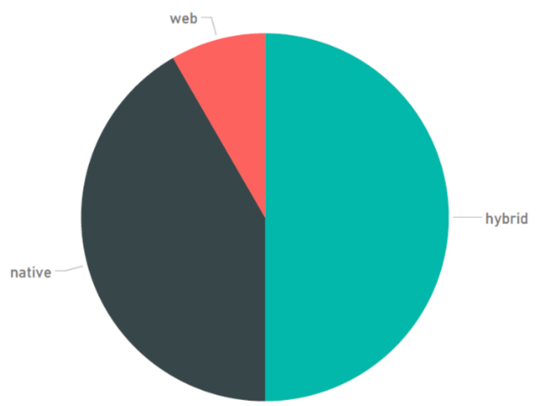


Figure 16: Platform type overview

Table 23: Specific platforms used by the experts

		Responses No.	Responses Per cent	Per cent of Cases
Platform name	Ionic	10	38.5	50.0
	Android studio	7	26.9	35.0
	Swift	5	19.2	25.0
	React-native	2	7.7	10.0
	Html5	2	7.7	10.0
Total		26	100.0	130.0

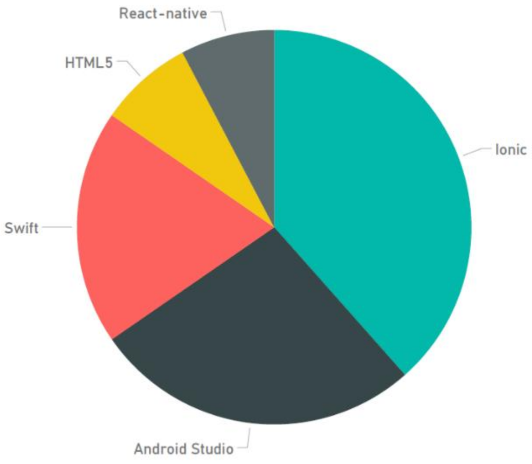


Figure 17: Specific platform overview

Table 24: Experts' use of mobile development frameworks

			Platform name Ionic	Swift	Android studio	React-native	HTML5
Job Role	Project manager	Count	3	1	1	0	1
	Software developer	Count	7	2	5	1	1
	QA	Count	2	2	1	1	0
	Freelancer	Count	3	1	3	0	0
	Team leader	Count	1	1	2	0	0
	Sales	Count	1	1	2	0	0
	IT director	Count	1	0	0	0	0

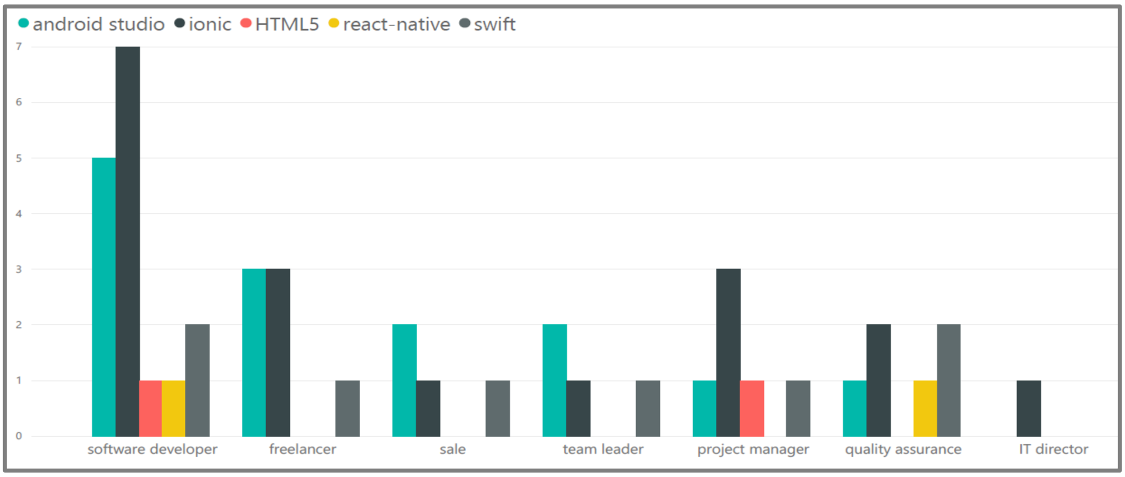


Figure 18: Mobile development frameworks by the experts' job roles

7.1.3. Effort estimation techniques

During the interview, a question was put to all 20 experts regarding the effort estimation method for a mobile app development project:

Table 25: Effort estimation technique question

Question: *Which of the following effort estimation methods/techniques are used in your organisation in terms of estimating the effort?*	
Estimation method	Select
Planning Poker	☐
Expert judgement	☐
COCOMO	☐
Delphi	☐
Analogy	☐
Use-case point method UCP	☐
Regression-based	☐
Other …………………….	

The respondents could select multiple estimation techniques, and there was an empty field for any further techniques that had been used yet were not one of the options.

As a result, it was found there are only three effort estimation techniques, Expert Judgment (EJ), Planning Poker (PP) and COCOMO II, used by these experts in the Agile process for developing mobile apps. More than half the experts had used the EJ technique to estimate effort, and about 40% had used PP, as shown in Table 26 and Figure 20. Only one had used COCOMO to estimate effort, as shown in Table 42 in section 7.3, and this expert worked as a project manager and had used it to obtain an idea of the effort required before a project started; this case will be discussed in more detail in the results and discussion section later in this chapter. From Table 26, it can be observed that the *percentage of cases* columns is higher than the *percentage of responses* columns, which means that four of the experts used multiple estimation techniques (see Table 69: Experts' estimation technique in detail, in the Appendix C).

Table 26: Estimation techniques used by the experts

		Responses		Per cent of Cases
		N	Per cent	
Estimation Technique	Expert Judgement	15	57.7	75.0
	Planning Poker	10	38.5	50.0
	COCOMO II	1	3.8	5.0
Total		26	100.0	130.0

Table 27: Measurement type for the estimation technique

		Measurement type		Total
		Ideal hour (IH)	Story point (SP)	
Estimation technique	Planning Poker	0	10	10
	Expert Judgement	8	2	10
	COCOMO	0	1	1
Total by cases		8	13	21

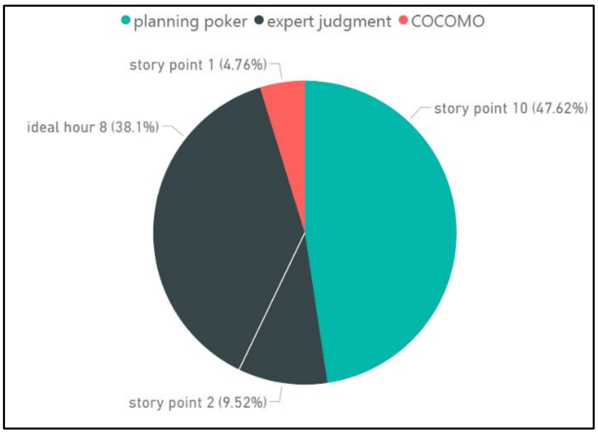


Figure 19: Overview of the measurement types for the estimation techniques

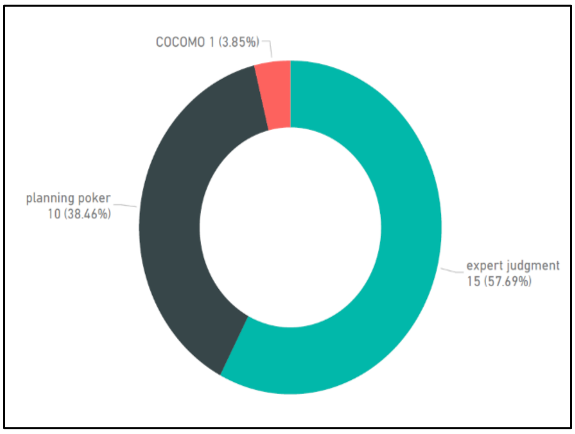


Figure 20: Estimation techniques overview

It can be seen from Table 27 that, regarding measurement type, the experts who use the EJ technique usually prefer to gauge the effort of the user story in ideal hours (IH). By contrast, all those who tend to use the PP technique prefer to use story point (SP). There is only one instance of using COCOMO, and the expert had used SP as the input for this method.

Chi-square test

To see the relationship between the two categorical variables, estimation techniques and measurement types, the Chi-square test (x^2) was used. This made it possible to establish the extent to which the two variables in different groups are associated. In this case, the test was to compare the distribution of the estimation techniques, PP and EJ, to the distribution of the measurement types, IH and SP. If the distribution shows no difference between the groups, then it can be concluded that the categorical variable and group are independent.

The Chi-square test equation was performed as: $x^2 = \sum \frac{(O-E)^2}{E}$ where O is the observed variable, and E is the expected frequency. In Table 27, the observed values are the frequency of the experts who were using a specific estimation technique for a specific measurement type, as shown in Table 28. However, the expected value is that all groups in the measurement types of IH and SP have equal frequency. For example, there were eight experts in the IH group, using IH as the measurement type, so the expected value for SP is four and for EJ is four, as shown in Table 28. The Degree of Freedom (df) is the number of observations that are free to vary when computing a statistic (Field, Miles & Field, 2018).

As shown in Table 29, the p-value or relationship significance value is an indicator of how likely it is that the result occurred by chance alone. A probability of 0.05 shows that there is a 5% chance of the data occurring in this way; and if the p-value is less than 0.05 ($P<0.05$), this means that we can be at least 95% sure that the relationship between the data did not occur by chance, thus there is a significant relationship statistically (Field et al., 2018; Saunders et al., 2009). The p-value, shown in the Table 29, is 0.0001, which is less than the significance level ($\alpha = 0.05$). Therefore, there is a significant association between the estimation techniques and the measurement types. The results' findings will be returned to in section 0.

Table 28: Relationship between the estimation techniques with the effort measurement type

			Measurement type		
			Ideal hour	Story point	Total
Estimation technique	Planning Poker	Observed	0	10	10
		Expected	4.0	6.0	10.0
	Expert Judgement	Observed	8	2	10
		Expected	4.0	6.0	10.0
Total		Observed Count	8	12	20
		Expected Count	8.0	12.0	20.0

Fisher's exact test

The Chi-square test relies on an approximate distribution, thus is not good for a small number of samples. As can be seen in Table 29, a note for Chi-square testing states that there are two expected frequencies of less than 5 in Table 28. Therefore, Fisher's Exact test is appropriate to cater for this small sample size number and compute the exact probability. The p-value of Fisher's test is 0.001 ($p<0.05$), and it can be said that there is a statistically significant relationship between the two groups' variables. The ribbon chart used in Figure 21 can be referred to quickly discover which variable has high usage in each category. The results will be discussed later in section 7.3: Analysis Summary and Discussion.

Table 29: Chi-square and Fisher's-exact tests

	Value	df	Significance (2-sided)	Exact Sig. (2-sided)
Pearson Chi-square	13.333[a]	1	.0001	
Fisher's Exact Test				.001
No. of Valid Cases	20			
Note: (a) 2 cells (50.0%) have expected count less than 5. The minimum expected count is 4.00.				

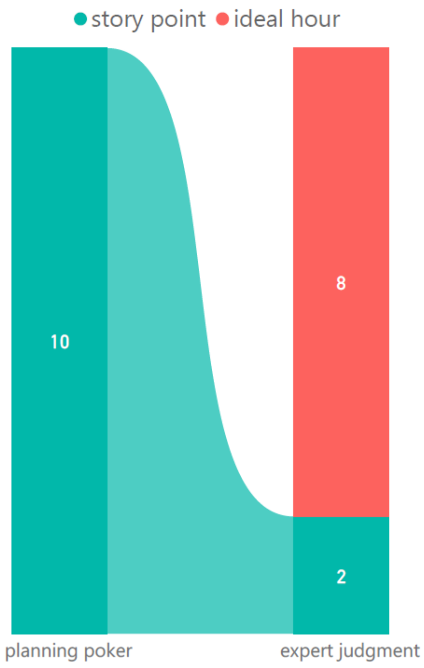


Figure 21 Ribbon chart: association between the estimation technique and effort measurement type

7.1.4. Effort estimation factors

From the Systematic Literature Review (SLR), 48 factors were obtained from previous studies on effort estimation using the Agile process. These can be categorised into three groups, as shown in Figure 22, on the basis of the aims and objectives of the studies examined in the SLR:

1) Mobile factors: these are related to developing mobile apps, and there are three sub-groups:
    a. Functional factors: a factor that is used in the early stages of the development process to estimate the effort of a software.
    b. Non-functional factors: a factor that can be used prior and during the development process to help to obtain a more accurate estimate.
    c. Platform factors: a factor related to the mobile environment.
2) Agile factors: a factor that could effect improvements to the accuracy of the estimation during the Agile process, and the factors that are considered by the team members during the estimation.
3) Project factors: factors related to the overall project.

The experts were asked to rate the importance of each of the 48 effort estimation factors. The responses were on a five-point Likert-style rating scale in which the respondent is asked how strongly they agree or disagree. The scale is denoted as follows:

5	4	3	2	1
very important factor	Important factor	neutral	Not important factor	strongly not important

All 20 experts answered this question and assigned a specific rank to each factor. The following sections analyse the results for the estimation factors on the basis of frequency, mean and relationship.

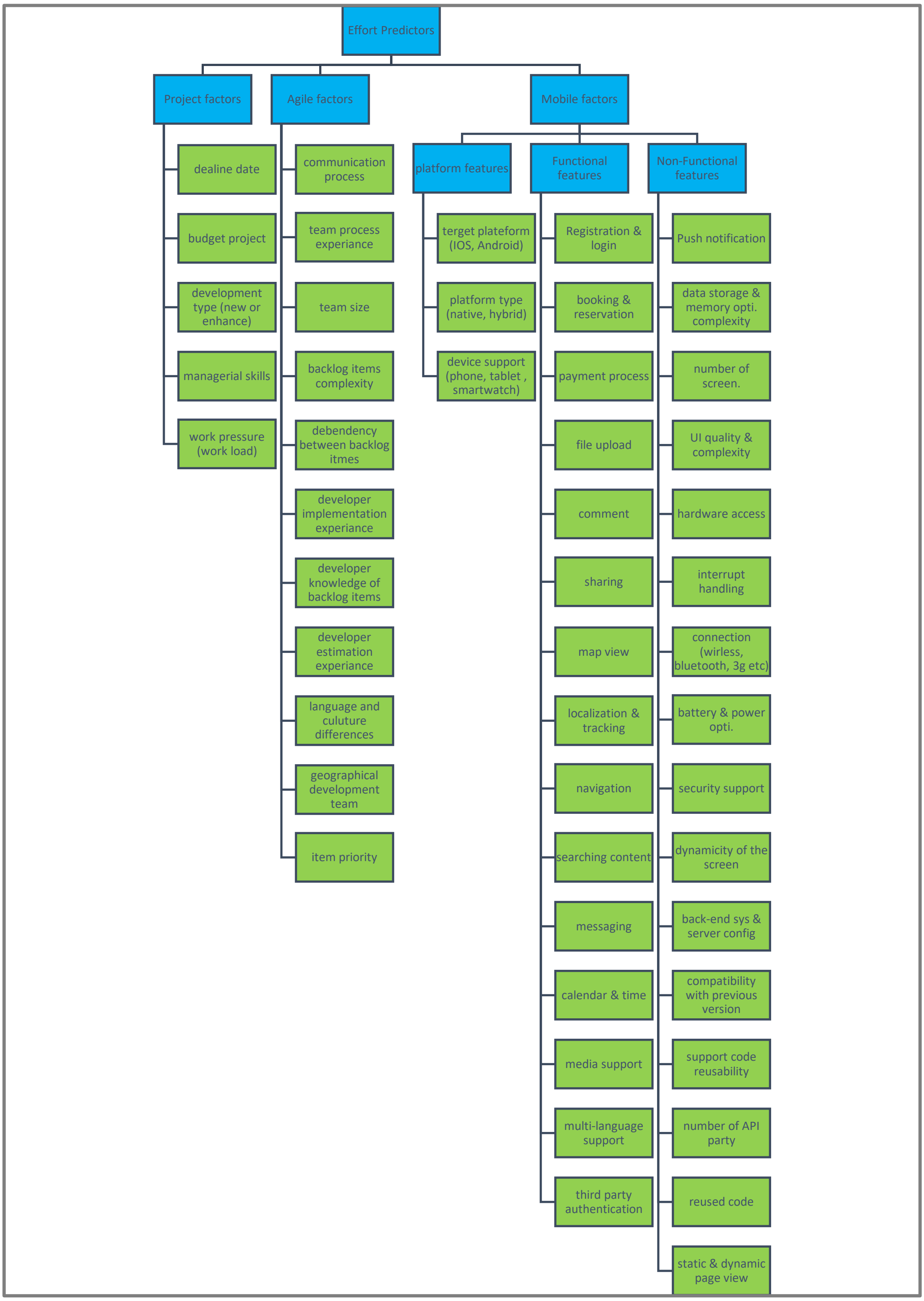


Figure 22: Overview of effort estimation factors

Descriptive statistics

Table 30 summarises the results for the importance of effort estimation, alongside the mean, median and standard deviation. Each group of factors is ordered by its mean. The mean value shows the average of the experts' answers, and the median shows the middle values. Full details of each factor's description are in the Appendix C, in Table 71.

Table 30: Experts' responses to level of importance of effort estimation factors

Estimation factor	No.	Missing	Mean	Median	Std. Deviation	Minimum	Maximum
Functional feature factors							
Payment process	20	0	4.55	5	0.686	3	5
Localisation & tracking	20	0	4.3	4.5	0.801	3	5
Registration & login	20	0	4.2	4	1.005	1	5
Map view	20	0	4.1	4.5	1.21	1	5
Messaging	20	0	4.1	4	0.912	1	5
Multi-language support	20	0	4.05	4	1.191	1	5
Third-party authentication	20	0	4	4	0.973	2	5
Booking and reservation	20	0	3.75	4	0.851	2	5
File upload	20	0	3.75	4	0.91	2	5
Media support	20	0	3.75	4	1.07	2	5
Searching contents	20	0	3.4	3	0.995	2	5
Comment feature	20	0	3.1	3.5	1.165	1	5
Navigation	20	0	2.8	3	1.322	1	5
Sharing	20	0	1.85	1.5	1.04	1	4
Calendar and time	20	0	1.55	1	0.999	1	5
Non-functional feature factors							
User Interface quality and complexity	20	0	4.7	5	0.571	3	5
Number of screens	20	0	4.35	4.5	0.745	3	5
Backend system availability and server config. flexibility	20	0	4.3	4	0.733	3	5
Security support	20	0	4.2	4	1.005	1	5
Number of API party	20	0	4.05	4	0.826	2	5
Support code reusability	20	0	3.85	4	1.137	1	5
Dynamicity of screen	20	0	3.7	4	1.081	1	5
Push Notification	20	0	3.45	3.5	1.146	1	5

Estimation factor	No.	Missing	Mean	Median	Std. Deviation	Minimum	Maximum
Compatibility with Previous Version	20	0	3.4	3.5	0.995	1	5
Hardware access	20	0	3.3	3	1.261	1	5
Data storage and memory opt. complexity.	20	0	3.25	3	1.118	1	5
Battery & power optimisation	20	0	2.9	3	1.21	1	5
Connection (wireless, Bluetooth, 3G, etc.)	20	0	2.55	2.5	1.146	1	5
Interrupt handling	20	0	2.5	2.5	1.192	1	5
Platform factors							
Supported platform type (IOS/Android./Win./etc.)	20	0	4.85	5	0.366	4	5
Platform type (native, hybrid)	20	0	4.85	5	0.489	3	5
Supported device (phone, tablet, smartwatch)	20	0	4.25	5	0.967	2	5
Agile factors							
Communication process	20	0	4.6	5	0.598	3	5
Backlog items complexity	20	0	4.6	5	0.681	3	5
Developer implementation experience	20	0	4.55	5	0.686	3	5
Developer knowledge of backlog item	20	0	4.4	5	0.883	2	5
Developer estimation experience	20	0	4.4	5	0.821	2	5
Team process experience	20	0	4.3	4.5	0.801	3	5
Dependency between backlog items	20	0	4.15	4	1.182	1	5
Team size	20	0	4.05	4	0.826	2	5
Geographical of the development team	20	0	3.8	4	1.24	1	5
Language and culture differences	20	0	2.9	3	1.119	1	5
Project factors							
Deadline date	20	0	4.4	5	0.821	2	5
Development type (new or enhanced app)	20	0	4.25	5	1.02	2	5
Work pressure (workload)	20	0	4.2	4.5	1.005	2	5
Item priority	20	0	3.85	4.5	1.309	2	5
Managerial skills	20	0	3.6	4	0.995	2	5
Budget for the project	20	0	2.8	2	1.281	1	5

Table 31: Importance level of the effort estimation factors by experts' job role

Job role	Software developer				Project manager / IT director				QA team			
	Mean	Median	N	Std. deviation	Mean	Median	N	Std. deviation	Mean	Median	N	Std. Deviation
Functional feature factor												
Payment process	4.5	5	10	0.85	4.6	5	5	0.548	4.6	5	5	0.548
Localisation & tracking	4.4	5	10	0.843	4.2	4	5	0.837	4.2	4	5	0.837
Registration & login	4.4	4.5	10	0.699	3.6	4	5	1.673	4.4	4	5	0.548
Messaging	4.2	4	10	0.632	4.4	4	5	0.548	3.6	4	5	1.517
Map view	4.1	5	10	1.449	4.4	4	5	0.548	3.8	4	5	1.304
File upload	3.9	4	10	0.876	4.2	4	5	0.837	3	3	5	0.707
Media support	3.8	4	10	1.033	3.8	4	5	1.304	3.6	4	5	1.14
Booking and reservation	3.8	4	10	0.789	3.6	4	5	1.14	3.8	4	5	0.837
Third-party authentication	3.7	4	10	0.949	4.6	5	5	0.548	4	4	5	1.225
Multi-languages support	3.7	4	10	1.494	4.2	4	5	0.837	4.6	5	5	0.548
Searching contents	3.4	3	10	0.699	4.2	5	5	1.095	2.6	2	5	0.894
Comment feature	3.1	3.5	10	1.101	3.6	4	5	1.14	2.6	2	5	1.342
Navigation	2.9	3	10	1.287	3	3	5	1.581	2.4	3	5	1.342
Sharing	2.1	2	10	0.994	2.2	2	5	1.304	1	1	5	0
Calendar and time	1.8	1.5	10	1.229	1.6	1	5	0.894	1	1	5	0
Non-functional feature factors												
User Interface quality and complexity	4.8	5	10	0.422	5	5	5	0	4.2	4	5	0.837
Security support	4.6	5	10	0.699	4.2	4	5	0.837	3.4	4	5	1.342
Backend system availability and server config. flexibility	4.5	5	10	0.707	3.8	4	5	0.837	4.4	4	5	0.548
Support code reusability	4.4	4.5	10	0.699	3.8	3	5	1.095	2.8	3	5	1.304

Job role	Software developer				Project manager / IT director				QA team			
	Mean	Median	N	Std. deviation	Mean	Median	N	Std. deviation	Mean	Median	N	Std. Deviation
Number of screens	4.1	4	10	0.876	4.6	5	5	0.548	4.6	5	5	0.548
Number of API party	4.1	4	10	0.738	4	4	5	0.707	4	4	5	1.225
Dynamicity of screen	3.9	4	10	1.197	3.4	4	5	1.342	3.6	4	5	0.548
Hardware access	3.8	4	10	1.229	3.4	3	5	0.548	2.2	2	5	1.304
Data storage and memory opt. complexity	3.8	4	10	0.919	3.4	3	5	0.548	2	2	5	1
Compatibility with previous version	3.7	4	10	0.823	3	3	5	0	3.2	4	5	1.643
Push notification	3.6	4	10	1.265	4	4	5	1	2.6	3	5	0.548
Battery & power optimisation	3.3	3.5	10	1.337	3.2	3	5	0.447	1.8	2	5	0.837
Interrupt handling	3.1	3	10	0.994	1.8	1	5	1.304	2	2	5	1
Connection (wireless, Bluetooth, 3G, etc.)	2.4	2	10	0.843	2.6	3	5	1.14	2.8	3	5	1.789
Platform factors												
Supported platform type (IOS/Android./Win./etc.)	4.9	5	10	0.316	4.8	5	5	0.447	4.8	5	5	0.447
Platform (native, hybrid)	4.8	5	10	0.632	4.8	5	5	0.447	5	5	5	0
Supported device (phone, tablet, smartwatch)	4.4	5	10	0.843	3.8	4	5	0.837	4.4	5	5	1.342
Agile factors												
Communication process	4.7	5	10	0.483	4.4	4	5	0.548	4.6	5	5	0.894
Developer implementation experience	4.5	5	10	0.85	4.4	4	5	0.548	4.8	5	5	0.447
Backlog items complexity	4.4	5	10	0.843	4.8	5	5	0.447	4.8	5	5	0.447
Developer knowledge of backlog item	4.4	5	10	0.843	4.4	4	5	0.548	4.4	5	5	1.342
Team process experience	4.4	5	10	0.843	4.2	4	5	0.837	4.2	4	5	0.837
Developer estimation experience	4.3	5	10	1.059	4.6	5	5	0.548	4.4	4	5	0.548

Job role	Software developer				Project manager / IT director				QA team			
	Mean	Median	N	Std. deviation	Mean	Median	N	Std. deviation	Mean	Median	N	Std. Deviation
Team size	3.9	4	10	0.738	4.6	5	5	0.548	3.8	4	5	1.095
Dependency between backlog items	3.9	4.5	10	1.595	4.4	4	5	0.548	4.4	4	5	0.548
Item priority	3.7	4.5	10	1.494	3.8	4	5	1.304	4.2	5	5	1.095
Geographical of the development team	3.6	4	10	1.265	4	4	5	1.225	4	5	5	1.414
Language and culture differences	3	3	10	1.155	2.6	3	5	1.14	3	3	5	1.225
Project factors												
Development type (New or enhanced app)	4.5	5	10	0.707	3.8	4	5	1.304	4.2	5	5	1.304
Deadline date	4.4	5	10	0.966	4.6	5	5	0.548	4.2	4	5	0.837
Work pressure (workload)	4.3	4.5	10	0.823	3.6	4	5	1.517	4.6	5	5	0.548
Managerial skills	3.5	3.5	10	1.08	3.8	4	5	0.837	3.6	4	5	1.14
Budget for the project	3.4	3	10	1.43	2.4	2	5	0.894	2	2	5	0.707

Mann-Whitney U test and independent sample test (T-test)

The independent sample test is usually used to compare the differences in the means of the estimation factors between two unrelated job role groups. The results from the t-test have been used to determine statistically whether there is a significant difference between the estimation factors' means between the experts' job roles. However, many aspects have reduced the power independent sample test (t-test) and affected its efficiency (Field et al., 2018). First, the experts' responses for effort estimation factors are based on ranking (ordinal), and the second reason is that some factors are not normally distributed, as shown in Table 72: Normality test for the estimation factors in the Appendix C, and below in Figure 24 and Figure 23. The third reason is that the sample size for the data collected is small. Therefore, the non-parametric Mann-Whitney test has been used, which is equivalent to the independent sample test used to compare the difference between two independent groups.

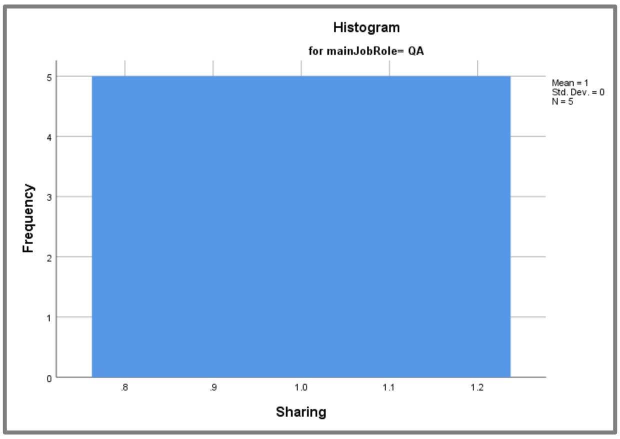


Figure 24: Example of normal distribution for Sharing factor for QA

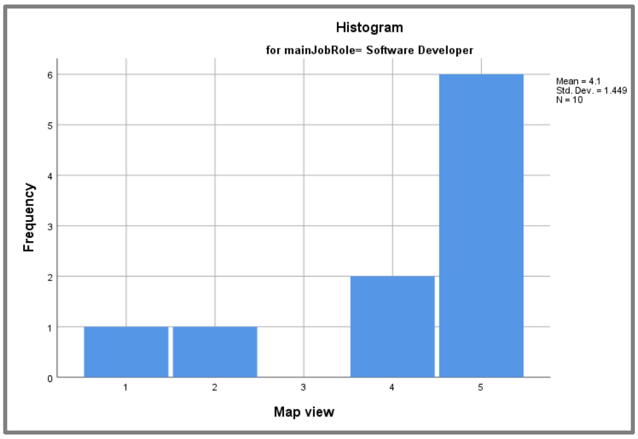


Figure 23: Example of normal distribution for the Map view factor for software developers

A Mann-Whitney test is basically to compare two sample means and assess whether two groups are different, and it is works by assigning a ranking to each respondent value (5-1) for each factor. The lowest rank is given the lowest value. There are 48 effort estimation factors and three expert groups (Software developer, QA and Project manager), so the following cases were evaluated:

- Whether there are any differences in the effort estimation factors between the software developers and project managers.
- Whether there are any differences in the effort estimation factors between the software developers and QAs.
- Whether there are any differences in the effort estimation factors between the project managers and QAs.

Table 32 shows that there are 13 significant differences (p-value<0.05) observed between the experts' job roles and their beliefs about the estimation factors. The experts' opinions on the importance level for the Sharing factor are different in the software developers and in the QA team. As shown in Table 31, the developers and project managers' mean values for the Data storage & memory opt factor are 3.8 and 3.4 respectively, which represents 'important to neutral'; however, the QA teams' mean and median values is 2, which represents 'less important'. Moreover, the experts' opinions on the Sharing factor show a significant difference (p-value=0.01<0.05) between the developers and the QA team, and between the project managers and the QA team, as shown in Table 32.

Table 32: Mann-Whitney test for the effort estimation factors

Main job role	Developers vs Managers		Developers vs QAs		Managers vs QAs	
	Mann-Whitney	Sig. (2-tailed)	Mann-Whitney	Sig. (2-tailed)	Mann-Whitney	Sig. (2-tailed)
Sharing	24.5	0.949	7.5	0.019	5	0.050
Registration & login	18.5	0.391	24.000	0.891	9.500	0.504
Payment process	24.5	0.942	24.5	0.942	12.5	1
Booking and reservation	23	0.796	25	1	11.5	0.827
File upload	20	0.517	11.5	0.077	3.5	0.049
Comment feature	19	0.435	19.5	0.472	7	0.23
Navigation	24	0.900	20	0.521	9.5	0.519
Map view	23	0.786	20.5	0.548	9.5	0.504
Localisation & tracking	21	0.590	21	0.59	12.5	1
Searching contents	14.5	0.142	11.5	0.071	3	0.039
Messaging	21	0.572	20.5	0.529	8.5	0.339
Calendar and time	23.5	0.839	12.5	0.065	7.5	0.136
Multi-languages support	22	0.692	15.5	0.203	9	0.419
Media support	24.5	0.949	22.5	0.75	11	0.746
Third-party authentication	11	0.070	19.5	0.48	9	0.419
Number of screens	17	0.290	17	0.29	12.5	1
Push notification	21.5	0.654	10.5	0.067	3	0.033
User Interface quality and complexity	20	0.299	14	0.104	5	0.053
Number of API party	23	0.787	24	0.895	11	0.735
Support code reusability	16.5	0.263	6.5	0.017	7.5	0.278
Data storage and memory opt. complexity	17	0.291	4.5	0.01	3	0.033
Interrupt handling	9.5	0.051	11.5	0.084	10.5	0.654
Hardware access	19	0.445	9	0.045	5.5	0.125
Battery & power optimisation	22.5	0.749	9	0.045	2	0.018
Connection (wireless, Bluetooth,3G, etc.)	21.5	0.651	22	0.704	11.5	0.83
Compatibility with previous version	10	0.045	22	0.689	10	0.576
Security support	17.5	0.294	8	0.023	8	0.288
Dynamicity of screen	18.5	0.366	16.5	0.255	11	0.699
Backend system availability and server config. flexibility	13	0.112	21.5	0.629	7	0.212

Main job role	Developers vs Managers		Developers vs QAs		Managers vs QAs	
	Mann-Whitney	Sig. (2-tailed)	Mann-Whitney	Sig. (2-tailed)	Mann-Whitney	Sig. (2-tailed)
Supported platform type (IOS/Android./Win./etc.)	22.5	0.604	22.5	0.604	12.5	1
Supported device (phone, tablet, smartwatch)	15	0.188	22	0.661	7	0.217
Platform type (native, hybrid)	23	0.679	22.5	0.48	10	0.317
Communication process	17.5	0.280	24	0.874	9	0.403
Team process experience	21	0.590	21	0.59	12.5	1
Team size	12	0.085	24.5	0.947	6.5	0.166
Backlog items complexity	19	0.379	19	0.379	12.5	1
Dependency between backlog items	24.5	0.947	24.5	0.947	12.5	1
Developer implementation experience	20.5	0.529	21.5	0.581	7.5	0.221
Developer knowledge of backlog item	23	0.786	22	0.661	9	0.403
Developer estimation experience	23	0.780	23	0.786	10	0.549
Language and culture differences	20.5	0.566	23.5	0.848	11	0.743
Geographical of the development team	19.5	0.473	19	0.445	11.5	0.822
Item priority	24.5	0.947	19.5	0.46	10	0.572
Deadline date	24	0.888	20	0.497	9	0.419
Budget for the project	14	0.139	11	0.067	10	0.521
Development type (new or enhanced app)	17	0.282	23.5	0.834	10	0.575
Managerial skills	21	0.609	23.5	0.849	11.5	0.827
Work pressure (workload)	18.5	0.396	20.5	0.541	8	0.307

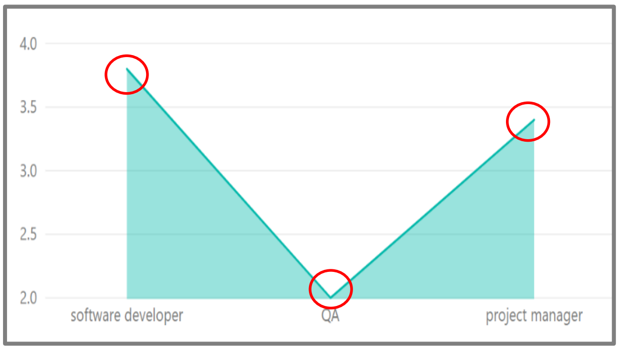


Figure 26: Mean differences values between experts for Date Storage factors as shown in the Mann Whitney test

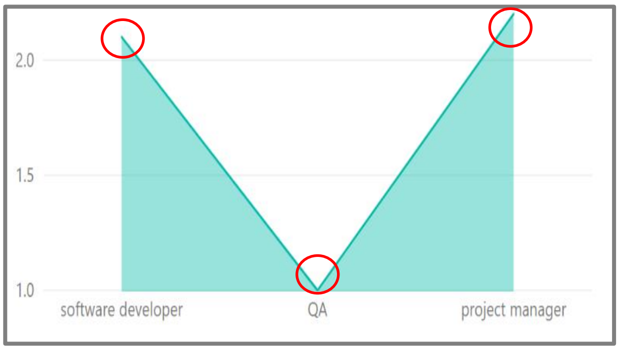


Figure 25: Mean differences values between experts for Sharing factors as shown in the Mann Whitney test

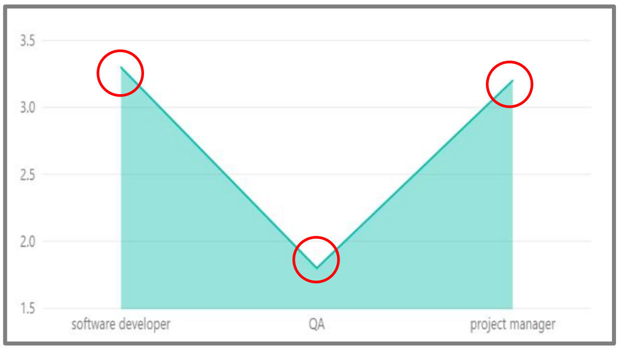


Figure 27: Mean differences values between experts for Battery power opt. factors as shown in Mann Whitney test

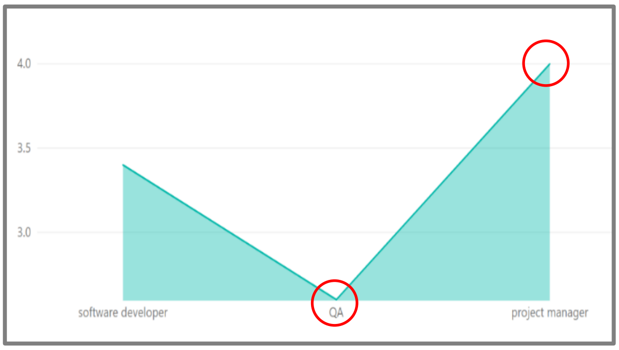


Figure 28: Mean differences values between experts for Push notification factors as shown in Mann Whitney test

One-way analysis of variance (one-way ANOVA)

In the last test, Mann-Whitney and T-tests were used to assess whether two groups of experts differed. By contrast, the one-way ANOVA tested whether three or more groups differed (Saunders et al., 2009). This test compares the means of more than two groups to determine their association, if any. In this study, there are three main groups of experts, on the basis of their main job role: Project manager; Software developer; or QA team. ANOVA tests overall groups – it does not provide specific information on which groups are affected. For example, if the results tell us that there is a significant difference between them, we do not know which groups are different from the others, therefore many assumptions must be made:

- There is a difference between the group software developers and QA team OR
- There is a difference between the group software developers and project managers OR
- There is a difference between the group project managers and QA team OR
- There is a difference between all the groups: software developers, project managers and QA team.

However, the previous test, Mann-Whitney, shows exactly which groups are affected. The reason for using the one-way ANOVA test is to confirm the Mann-Whitney test results.

Table 33 presents the results of the ANOVA test, and there are four significant differences between the groups of experts: software developers; project managers; and QA team:

1) For the Searching estimation factor, the p-value = 0.029, and the difference is between the Project manager group and the QA group, as shown in Figure 30.
2) For the Support code reusability factor, the p-value = 0.026, and the difference is between the software developers group and the QAs group, as shown in Figure 29.
3) For the Data storage and memory optimisation factor, the p-value = 0.005 which indicates a very significant difference, and the difference is between:
    - the Project manager group and the QA group, and
    - the Software developer group and the QA group, as shown in Figure 31.
4) For the Battery and power optimisation factor, the p-value = 0.05, which indicates a small difference, and the difference is between:
    - the Project manager group and the QA group, and
    - the Software developer group and the QA group, as shown in Figure 32.

Also, it can be observed from the remaining effort estimation factors, shown in Table 33, that there are no differences in terms of the effort estimations' mean values between the expert groups, and there are two examples in Figure 33 and Figure 34 that show that the differences between the means are very small. For more details about one-way ANOVA tests for all estimation factors, see Table 76 in the Appendix C.

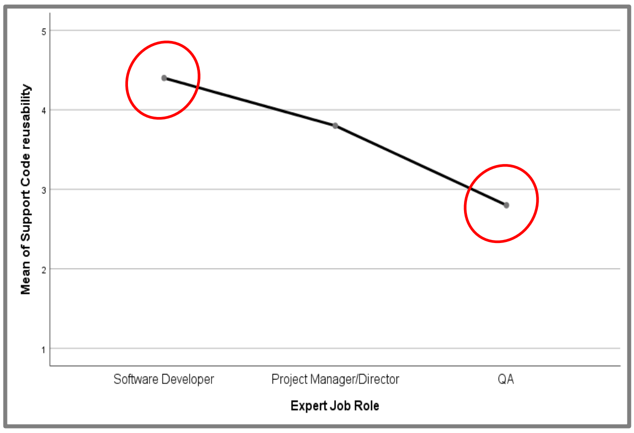


Figure 29: Mean differences between the expert groups for support code reusability factors

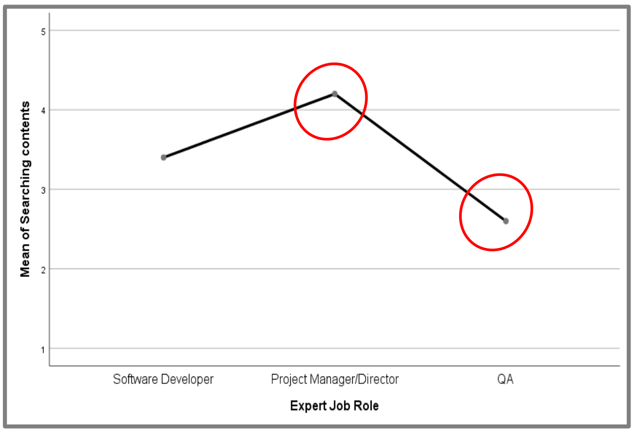


Figure 30: Mean differences between the expert groups for searching factors

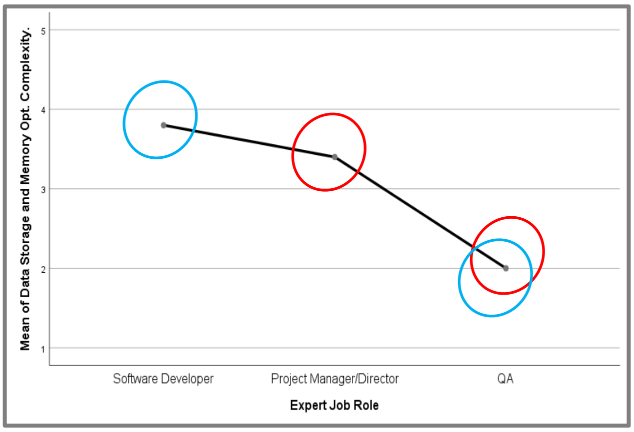


Figure 31: Mean differences between the expert groups for Data storage factors

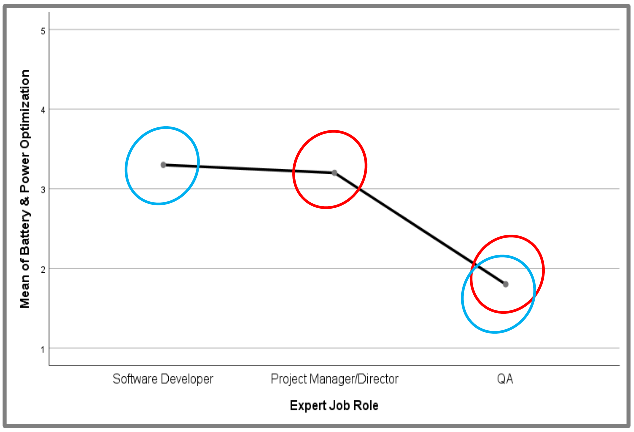


Figure 32: Mean differences between the expert groups for Battery & power factors

Figure 33: Mean differences between the expert groups for Booking & reservation factors

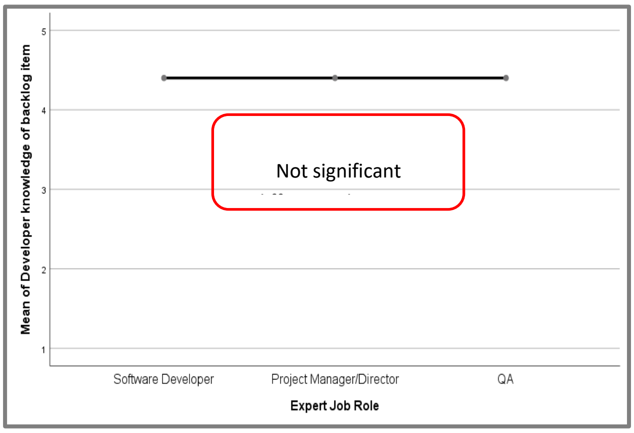


Figure 34: Mean differences between the expert groups for Knowledge of product backlog item factors

Table 33: One-way ANOVA test for associated factors

		Sum of Squares	Mean Square	F	Sig.
Booking and reservation	Between groups	.150	.075	.094	.911
	Within groups	13.600	.800		
	Total	13.750			
Localisation & tracking	Between groups	.200	.100	.142	.869
	Within groups	12.000	.706		
	Total	12.200			
Searching contents	Between groups	6.400	3.200	4.387	.029
	Within groups	12.400	.729		
	Total	18.800			
Support code reusability	Between groups	8.550	4.275	4.542	.026
	Within groups	16.000	.941		
	Total	24.550			
Data storage & memory opt. complexity	Between groups	10.950	5.475	7.271	.005
	Within Groups	12.800	.753		
	Total	23.750			
Battery & power optimisation	Between groups	8.100	4.050	3.5	.050
	Within groups	19.700	1.159		
	Total	27.800			
Developer knowledge of backlog items	Between groups	.000	.000	.000	1.000
	Within groups	14.800	.871		
	Total	14.800			

Correlation coefficient analysis

A coefficient correlation enables us to quantify and assess the strength of the linear relationship between each of the effort estimation factors. The correlation value (r) can be between -1 to 1, if the r value is a positive number +1; this means the two estimation factors, F1 and F2, for example, are strongly related to each other, and the experts' ranked value regards the factors F1 and F2 as close and tending to be similar. In contrast, if the r value is -1, this mean the two factors, F1 and F2, are strongly related, and the experts' opinions regarding this factor are contradictory.

Figure 89, in the Appendix C, shows the correlation between the effort estimation factors for all 20 experts. From the correlation results, it can be observed that there are nine significant relationships between the 15 effort estimation factors, as shown in Table 34 below. The figures (Figure 37, Figure 38 and Figure 35) are scatter plot representations, used here to graphically present the significance of the relationship between the two estimation factors. By contrast, Figure 36, for example, does not show any relationship between the Compatibility and the Previous version and data storage factors, and the plotting variables are not close to each other, thus the r=0.52.

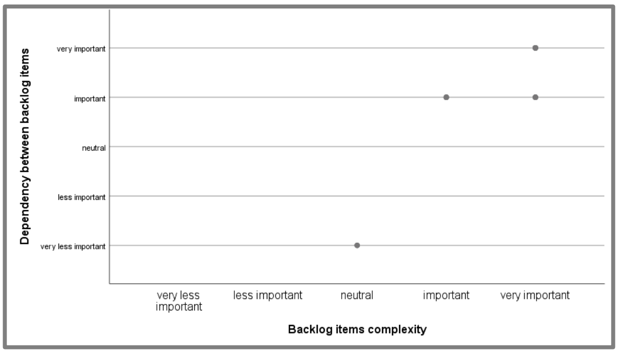


Figure 38: Coefficient correlation between Backlog items complexity and dependency between Backlog items factors

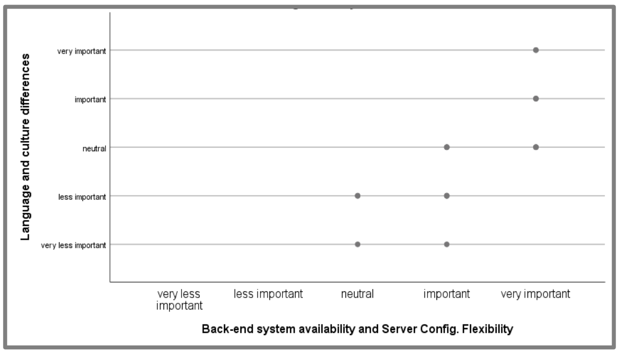


Figure 37: Coefficient correlation between Backend system Ava. and Language and culture diff factors

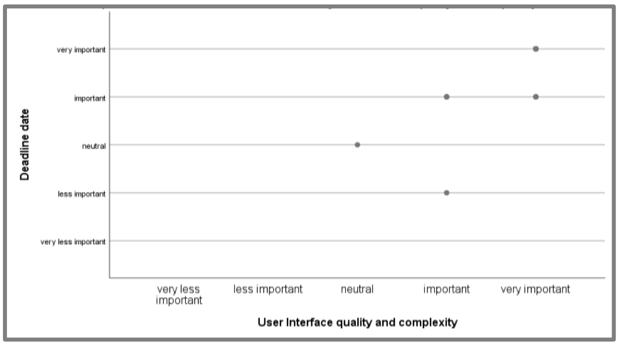


Figure 35: Coefficient correlation between User interface quality and Deadline date factors

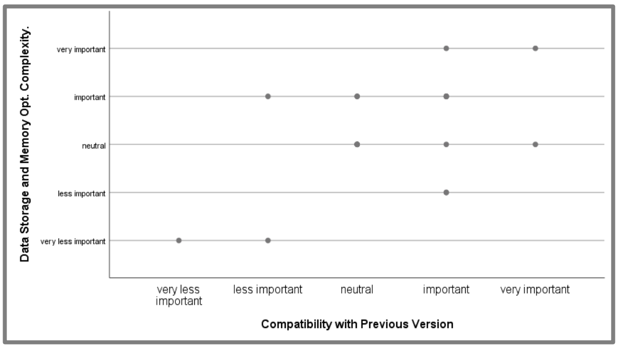


Figure 36: Coefficient correlation between Compatibility with previous versions and Data storage factors

Table 34: Coefficient correlation for selective effort estimation factors

	Map view	Push Notification	Support Code reusability	Interrupt handling	User Interface quality and complexity	Deadline date	Security Support	Development type (New or enhanced app)	Language and culture differences	Back-end system availability and Server Config.	Backlog items complexity	Dependency between backlog items	Developer implementation experience	Developer knowledge of backlog item	Geographical of the development team
Map view	1	0.763	-0.218	-0.037	0.503	0.541	0.502	0.192	0.319	0.38	0.243	0.283	0.374	0.454	0.33
Push Notification	0.763	1	-0.026	0.096	0.619	0.526	0.375	-0.056	0.078	0.27	0.108	0.258	0.271	0.333	0.474
Support Code reusability	-0.218	-0.026	1	0.757	-0.154	-0.214	0.534	0.397	-0.137	-0.07	-0.286	-0.335	-0.226	-0.304	-0.247
Interrupt handling	-0.037	0.096	0.757	1	-0.155	-0.161	0.527	0.455	-0.118	0.121	-0.195	-0.168	0.032	-0.1	0
User Interface quality and complexity	0.503	0.619	-0.154	-0.155	1	0.718	0.11	-0.226	0.115	0.101	0.081	0.226	0.175	0.355	0.357
Deadline date	0.541	0.526	-0.214	-0.161	0.718	1	0.153	0	0.16	0.228	0.207	0.423	0.336	0.349	0.497
Security Support	0.502	0.375	0.534	0.527	0.11	0.153	1	0.719	0.393	0.414	0.046	0.018	0.061	0.083	-0.008
Development type (New or enhanced app)	0.192	-0.056	0.397	0.455	-0.226	0	0.719	1	0.484	0.388	0.076	-0.076	0.019	0	-0.083
Language and culture differences	0.319	0.078	-0.137	-0.118	0.115	0.16	0.393	0.484	1	0.745	0.29	0.171	0.212	0.256	0.137
Back-end system availability and Server Config. Flexibility	0.38	0.27	-0.07	0.121	0.101	0.228	0.414	0.388	0.745	1	0.253	0.249	0.492	0.456	0.417
Backlog items complexity	0.243	0.108	-0.286	-0.195	0.081	0.207	0.046	0.076	0.29	0.253	1	0.864	0.721	0.28	0.399
Dependency between backlog items	0.283	0.258	-0.335	-0.168	0.226	0.423	0.018	-0.076	0.171	0.249	0.864	1	0.736	0.141	0.417
Developer implementation experience	0.374	0.271	-0.226	0.032	0.175	0.336	0.061	0.019	0.212	0.492	0.721	0.736	1	0.573	0.693
Developer knowledge of backlog item	0.454	0.333	-0.304	-0.1	0.355	0.349	0.083	0	0.256	0.456	0.28	0.141	0.573	1	0.702
Geographical of the development team	0.33	0.474	-0.247	0	0.357	0.497	-0.008	-0.083	0.137	0.417	0.399	0.417	0.693	0.702	1

7.1.5. Effort estimation accuracy

A question was put to all participants concerning the accuracy of their estimates: How accurate are the effort estimates in your organisation?

The aim of this question was to identify the respondents' beliefs regarding the accuracy of the effort estimation process and techniques in their organisation. From Figure 39, we can observe that 75% of practitioners tended to underestimate the amount of effort involved in fulfilling a user story, rather than overestimate it. Around 40% stated that they underestimated the effort value by 25% to 45% of the actual effort involved. The respondents' results show that it is rare to overestimate effort by more than 25% of the actual expended.

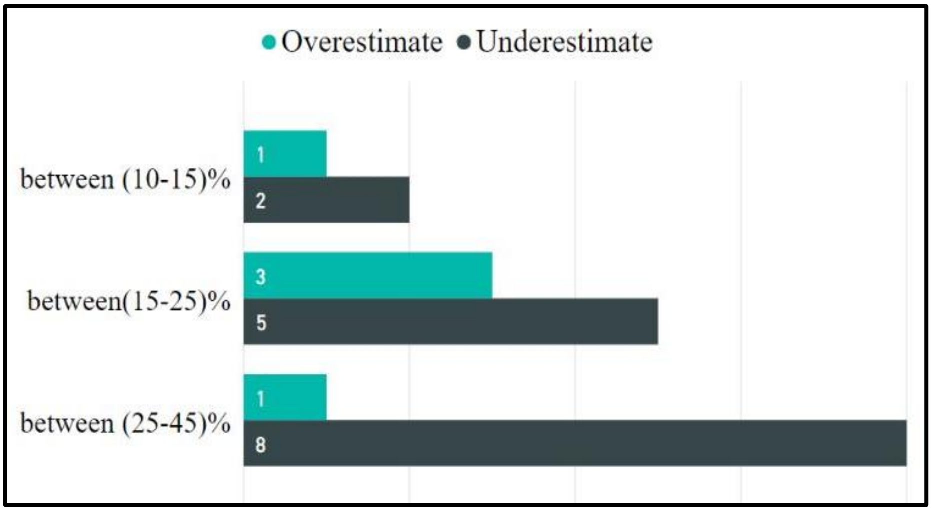


Figure 39: Effort estimation accuracy from the survey

A discussion with the practitioners regarding the reasons for inaccurate estimation of a user story showed that one of the main reasons for the high error in accuracy was the value being assigned by a team leader or project manager without consulting the developer who will undertake the task. Another reason was when either the EJ or PP technique is used alone, as a combination will reduce the error range. Another reason stated was that the value is estimated by all team members, using the PP technique, yet during the sprint the task is assigned to just one developer. The developer could be a junior, but the estimated value may be based on a similar task completed previously by an expert developer. Some practitioners claimed that there is no clear guidance for giving an estimation value. EJ and PP suffer from their requirement for formality in the estimation process. Further reasons are mentioned in the estimation process section.

7.2. Qualitative Analysis

In this section, the qualitative analysis of the semi-structured interviews, which were designed to answer complex questions, are presented. The nature of the questions put to the experts were more descriptive and included 'what' and 'how' questions. Since the research approach in this study is inductive, the aim was to explore the collected data and obtain themes from the experts' responses. Sub-section 7.2.1 discusses the estimation processes that the experts used in developing apps. Sub-section 7.2.2 discusses additional factors that the experts rely on for effort estimation. Finally, the experts' opinions and experience concerning the Agile process in mobile app development is presented in sub-section 7.2.3.

7.2.1. Effort estimation process

The question put to the experts was:

Question	Answer
How do you estimate the effort of your mobile app project? And what is the process?	

All the experts answered the above question, and the following sections summarise their description of the processes involved in estimating the effort to fulfill a user story. In the following, the experts' answers are categorised on the basis of job role.

1. Project managers

Expert A: The product owner explains a user story in terms of its features to the development team, and then divides the tasks into subtasks: frontend and backend. For the initial estimation, the senior developer makes an initial estimation for a user story before applying Planning Poker with the entire development team. As the IT director, 'A' performs this technique to avoid extremely high estimations by the team. After that, all development team members, including the Scrum master, are asked to participate and make an estimate for the whole user story. If the estimate by the team member who will undertake this feature is close to that of the rest of the development team, the group will use this figure, otherwise the team leader will become involved and ask the developer for more clarification until they agree on a specific figure. In 'A's experience, developers usually assign a high estimate to a user story to avoid work pressure, and that is why 'A' uses a combination method to assign effort to a task.

Expert I: As a project manager, 'I' usually relies on experts from the development team to assign an expected effort value. Usually, 'I' asks a senior developer about their expectations of a project.

Expert J and R: 'J' and 'R' had similar opinions on their estimation techniques, and they usually use PP to estimate the time for a project's delivery. The reason that they use PP is because they want to hear feedback from each member of the project and then take the average for each task. The risk is very high when they rely on an expert from the development team to estimate the effort, as the expert could leave for any reason, and the estimates are based on their opinion only. 'J' and 'R' use the EJ technique only when they familiar with a project and need very quick feedback from the team. Only 'J' uses COCOMO as an initial estimation for a project, but it is not an accurate technique due to the difficulty in measuring the complexity of a project, the team's capability and other reasons.

Expert K: 'K' asks the developer to assign an estimate for effort for the task, and then asks other team members for their estimates. If the difference is not great, 'K' confirms the developer's estimate; otherwise 'K' discusses it with the developer and takes it to make it more reasonable.

2. *Software developers*

Expert B: The product owner explains the product backlog items to the entire development team and answers their questions. After that, the team discusses what kind of task could be done during the work, based on the previous sprint. As a whole team, a story point is assigned to every user story in one day. 'B' starts with a small task to create a base for the story point, and then compares the other user stories with the base. 'B' uses the Fibonacci sequence and, when a user story achieves 64 points, divides this story into two or three subtasks as required. They use PP to simplify the business requirements, make the requirements of user stories clear to all team members and open up a good discussion.

Expert C: The one who will do the task should be responsible for assigning the effort. The problem is when a manager assigns an estimation of effort, or lets a backend developer assign the effort for a frontend task, as then the result for the estimation will not be accurate, and it could lead to the failure of the task. Moreover, in order to estimate, you have to be the person doing the task and understand the big picture of the project.

Expert D: A senior developer, 'D', assigns the estimated effort and informs the team leader. Junior developers may estimate effort on the basis of fears about unexpected issues that could arise during the development. If this is the case, the team leader should sit beside them to make the task clear, including what kinds of tools are needed, then they can agree on a fair effort. Sometimes senior developers may assign a high estimation value to a task that they have not done before. 'D' does not believe in assigning an effort by story point, because it does not help in measuring the actual effort, and prefers to use IH as a meaningful measurement. When ‘D’ needs to design a user interface for a mobile app, ‘D’ knows how long it could take, for example one day or two to three days, yet cannot say how many story points are needed.

Experts E and T: At the start, each developer assigns their estimated effort value to their task, and then discusses this estimated value with the team leader. Following that, the developer and team leader come up with a final estimated value after discussion. Usually, team leaders agree with the figure that the developer came up with, unless the developer assigns a very high estimated value. No one interferes with estimated values, apart from the developer who is to carry out the task and the team leader.

Expert F: Everyone is assigned a task and then assigns their expected effort value to that task. After that, each explains the task and effort value to the other team members, and the whole team discusses the estimate by applying the PP technique. The team accepts the estimated value if the value is close to the result obtained from PP; otherwise, it asks the developer to re-estimate that task.

Expert G: If the developer is to undertake the task alone, then the developer assigns the effort value for the task and then discusses it with the team leader. If a task needs group work, then the team applies the PP technique by holding a long discussion with all the team members (developer, tester, designer, etc.) and assigning an effort value at the end. ‘G’ prefers to be assigned a specific task to work alone and not to relate to other team members, as that requires more communication and could delay the delivery of a user story.

Expert H and M: The whole team assigns the effort value to each task by applying a PP technique. It usually takes the average of estimated effort to avoid a second round of PP, unless the range of estimated values is very wide. ‘M’ reported that the team tried to avoid individual estimations and instead preferred to discuss all tasks together, to make a user story clearer.

Expert L: The team leader explains the user story to all team members, who participate by giving their opinion on this task, and at the end they all assign a value. No specific techniques are followed.

3. Quality assurance team

Expert N and O: Apply the same method as ‘L’: when the task comes to them, they assign the estimated effort to the task and let the team leader know how long it could take them. There is no specific method used, and they consider their approach an EJ technique.

Expert P: There are two techniques. The first is the product owner explaining the detail of the user story to all the development team members involved in the project. In the development team are two groups: frontend and backend. One senior expert from each assigns the effort estimation (story point) to the user story. The second is traditional PP, as every member gives their opinion until a consensus value is reached. From experience, the first technique is more accurate, as when PP was applied the developers' experience was varied and the team new.

Expert Q and S: Both mentioned that there is no specific method followed in their companies. The task is assigned to 'Q' and 'S' by the team leader along with a given estimated effort. If the deadline arrives and the task is yet not yet finished, they need to justify the delay.

Summary of estimation process

After describing what the experts do to estimate effort, it is necessary to integrate the related data from their responses to identify key themes. Also, it is necessary to generate categories of the estimation processes from the responses and design a matrix to represent the data. This required computer-aided qualitative data analysis software (CAQDAS), such as NVivo (Saunders et al., 2009). After applying this software, the coding results were extracted and organised in a thematic format, as shown in Figure 95 in the Appendix C. Table 35 is a summary of the key points that compiles the experts' responses into a coding system and a brief statement.

Table 35: Summary of experts' estimation process

Respondent ID	Explain the task feature to:		Responsibility for a task:		Estimated effort to a task assigned by:			
	The developer who will do the task	All the developers	All developers	Who will do the task	Expert/ senior developer	The all team	Team lead	A developer who do the task
A		✓		✓	✓	✓	✓	✓
B		✓		✓		✓		
C		✓		✓				✓
D		✓		✓			✓	✓
E	✓			✓			✓	✓
F		✓		✓		✓		✓
G	✓	✓		✓			✓	✓
H		✓	✓			✓		
I					✓			
J		✓	✓		✓	✓		
K		✓		✓		✓		✓
L		✓	✓			✓		
M		✓	✓			✓		
N	✓			✓				✓
O	✓			✓				✓
P		✓	✓			✓	✓	
Q							✓	
R		✓	✓		✓	✓		
S							✓	
T	✓			✓			✓	✓
Total	**5**	**13**	**6**	**11**	**4**	**10**	**8**	**10**

From Table 36, a relationship is found between:

- Who assigns the estimated effort to the task: **four options,**
- To whom the user story is explained: **two options.**

It is clear that if all team members are to assign the effort value to a user story, then the task should be explained to all the team members. Also, based on Table 37 it can be said that if the person who will do the task assigns the effort value to a task, then that person should take responsibility for the task.

Table 36: Relationship between who explains the task and who assigns the effort

			Explain the task 'user story' to:				
			All development team members	The person who will take on the task	Both of them	Not declared	Total
Effort assigned by:	Expert developer	Count	3	0	0	1	4
	All the team	Count	10	0	0	0	10
	Team leader	Count	3	2	1	2	8
	The developer who will do the task	Count	5	4	1	0	10
Total		Count	12	4	1	3	20

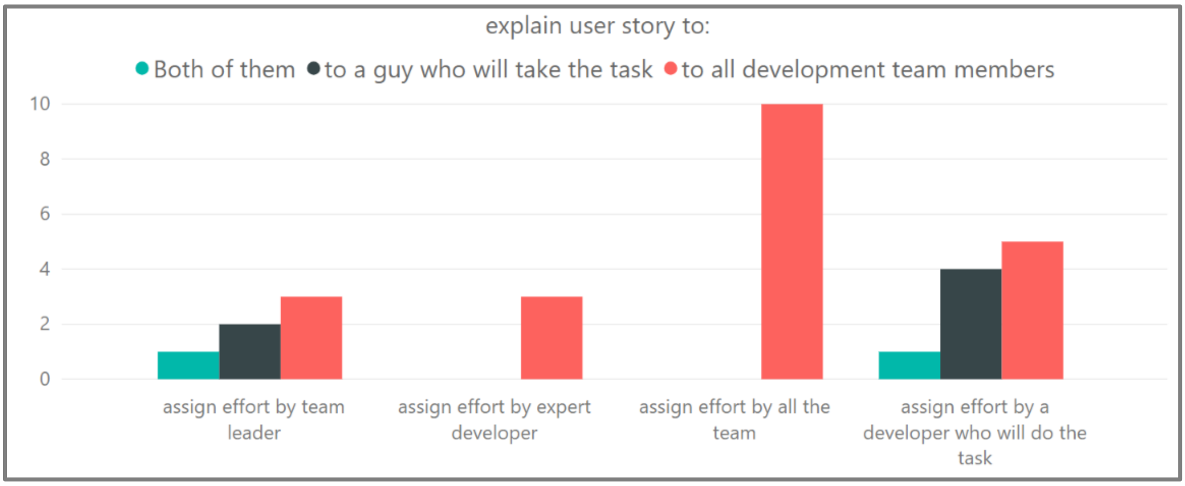


Figure 40: Overview of the relationship between who assigns the effort and to whom the task is explained

Table 37: Relationship between who is responsible for a task, and who assigns the effort

			Who is responsible for a task			
			All the team members	The person who will do the task	Not declared	Total
Assign effort by:	Expert developer	Count	2	1	1	4
	All the team	Count	6	4	0	10
	Team leader	Count	1	5	2	8
	The developer who will do the task	Count	0	10	0	10
Total		Count	6	11	3	20

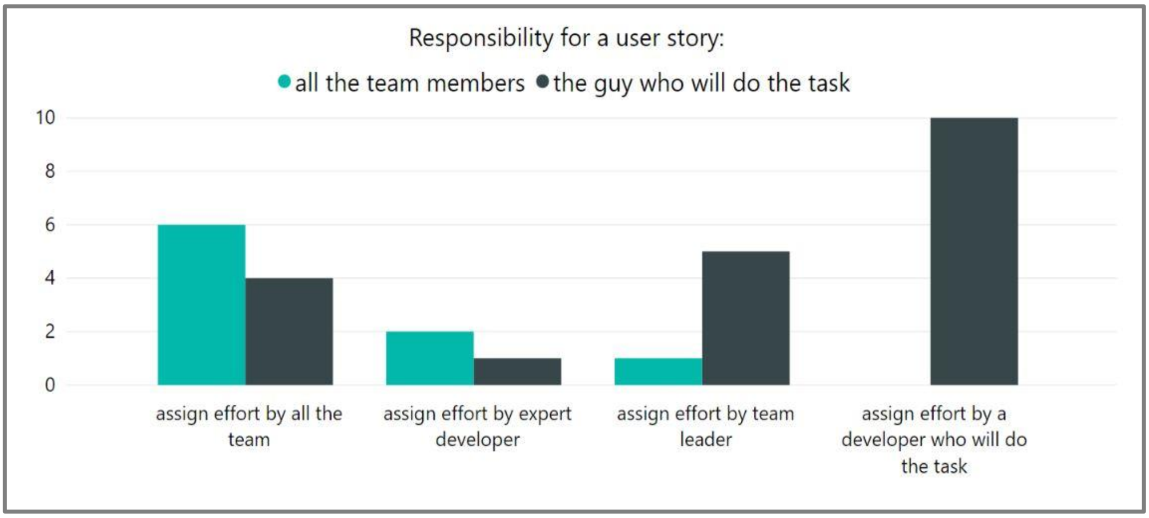


Figure 41: Overview of the relationship between who assigned the effort and who takes responsibility for the task

7.2.2. Effort estimation factors

The following question was put to the experts:

Question	Answer
From the previous question, you ranked the importance level of the estimation factors. Now, are there any additional factors that you rely on during your estimation?	

All the experts answered the above question, and summaries of their responses are presented below. Some shared the same perspective, as reported, and at the end of each section a single table shows all the suggested factors. In the following sections, the experts' responses are categorised on the basis of their opinions about the estimation factors.

1. Factors concerning the complexity of the task

This category contains many factors that experts believe affect the effort estimation of mobile app development. In the following sections, statements related to the complexity of business requirements are presented. At the end of the section, the themes from the experts' answers are set out, and the thematic coding for the effort factors is presented in Table 38.

a) Clarity of the task and transaction journey

Experts A and C believe that the user story's clarity is very important to estimation, therefore it should be presented in a clear and concise way. The product owner should focus on the complexity of a user story and how a developer could understand both the story and beyond. In addition, Expert A mentioned that how, in order to estimate the effort, a developer should think deeply about how to integrate existing business code into a new task. Expert F emphasised that to understand the business complexity a developer should know the transaction journey from the point when a user clicks a button to the point at which that user receives a response. Expert L mentioned the same issue, in that development team members must focus on the complexity of the business workflow and the transaction steps from the beginning until the very end.

b) Rely on another task, use an existing code or have done a similar task before

Experts B and C stated that a developer needs to be concerned about whether an existing function or code relates to another task. Sometimes, the developer needs only to reuse this function by calling it up and making a few new functions. Expert P and L explained that if a task is related to existing code in the system, they need time to understand the existing code to integrate it with new code, and that there is a chance of this creating new bugs. Moreover, Experts B, F, G, H, I and J stated that a developer can determine the complexity of the task by asking this question: Did I do this task before? Did I do a similar task to this? These remind the developer about previous experiences. Expert F noted that the hardest task is one that a developer has not done frequently or only once every few years. Expert C mentioned the same point and was concerned about whether the task is 'stand alone' or if there is dependency on another task. Experts D and H explained that sometimes, if you have a new task or any similar tasks before, you do not know exactly what kind of tools or libraries you will need.

c) Thinking about the task scenario and approaches to implement the task

Expert C was concerned about the task scenario and the details of the task. Experts E and G claimed that a developer should think about the methodology to implement the business logic and how to achieve all the scenario cases involved in the task. Expert D explained that to store a picture on a database, for example, a developer needs to think about the best method to save the picture in a database; if it is possible to save a picture in database as a binary or to save a picture in a directory; and then how to save the URL of the picture in the database. Expert F stated that any task that is based on transactional approach (request - response) is usually easy; however, a task that is based on algorithms or integrations with other systems is usually hard. Expert K described how sometimes we understand the user story 'task' yet do not know how to implement it, especially if it relates to encryption.

d) Complexity of the application form

Experts B and G mentioned the complexity of application forms, and that sometimes a customer requires a highly complex form. Expert G added that sometimes a product owner requires an auto complete for a field, which involves retrieving data from a backend system. Expert J mentioned an important issue, in that for an application form there are usually many users who can access the same web form, and for each role there is a separate form, therefore a developer should consider that this takes more time than a simple form. Moreover, this expert observed that generating a report form sometimes involves retrieving data from a complex database schema or from multiple systems, so the effort varies from one report form to another.

From the previous statements, it can be concluded that the experts' experience concerning the effort estimation of user story and complexity can be split into eight factors. These can be used as a definition of the business requirement complexity. The eight factors that are recommended for use in effort estimation are:

- The transaction journey (from request until response time)
- The clarity of the business requirements: 'user story'
- Whether the expert uses existing code or function in a task
- If a task relies on other tasks or is 'stand alone'
- Investigating all scenario cases for a task
- If the expert undertook a similar task before or not
- The complexity of application forms
- Methods and approaches to implementing business logic into code

Table 38: Experts' summary of estimation factors from business complexity perspective

Expert ID	Use existing business & code in a task	Rely on other task / stand alone	Task scenario	Complexity of business task and clarity of task	Did similar task before	Transaction journey (request / response)	Complexity of application form	Method and approach business logic into code
A	✓			✓		✓		
B	✓	✓		✓	✓		✓	
C		✓	✓	✓				✓
D					✓			✓
E			✓	✓				✓
F				✓	✓	✓		✓
G			✓	✓	✓		✓	
H			✓	✓	✓			
I				✓	✓			
J	✓	✓		✓	✓		✓	
K				✓	✓			✓
L	✓	✓		✓	✓			✓
M	✓	✓	✓		✓	✓		
N				✓				
O								
P	✓	✓		✓				✓
Q			✓		✓			
R				✓		✓		
S			✓		✓			
T	✓	✓		✓			✓	
Total	7	7	7	15	12	4	4	7

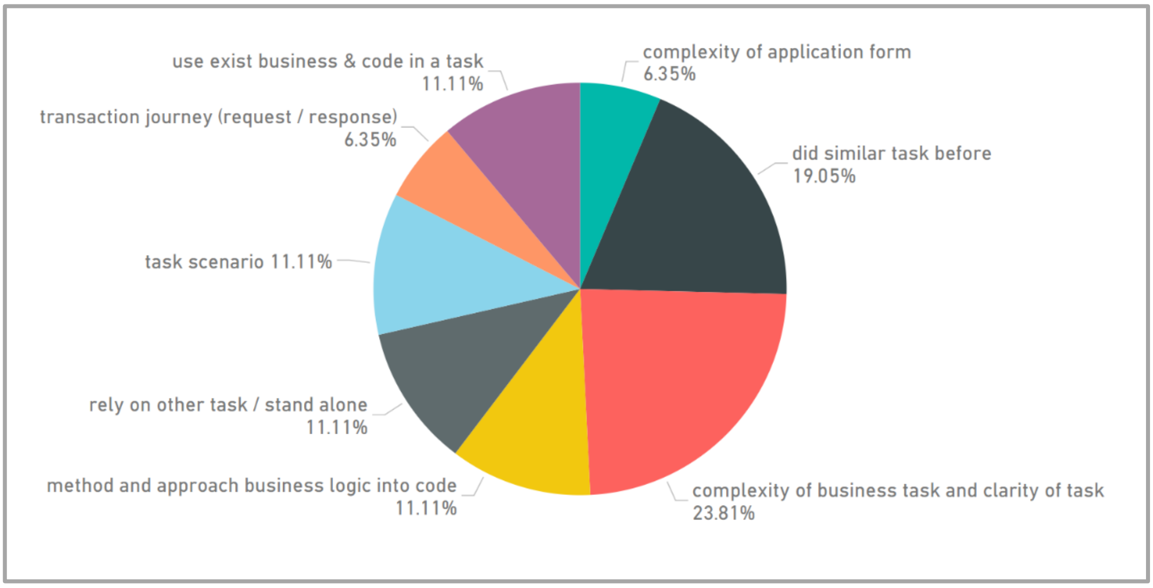


Figure 42: Overview of business complexity factors suggested by experts

2. *Factors for the technical side of the task*

Under this category, some of the experts' experience of estimating the effort involved in developing mobile apps will be presented. There are six factors that the experts considered.

a) Backend response structure

Expert B said that a developer should be concerned about the structure of the transaction data when a response comes from the backend, and how the data structure appears.

b) UI animation and graphics

Expert B explained that when developers use a hybrid framework, such as Ionic, they should think about the data view (UI) in various mobile devices to make sure it is fitted correctly for all screen devices. Also, Expert E was concerned about whether the screen has an animation or graphics complexity, when estimating the effort required for a task. Expert F emphasised UI and UX, and claimed that for a developer this is the most complex phase.

c) Web service, system integration and third-party complexity

Expert B believes that if a developer is to perform a task, he or she should think about how many web services have to be integrated. Expert F claimed that experience with a task needs to be integrated into a legacy system. The challenge is that the integration with a legacy system cannot be done until a bridge system is complete, and this requires additional effort. Also, Expert F thought about the payload and structure of the data that pass from the backend to a client's mobile device through API, as some developers pass a huge amount of data, which causes a high level of processing in the client's device. This means that developers need to deal very carefully with a client's device, and this requires time and effort to think about the optimal solution. Expert J explained that a developer might need time to understand how to integrate code with an existing system or service, and stated that any change to the existing code could cause new bugs or errors in the system. Expert T explained that if a task needs to be integrated with another service, it is complex and needs to be tested further.

d) API: existing and clarity

Expert D explained that clarity of use of an API for a mobile device is helpful for a developer to give an estimation of the task, such as 'android.hardware.camera2' API. Expert F was concerned at the number of APIs as needed to perform a task. Expert B described the effort required to connect with a third party for authentication services from Facebook or Twitter, and how easy it is to connect with these APIs. Another challenge that experts claim is changes to APIs. Dealing with changing behaviour of API versions is a challenge for developers, to understand the new set of parameters and response structure.

e) Availability of libraries and tools

Expert D stated that the availability of development tools and libraries helps a developer to start the task immediately, instead of looking for a suitable tools and setup up from the development environment. Expert E emphasised the importance of advanced tools, such as Firebase, which provide powerful features such as managing infrastructure such as database, tracking services and support for a push notification service, as this allows developers to carry out their task easily. In Expert G's experience there are many plugins in frameworks, such as the Photo-Library plugin in Ionic, and a developer needs to learn and understand how to use these plugins and think of others that could provide a better solution. Expert L mentioned the advantage of source code availability on the internet, such as on the Github or StackOverflow websites, and using it for development, as well as the availability of problem-solving for errors. In addition, Expert E and N mentioned the build and deployment tools for their code. They stated that it is necessary to have a continuous deployment tool for work, to speed up the deployment. The experts also claim that most current tools and platforms are unreliable due to no or very limited technical support.

f) Local storage database and storage procedures

Expert D stated that a developer needs to think about how to deal with a local storage 'database' for mobile devices and backend databases. Expert K was concerned about real-time communication between the backend and the mobile device database, and when/how to exchange the data. Expert F and N had experience of unexpected cases arising during development; Expert N described designing a mobile app so that when the mobile device was in an isolated area (without a network connection) or offline, the data for the app was stored on a local device until the connection came back and, when back online, the data were pushed to the backend database into the server. However, some product owners or business analysts do not think about technical issues when gathering the requirements. Expert R mentioned the advantage of using a local database, such as SQLite, to make a mobile app more responsive and less dependent on the network by copying essential data into a local device. In this case, a developer could take more time to think about what kind of data needs to be synchronised from the server's database, and when to conduct the synchronisation. Expert J stated that a developer should consider the structure of the retrieved data from the database - and how to deal with it. Expert L noted that a developer could think about whether the task required modifications to the database schema to connect the task to it. Table 39 shows an overview of the experts' opinions on estimating the effort of mobile app tasks.

Table 39: Experts' summary of estimation factors from a technical perspective

Expert ID	Local and backend DB / store procedure	Backend response structure	Library and tools availability	UI animation & graphics	No. & complexity of 3rd party/web service / system integration	API existing and clarity
A						
B		✓		✓	✓	
C						
D	✓		✓			✓
E			✓	✓	✓	
F	✓	✓	✓	✓	✓	✓
G			✓	✓		
H			✓		✓	
I						
J	✓	✓			✓	✓
K	✓	✓	✓			
L	✓		✓		✓	✓
M	✓				✓	
N	✓		✓			
O						
P						
Q			✓			✓
R	✓		✓			
S	✓	✓				
T					✓	✓
Total	9	5	10	4	8	6

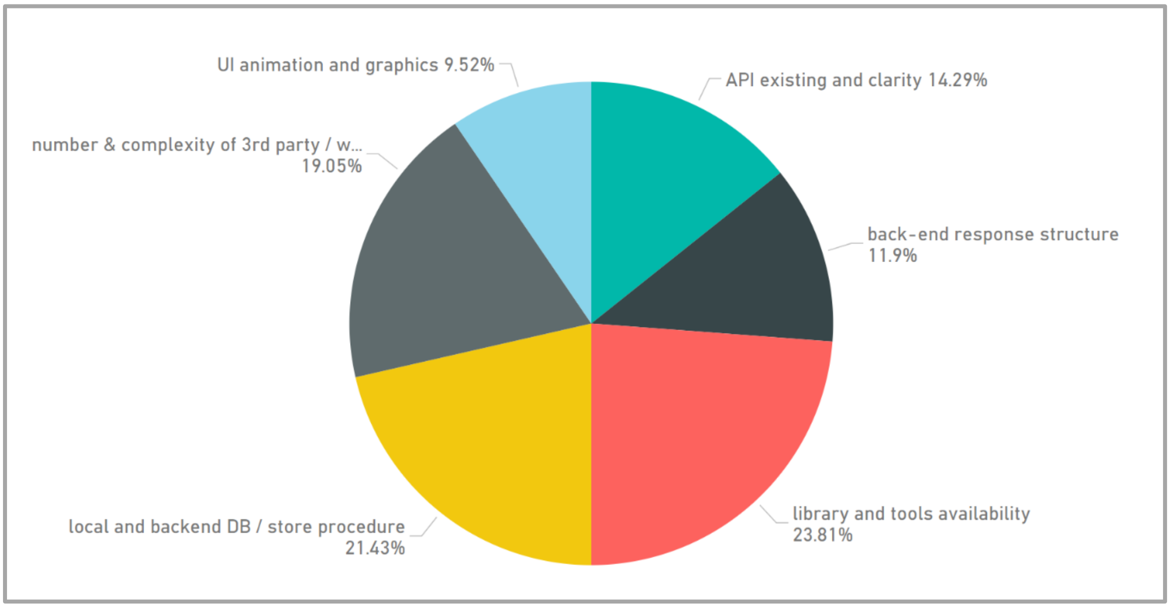


Figure 43: Overview of the technical factors suggested by experts

3. *Other factors*

In this category are further factors that the experts, in their experience, have relied on to estimate the effort involved in developing a mobile app.

a) Working under pressure

Experts A and C stated that a developer often assigns a high estimation value to the effort to avoid working under pressure. Therefore, as IT directors, their goal was to make sure that developers assign a fair effort value to their task and deliver the project on time. Also, Expert A claimed to push the developers as much as possible to encourage them to be productive while maintaining a reasonable quality, for them to do their jobs. Expert A continued, stating that rather than a perfect feature, what was needed is a reasonable quality of delivery and maintaining the developers' input. Expert R explained that they wanted to push many features with reasonable quality in a short time. Expert C described how, as developers, they are usually under pressure from managers to deliver a task in a short time, and this will affect the code's quality.

b) Team members' movement

Expert A explained that a developer who has to switch from one team to another or experiences interruptions from team groups is using more effort. Expert J noted the problem when a developer leaves the development team during the project for any reason, as this will involve increased effort by the others to deliver tasks by the due date.

c) Team enthusiasm and motivation

Expert A claimed that team engagement and motivation cause dissimilar productivity among development team members. Expert C explained that when members take responsibility for the success of the project, it helps to improve the effort put into the task and ensure delivery on time. Expert M stated that when a team's members collaborate and are happy to help each other, this enhances the effort put in.

d) Quality of code and App store standards

Expert A was concerned with the acceptance criteria of the project and said that a task should satisfy and pass the acceptance criteria, and a developer should consider this during development and estimation. Expert C discussed this point from another angle and explained that they are trying to achieve the Quality Triangle concept (quality – cost - time), but that it is difficult to deliver a high-quality app when there is a limited budget and/or time. Expert F explained that the Apple Store has policies that a developer should follow, for example a developer cannot allow the app access to the client's device's GPS until the client gives the app permission. As Expert F stated, they cannot deploy any changes until Apple Store has given its authority.

e) Prototype and UI design of mobile apps

Experts D, F and J emphasised the crucial issue that a High-Fidelity Design (HFD) is vital for a developer to provide a high level of detail and functionality in a prototype of the UI of a mobile app. A prototype could be a sketch or a mock-up design, or implemented by HTML and JavaScript.

f) Code testing and data validation

Experts E, L, N, P and Q explained that it is necessary to think about all the test cases scenarios to validate a code. Also, a developer needs to test code before submitting it. Experts J and L claimed that some tasks are easy to develop but hard to test, and so require more time to be allocated. Expert E stated that a developer sometimes prefers to have a log file to trace and record all crashes that could arise in future to help to find errors easily. Experts E and F mentioned data validation, for example the username not containing a number, and stated that a developer could take more time to design a data validation on JavaScript that was not noted in a user story.

Table 40 is an overview of the experts' experience in estimating the effort of a mobile app's tasks.

Table 40: An overview of the experts' effort estimation factors suggestion

Expert ID	Prototype and fidelity design	Code testing & logs file	Data validation	Quality triangle & definition of done	Fit IOS / android standards	Team enthusiasm & motivation/ balanced skills	Team member movement	Pressure time
A				✓		✓	✓	✓
B								
C				✓		✓		✓
D	✓							✓
E		✓	✓	✓				
F	✓		✓	✓	✓			
G				✓				
H			✓					
I								
J	✓	✓	✓	✓		✓	✓	
K				✓				
L		✓						
M						✓		
N		✓						
O								
P		✓						
Q		✓				✓		✓
R							✓	✓
S		✓						
T								
Total	3	7	4	7	1	5	3	5

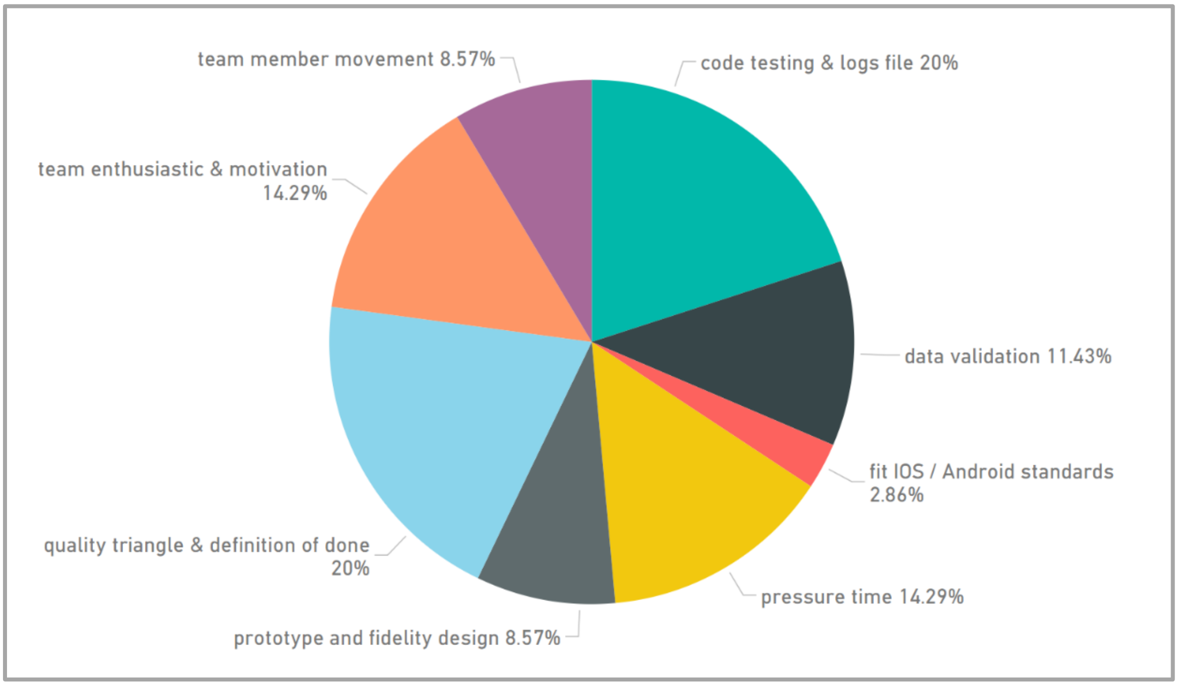


Figure 44: Overview of additional factors suggested by the experts

7.2.3. Agile process in mobile app development

This part of this chapter will discuss the suitability of the Agile process for mobile app development. The experts were given a brief description of other development processes that used the Agile process, such as Mobile-D. After that, the 20 experts were asked about the suitability of the Agile process for mobile app development, based on their experience, and for their opinions of the other development processes. The question was as follows:

Question	Answer
Is the Agile process suitable for your organisation? And what do you think of other development processes?	

Experts' explanations and answers

All the experts answered this question, and all believed that the Agile process is suitable for mobile app development. The details of the experts' discussion are presented as follows:

Expert A had used Scrum framework in their organisation, and explained that Scrum is not a technique or guidelines with steps to follow; it is framework that can be used to employ any process or technique on the basis of the development team's preferences. Therefore, Agile is suitable for any software development, including mobile apps.

Expert J claimed that Agile is an approach, and it is not related only to software development but can be used in marketing and other fields. Thus, it is suitable for any software development and application and more convenient than other processes. Expert C stated that software development for mobiles or the web is the same concept, because both are based on code, so thinks that Agile is suitable.

Expert B did not see any real difference when the company applied Agile in mobile development for both hybrid and mobile web platform, and it worked smoothly. Nevertheless, 'B' wanted to have pair programming in some sprints for complex UI design since this technique will improve the development. They added that the user interface in mobile apps, like web user interfaces, is not easy due to the mobile screen being limited in size and content.

In Expert D's experience, when the fidelity design of the UI is ready for a user story 'task', the Agile process works well in the development phase. Otherwise, a sprint with Scrum may run the risk of taking more time to design and implement the UI and UX.

Expert D claimed that pair programming is good for teaching junior developers new technology. Expert E stated that it wastes time and resources, but it could work in special cases for a junior developer for learning purposes. Expert H claimed it could work if there is a new tool or technology that needs to be shared with team members.

Expert K noted that Agile is suitable for mobile app development but that it is difficult to push the release phases through each sprint to the app's store, such as AppleStore. Expert N explained that the only problem with the Agile process for mobile apps is when the nature of the development platform is native. The development team needs to be concerned with two developments, and the effort is duplicated in each phase (coding, test, quality and release). Expert S stated that Agile in mobile usually takes more time than any other software development. The reason is that developers implement the app in native yet need to test all mobile device models for Apple and Android. This usually takes longer time than other software.

Overview of the Agile process in mobile app development

To sum up, Table 41 shows the experts' opinions on the Agile process in mobile app development. Also, the table presents the experts' feedback on pair programming, which Mobile-D uses. Moreover, the table shows the main challenges of applying the Agile process in mobile apps. It can be seen that all the experts agree that Agile is suitable for mobile app development. The main challenges are the multiple mobile development frameworks and platforms. Another challenge is that the UI and UX for mobile apps take more time in a sprint and need to be considered throughout, although this issue can be solved by having pair programming for complex UI that demands collaboration between mobile developers. Experts' opinions on pair programming varied. Some think it will be costly, while others can see advantages, such as sharing new knowledge between the team, especially for new developers.

Table 41: Overview of Agile's suitability for mobile app development

Expert ID	Agile is suitable for mobile	Agile challenges		Pair programming			
		Development platform (native-hybrid) challenge	UI and UX challenge	Pair programming is good for sharing knowledge	Pair programming good for complex UI and UX	Pair programming good for junior developer	Pair programming is costly
A	✓			✓	✓		✓
B	✓		✓		✓		
C	✓	✓					✓
D	✓		✓	✓	✓	✓	
E	✓					✓	✓
F	✓						
G	✓						
H	✓		✓	✓	✓	✓	
I	✓						
J	✓	✓		✓		✓	✓
K	✓						
L	✓		✓				
M	✓	✓					
N	✓	✓	✓				
O	✓						
P	✓			✓			✓
Q	✓						
R	✓						✓
S	✓	✓	✓				
T	✓			✓			
Total	20	5	6	6	4	4	6

7.3. Analysis Summary and Discussion

In this section, the results from the findings of the quantitative and qualitative analysis are explored. The first part addresses the appropriate effort estimation techniques for mobile app development. The second explores the factors that affect the estimation value. Following this, the estimation process in mobile app development is focused on and, finally, the suitability of the Agile development process for mobile apps is discussed.

7.3.1. Effort estimation techniques

From the quantitative analysis, it was found that EJ is the most commonly used technique, used by 15 experts, to estimate the effort in mobile app development. PP is also a common technique, used by 10 experts. Table 42 presents the experts' distribution, based on the estimation techniques used. It can be seen that four experts prefer to use a mix of PP and EJ. They prefer a mixed technique because they want to obtain a more accurate estimation value or to take a confirmatory approach. Project managers or developer team leaders tend to conduct EJ before PP in order to avoid unrealistic estimated values from the latter.

None of the developers or QA had used the COCOMO technique, which is based on the expression technique. It has been used only by project managers as an initial estimate before a project starts.

Table 42: Estimation techniques used by experts by job role

<table>
<tr><th colspan="3" rowspan="2"></th><th colspan="7">Job role</th><th rowspan="2">Total</th></tr>
<tr><th colspan="2">Developers</th><th colspan="3">Project managers</th><th colspan="2">QA</th></tr>
<tr><td rowspan="3">Estimation technique</td><td>Planning Poker</td><td>Count</td><td>4</td><td rowspan="2">2</td><td>1</td><td rowspan="2">1</td><td rowspan="3">1</td><td>0</td><td rowspan="2">1</td><td>10</td></tr>
<tr><td>Expert Judgement</td><td>Count</td><td>4</td><td>2</td><td>4</td><td>15</td></tr>
<tr><td>COCOMO</td><td>Count</td><td colspan="2">0</td><td colspan="2">0</td><td colspan="2">0</td><td>1</td></tr>
<tr><td colspan="2">Total</td><td>Count</td><td colspan="2">10</td><td colspan="3">5</td><td colspan="2">5</td><td>20</td></tr>
</table>

The effort estimation techniques are analysed in section 7.1. A a Chi-square test and Fisher Exact test were applied to obtain the relationship between the estimation techniques and measurement types for the estimation effort. The significance value (p-value) of both tests shows that there is a significant relationship between estimation methods and measurement types, as shown in Table 29: Chi-square and Fisher's-exact tests. The results on relationships show that when using the PP technique, the expert usually uses a story point to measure the effort involved in the user stories. Conversely, when an expert uses the EJ method to estimate the effort, usually IH is chosen to measure the user story in the Agile process.

Table 43: Effort estimation techniques with its measurement type

Estimation technique	Optimal measurement type
Planning Poker technique	Story point
Expert Judgement technique	Ideal hour

7.3.2. Effort estimation factors

Quantitative analysis

For the quantitative analysis, 48 factors were collected from previous studies examined in the SLR that relate to software development in Agile mobile app development. These factors have never been examined or validated empirically for this use, especially PP or EJ techniques. From the descriptive analysis, the concern focuses more on the factors' importance at the median value of the experts' answers, which are above 3 (neutral). These factors can be considered as influential and to affect the effort estimation value in the development of mobile apps. The median value has been selected because it is less unduly influenced by extreme data values than the mean value, and is considered a more useful descriptive analysis statistic (Anderson, Sweeney, & Williams, 1989; Saunders et al., 2009).

For the effort estimation factors for mobile app development, several testing techniques were applied to assess the strength of the relationship between the estimation factors and expert groups. As can be seen in Table 30 and Table 31, the experts evaluated the importance of each estimation factor. All factors have been used, and their mean values are between 4 and 5 (important to very important), thus have been incorporated into the estimation framework. Figure 90 to Figure 94 in the Appendix C show the mean values for all the factors by the experts' roles.

The Mann-Whitney test was applied to assess whether the two sample means of the groups' variables are equal or not. As can be seen from the test results in Table 30, there are 13 observed significant relationships between the expert groups for the estimation factors, as shown in Figure 45. The variance in the "push notification" factor, for example between the project manager and QA, is high, showing that the project managers are concerned with this factor and consider it important to estimation, whereas the QA team considers it not to be important.

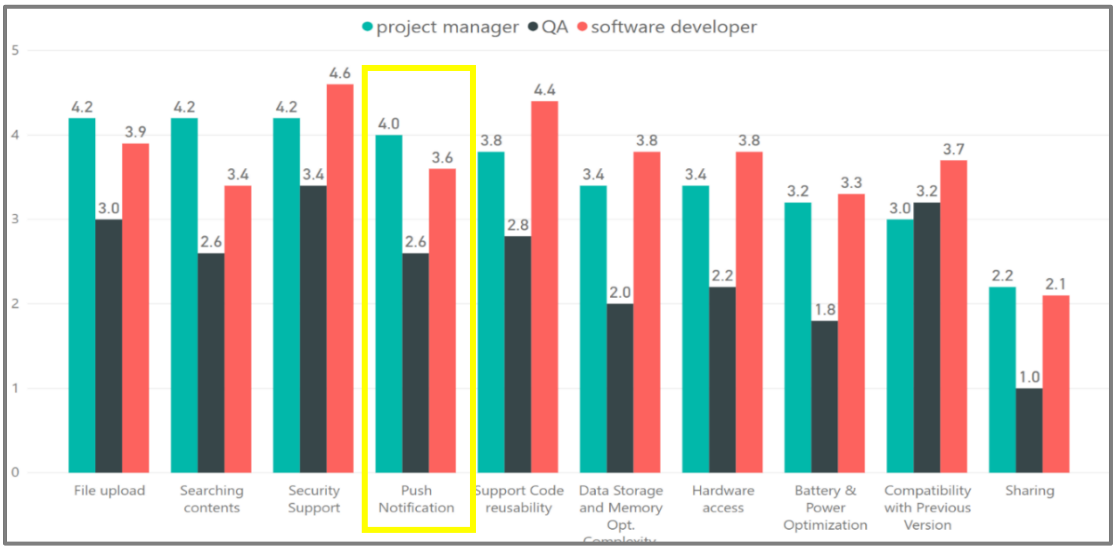


Figure 45: (13) Factors that have a significant relationship, according to the Mann-Whitney test

In addition, a one-way ANOVA test was applied to obtain the relationship between the factors for all three expert role groups. This result can be used to validate the findings from the Mann-Whitney test. Four significant differences between factors were obtained, in terms of experts' role groups (see Figure 46).

Taking the example of the 'Support code reusability' factor, the mean value for software developers is 4.4, which represents 'important-very important'. The QA teams, by contrast, does not believe that 'Code reusability' is a matter of importance, since their mean value is 2.8, which represents 'neutral-not important'.

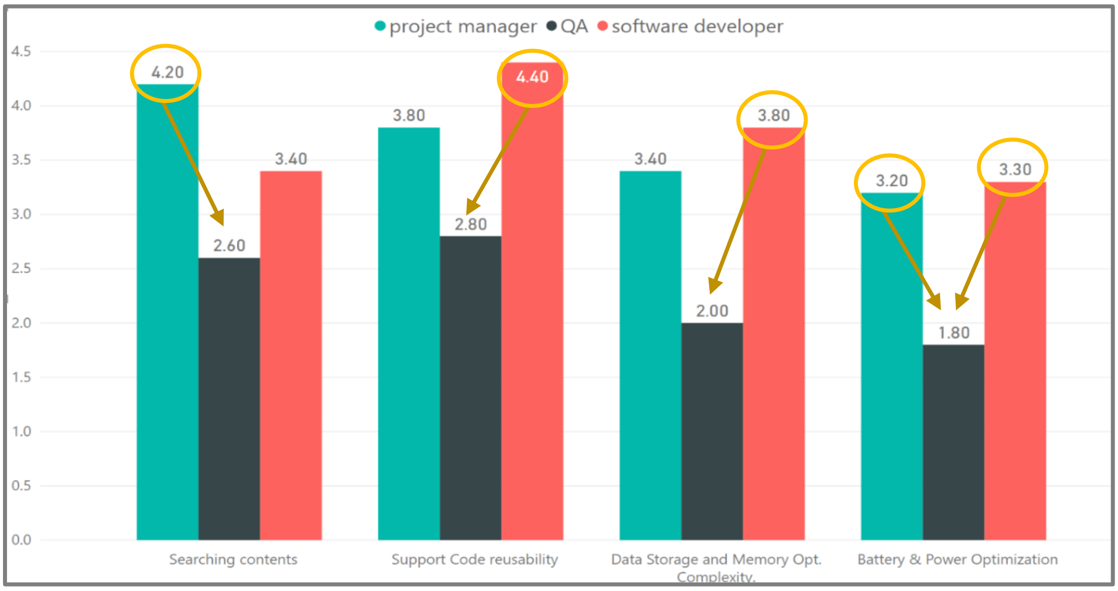


Figure 46: (4) Factors have a significant relationship with the one-way ANOVA test

Finally, a coefficient correlation was used to ascertain the strength of the relationship between two estimation factors. From the correlation results, shown in Table 34:

Coefficient correlation for selective effort estimation factors, a significant relationship was found for nine estimation factors, highlighted in green. These are positive relationships. It can be seen that there is a very strong relationship between the following three factors:

1. Backlog item complexity
2. Developer's implementation experience
3. Dependency between backlog items

Any of these three factors can affect the others, therefore it is possible to see an association between the three: If an expert is concerned with any, for example 'Backlog item complexity', he/she should think about 'Backlog item dependency' and 'Developer implementation experience'. This is a positive relationship, as shown in Figure 38, which means when one factor is considered to be an important factor, the other is important as well. In addition, there is a positive relationship between the two factors of 'User interface quality and complexity' and 'Deadline date' as shown in Figure 48, where the former can affect the deadline submission of a user story.

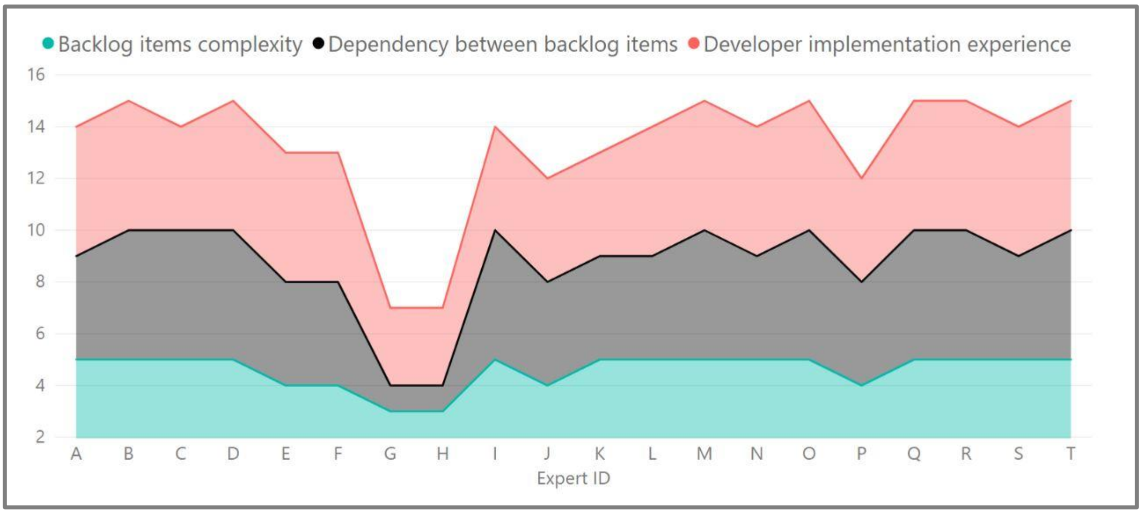


Figure 47: Relationship between the three factors: Backlog item comp, dev. Implementation exp. and backlog item dependency

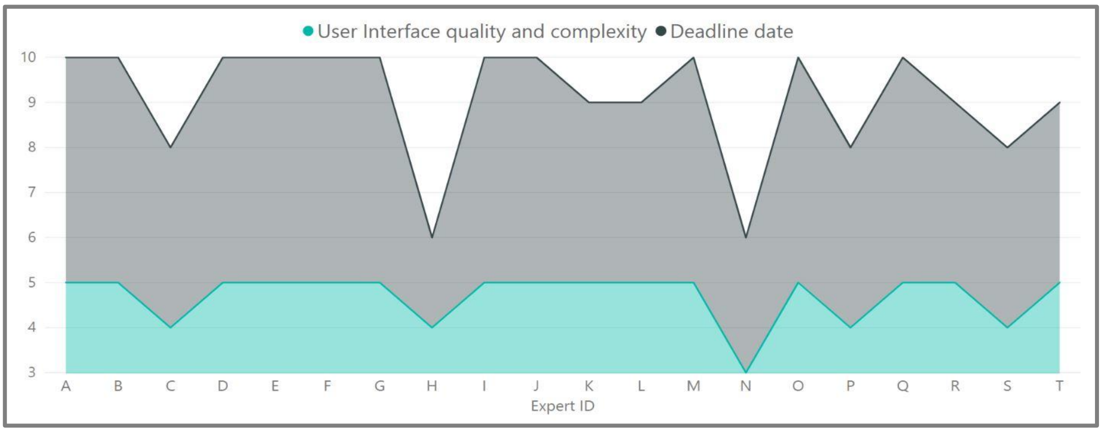


Figure 48: Relationship between two factors: interface comp and deadline

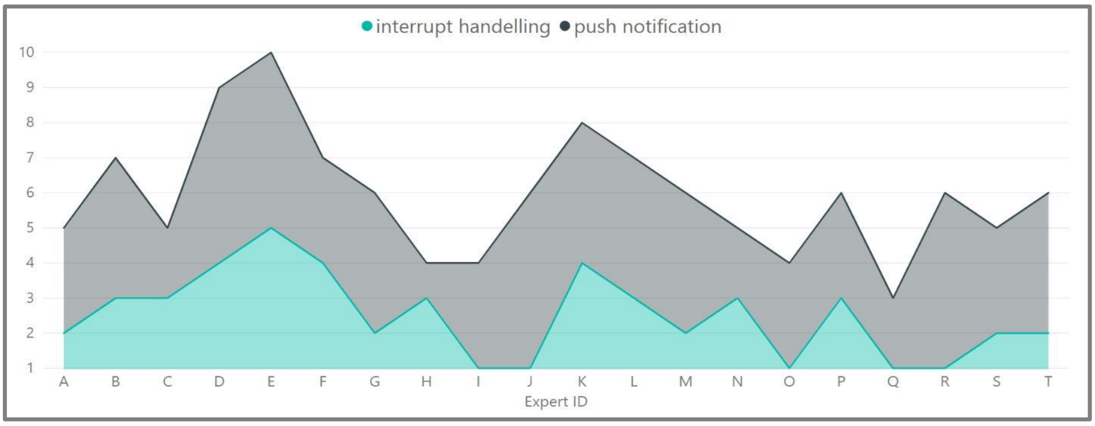


Figure 49: No relationship between two factors: interrupt handling and push notification

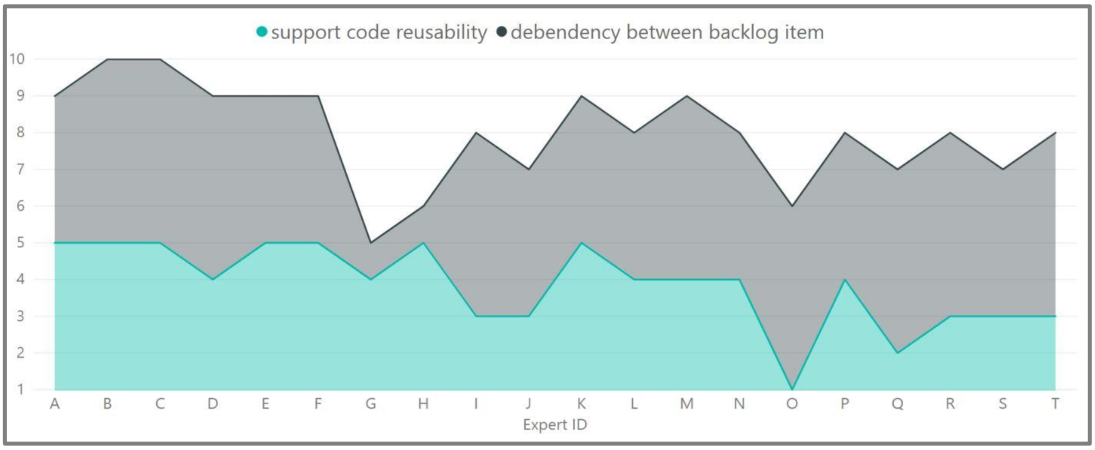


Figure 50: (negative relationship) No relationship between two factors: support code reusability and dependency between backlog item

Qualitative analysis

The experts were asked to add further factors that they use during estimation. From the qualitative analysis, 20 additional factors were obtained that they rely on in the estimation phase in the Agile process. The effort estimation factors have been categorised according to the analysis of the experts' responses and the resulting patterns, themes and coding. The factors are:

1. The complexity of the user story 'task': the experts defined the complexity of the user story for mobile app projects as follows:
    a. The transaction's journey (from request until response time)
    b. The clarity of the business requirement 'user story'
    c. Whether the expert uses an existing code or function in a task
    d. If a task relies on other tasks or is stand alone
    e. Investigate all scenario cases for a task
    f. If an expert conducted a similar task before or not
    g. Complexity of the application forms
    h. Methods and approaches to implement business logic into a code
2. Technical factors: this factor consists of multiple sub-factors:
    a. Library and tools availability
    b. Local and backend database / store procedures
    c. Number and complexity of third party / web service / system integration
    d. Existing API and clarity
    e. Backend response structure
    f. UI animation and graphics
3. Other factors:
    a. Prototype and fidelity design code testing and log files
    b. Data validation
    c. Quality triangle and definition of IOS / Android standards
    d. Team enthusiasm and motivation/ balancing of skills
    e. Team member movement
    f. Pressure time

Summary

To sum up, all the effort estimation factors were analysed both quantitatively and qualitatively, and several associations between factors were found. Most factors have a strong influence on the effort estimation value on the basis of the experts' evaluations. The effective factors will be presented in a single table and used in the proposed effort estimation technique.

7.3.3. Effort estimation process

From the qualitative analysis, each of the experts shared their experience of applying estimation techniques in their organisation. The answers have been analysed, and important themes, patterns and relationships between the collected data were recognised and presented in section 7.2.1: Effort estimation process. From the results, relationships between the themes are as follows:

- If a task is to be done by a developer, then:
    - most of the experts preferred that: the developer assigns the estimated effort value for the task. See Finding 1 in Figure 51.
    - the expert accepted a certain level: the team leader assigns the effort value for the task. See Finding 2 in Figure 51.
    - the experts did not prefer the effort value to be assigned to a different senior developer. See Finding 3 in Figure 51.
    - the experts did not prefer the effort value to be assigned to all the team members. See Finding 4 in Figure 51.
- If the user story 'task' is to be done by all development team members, then:
    - most of the experts preferred the effort to be assigned to all development team members. See Finding 4 in Figure 51.
    - the experts at a certain level accepted the effort being assigned by an expert senior developer. See Finding 3 in Figure 51.
    - the experts did not prefer the team leader to assign the estimated effort value. See Finding 2 in Figure 51.
    - the experts did not accept the estimated effort value being assigned by a developer. See Finding 1 in Figure 51.

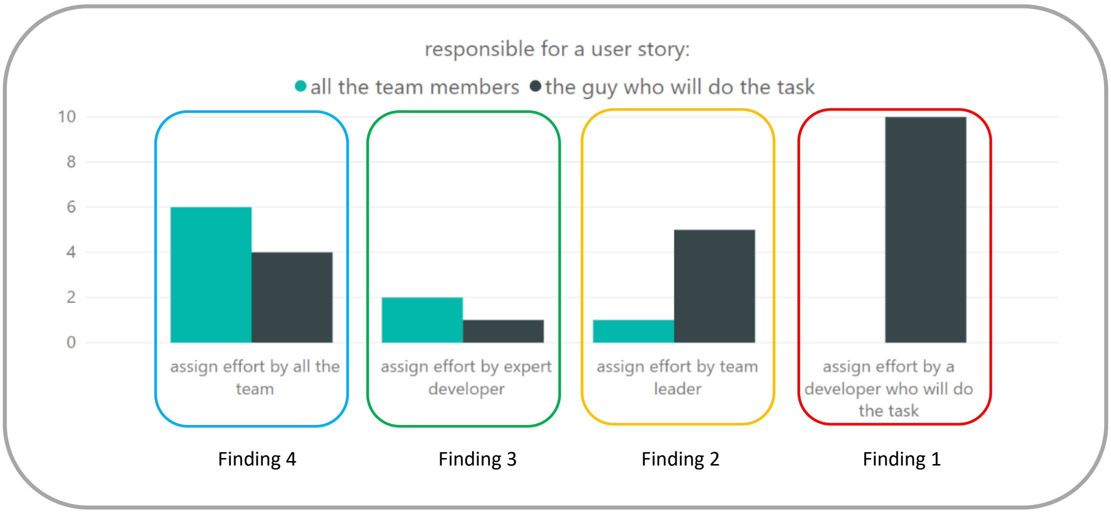


Figure 51: Expert opinion on the estimation process

7.4. The Initial Proposal of the Effort Estimation Technique

The previous sections, 7.1, 7.2 and 7.3, presented the analysis of the estimation factors and techniques used for mobile app development quantitatively and qualitatively, based on the survey and interviews. Following on from this, the present section provides a proposed effort estimation technique in a checklist format. The first part of this section provides the background of the current state of practice and existing models used for estimation of effort. Section 7.4.2 presents an overview of the proposed effort estimation technique for mobile apps. Section 7.4.3 presents the opinions of 20 experts on the suggested estimation technique, as obtained in interviews. Finally, section 7.4.4 provides the full details of the process and initial design of the proposed effort estimation technique.

7.4.1. The background of the proposed estimation technique

Before discussing the initial proposal of the effort estimation technique, it is necessary to summarise the research analysis and other articles and studies on effort estimation techniques. From the results of the data analysis, it was found that the EJ and PP techniques are the most commonly used by companies to estimate the effort in mobile app development. From the SLR, few research studies were found to have investigated the EJ technique for this use. Moreover, other reviews on effort estimation in the Agile process show that EJ and PP were the most commonly used in the Agile process from 2001 to 2013 (M. Usman et al., 2014). An update of a previous SLR was presented by Dantas (Dantas et al., 2018). This covers the period from 2014 until 2018 and contains 24 articles, and it reveals that PP is the most cited article, relying on expert subjective assessment, and story point as the most reported size metric. Moreover, a survey on the state of practice for effort estimation in the Agile process involving 60 practitioners in 16 countries shows that 63.3% used PP, 46.67% used analogy and 38.3% estimated effort by EJ, while only 1.67% used the COCOMO model (Usman, Mendes & Börstler, 2015). To sum up, practitioners rely on expert subjective assessment to estimate effort, not a formal model. Over a thousand research studies have reported on formal software development effort estimation models, yet existing empirical studies show such models are little used (Jørgensen et al., 2009).

There is a debate between Jørgensen and Boehm (2009) over the best approach to estimating the effort in developing software. The article found that formal models are less used than EJ, and 10 out of 16 studies show that the EJ-based effort estimation technique is more accurate than formal models. This debate lists several reasons why EJ is more accurate and most used. Formal models, such as COCOMO, rely on essential inputs, such as the line of code of function point, which is based on EJ. As a result, ultimately, accuracy is based on expert judgement. Magne argues that a combination model, using both a formal model and expert judgement, are easy to claim yet less easy to implement and translate into an organisational decision. A better structured process for the EJ model, with further supporting elements such as a checklist, will improve the effort estimation accuracy of this model.

7.4.2. The overview of the initial proposal of effort estimation technique.

From the background and analysis, EJ and PP are the most commonly used and suggested for use in effort estimation. However, these techniques, especially EJ, lack formality. PP has a clear process for estimation, yet still the development teams assign their estimate figure on the basis of ad hoc activity in estimation rounds. There is a need to enhance current estimation techniques.

For this reason, the proposed enhancement will adapt these techniques of PP and EJ, and will contribute a proposed estimation technique in the current study. A checklist is the solution proposed to organise the estimation process by documenting the relevant factors and activities to be considered during the estimation. The checklist is widely used in software engineering and specifically in effort and cost estimation (Jørgensen, 2004a). Harvey provides the advantage of using checklist that improve judgment in forecasting by support people remembering important variables and reduce inconsistency (Harvey, 2001). Passing and Shepperd evaluated the checklist technique by performing an experiment with student, and resulted an improvement on the size estimation accuracy (Passing & Shepperd, 2003). Moreover, the checklist process has been evaluated empirically in three companies (M. Usman, Petersen et al., 2018), improving the accuracy of effort estimation in all three companies. There are many advantages in using a checklist in effort estimation (Furulund & Moløkken-Østvold, 2007; Jørgensen, 2015; Muhammad Usman, Petersen, et al., 2018), as follows:

- Improving the team's confidence in estimation.
- Reminding the development team of important factors during the estimation process.
- Improving the estimation process.
- Helping to understand the implementation of complex tasks by giving an idea of the tools and libraries that need to be used in this task and of the implementation and the structure of the tasks' code.
- It is helpful for a new team member.

7.4.3. Experts' opinion on the Checklist's based technique

At the end of each interview, a question was put to the experts about the checklist process in the estimation technique. Before asking the question, a brief explanation of the checklist was provided to give them an idea of the checklist method. The question was as follows:

Question	Answer
Do you think the Checklist process will help you to improve your estimation accuracy?	

All the experts answered this question, and the results are shown in Table 44 below.

Table 44: Experts' opinion on Checklist process for effort estimation

	Frequency	Per cent	Cumulative per cent
I think it will be helpful	18	90.0	90.0
I do not know	2	10.0	100.0
I do not think it would help	0	0.0	0.0
Total	20	100.0	

Ninety per cent of the experts believed that the checklist could help them to consider all task aspects when estimating the effort required to implement a task. Some interviewees claimed that there is a danger of omitting important factors during the estimation process that could affect the estimation value and that the checklist method will encourage estimators to recall these factors. On the other hand, 10% of the experts did not know if this model would help to give an estimation value or improve its accuracy. However, no one thought that this model would not be helpful.

Some experts justified their answers. For example, Expert J explained that a checklist would act as a guideline for estimation, and Expert K noted that using a checklist would enhance the accuracy of estimation, and suggested having one for project managers and one for the development team, as each group has a different interests and perspectives on estimation. Expert F and M claimed that checklist required less computational process comparing with other formal techniques, and encourage a developer to have the confident to give the estimate value.

7.4.4. The design of the initial proposal of the effort estimation technique

Collaboration between development team members is essential to construct the checklist's procedure, technique and content. Generating the content can be achieved when the development team meets and decides on the main and critical factors to be considered during the estimation process. Understanding the estimation technique is mandatory to specify how and when to use the checklist during that phase. The development team members could generate multiple checklist forms for a specific team, based on the roles in the development cycle. Figure 52 gives an overview of the workflow process for how to design the proposed estimation technique. The process structure helps the researcher and experts use the output from the survey method as an input for the upcoming method “case study” on how to build and generate an estimation technique based on a checklist form. The process contains from three major elements to proposed effort estimation technique, and the three elements are:

1) Effort estimation factors for mobile apps: multiple effort estimation factors were obtained from the SLR, and 20 experts were asked to classify and identify the important factors before defining further factors for mobile app development. The factors have been classified as functional, non-functional and development process.
2) Development team members: this is all developers and QAs in the team; it includes all project managers involved in the project.
3) Estimation techniques: PP and EJ are the most commonly used in the IT sector based on the SLR and other research studies. The proposed technique need to rely as a concept on these two estimation techniques.

The effort estimation factors, as described in element (1), need to be discussed with specialists from several IT companies, in element (2), with concern of the most used estimation technique in IT market, as explained in element (3). From these three elements, a deep thinking and group discussion are required with experts from several IT companies to generate a proposed estimation technique as explained in the element number 4 of the process:

4) Generate a proposed estimation technique and its process: collaborative work between the development team or a representative from each team to design a proposed estimation technique. To generate the proposed technique, there is a need to:
    - undertake collaborative work between the development team members to refine their current estimation technique and process, and make sure it is adaptable to their development and organisation process.
    - encourage the development team members to use and employ the estimation factors as a checklist, for example to support them to provide an accurate estimation.
        - How to adapt the checklist to an estimation technique
        - What are the checklist contents
5) As a result of group discussion, an estimation technique will be proposed.

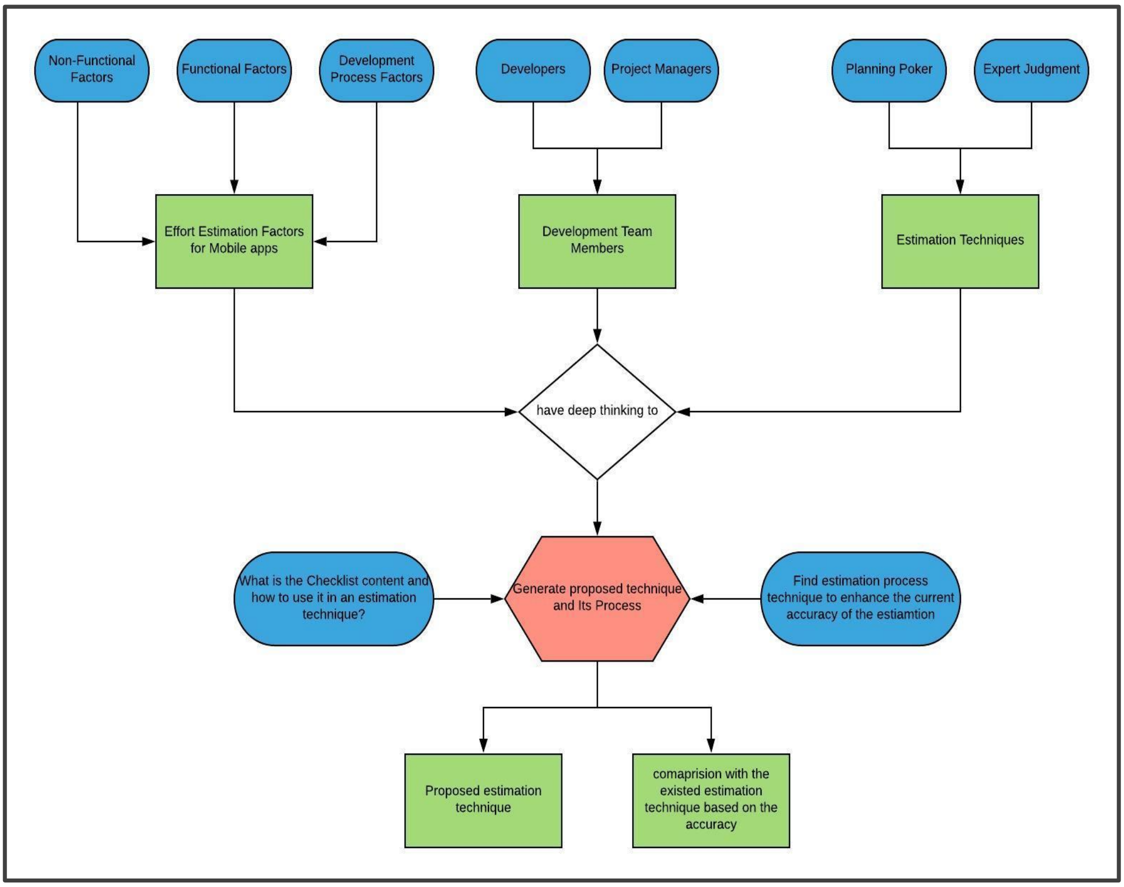


Figure 52: Design process to build the proposed effort estimation technique

7.5. Limitations of the Interview Method

The interview method has limitations in terms of its potential shortcoming in conducting sessions. One of these is participants fearing to speak freely to share their experience with the researcher. Another is the researcher could missing part of the interviewee's dialogue; moreover, there is a chance that the researcher could misinterpret a participant's explanation. To mitigate against these limitations, the researcher constructed a thematic analysis form to record participants' responses and re-listened to the audio recordings of the interviews to ensure a correct interpretation and record of the information.

In addition, it was hard for the researcher to access companies to apply this survey method; therefore, some of the participants was based on the researcher's connection. The researcher has worked for several companies in different countries, and he selected some of his samples based on these previous work experiences. Moreover, the researcher asked the participants to nominate other experts to participate in this survey, and this approach helped the researcher to involve more experts from multiple companies to obtain data from several resources.

7.6. Summary

This chapter provided the analysis of the survey method both quantitatively and qualitatively. The survey included semi-structured and structured questions that covered estimation, using the Agile process, in terms of its techniques, process, accuracy, efficiency and factors for mobile app development. The survey involved 20 participants across 18 organisations with varied background experience: Quality assurance; mobile developers, both senior and junior; and Project management. EJ was the most used technique for effort estimation, used by 75% of participants.

The survey evaluated the 48 factors that could affect effort estimation accuracy; a further 20 factors were provided by the experts. The total number of factors collected and evaluated is 68, and is regarded as comprehensive. Around half of all estimates of the effort involved in projects is inaccurate by 25 to 45%. This survey discussed the estimation processes and methods used in the IT sector and evaluated their efficiency. This chapter also provided an initial proposal of an effort estimation technique based on a checklist, to be evaluated and validated as a case study in the IT sector.

Chapter 8: Data Collection Preparation for the Case Study

Interviews were conducted with 20 experts from 18 organisations to investigate the state of practice in effort estimation techniques using Agile processes and the factors affecting mobile app development. The results described in the previous chapter need now to be validated in a case study. This chapter provides a clear plan and design for the three case studies, and the results are given in Chapter 9. The first two sections will discuss the scope and main objectives. Following this, the possible scenarios and its processes are given in sections 3 and 4. Lastly, the case study questions and data collection methods are provided in section 5.

8.1. Overview of the Case Study

Case study can be called a 'field study' or 'observational study', and involves focusing on a particular aspect of the research methodology (Runeson et al., 2012). Robson defines case study as a research strategy that involves an empirical investigation of a specific contemporary phenomenon within its context, using multiple source of evidence (Robson, 2002). In a software engineering context, a case study is defined as an 'empirical enquiry that draws on multiple sources of evidence to investigate one instance (or a small number of instances) of a contemporary software engineering phenomenon within its real-life context, especially when the boundary between phenomenon and context cannot be clearly specified.' (Runeson et al., 2012). In this case study, there is empirical investigation of effort estimation techniques in three companies to understand how they estimate the effort involved in user stories to develop a mobile app and verify the influence of estimation factors/predictors on the accuracy of the effort estimation. In addition, through the case study the development teams will be encouraged to incorporate a proposed technique into their companies' current estimation technique to measure its efficiency.

Several elements need to be considered in the design of the case study (Runeson et al., 2012; Runeson & Höst, 2009).

8.2. Objectives of the Study

The expected achievement of a case study should be stated as a result of undertaking the study. In general, there are four types of research design strategy: explanatory, exploratory, descriptive and improving the research purpose (Runeson et al., 2012; Saunders et al., 2009). The research design strategy for this study is based on exploratory and explanatory strategies, as discussed in Chapter 3, to find out the current state of the practice and seek an explanation for a situation or problem. In this case study, a strategy to improve certain aspects of estimation accuracy is added.

To establish the objective and goal of the case study, a question may be posed to simplify and make it clear what is expected to be achieved by the case study. The objectives are to:

- Understand the current state of the practice of the estimation process using the Agile process and its techniques used in mobile app development, and evaluate the accuracy of the current estimation techniques in an organisation.
- Better understand of estimation method and the factors that affect the accuracy of the estimation value.
- Explore the effectiveness of the current estimation techniques, PP and EJ, in the context of mobile app development.
- Explore the challenges that affect estimation accuracy.
- Validate the effectiveness of effort estimation factors/predictors of the estimation accuracy.
- Examine the validity and effectiveness of the proposed estimation techniques and its adoption in an organisation.

8.3. The Case Study and Unit of Analysis

The case is usually considering and examining a contemporary phenomenon in the real-life context based on Yin's definition (Yin, 2009). In this research study, the research context of the case will be a mobile app development project using Agile in multiple companies to examine their effort estimation models and measure their accuracy and efficiency (Runeson & Höst, 2009; Yin, 2009). There are two types of case study:

- holistic case study, which is examining the case as a whole; and
- embedded case study, which is examining some aspects within the case.

Since case studies are proposed in three companies to investigate their estimation accuracy over an extended period of time, based on the research context, the embedded case study design will be used to investigate several issues and aspects. Holistic case study design has limitations in terms of both access and authority from the companies' development teams to assess and measure all aspects and issues. The embedded case study design will emphasise the investigation into two major aspects within the case:

- The accuracy of the effort estimation for the proposed technique over Agile sprints; and
- The effectiveness of the estimation factors/predictors in the estimation techniques.

The case study will be conducted in companies chosen using the following criteria, to obtain valuable results from an appropriate domain:

- Projects should follow Agile processes in software development.
- The company has experience of applying Agile processes in software projects.

- The project should be a mobile app, or contain a mobile app as a part of its development.
- Team members have experience in Agile process and mobile app development.

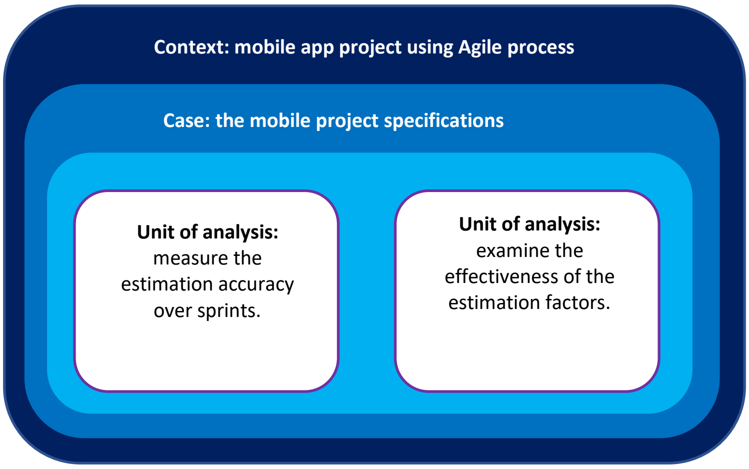


Figure 53. Case study type: embedded case study

8.4. Case Study Process and Possible Scenarios

The case to study is based on the company's project, in order to collect the data and to observe and validate the accuracy of the proposed model, confirming the most influential factors in effort estimation. The process of the case study is shown in Figure 54.

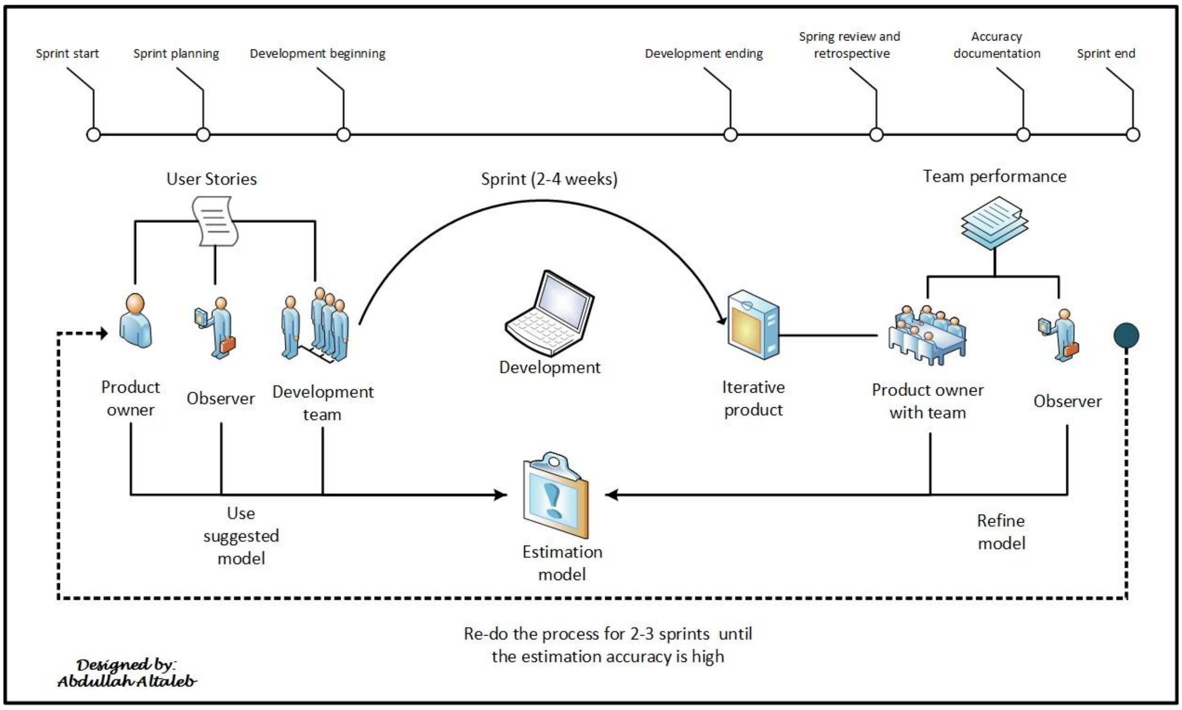


Figure 54: Overview of the case study

The case study in all the companies will be directed and processed as in the following steps. However, some companies impose limitations and constraints on the accessibility of the data and/or communication with the development team during the case study. Therefore, the case study scenarios will be based on the feasibility of access to the information.

8.4.1. Step 1: Obtain historical data from previous projects

At the beginning of the case study, the observer/ the researcher will discuss with the project manager/product owner the following:

- Previous estimation models or techniques the company has followed in previous projects.
- Historical data of project and team performance to know the speed of the development team.
- From the data history, discuss the accuracy of the estimated effort and actual effort of the project overall and the user stories to establish the accuracy of estimation.
- If historical data of previous projects are not available, for any reason, the project manager or product owner needs to share a rough guide to the company's accuracy of estimation, based on his/her experience, for example within 20 to 30%. The product owner could consult an appropriate person from the development team to indicate this accuracy level.

8.4.2. Step 2: Types of current estimation techniques

From the previous data, there are two possibilities:

- If the company has a model or technique to estimate development effort, hold a focus group meeting with the product owner and the development team to discuss:
    - How to improve the existing model or technique.
    - Present the proposed technique checklist model and discuss whether the model could help to improve their estimation.
    - How to introduce/adopt the proposed model into the current estimation model.
    - Assess the effectiveness of the estimation factors/predictors in terms of accuracy.
- If the company does not have model or technique to estimate the effort of a user story, consider whether the company is following an EJ technique, then conduct a focus group meeting and follow the first option.

The effectiveness of the adoption of the estimation factors and the proposed technique by the company needs to be measured. In section 4 there is further clarification of the data collection methods and focus group approach.

8.4.3. Step 3: Nature of the project

After conducting the focus group meeting with the development team members, the observer and product owner will discuss the type of project to start the case study. The project should satisfy the criteria discussed in the case study context and phenomena from section 8.2. The case study could be applied to either a new or an existing project.

There are two possibilities for a case study in a company: a new project or a current project. If the company is planning to start a new project and need to apply the case study to that project, historical data from previous projects are needed, if available, as discussed in Step 1. On the other hand, if the company is working on an existing/current project, there is a need to wait until the current sprint is ended, then start the case study on the next sprint. While waiting for the next sprint, the observer needs to contact the product owner regarding the performance of the development team and their estimation values. Figure 55 shows a flow chart of the possibilities of working on a project. At this point, the following information needs to be gathered before proceeding to Step 4, Sprint planning event:

- The historical data of previous project or sprint.
- The current and previous effort estimation technique and model of the company.
- The accuracy of previous estimation from previous project or sprints.
- The type of projects to which to apply the case study, whether a new or existing project.
- Conduct a focus group and discussion on improving the estimation accuracy.

As explained before, some data may not be provided due to companies' privacy and/or limited access to the data.

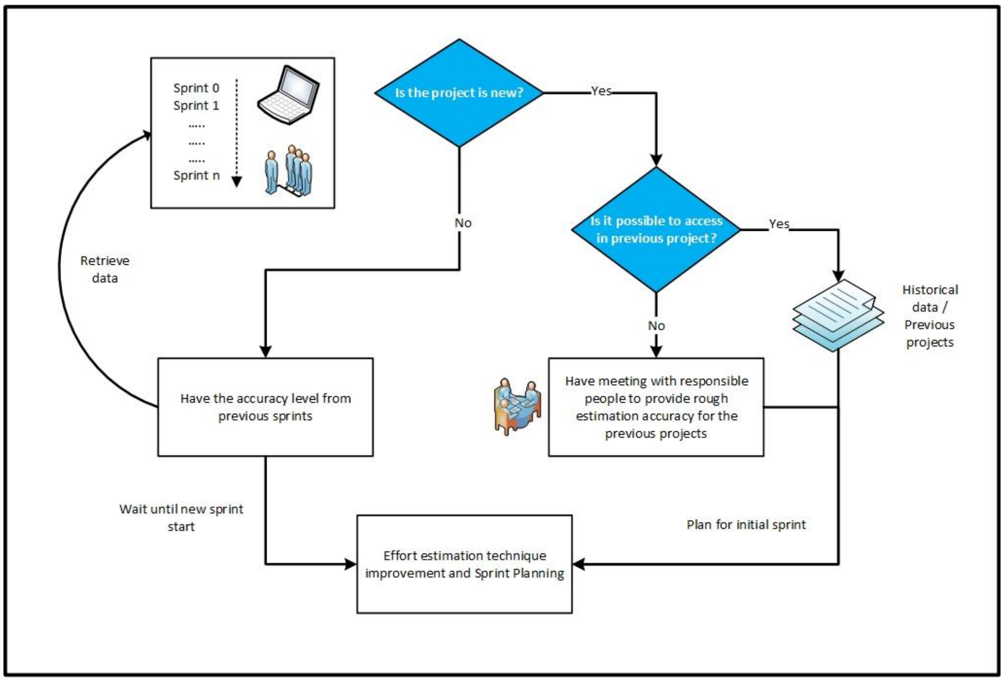


Figure 55: Nature of the project to which to apply the case study and its possibilities.

8.4.4. Step 4: Sprint planning, review and retrospective phase

In the sprint-planning phase, the development team members should follow and apply what was discussed and agreed at the focus group meeting regarding the estimation process. The observer ensures that the proposed estimation process or technique is conducted appropriately.

At the end of the sprint, various activities are conducted regarding sprint review and a retrospective event:

- Obtain the actual and estimated effort for the sprint.
- Compare the estimated effort to the actual effort to measure the accuracy level of the estimation for the sprint.
- Compare the accuracy level to previous projects at the organisation to measure the improvement and find out the effect of the proposed technique/process and the estimation factors/predictors.

Figure 56 shows an overview of measuring the accuracy of effort estimation in a sprint.

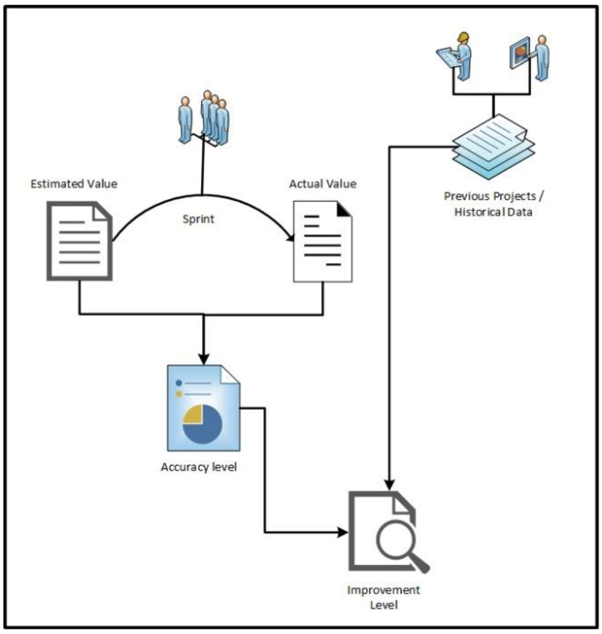


Figure 56: Measurement of the effort estimation accuracy

At the sprint review event, there are two possible scenarios we could have:

- If there is improvement in the accuracy of the effort estimation, another focus group will discuss any suggested improvements in the model to provide more accuracy in the estimation value. Also, if the accuracy of the effort estimation in the current sprint is better than previous projects or previous sprint, another sprint will apply the estimation model to confirm its accuracy and ensure the proposed method works properly.

- If there is no improvement in the accuracy of the effort estimation, another focus group will diagnose the problem with the model and make suggestions to improve the estimation of the subsequent sprint.

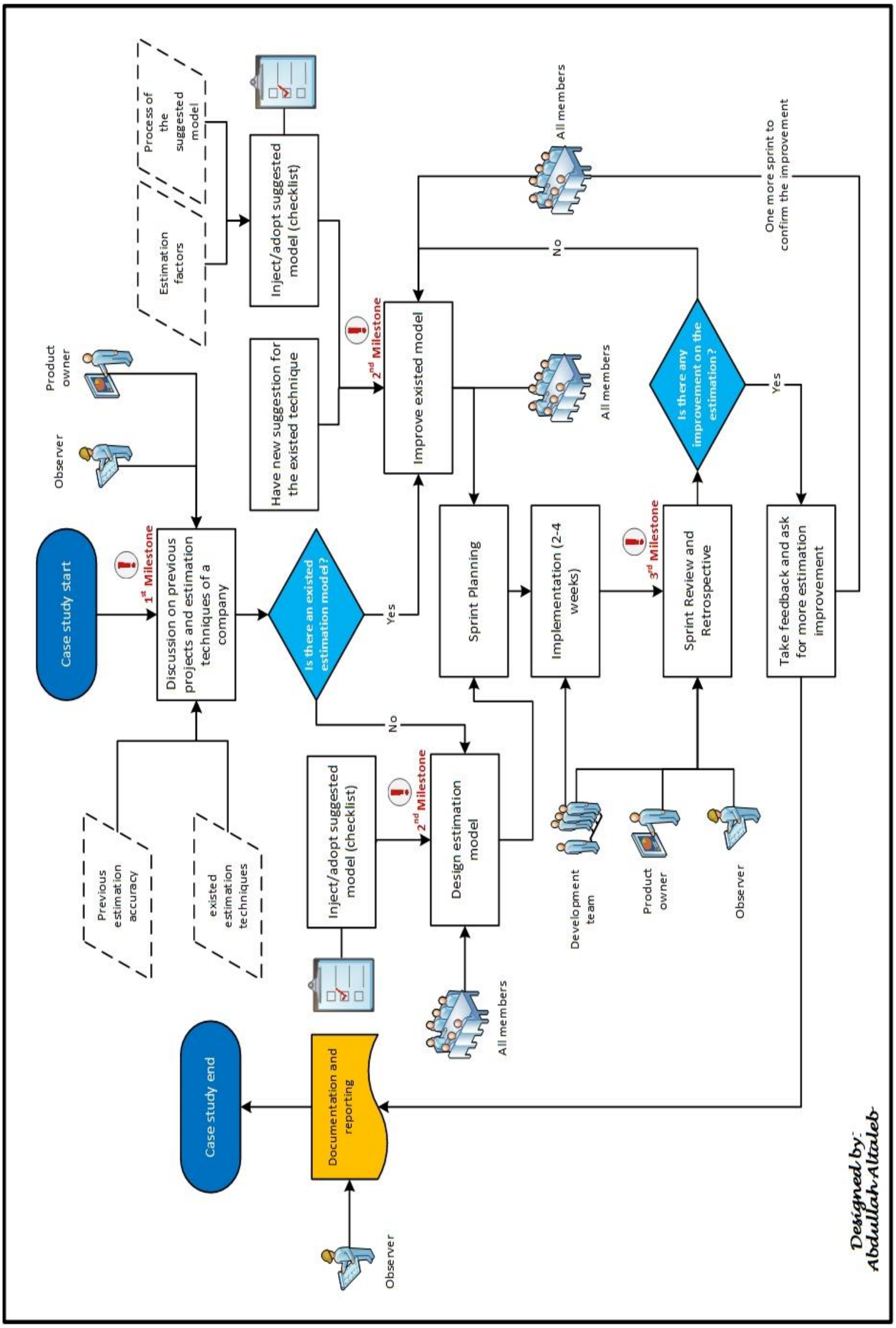


Figure 57: Case study process

8.5. Case Study Questions and Data Collection Methods

8.5.1. Data collection method

This section clarifies the data collection method and approach of the case study. There are three types of methods of collecting data: direct, indirect and independent. The direct method involves contact with practitioners in the case study, such as interviews and focus groups. The indirect method obtains raw data without contact with practitioners, such as using tools to mentor a practitioner's performance and productivity. The final approach is the independent method, which relies on analysis of documentation and reports. In this case study, both direct and indirect approaches are taken to obtain data for the case study.

The direct method of data collection through a focus group will be used in the case study, allowing the observer/researcher to maintain full control over the collected data and obtain them in the required context and form. A focus group is an interview with a group of participants, asking questions to stimulate discussion and obtain responses. In addition, a discussion and interview will be conducted with the product owner on the behaviour and performance of the development team, which represent indirect methods. Moreover, there will be observations of the development team's behaviour and approach to estimating their effort in the sprint planning event to understand their estimation process. The questions of the case study of both methods, direct and indirect, are discussed in more detail in the following section.

8.5.2. Selecting the data

As stated in section 8.2, criteria need to be applied to the case study at the organisation. Since the study takes both direct and indirect methods, more needs to be known about the source of the data for each. In the focus group, questions will be put to several practitioners at the same time in one session to obtain new insights and opinions from all practitioners regarding their estimation techniques' efficiency, process and potential improvement on the estimation models currently used in their organisation. From the discussion, results concerning the estimation model can be confirmed that would be difficult in individual interviews. Particular topics and issues will be raised in the focus group session to encourage participants to share their points of view freely to reach consensus. Participants will be selected for their characteristic and roles, as discussed in section 8.2 and 8.3.

The observation method is another to be used in the case study to collect data. This relies on the think-aloud protocol, where the observer asks questions of the product owner and has a discussion about the estimation techniques used in previous project and the main causes of the low accuracy seen in the project's documents. Also, during the development phase of a project, the developer's behaviour will be observed, if possible, and how they estimate their user stories and assign an value to each story. Moreover, observations will be made during meetings with the product owner to understand the current estimation models of the company and the main causes of their low accuracy.

8.5.3. Case study questions

The research questions cover what is required or expected to be found by the case study in order to satisfy and achieve the case study's objectives. Usually, the nature of the research questions in the case study is 'why' and 'how'. The general questions of the case study are stated as following:

- How did the development team estimate the user story's effort during sprint planning?
- What are the existing estimation techniques' accuracy and performance?
- How can the development team improve the accuracy of the current estimation technique?
- What is the effectiveness of the estimation factors/predictors and their impact on the accuracy of the estimation?

The above questions are general enquiries about the estimation technique and processes that need to be investigated and observed in the case study. In the process, there are three major milestones, as shown in Figure 57, that involve further investigation and observation to record and obtain required data:

1) The start of the case study: preparing historical data from previous projects/sprints and understanding the current estimation technique in the organisation,
2) Before sprint planning event: having a discussion before the event on the suggested improvement to the current estimation technique, and
3) Sprint review and retrospective event: measuring the accuracy of the estimation and improving the estimation model, if needed.

For each milestone, the researcher needs to determine which data collection method to use, then ask questions, observe behaviours and investigate the current situation of the development team. The following provides the appropriate research method for each milestone and states the questions to be answered.

Frist milestone questions: at the start of the case study

The main point of the first milestone of this case study is to understand the current status of the company and the performance and velocity of the development team. Also, in the first milestone, the estimation technique that has been used in the previous projects/sprints has to be ascertained. As has been discussed in Step 3 in section 8.4, at the beginning of the case study there are two possibilities for each case study: working with a new project; or working on an existing/current project. Moreover, there are two possibilities about the access to data: the company is willing to share their data; or the company is reluctant. Table 45 presents all the possibilities of the case study project to be worked to, either in a new or a current project. Table 45 shows the data collection approach and who is to be involved and participate in this study. The questions are to meet the various possibilities, based on the project type and data collection method.

Table 45. First milestone questions of the case study process

Project type	Accessibility of data	Data collection method	Participants	Questions
New	Yes	Indirect method (observe the raw data from previous projects documents)	Observer, Product owner	What was the estimation technique and process that used in an old project?
				How was the accuracy for each sprint of the old project?
				What was the development team level of experience, their development velocity and challenges from an old project?
	No	Direct method (focus group)	Observer, Product Owner, Development Team	What was the estimation technique and process that you have used?
				From your working experience on previous projects, how was the estimation accuracy of your development for the user stories?
				What was the challenge of your estimation?
Existing	Yes	Indirect method (observe the raw data from previous Sprints documents)	Observer, Product owner	What was the estimation technique and process that used in previous sprints?
				How was the accuracy for previous sprints of this project?
				What was the development team level of experience, their development velocity and challenges from previous sprints?
	No	Direct method (focus group)	Observer, Product owner, Development team	What was the estimation technique that you have used?
				From your experience of this project, how was the estimation accuracy of your development for the sprint?
				What was the challenge of your estimation?

Second milestone questions: before sprint planning event

The second milestone of the case study is basically focused on what to do in the following sprint of the project, how to estimate the effort of the user stories, and how to improve the current estimation model that the company has previously used to estimate effort and its effectiveness. Also, before starting the sprint planning event, the proposed technique checklist will be provided to the participants to ask them about their opinion and suggestions for any possible improvement/enhancement to this model.

Table 46. Second milestone questions of case study process.

Data collection method	Participants	Questions
Direct method (Focus group)	Observer, Product owner, Development team	From the previous sprints/projects, how can we improve the estimation technique to obtain high accurate estimation? Any suggestion technique or improvement model?
		What is the effectiveness of estimation factors on the estimation accuracy and how can we rely on during your estimation?
		How can we adopt the proposed technique, checklist model or the team suggestion's technique, in the current estimation technique?
		How can we avoid the challenges from the previous/old estimation techniques?

Third milestone questions: sprint review and retrospective event

The third milestone is basically about the evaluation and assessment of what was done in the second. At this milestone, the estimation accuracy of the suggested technique is assessed and its efficiency examined. In Step 4 of section 3, the process and approach to measure and evaluate the accuracy level of the suggested estimation model is described. There are questions to be asked, as shown in Table 47.

Table 47: Third milestone questions of case study process.

Data collection method	Participants	Accuracy level (compared with previous sprint/project)	Question
Indirect method (observation)	Observer, Product owner		From the velocity and development performance of the development team, what is the accuracy level of the estimation model?
Direct method (focus group)	Observer, Product owner, Development team	High	What was the elements that make the suggested model provide accurate estimation?
			What are your suggestions that could make the proposed model provide more accurate result? If possible
		Same or Low	What was the main challenges that make the suggested model is not working?
			Are there any challenges when you are applying the proposed model?
			How could we improve the model?

8.6. Ethical Considerations

Dealing with human participants raises ethical issues that need to be addressed. The case study questions and observation scenarios were formulated to be respectful and appropriate to the participants. An information sheet and a consent form were given to all participants to sign before taking part in the case study to ensure that they were happy to participate and understood what was involved. To ensure the confidentiality of the participants and build trust between the researcher and the participants, they were assured that the stored data would not be linked to their names or their organisation's name. The data will be stored on secure systems during the research study. Once the research is completed and the results from the data analysis achieved, the data will be destroyed by deleting all data files relating to the participants on laptops, desktops, emails and physical data through shredding paper documents and deleting electronic files, including audio recordings.

Ethical approval was granted by the Ethics Committee team at the University of Southampton under reference number: 52598 on 29/08/2019. The application included many forms: Data Protection Authorities form, which is responsible for protecting the personal data of the participants; the Participant Information Sheet; the Consent form; and the Risk Assessment form.

Chapter 9: Analysis and Discussion of the Case Study Results

This chapter discusses the case studies conducted in three companies. The aim was to observe the current state of practice in effort estimation techniques used in the companies and validate their efficiency. This chapter, in addition, validates the proposed estimation technique in mobile app development project in the Agile process. The first section of this chapter, section 9.1, presents the first case study analysis and results for Company A. Following this, the second and third case studies are discussed in section 0 with Company B, and section 9.2.6 with Company C.

9.1. Case Study at Company A

9.1.1. Company's background and project information

Company A is in Alkoubar in the Kingdom of Saudi Arabia, and was established early in 2009. It is dedicated to producing technology solutions around the world. The company holds seven awards from the Saudi government, one for the best promising enterprise in the eastern province. The company follows ISO-20000 as best practice for IT service management. It has around 150 employees, mostly specialised software and application developers.

Company A was happy to participate, and decided to apply this case study to its current project, 'Project X'. The project is basically about evaluating the services provided by the government's ministries. The company has completed four sprints in this project, and the duration of each is two weeks. Since the company is working on many projects, this project consists of five development team members, one product owner and one project manager, as shown in Table 48.

Action research method was applied at Company A that involved more than solving problems and providing solutions. The case study allowed investigation of the phenomenon of the estimation process in the Company A; however, there was further work to evaluate the current estimation techniques and provide solutions, with direct contact with the development team members. In the action method, iterative work assessed the estimation process/technique in each sprint and adjusted the technique until the problems were solved.

Table 48: Project team members in Company A

Development member name	Years of experience	Member role in the team
T-A	4	Mobile app developer
T-B	3	Mobile app developer
T-C	8	Frontend developer
T-D	6	Backend developer
T-E	4	QA
T-F	3	Product owner
T-G	9	Project manager

9.1.2. Current situation and proposed estimation method in Company A

❖ *Meeting with project manager before starting the case study to understand the current estimation process and previous sprints' performance.*

The project manager wished to apply the case study to an existing project, 'Project X'. They were on Sprint 5 and the duration of the sprint was two weeks. To understand the velocity and the progress of the development process, the performance of the last four sprints was examined. The project manager, T-G, was happy to share the progress of the development team during the last two sprints (Sprints 4 and 5). The company chose to apply this case study to a development team of five or six members. The details of the team members are in the following section.

Figure 58 and Figure 59 show the progress of the development team over the last two sprints. As we can see from the Burndown chart, the development team estimated the user stories and tasks at 81 to 89 story points and had committed to developing these tasks within two weeks. In fact, the development team delivered only 10 story points at the planned end of Sprint 4 and nothing in Sprint 5. The team worked over the weekend to deliver the rest of the user stories in Sprint 4, and in Sprint 5 the team took three more days to complete and deliver all the user stories. The estimation technique and reasons for the underestimation are discussed in the focus group and interview.

The Burndown chart is a graphical representation usually used in an Agile project to help the product owner with important information about the progress of the sprint (Stacia Viscardi, 2013). The chart displays how much work remains, in term of hours, in the release backlog, and provides an indication about the scope of the work of the sprint. The chart also displays the team working progress through the customer's user story and the team alignment with the planned time of the user stories and tasks. The chart provides the total effort against the completed and planned effort of the sprint.

In the first group, a question was put to the development team about the causes of failing to deliver the user stories by the time planned. It listed the points in the next section, and project manager T-G expressed that the clients changed the requirement of the user story during the sprints. The project manager and product owner knew that should not happen, but the clients needed it to be delivered during the current sprint. As seen in Figure 58, at the end of the first week of Sprint 4 the client requested changes on the current user stories. The development team claimed these changes required additional efforts, because it had already started implementing the stories.

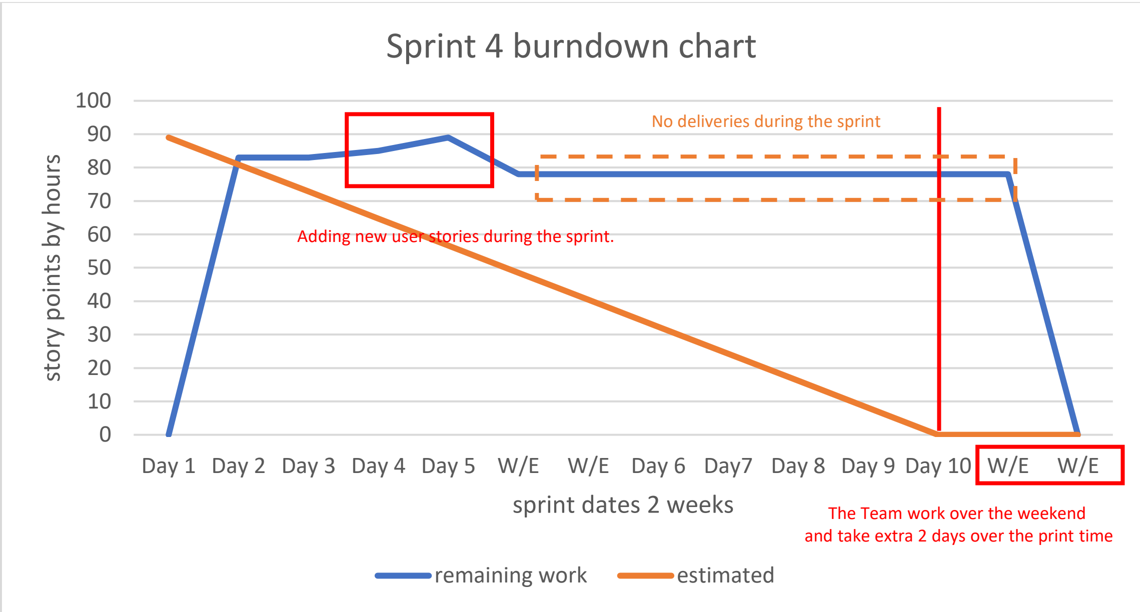


Figure 58: Performance of the development team for Sprint 4

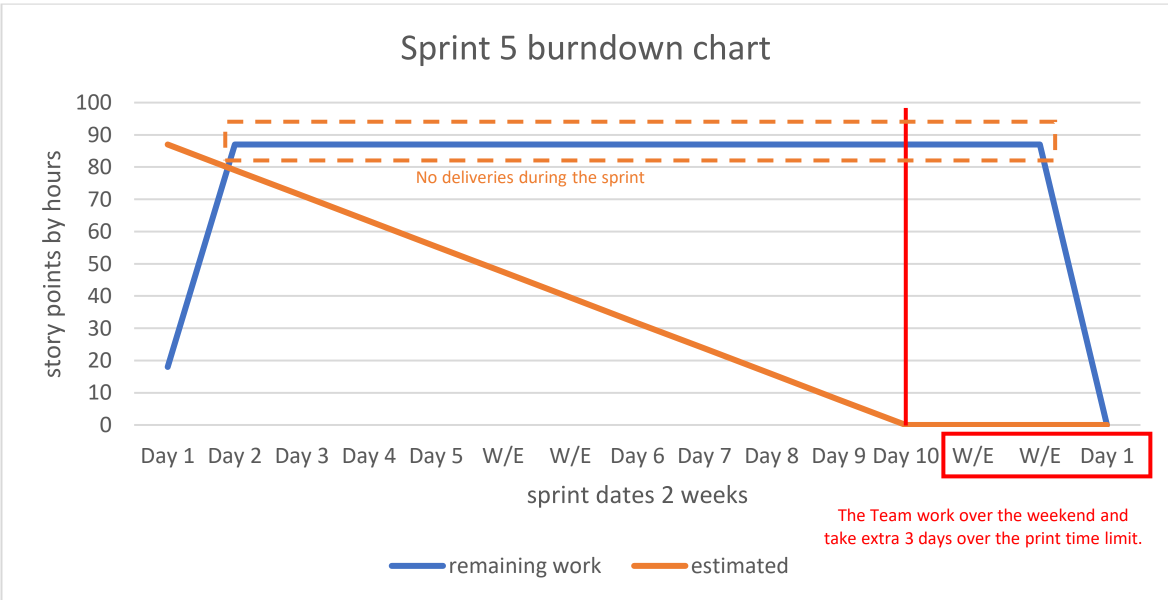


Figure 59: Performance of the development team for Sprint 5

❖ *First focus group discussion with the development team to understand their estimation process and their challenges.*

A group discussion took place with five members of the development team regarding the estimation techniques and their accuracy. The session was held prior to the sprint planning meeting of Sprint 5. The goal of the group discussion was to understand the estimation techniques used in previous sprints, and the main reasons for the accuracy of the estimation to be low. There were two group discussions with the development team; the first was concerned with: understanding the current estimation process of the development team; and discussing the main causes of the underestimation. The second was held later on, after the observation was completed by the researcher.

Current estimation technique and process: A question was put to the development team concerning its estimation process in the last four sprints. The technique used during the previous sprints was EJ. In this company it works as follows: at the beginning of the sprint planning, the product owner explains the user story to all development team members. The user story could include frontend tasks for the web developer, mobile app tasks, backend tasks or QA tasks. Then, the team members explain what they would do in the user story. It could be that several share responsibilities for one user story. For example, in Figure 60, the web developer, QA and mobile developer are involved in one user story. If there are two web developers in the team, the leader of the web-developing team assigns the effort for that part to the user story. Also, the team divides the user story into certain tasks to allow each member to take a task and perform it alone. After assigning the tasks for the user story, the development team has a short discussion to decide whether to take on more of the user story or not. The product owner and client usually push the development team to take on more of the user story to achieve the project delivery plan. The development team sometimes takes the risk by accepting the pressure from the product owner and the client and undertakes more.

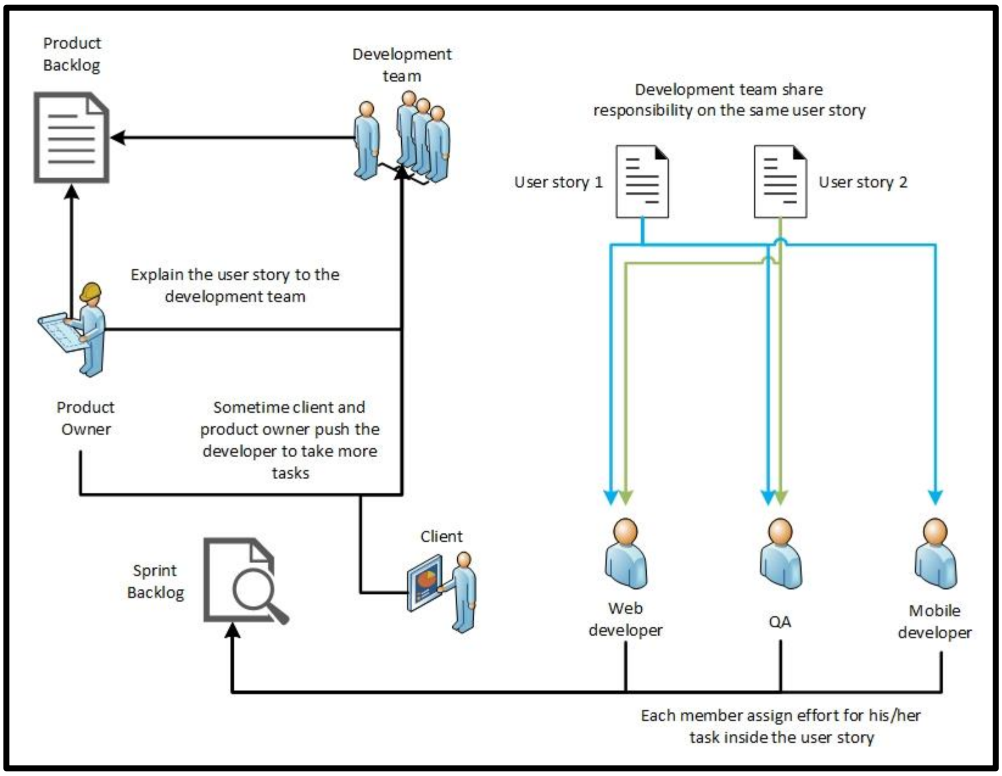


Figure 60: Current estimation process in Company A

Main causes of the low-accuracy estimation in the previous sprints: The second part of the group discussion was about the reasons and main causes of the low accuracy of the effort estimation in the last four sprints. There were several reasons for the poor estimation accuracy, and one is that the definition of the user story was unclear to the development team. The product owner did not have a full understanding of the requirement specifications of the user story. The client and product owner discussed the user story during the sprint planning ceremony and gave their suggestions about the needs of the user story. After their discussion, they explained the user story to the development team. The discussion and changes in requirements during the sprint planning caused confusion among the team, and this created ambiguity around the requirements. The researcher noted this concern, as discussed in more detail in the researcher observation section. Another concern is that when the team gave its estimation for the user story in the sprint planning, it asked for clarification of some points in the user story during the sprint. As a result, this clarification could raise further concerns that need additional time from the developer - more than they had expected. To avoid this happening again, the development team overestimates its effort estimation for user stories that are insufficiently clear.

In addition, the development team suffered from external interference that required it to take on more tasks. The company agreed to deliver all the project requirements in 10 months in the project contract. In fact, the company has an issue with initial estimates for clients for the overall project. The project manager gives an estimate for the delivery of the entire project based on their experience in previous projects, which puts the developers under pressure and requires them to work beyond their capacity.

❖ *Observation of the current estimation process of the development team performance.*

The researcher attended the sprint planning meeting for Sprint 5 to observe the development team's behaviour when they had a discussion with the product owner and the client on the user stories. During sprint planning, several issues were observed, as discussed in the following sections, and these were raised by the researcher and discussed with the project manager to take action to resolve them.

- **Lack of valid justification to the product owner and clients for the effort estimation:** The development team suffered from poor justification of their estimation to the product owner and customer. It had a challenge to persuade and convince the customer and product owner of their estimate for the selected user story. For example, in one case there was a push notification task for which the mobile developer gave an estimated value as 'two days', without any clear plan about what would be done in those two days. The problem is that the developer sometimes cannot explain why a task takes that time. The observer asked the developer at the end of the session why it was hard to explain why this task would take that long, and the answer was that the product owner and client would question it and argue over the effort assigned. The client was not happy with any developer's justification and felt that developers are incapable of the task, based on their discussion with the project owner. The development team could not persuade the product owner and customer of their suggested effort by providing evidence why this effort takes this amount of time.
- **Development team under pressure:** Following from the previous point, the customer and product owner put pressure on the development team to take on as much as possible of the user stories from the product backlog in the sprint. The project delivery was in deployment and the customer needed to finish this project as soon as possible. As shown from development team performance in Figure 58, 34 story points were not completed in Sprint 4. The team expected to do these user stories within the sprint period, but in fact it faced challenges that it did not expect.
- **Mono decision-making on effort estimation:** Each member of the development team gives an effort estimate alone, without negotiating with colleagues, because each member of the team has their own specialties and the team prefers the person who will do the task to be responsible for assigning its effort value. If the user story consists of backend and frontend tasks, usually one of them assigns the effort value for the whole user story alone. In fact, if the user story contains a backend task, the backend developer assigns the effort for the whole user story, because they have about six years of experience and thus leads the user story. This habit causes uncertainty for other tasks

in this user story and results in accurate estimation value for frontend tasks, for example.

- **No time allocated for taking decisions on effort estimation:** There is not enough time for the development team members to think about what they will do in the task to give more detailed plans for their task. After the product owner has explained the user story, the developer who is role related to this task gives an estimate immediately. The observer counted the period for three members, from the time the product owner finished explaining the user story to the time when the developer gave their estimate. The first took 5 seconds, the second around 7 seconds and the third only 4 seconds. This is a very short time for a developer to think about the effort that a task could be expected to take.
- **Unclear user stories for the product owner and clients:** from observations during the sprint planning event, one of the main issues that the product owner and clients discuss during the sprint planning event is the functionality of the user story. For example, at the sprint planning event for Sprint 5, the clients discussed the functionality of the 'rating feature' user story. They took about 20 minutes to decide between them what should be included in this user story. The product owner tried to understand the new features of this user story from the clients. The development team was in confusion and waited for the clients to reach their final decision. While it was waiting, its members were busy trying to understand the previous user story and segment the task between them. The clients should have had this discussion before the sprint planning and consulted the product owner about the feasibility of these features for the app.
- **User story related to unknown or legacy system:** One main challenges for the development team is being asked to make changes to or investigate a system that its members know nothing about. They cannot make an estimate for something that they do not know. There was an instance during sprint planning for Sprint 5 when the product owner explained a new user story to the development team to make enhancements to an integrated system. The team did not know what was behind the system and needed time to understand it before giving an estimate. The client was not happy with the developers when they were reluctant to give an estimate for that user story. There is a type of user story called Spikes (Leffingwell, 2011) for exploring, to gain more knowledge about an existing system. This was later discussed with the development team to help it to estimate this user story.
- **User stories are not broken down into small, manageable tasks:** It was hard for the development team to estimate the entire user story. Usually, story points should be broken down into small tasks to make it easy to assign an estimated value. Sometimes the development team gives its estimate in days, 'two to three days', for example, which tends to make the customer and product owner dissatisfied. Also, this high value is not traceable and manageable by the project manager and developer. An estimate in

days instead of hours gives the impression to the customer and product owner that the development team is incapable and 'lacks technical knowledge' on this task, or does not know what it involves. Breaking down the user story into small tasks is helpful for a developer to manage the time and understand the detailed functionality of the user story.

- **The 'definition of done' is not stated and defined well**: there were misunderstandings among the development team and client on the meaning of 'done', for the user story.
    - Developers assumed that the user story would be 'done' after they had finished doing the 'development, testing and QA'; however, the customer claimed that the task is 'done' only upon completion of the UAT (user acceptance test), which was supposed to be undertaken on the customer side.
    - The development team claimed that the deployment phase is excluded from its effort; however, the customer and product owner wanted this phase to be completed during the sprint. If deployment is included in the sprint, the effort estimate will be considerable.
- **Changed priority of user stories during sprint planning:** The priority of the user story was altered by the product owner and customer midway through the sprint planning phase.
- **Some team members did not participate in the sprint planning event:** Backend developer T-D was absent from the sprint planning event, and T-C spoke to T-D to ask about the effort required for their user stories. T-D always left at that time to pick up children from school, yet the client and product owner did not change the time of the sprint planning.

❖ *Second focus group discussion with the development team to improve the estimation process and accuracy.*

During Sprint 5, a second group discussion session was held with the development team members and the project manager to improve the estimation accuracy and process. The discussion covered the following topics: explain to the team about the main factors that affect the accuracy of estimates; and provide suggested solutions to resolve their low accuracy.

Topic 1: Explain to the development team the factors that affect estimation accuracy

In the group discussion session, the observer presented all 68 effort estimation factors, 'comprehensive factors', to the development team and discussed their level of impact and influence on estimation accuracy. The observer explained each to the team members and asked how they would use them in their effort estimation and to provide the observer with further factors. The team discussed together and came up with these statements:

- We can use these factors to let us think more about new user story in more technical details. Before, we usually compare the new user story with the one that we did before, but with these factors we can think more in more detail what we can expect from the user story.
- For example, the transaction journey factor, helps us to think about the structure of the data that we need to send to the backend and the result data structure from backend to the frontend. Also, these factors help the backend developer, for example, to discuss with the mobile app developer about the user story and explain to each other what who will do this and split the user story into small tasks.
- The factors overall are comprehensive, and we can put them in our mind before we give an estimation value.
- The effort factors help the development team to break down the user story into small tasks.
- In order to recall the estimation factors during estimation, the development team prefers to present the estimation factors using a projector in a meeting room while the estimators make their decision.
- The development team agrees that the 68 factors are comprehensive, and they do not have any additional factors.

The mobile developers T-A and T-B added some notes on the segmentation of a user story into subtasks: 'The estimation factors help us to break down the user story into small tasks'. However, both concluded that a task could be developed for two platforms, IOS and Android, and involves thus different effort estimation values. T-B claimed that the UI design of a task in Android devices sometimes takes more time than in IOS. The reason is that the task needs to be tested in multiple Android devices, unlike IOS, as the Android emulator does not accurately reflect the real UI of Android devices. Also, T-A said: 'The drag and drop feature of designing UI in XCode IDE is more supportive and accurate than Android studio'. Regardless of the pros and cons of each of the mobile framework, IDE, tools and platform, this argument is debatable, and professionality depends on the developer's capability and experience in development skills, and these aspects underpin the six technical factors mentioned in Chapter 7.

Related to this, the researcher put a question to the development team members on the comprehensive estimation factors and their relationship to the usability heuristics for mobile app interfaces from these studies (Ickin et al., 2012; Inostroza et al., 2013; Yáñez Gómez et al., 2014). Usability heuristics focus on measuring the quality of design in a mobile app interface, such as customisation and shortcut, minimising the user's memory load, consistency, and so on. The development team concluded that these kinds of criteria usually were deployed during the building phase of product backlog and in the early stage of gathering the requirements. Designing the UI and UX should be agreed at an early stage of a project phase and a mock-up design usually took place before the sprint kicked off. During the sprint, the development team follows the standards agreed in the fidelity design. From their response, the researcher found agreement between the team's answers and others from the survey method in section 7.2.3. Preparing a detailed fidelity design of mobile app and clear design of UX and UI will help the team to present a good image and have a secure understanding of what is to be built and developed during the sprints.

Topic 2: Provide suggested method and process to estimate effort in future sprints

In the group discussion session, the development team was asked to devise and discuss an appropriate proposed estimation model to help them to understand the user story and give highly accurate estimates. As a starting point, the researcher presented the checklist model and asked if this could help in the estimation process.

After a long discussion, the development team came up with a proposed estimation model termed the 'pair-estimation model'. The fundamental of this model is to encourage a pair of members within the development team to talk to each other. An issue that arose in the session is discussed below, as well as its solution. All the solutions are the outcomes from the workshop discussion.

- **The issue:** In the session, the development team claimed that the development team members should not give an estimate for something that they will not undertake. For example, the frontend developer T-C could not give an estimate for the backend task as T-C does not know what is behind this task; therefore, the backend developer T-D should take responsibility for assigning the effort value for this task.
- **The solution:** In the session, the development team agreed that a team member should communicate with 'at least one person', even if there is no direct impact on his/her task. In Figure 61 is an approach whereby each member contacts his/her pair on the basis of their share of interest. For example, backend developer T-D could communicate with frontend developer T-C to ask about the expected response of data structure from backend to frontend, whether in stack or array, how the data is to be stored, from which database the data will be retrieved and how big the data will be. This communication style will help to generate deep discussion between pairs. Also, it will help each member of the development team to obtain feedback on their estimates.

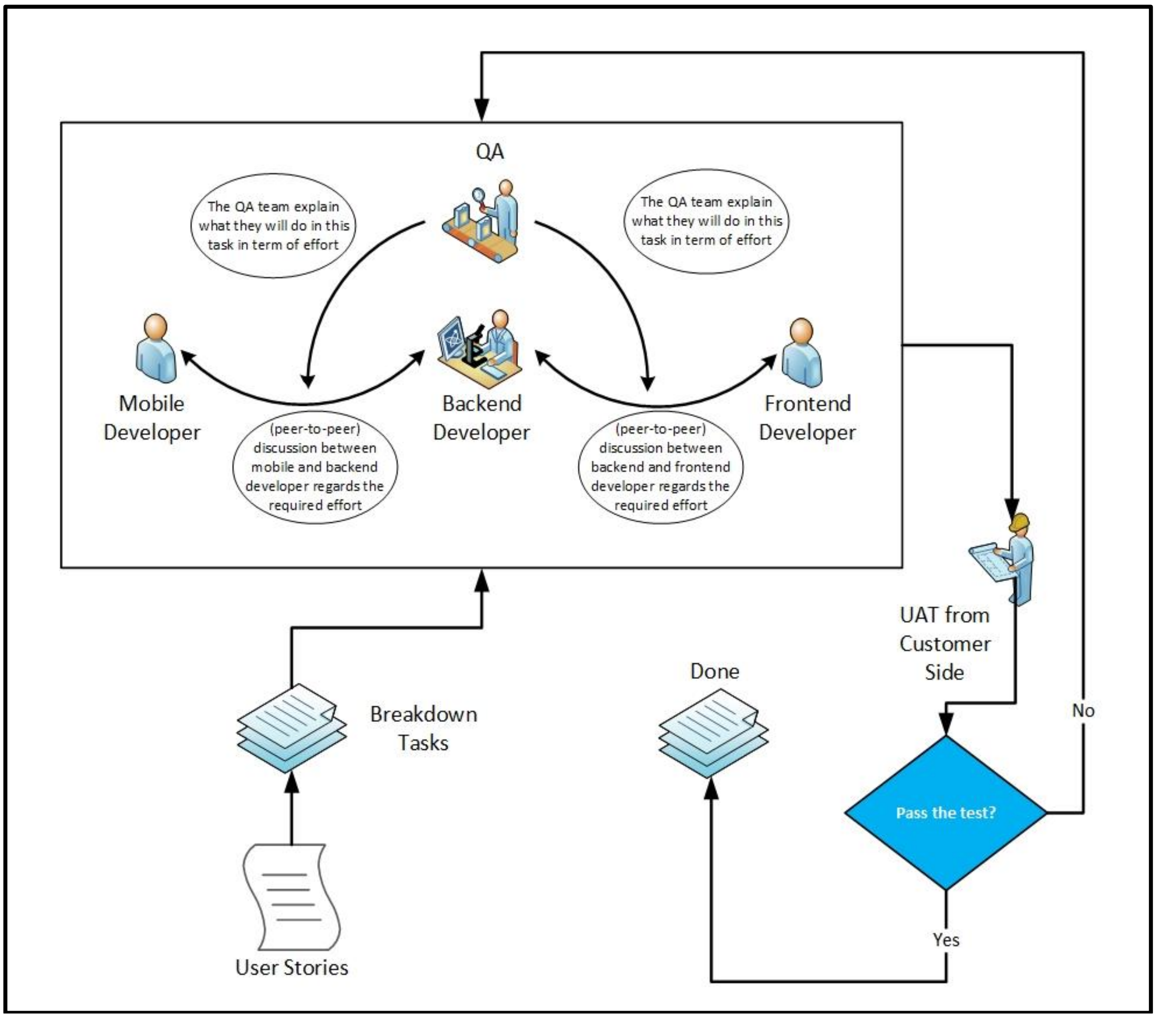


Figure 61: Pair-estimation model

Topic 3: Discuss with the development team what the researcher observed at the sprint planning event

Several concerns arose in the previous section regarding the effort estimation process and technique, and in the group session the observations were shared with the development team. From the discussion, it was concluded that certain actions needed to be taken during estimation:

- Break down the task/user story into subtasks that should not take over 8 hours. If a task reaches 8 hours, as an estimate, the developer needs to divide it into subtasks as shown in Figure 62. The subtask could include technical subtasks that help the developer to measure the effort. The effort estimate should be based on hours, not days.
- After breaking down the user story into small tasks, every member of the team takes the relevant task from the user story and discusses with peers their shared interest, integrated data, APIs, etc., as shown in Figure 61.
- With an hour or two of the sprint planning event, the development team holds a meeting to understand the first five to six priority user stories and discusses the effort

estimation value for each. This allow the development team to understand the user story and gives them more time to prepare to implement them technically. This resolves the issue of T-C's presence to share their suggested effort estimate for their user stories or tasks.

- The development team should provide reasonable factors to the customer and product owner and present a good justification for assigning a certain effort value to a user story or task.
- Although it is agreed that the project manager or Scrum master should prevent interference from the customer and product owner on assigning an effort value to user stories, the development team should present a good justification of its estimates to satisfy them.
- It is agreed that clarity regarding the 'definition of done' will improve the accuracy of the effort estimation; therefore, for each estimate, the development team should consider the workflow of the user stories process, as follows:
    - **Action by development team:** user stories go through the following stages:
        - Design the UI
        - Coding
        - Testing and QA
        - Deployment: deploy the user story internally.
    - **Action on the customer side:** after the user story has gone through the previous stages, the last stage is:
        - Acceptance testing 'UAT': this is conducted on the customer side, and they should give their estimate for how long each user story will take. After the UTA stage, the user story may be considered to be done.
- A sprint takes two weeks (10 working days):
    - First day for the sprint planning event.
    - During the sprint, the development team undertakes the development and, when each task is finished, deploys it to allow the UAT team to conduct testing during the sprint.
    - Last day for the UAT to undertake testing on the customer side for the final deployed task.
- The client or product owner should be aware of the consequences of adding or change a user story during a sprint.
- The development team members should talk to each other. Below is an issue that arose in the workshop session and a solution:
    - **The issue:** In the workshop session, the development team members claimed that members should not give estimates for something that they will not undertake. For example, frontend developer T-C should not give an estimate for

a backend task because of what lies behind this task; therefore, backend developer T-D should take responsibility for assigning the effort to this task.

   - **The solution:** the team member should talk with his/her pair to 'at least one person', even if there is no direct impact on their task. In the following diagram is an approach whereby each member communicate with a peer based on their interest. For example, backend developer T-D could communicate with frontend developer, T-C, to ask about the response structure from backend to frontend, whether in stack or array. This will help each member of the development team to obtain feedback from peers about their estimates.

- The development team agreed that the PP method does not work properly for them, based on their experience with this technique in earlier projects, because:
   - It takes a long time to hear from each member.
   - It allows non-specialist members to give an estimation for a task unrelated to them: for example, a backend developer would give an estimate for a mobile app task.
- The development team agreed that estimating the effort of a spike is difficult, due to the uncertainty beyond investigation and the vagueness of the legacy system; however, it was agreed that assigning a random or arbitrary value damages the velocity of the development team and turndown chart. Therefore, it was agreed that the product owner should assign a sprint with a spike to a member of the team to conduct an initial investigation, making a corresponding reduction in workload for that member. The member will continue the investigation until they feel that the investigation may affect their delivery of the sprint. At the end of the sprint, either the initial investigation is sufficient or the member provides a rough estimate for a more detailed spike in the next sprint.

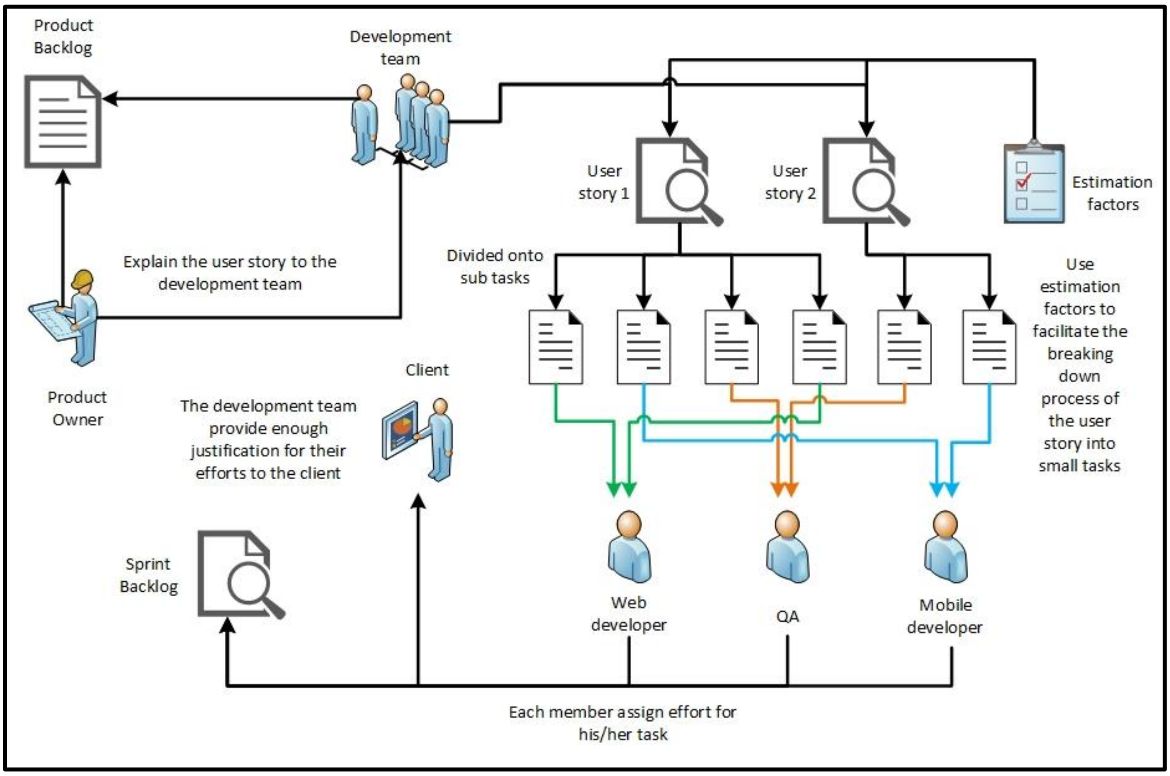


Figure 62: Subtasks: Breaking down user stories into independent tasks

9.1.3. After applying the proposed estimation technique and accuracy's results

After constructing the proposed estimation technique from the focus group with the development team members and the project manager, the team applied the new estimation technique at the sprint planning event for Sprints 6, 7 and 8. The development team used the estimation factors to help to achieve a precise estimate, following what they agreed from the first and second group discussions to enhance estimation accuracy.

In the sprint planning for Sprint 6, the development team had 16 user stories and divided them into 25 subtasks. The team estimated the user stories and its subtasks as around 165 story points. The team delivered all the subtasks by the end of Sprint 6. The team delivered the subtasks and user stories frequently and during the planned time, as shown in Figure 63, whereas in Sprints 4 to 5 the team delivered all the user stories at once at the end of the sprint time frame, as shown in Figure 58 and Figure 59. In Sprint 6, the clients and product owner were satisfied with the number of tasks delivered. The team took 165 user stories in a sprint backlog of Sprint 6, compared to around 80 user stories in Sprints 4 and 5. The proposed estimation process and technique make the task more organised and 'doable' for team members. Each knows what they will do in the sprint. Moreover, the quality of the development is enhanced; 11 and 9 bugs from the development were found in Sprints 6 and 7 respectively, whereas 20 bugs were found in Sprint 4 and 17 in Sprint 5.

In the sprint review of Sprint 6, the clients were satisfied with the results from the sprint. The team felt that the user stories were clear enough to provide a good plan and estimate for this sprint. The estimation technique not only provided an accurate value; it helped the team to organise the work and allowed it to have a clear plan, permitting delivery of the tasks on time and informing the stakeholder of the actual effort, keeping them satisfied. Figure 98 in the Appendix D shows the client representative's appreciation email to the project manager and the product owner for the noticeable improvement in Sprint 6, and the clients were happy that all the user stories were successfully delivered to plan.

Table 49: Overall sprint performance before and after the case study

		Before		After		
		Sprint 4	**Sprint 5**	**Sprint 6**	**Sprint 7**	**Sprint 8**
Number of user stories		8	7	12	4	6
Number of subtasks		0	1	25	35	32
Number of bugs		20	17	11	9	13
Number of estimated story points		89	87	165	161	Not available
Delivery of story points per day (hours/day)	Mean	9.9	6.7	20.6	16.10	Not available
	Median	0	0	17.5	11	Not available
	Std. dev	25.8	24.1	18.6	15.8	Not available

❖ *Focus group discussion on the sprint retrospective session to validate the result from the development team and researcher observations*

At the request of the project manager, the observer did not attend the sprint review; however, the researcher was allowed to attend the sprint retrospective of Sprint 6, when the team shared the success story about why it had been unlike previous sprints. T-C said: 'In this sprint, we organised our work and simplified the complexity of the user stories by breaking them down into small tasks to allow us to understand the details behind the user story'. T-E added: 'The estimation factors are very helpful for us to facilitate the breaking down and categorisation procedure of the user story into small tasks'. The observer asked the development team to provide feedback on two points: the effectiveness of the estimation factors that helped it to provide an accurate estimate; and the feasibility of using the checklist in the format of factors on printed on paper sheets, instead of presenting them using a projector. The team's responses can be summarised as follows:

- The comprehensive factors support the team to divide the user story into subtasks. T-B said: 'The overall factors open my mind to break down the complexity of the user story into small pieces of tasks'. T-A said: 'UI animation, prototype/fidelity design and availability of the API tools are the most factors that help me to think more and deep about the user story before give my estimation'. T-D noted: 'Before, I was compare the new task/user story with similar ones that I have done previously, but now the factors support me to how facilitate the complex user story and allow me to understand how to collaborate with my colleagues. For example, I was thinking about the transaction journey and what is the structure of the request and response.' The observer recognised from the team work during Sprint 6 that the members recalled the explanation of the estimation factors from the projected presentation and broke the user story into small tasks as shown in Table 79 in the Appendix D. The factors encouraged the team to evaluate the complexity of the user story and helped them to translate the complexity into the effort value.

- The project manager, T-G, extracted the burndown chart of Sprint 6, as shown in Figure 63, and noted that the development team continued breaking down the user story during the sprint development. The concern is that the team identified additional details of the requirement specification in the user story, resulting in more than they had expected. This scenario required additional effort above what was initially expected at the start of the sprint. The project manager said this situation arose because it was the first sprint for the team using the new estimation method.
- The pair-estimation model encourages the team members to talk to each other. The team had experienced disorganised discussion that led to misleading estimation values from nonspecialised people. The proposed 'pair estimation' method allows pair professionals to exchange their opinions, experience and understanding about the user story specification to achieve a highly accurate prediction.

The number of bugs fell in Sprint 6 compared to previous sprints, as shown in Table 49, and in Table 77 and Table 78 from the Appendix D. As explained before, the pair-estimation method allows pair professionals to spend more time delving into the specification of the user story and interpreting their understanding in a valuable and manageable context. Also, the proposed model allows the team to spend its time developing without any pressure to take on more tasks in a short period of time. The breaking down of the user story allows the QA team to design a test case to verify that the delivery achieves its goal.

The researcher observed that there was no opposition to or negotiation by the client about the team's estimate during the sprint planning. In fact, the client and product owner were happy and satisfied with the team capacity. The team claimed that it had not added much to the work compared with Sprint 5; members just explained what they intended to do in more detail and organised their work to make it recognisable and remarkable. In fact, the new method makes their work measurable and allows them to show off their work and make it visible. This method also allows the team to manage their work and make it measurable, so they understand their own capacity.

The researcher observed and recorded instances when the development team discussed with the client representative and product owner to gather more information about the user story and facilitate its breakdown into small tasks. The following dialogue is an example of how the user story can be discussed during the sprint planning event.

- The team broke down a user story into three subtasks and the product owner asked the team to give an estimate for the overall user story. T-A asked the product owner further questions to cover all possibilities and wanted to create further subtasks to meet all aspects. The story is about allowing the client to send a general notification to all users, as shown in Table 79 in the Appendix D. The developer asked in which language the users are to receive the message: in English or Arabic, or both: 'Are they going to receive the message with both languages or receive the message by the default language of the app'. T-A continued to explain the current situation of the app in terms of its default language, and said, 'There is no feature that allows the user to select the default language, therefore we need to add the feature to the settings to allow the user to select the default language'. At this point, the T-A was able to give an estimate for this user story and its subtasks. The team took advantage of the estimation factors and asked the product owner about all possible scenarios before committing to an estimate.
- The members T-A and T-B explained the suggested scenario for sending the notification to the apps. T-B said: 'The admin of the app will have a drop-down list to select the receiver type for this notification. From this selection, there is a sub-role type for this notification: general notification or send notification to a specific people based on their: gender/nationality/ location of the user/user age range from …. to …. / etc., and also we send scheduled notification to the user about the holidays and events etc'. T-B continued to explain the structure of the push notification form on the apps and the complexity of the form. Also, the client consulted T-A and T-B: 'What will the form style of the notification feature look like?', and continued to ask for more details of the UI design of the app form. This kind of communication clarifies the user story and makes it clear to both the development team members and the clients. T-B said: 'During the sprint, we will show you the UI design for this form and ask for your approval before continuing the development'. The client representative and team discussed the workflow of the notification message, and T-F and client agreed: 'A confirmation message must appear to the Admin user before sending the notification.'

In Sprint 7, the team used the same proposed method and focus to avoid the issues mentioned in the sprint review and retrospective from Sprint 6. The development team estimated 161 story points for Sprint 7 and delivered all the tasks on time, as shown in Figure 64. It also delivered all the user stories on time, with just nine bugs in 35 subtasks, as shown in Table 49 above and Table 78 in the Appendix D.

In general, the new estimation technique focused on using pairs of team members to share opinions and experience regarding their user story. Each member of the development team should have his/her pair, under this model, with a common interest in terms of job role, as described. The proposed model relies on the estimation factors that facilitate the user story being broken down into small tasks. The workflow of the sprint's progress is different before and after the new estimation technique and process, as shown in Figure 101, Figure 102 and Figure 103 in the Appendix D. Comparing the estimated and actual effort of the development team, the team had 87 to 89 story points in Sprints 4 and 5, and the user was unable to deliver all the tasks on time. The team took an additional two to three days to deliver all the user stories and consider them as done. In Sprints 6 and 7, the team was able to organise the work and make subtasks of the user story by the category of the work, the estimation factors and the responsibilities of each member. At the end, it had delivered all the user stories. Also, the quality of the code was enhanced under the new methodology, as shown in Table 49.

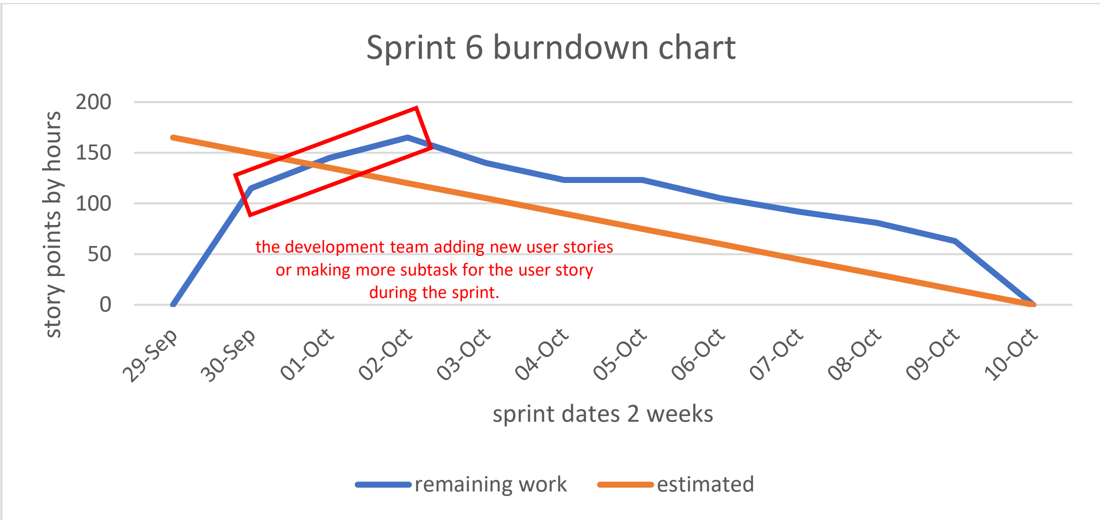


Figure 63: Burndown chart of the development team for Sprint 6

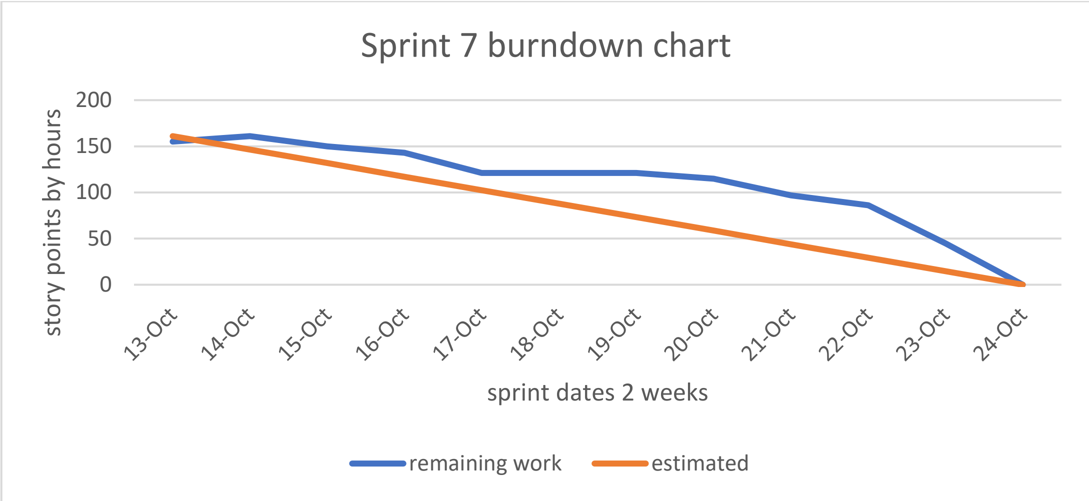


Figure 64: Burndown chart of the development team for Sprint 7

❖ *Result validation using correlation test*

In order to validate the findings from the focus group discussions, a statistical correlation test measured the strength of the association between estimated effort and the actual effort values during the sprint. As shown in Table 50 and Table 51, the test was applied in Sprints 4 and 5. The result shows that there is no association between these values, and this indicates that the team's development was not performed as expected or planned. Next, the correlation test was applied to Sprints 6 and 7, after the development team had started to apply the pair-estimation technique to enhance the accuracy of user story delivery during the sprint. Table 52 and Table 53 below show that there is a significant relationship between the estimated effort values and the actual effort, indicating that the delivery of user stories were delivered as planned and expected when the team used the proposed pair-estimation technique.

Table 50: Correlation test for Sprint 4

Correlations			
		Estimated effort	Actual effort
Estimated effort in Sprint 4	Pearson Correlation	1	.151
	Sig. (2-tailed)		.592
Actual effort in Sprint 4	Pearson correlation	.151	1
	Sig. (2-tailed)	.592	

Table 51: Correlation test for Sprint 5

Correlations			
		Estimated effort	Actual effort
Estimated effort in Sprint 5	Pearson Correlation	1	-.048
	Sig. (2-tailed)		.866
Actual effort in Sprint 5	Pearson correlation	-.048	1
	Sig. (2-tailed)	.866	

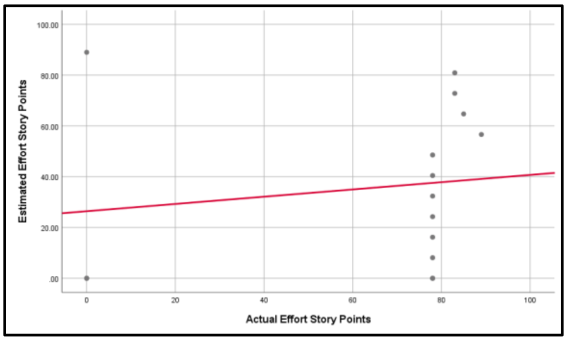


Figure 65: Scatter graph for Sprint 4, before the case study

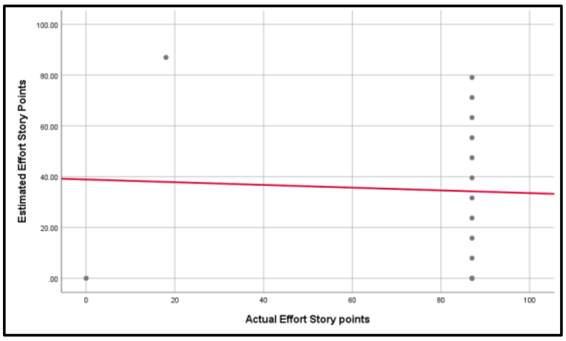


Figure 66: Scatter graph for Sprint 5, before the case study

Table 52: Correlation test for Sprint 6 using pair-estimation technique

Correlations			
		Estimated effort	Actual effort
Estimated effort in Sprint 6	Pearson Correlation	1	.569*
	Sig. (2-tailed)		.027
Actual effort in Sprint 6	Pearson Correlation	.569*	1
	Sig. (2-tailed)	.027	
*. Correlation is significant at the 0.05 level (2-tailed).			

Table 53: Correlation test for Sprint 7 using pair-estimation technique

Correlations			
		Estimated effort	Actual effort
Estimated effort in Sprint 7	Pearson Correlation	1	.932**
	Sig. (2-tailed)		.000
Actual effort in Sprint 7	Pearson Correlation	.932**	1
	Sig. (2-tailed)	.000	
**. Correlation is significant at the 0.01 level (2-tailed).			

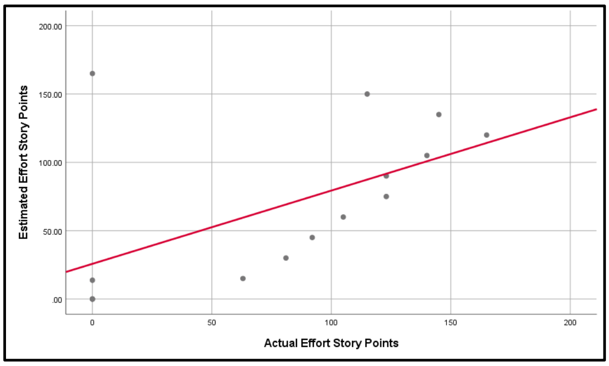


Figure 68: Scatter graph for Sprint 6 during the case study

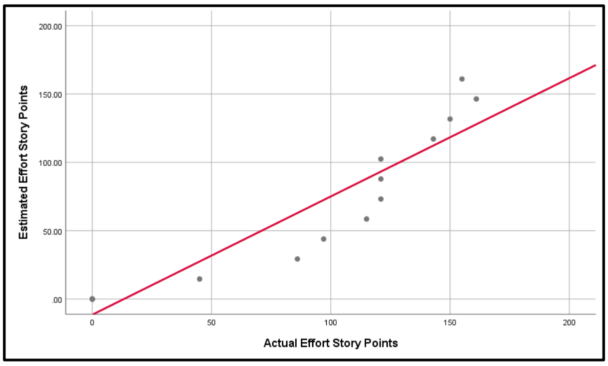


Figure 67: Scatter graph for Sprint 7 during the case study

9.1.4. Summary of Case Study A

Before the case study, the EJ technique was used in the company. Each member of the development team gives an effort estimate alone, without negotiating with colleagues.The team divides the user story into certain tasks to allow each member to take a task and perform it alone. After assigning the tasks for the user story, the development team has a short discussion to decide whether to take on more of the user story or not. The product owner and client usually push the development team to take on more of the user story to achieve the project delivery plan. The accuracy of the sprint's deliveries were not accurate enough. Several group discussions were conducted with the development team and came up with a proposed estimation technique named as 'Pair-estimation'. The fundamental idea of this technique is to encourage a pair of members within the development team to talk to each other. The Pair-estimation technique resulted in high accuracy of deliveries and made the development team more confident about delivering their tasks on time.

9.2. Case Study at Company B

9.2.1. Company and project information

Company B is a small company in Riyadh. The company was founded in 2017 and employs around 40. The company has one software development team of four members to produce mobile apps, two mobile native developers, one backend developer and one QA. The company allowed the researcher to work on a project in the late stages of its development. The project needed about three or four sprints before it was completed. The sprint length of this project is two weeks, and the project is currently in Sprint 11.

Scrum methodology has been used in this project and there is no project manager for this project; the product owner has direct contact with the clients and the development team members are self-organised. The client of the project is the company itself, and the development team produces software products for Company B to allow its customers to use the app. The researcher had limited contact with the development team members directly to observe their activities; however, the product owner acted as the correspondent for the case study to answer the case study's questions as fully as possible.

9.2.2. Current development process of Company B and estimation process

Development process: Company B follows the Scrum methodology of the Agile process. The development team is self-organised and cross-functional, having individuals with various functional and domain expertise.

The effort estimation process: Company B applied two estimation processes during all 11 sprints. The first estimation technique was a PP technique, a consensus-based estimation process commonly used with Agile processes, as discussed in more detail in Chapter 2. Due to its low accuracy and efficiency, the technique was changed by the company in Sprint 4 to self-estimation. This allows the developer who takes on a task to assign the effort estimation for that task. Estimation accuracy improved when the company changed from PP to self-estimation.

There are three reasons why PP did not succeed at this company. The first is the long time that it took for the estimation procedure to reach a consensus. The PP process involved all the team members in discussion about a user story or a task over several sessions. It took about 45 minutes to explain to other team members why one user story involved the estimated value. On top of that, explaining the PP methods to the team members took time. The second reason why PP failed is that a member of the team was involved in estimating tasks that they were not specialised in. In sprint planning, each developer chooses a task that to do in the sprint, and to let a web developer be involved in estimation for a mobile app screen task will lead to inaccuracy in estimation. The third reason is the widely varying level of experience among the team members. Each member had different capability and skills. They were not full stack developers, and each had tools to use during the development, therefore, each assigned the estimate according to their capacity.

Self-estimation is an alternative PP technique that allows team members to give their estimate for a task in a short time. Each provides an estimate based on experience, skills and profession. For example, a QA member makes the effort estimate on how long the testing and inspection will take, and the mobile developer estimates how long this feature or screen will take, and so on. The accuracy improved over the PP technique; however, the process is still not accurate enough, despite the product owner being satisfied to some extent with the results. Figure 69 is an accuracy comparison between the two estimation techniques used in Company B, based on the product owner's judgement.

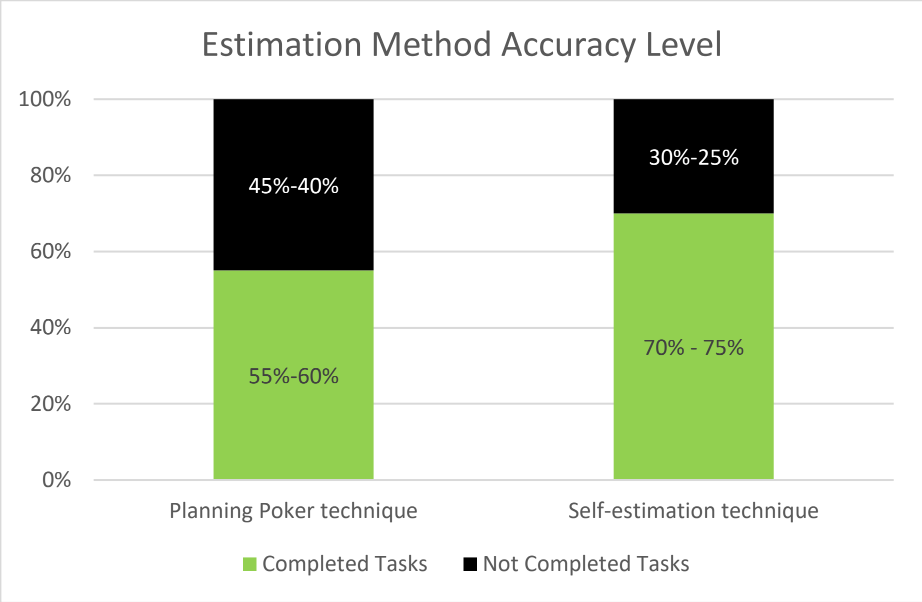


Figure 69: Accuracy level of effort estimation methods used in Company B

Estimation accuracy level

Company B provided the accuracy information of the user stories in Sprint 11. The task performance in Sprint 11 is shown in Table 54 and Figure 70. There were five user stories in that sprint, and 12 tasks related to these stories. The development team was able to deliver only nine, and it spent 129 ideal hours to do so. From the information given on Sprint 11, the accuracy of this sprint is around 76%. The level was calculated by dividing the total estimated effort of this sprint with the total of actual effort of the completed tasks (98/129). From Table 55 and Figure 71, the team development capacity per day is between 12 to 16 ideal hours, apart from the first and last day of the sprint due the sprint planning session at the start and the sprint review and retrospective at the end. Also from that table, the development team was be able to deliver 75 ideal hours out of 98 in Sprint 11, and dividing the earned value with the estimated value (75/98) is 77%, confirming the estimated effort accuracy of this sprint. The detailed information about the sprint deliveries and plan are in Table 80 in the Appendix D.

Table 54: Task performance for Sprint 11

Task ID	Estimated effort	Actual effort for completed task
T1	7	9
T2	8	15
T3	4	8
T4	8	16
T5	10	17
T6	8	15
T7	10	16
T8	8	14
T9	12	19
T10	10	0
T11	5	0
T12	8	0
Total	98	129

Table 55: Team delivery performance per day for Sprint 11

Date	Estimated	Actual	Completed tasks
Sep 22, 2019	7	9	7
Sep 23, 2019	8	15	8
Sep 24, 2019	12	16	4
Sep 25, 2019	10	12	8
Sep 26, 2019	8	14	0
Sep 29, 2019	10	16	10
Sep 30, 2019	8	15	8
Oct 01, 2019	12	14	10
Oct 02, 2019	15	15	8
Oct 03, 2019	8	6	12
Total	98	132	75

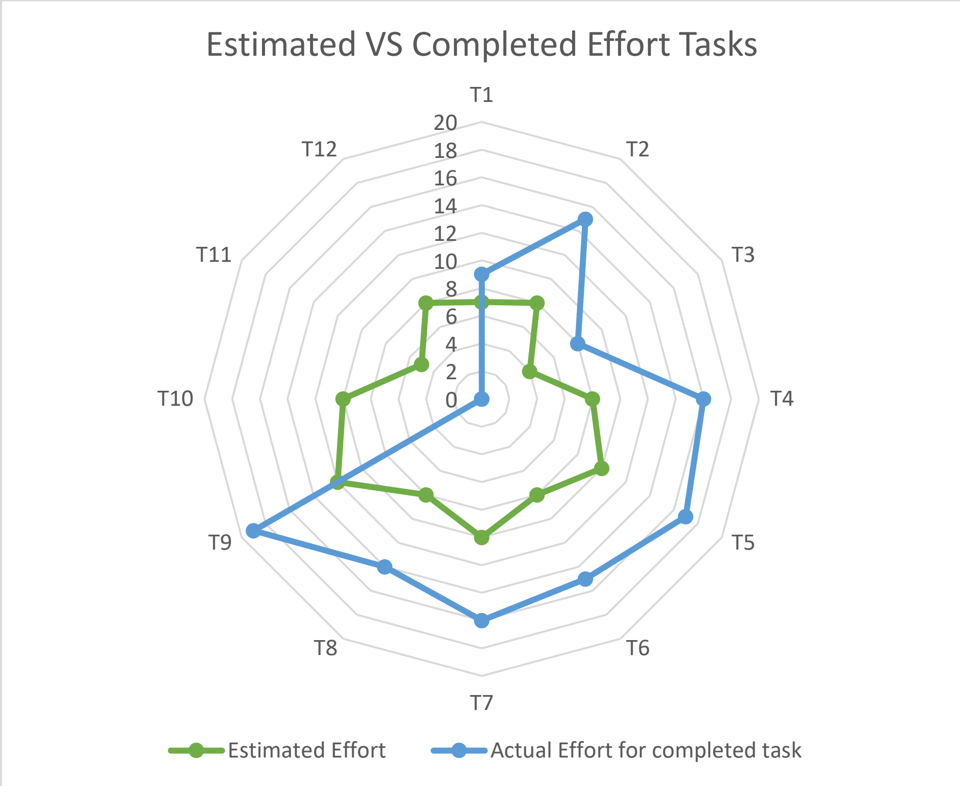


Figure 70: Task accuracy level (estimated vs actual)

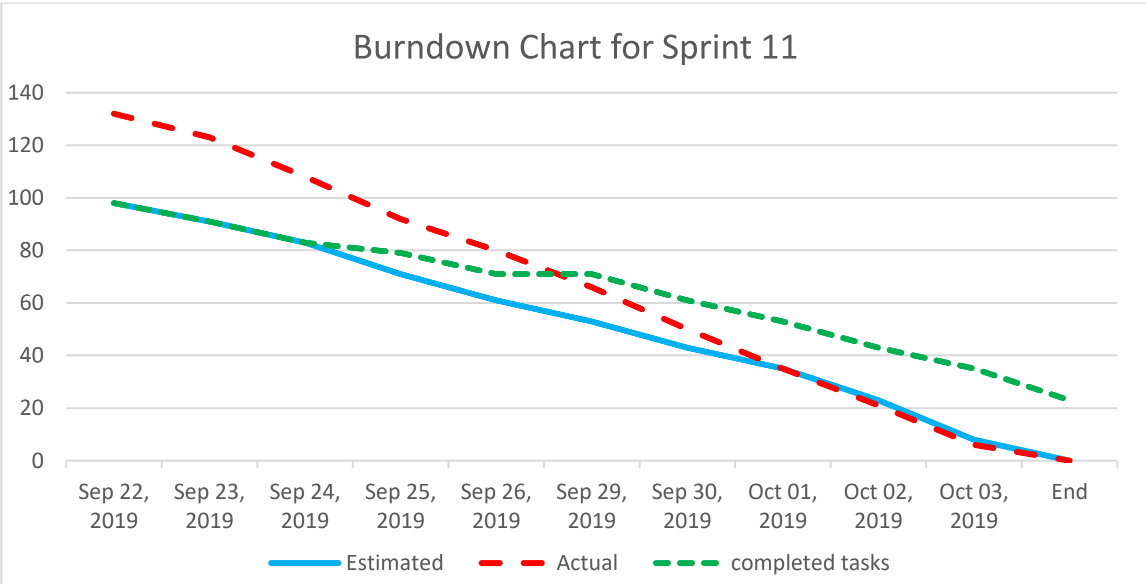


Figure 71: Burndown chart for Sprint 11 to compare the estimated effort to the actual and earned effort values

9.2.3. Focus group discussion to enhance the self-estimation method

The researcher held a group discussion interview with the product owner and two developers from the team to discuss the existing estimation process and how to improve it to achieve a more accurate estimate. The group discussion goals were to modify the current model and make sure the team was able to adopt the suggested model. The product owner and developers emphasised that the estimation model should be easy to understand and be applied by the development team, and the enhanced model should not take long time during sprint planning.

Challenges of the self-estimation method: In the group discussion interview, the researcher asked the members why self-estimation was still not providing good effort estimation accuracy. The developers claimed that there was no baseline to undertake estimation. Before, the development team used the PP technique and selected the easiest user story as the baseline for comparison with other user stories, and then assigned effort based on the comparison's differences. The challenge was now how to measure the differences against other user stories. The team spent time comparing the baseline user story and figuring out by how much the new user story is bigger than the baseline user story. The self-estimation method is providing reasonable accuracy compared with PP, as explained, but still there is no baseline for a team member to rely on to for estimation.

Checklist method: The checklist estimation method was explained to the members, and they were asked for their opinions on this method. The developers agreed that the checklist could be incorporated into self-estimation method to facilitate comparison with other user stories. The effort estimation factors facilitated showing the complexity of the user story to the development team and allowing them to find attributes to measure the difference between the user stories.

Development team's opinion of pair-estimation technique: Another issue arose in the discussion in that, instead of self-estimation in the sprint planning, the team were encouraged to try the pair-estimation method. The product owner supported this idea and believed that this kind of discussion between two developers is better than a one-sided decision. In the focus group, the two members of the team and product owner agreed that the technique has good potential to enhance estimation accuracy by helping the pair developers to have an argument and support to each other to find an appropriate estimation value. Moreover, the product owner said that pair estimation is better than PP, in their opinion, for two reasons: reducing the participation of an unrelated person in an estimation that they have no idea how to develop it; and reducing the time wasted in multiple estimation rounds. The developers suggested applying this technique in the final sprint of this project first, to see if there was any improvement on accuracy or not. The pair-estimation method provided many factors and metrics to help the team, including the developer, tester and product owner, to establish a baseline and foundation to make the estimation.

9.2.4. Result from the suggested method

The product owner explained the pair-estimation method to the development team members, providing a sheet of paper showing a comprehensive list of estimation factors as a checklist. Also, the product owner explained the estimation factors to the team, based on the researcher’s instructions, and applied the method to the last sprint of the project.

The development team applied the pair-estimation technique in Sprint 13, before the last sprint of this project. From the product owner’s report, the suggested method enhanced the accuracy of the team’s estimates to some extent, by 10 to 20%, compared to its current self-estimation method. The suggested method encouraged the pair developers to speak candidly, without monitoring by the product owner. The suggested method allowed the team to justify its estimate and defend members’ opinion of the user stories.

With self-estimation, according to the product owner, sometimes developers try to pretend to themselves that they can do considerable work within a short time to prove their capability to the product owner or their managers. Sometimes the members cannot be direct and speak freely to the team. Pair discussion with two members, who feel comfortable to speak openly, shares the knowledge ability on technical skills, libraries or tools. The pair-estimation technique supports dialogue between members in a more practical, advanced and technical manner. In addition, the discussion is highly likely to use less time than the PP technique. PP involved unrelated specialists in tasks, something that is not present in the pair-estimation technique. In term of estimation factors/predictors, the development team concluded that the factors/predictors are good enough to start the estimation technique for effort estimation; however, the factors/predictor need to be shaped and enhanced over time to become more detailed and specific to the project.

In Sprint 13, the team estimated four user stories with 93 ideal hours. The four user stories were broken down into 26 subtasks, as shown in Table 56. The estimation accuracy for Sprint 13 is around 84%, an improvement of 10% on Sprint 11. The development team delivered all four user stories with 26 subtasks by the end of the sprint. There are more details on the user stories and subtasks for Sprint 13 in Table 81 in the Appendix D.

Table 56: Task performance for Sprint 13

Task ID	Estimated effort	Actual effort	Task ID	Estimated effort	Actual effort
T1	2	2	T14	5	5
T2	4	4	T15	5	6
T3	4	5	T16	4	5
T4	4	4	T17	4	5
T5	4	4	T18	4	4
T6	3	4	T19	3	4
T7	5	6	T20	2	3
T8	4	4	T21	3	3
T9	3	4	T22	2	3
T10	2	2	T23	4	5
T11	4	5	T24	4	5
T12	4	5	T25	3	5
T13	3	5	T26	4	4
Total estimated effort:		**93**	**Total actual completed task effort:**		**111**

Table 57: Team delivery performance per day for Sprint 13

Date	Estimated	Actual	Completed tasks
Oct 20, 2019	6	6	6
Oct 21, 2019	12	13	8
Oct 22, 2019	12	14	12
Oct 23, 2019	9	11	9
Oct 24, 2019	12	15	11
Oct 27, 2019	9	11	10
Oct 28, 2019	11	13	8
Oct 29, 2019	7	9	9
Oct 30, 2019	8	10	9
Oct 31, 2019	7	9	11
Total	93	111	93

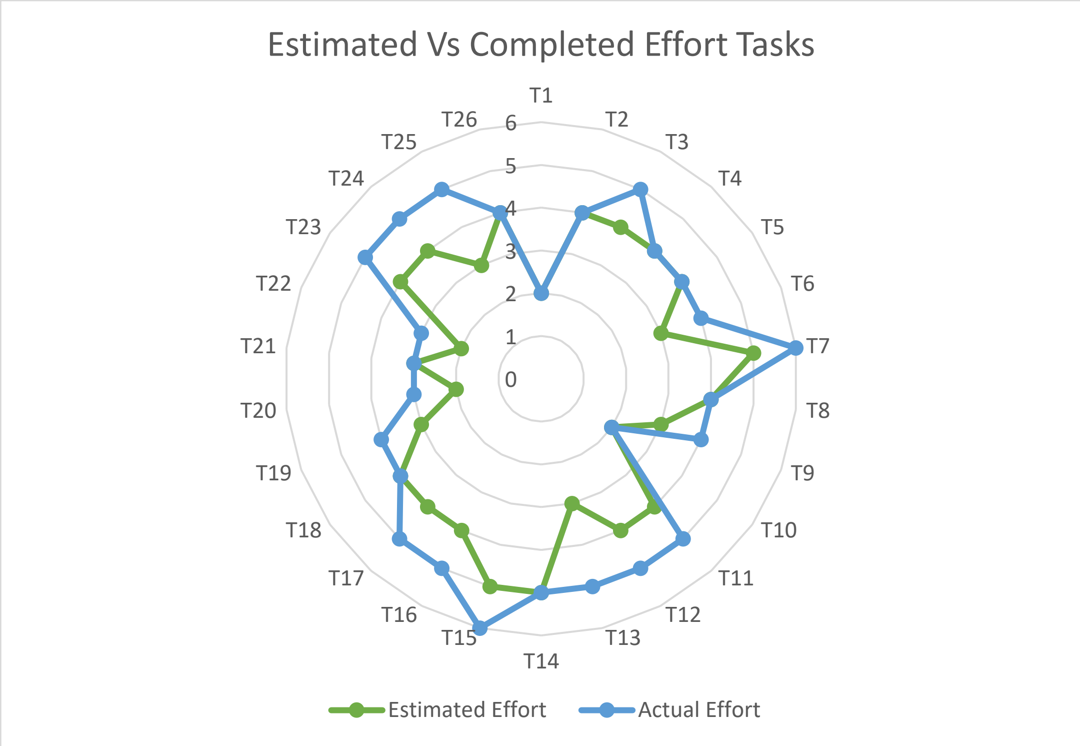


Figure 72: Task accuracy level (estimated vs actual)

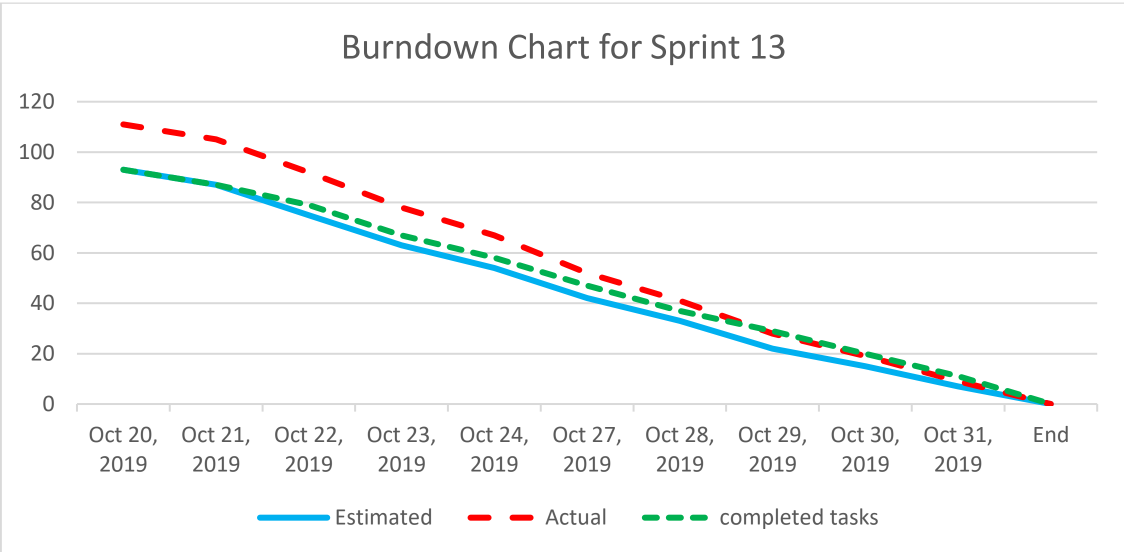


Figure 73: Burndown chart for Sprint 13 to compare the estimated effort to actual and earned effort values

Table 57 shows the delivery performance for the development team and Figure 73 its burndown chart. The product owner of the project, in comparing Sprint 11 with Sprint 13, said that in the former two things helped to estimate the effort accurately: breaking down the user story into subtasks by the role of the user; and assigning the subtask effort personally. However, the pair-estimation technique supported the estimate, using a large number of estimation predictors to help the team to think deeply about the task requirements.

9.2.5. Pearson correlation test

In order to validate the findings from the focus group discussions and team performance outputs, a statistical correlation test measured the degree of the relationship between the estimated effort values to the actual effort values of completed tasks during the sprint. Table 58 shows that there is no strong relationship between the estimated and actual effort values in Sprint 11. By contrast, after the development team applied the pair-estimation technique in Sprint 13, the association between the estimated and actual effort values is strong, as shown in Table 59. From the association result, it can be concluded that the accuracy of the effort estimation in Sprint 13 is higher than in Sprint 11.

Table 58: Correlation test for Sprint 11 to compare the estimated effort to actual effort

Correlation test for Sprint 11			
		Estimated effort values	Actual effort values
Estimated effort values	Pearson correlation	1	.440
	Sig. (2-tailed)		.152
	N	12	12
Actual effort values	Pearson correlation	.440	1
	Sig. (2-tailed)	.152	
	N	12	12

Table 59: Correlation test for Sprint 13 to compare the estimated effort to actual effort

Correlation test for Sprint 13			
		Estimated effort values	Actual effort values
Estimated effort values	Pearson correlation	1	.832**
	Sig. (2-tailed)		.000
	N	25	25
Actual effort values	Pearson correlation	.832**	1
	Sig. (2-tailed)	.000	
	N	25	25
**. Correlation is significant at the 0.01 level (2-tailed).			

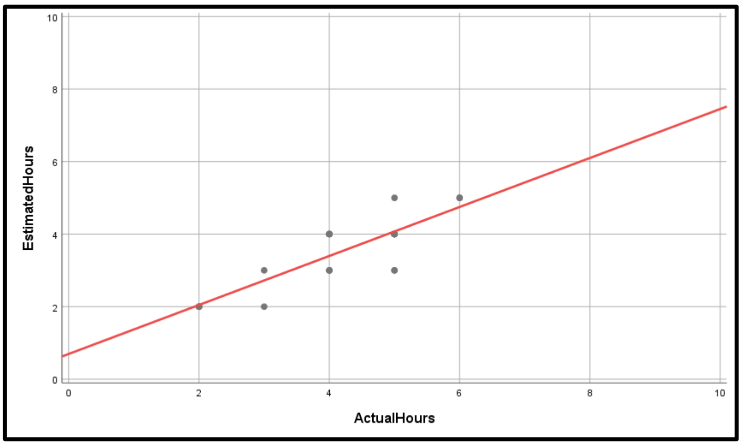


Figure 74: Scatter graph for Sprint 13

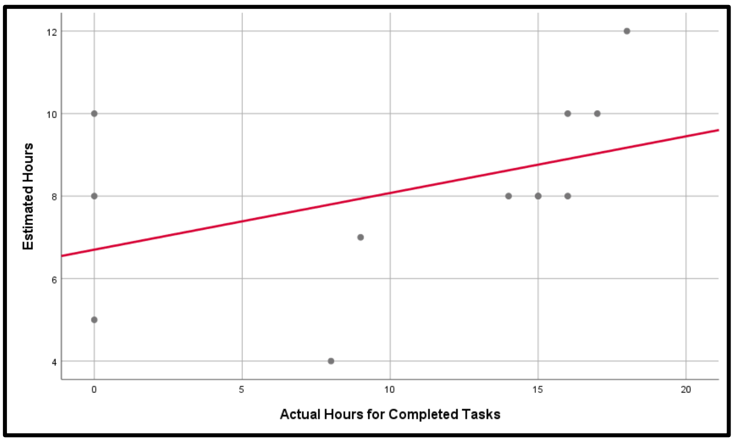


Figure 75: Scatter graph for Sprint 11

9.2.6. Summary of Case Study B

The company applied the PP estimation technique at the beginning and changed it to self-estimation technique due to its low accuracy and efficiency. This allows the developer who takes on a task to assign the effort estimation for that task. The PP did not succeed at this company due to the long time of the estimation process, level of experience among the team members and other reasons. Comparing with EJ, the accuracy improved over the PP technique; however, this is still not accurate enough due the unavailability of the baseline. The researcher presented the Pair-estimation technique and explained its process to the development team. The accuracy of the effort estimation was improved from 76% to 84% after applying the Pair-estimation technique. From the discussion with the product owner, the accuracy with the proposed technique "Pair-estimation" has potential to improve still further when the development team adapt to using this technique.

9.3. Case Study at Company C

9.3.1. Company and project information

Company C was founded in 2011 in Riyadh, and is owned by the Saudi government. This company has around 800 employees and is considered as an information technology and services enterprise that provides e-services and solutions to hundreds of customers, both in and beyond the Kingdom.

Company C was happy to participate in this case study, giving limited access to its data. Also, it allowed the researcher to observe the development team without undertaking any action or making any change to the current processes. The result of applying the proposed technique was given as general information, without any details of the user story. The researcher worked closely with two project managers on two projects to monitor and record the current behaviour of the development team. Also, the researcher provided suggestions and ideas for enhancements to the project managers to use with their development teams and then record the results. In general, the company is strict about not sharing information with a third party, therefore most of the project information is confidential, under the agreement with the NDA and the study's ethics regulation number 52598.

In the following sections, further explanation of the case study with Company C is provided. The result from the case study and suggested model are presented in the coming sections.

Table 60: Case study participants in Company C

Project manager	Years of experience	Project name
M-A	7 years	P-A
M-B	5 years	P-B

9.3.2. Current development process and estimation process in Company C

<u>Current development process</u>

In a large organisation, the Agile development process is unlike that in a small- or medium-sized company. Company C adopted an Agile process in some projects recently, as follows:

- The project manager (PM) is responsible for the project committee and assigns the solution architect, development team and business owner for the project. Also, the project manager is responsible for measuring the development performance of the team and is accountable for managing the project within the approved budget and Company C's quality standards.

- The business analyst (BA) is responsible for developing the documents and analysis covering all project requirements and stakeholder needs, working together with the system analyst (SA) team to translate the customer requirements into technical aspects and provide a business requirement specification to the technical team. The role is considered as a product owner of the project and collaborates with SA to facilitate the project in the development team.
- The development team consists of development, integration, quality and infrastructure professionals working together to deliver continuous development work over several sprints.
- The sprint length was three weeks on this project, and only one development team worked on this sprint. The sprint contained sprint planning, development work, sprint review and sprint retrospective phases. The sprint planning took about three days and more detail is given in the effort estimation process in the next section. The sprint development work began after the sprint planning session to undertake the development of the user stories. The sprint review event at the end of the sprint with the clients of the project and development team demonstrated the results of the sprint, then the sprint retrospective allowed enhancements and improvement by the team.

<u>Current effort estimation process</u>

Based on the discussion with two of the project managers, M-A and M-B, regarding the estimation process of the development team, the estimation process involves the following process:

- The BA, with the collaboration of the SA, explains the requirement specification of the user story to the development team and makes sure that they understand the user story that is to be delivered in the sprint.
- The development team takes the requirement specification documents of the user story and each member assigns an estimate to the task that he/she will work on. The estimation process work is based on individual, not collaborative, work.
- The effort estimation value is returned to the BA and the project manager on the next day.
- The BA discusses with the project manager the estimation values of the team, and either they approve it or ask the team to re-evaluate. Also, from the estimation value, the BA can recognise if the team understands the business requirement properly or not.
    - If the task is easy and the team assign a high estimate, the BA asks for clarification why this it will take that long.

    - If the task is complex and requires many integrations with other components and the team assigns a low estimate, the BA asks the team why it will be so short a time and makes sure they understand the task properly.
- Usually, the development team starts development on the third day of the sprint after the BA and PM accept their estimates.

The estimation accuracy of the last three sprints of Project P-A was given by the project manager to the researcher, and all three were underestimated by more than 50%. As seen in Table 61, the accuracy levels in Sprints 2, 3 and 4 are around 25%, 50% and 35%, respectively. The percentages were given by the project management office PMO in Company C and are an approximation based on the M-A and M-B's explanation.

Table 61: Effort estimation's accuracy level in the last three sprints in Company C

Sprint number	Accuracy level
2	25%
3	50%
4	35%

<u>Reasons for low accuracy and proposed solution</u>

During the regular meeting of the two project managers, I met M-A and M-B and discussed the reasons why the estimation accuracy of this project is unacceptably poor. The project manager concluded the reasons were as follows:

- The structure and hierarchy of the company does not support the development team to work independent of external interference. The Agile principle supports the team being self-organised and taking decisions on the project. The BA and SA team work under the PMO department, the developers work under the department of application development and the QA is a separate department, too, and each has its own manager. There are many departments in this organisation, such as database, security, integration and system architecture, infrastructure and network. Therefore, the integration between them involves considerable effort and policies.
- The Agile concept supports a team to work in a cross-functional manner; a big organisation with a complex structure is not helping the team to work without the collaboration of other team/departments. The Agile development team consists of developers and QA members; when a task is done by the team, it has to be passed to other departments to make sure that the team is following the organisation's standards, such as the quality of designing the database schema, hosting the services, complexity and security of the code, UI and UX standards, and so on.

- The development team does not use a clear process to arrive at its estimates. Each member assigns his/her effort estimation for a specific task that he/she will work on. The individual estimation method does not work properly for the team.

In discussion with the project managers, it was agreed that changes to the company structure are beyond the scope of this case study, due its hierarchy, and are also out the project managers' hands since it requires high-level authorisation from the board of directors. However, it was agreed to enhance the effort estimation process in the Agile development team and make changes to the current estimation method. The researcher shared the experience of Company A with the project managers at Company C and asked the project managers to adopt that method. The discussion with the project managers came up with the following suggestion:

- Instead of each member of the development team making his/her estimation alone, encourage each to share the effort estimation with a partner. The partner could be selected on the basis of a shared interest of the user story or task, as described in the proposed estimation technique in Company A.
- Encourage the participation of a representative member from each department in the sprint planning session, as this is helpful to provide and share their opinion on their department's standards and how to meet the development regulations. There are documents for each department showing their own standards and regulations; however, these need to be explained to the development team members by representatives during sprint planning and their questions answered directly. The representative could participate in the first two or three sprint-planning sessions until the team feels comfortable with the standards and software architecture. The representatives are recommended to work with the BA and SA to promote the user story in the development team and help them to construct the UAT.
- The project managers agree that the effort estimation factors play a vital role in enhancing the accuracy of the effort estimation and supporting the development team members to facilitate their tasks by breaking into small, understandable tasks. The factors can be shared by projector or printed on paper for the development team to use during the estimation period.

The diagrams in Figure 77 and Figure 76 demonstrate the effort estimation method before and after the modifications agreed at the meeting with the project managers M-A and M-B. The project manager M-A agreed to apply the changes to the estimation model with the development team and notify the relative departments. M-A met the practitioners responsible to explain the proposed method and ask them to apply it on the next sprint.

Proposed technique and its result

The proposed technique was to be applied in Project P-A with M-A as project manager. Project manager M-B only attended the meeting and shared opinions on the estimation result and technique. In the sprint planning of Sprint 5, the development team followed the proposed method and the project manager attended the planning session to make sure the team and all the responsible participants understood and followed the suggested estimation method. The project manager M-A explained the sequence of estimation process in the sprint planning as follows:

- First of all, the BA explains the user story to all participants in the sprint planning session.
- Then the BA asks a representative of each department to provide the acceptance criteria to achieve the departmental standards.
- The software architect provides the department standards on how the developers do their codes to make sure the code is reusable and understandable, and also follow the appropriate design pattern, framework, platform, etc.
- The development team asks questions to make sure the user story and company standards is clear to them. Then, each member discusses with his/her pair to assign an effort value for their tasks.
- The estimate is by the development team 'pair members', with no interference from other participants.
- The relevant representative from each department may attend the estimation session with the development team to help them to assign effort, if required.
- Then, BA and SA decide if the estimate is acceptable or ask for clarification and justification from the team. The BA wants to make sure the development achieve the delivery plan agreed with the clients.

At the end of Sprint 5, the project manager M-A shared the accuracy of the effort estimation. The estimation accuracy was around 70%. The effort estimation accuracy of Sprint 5 had improved by more than half compared to Sprints 2, 3 and 4, as shown in Figure 78. M-A attributed the improvement to the collaboration of the development team and the influence of the representative from each department. The effort estimation factors/predictors had a major influence on enhancing the estimation accuracy, from the project managers' observation, and helped the team to evaluate the complexity of the user story.

The shortfall of 30% in the accuracy level of the effort estimates still required further investigation and improvement, and it stemmed from the hierarchy of the development process, not from the development team, according to M-A. There are several management roles involved in this project, and the adoption of Agile process in this company required more investigation. The clients or customer representative in most cases were unaware about the conflicting requirements of the business, and for this reason there were sometimes modifications to the specification during the sprint. Moreover, the client on this project did not attend the sprint planning session to help the BA and SA with further explanation or enquiries. There were instances where the software requirement specification was not yet mature enough for the BA and SA, and this misinformation caused low accuracy in the effort predictions.

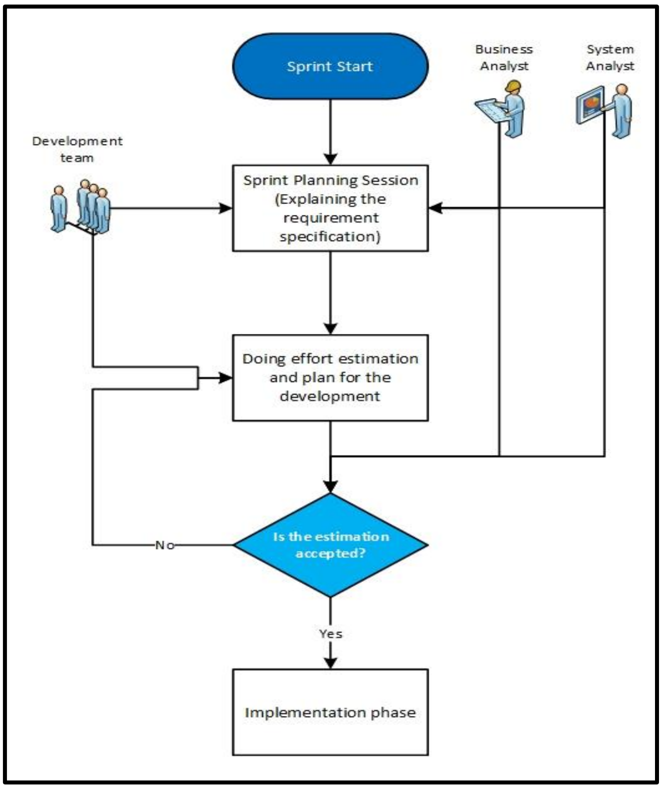


Figure 76: Existing effort estimation method in Company C

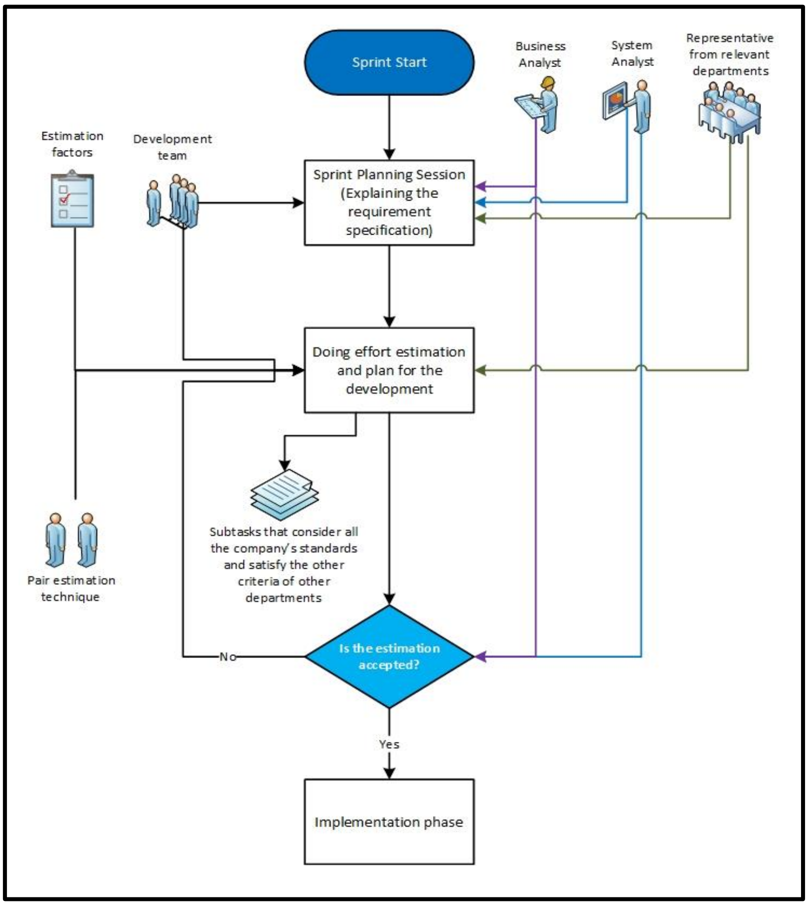


Figure 77: Modified effort estimation method in Company C

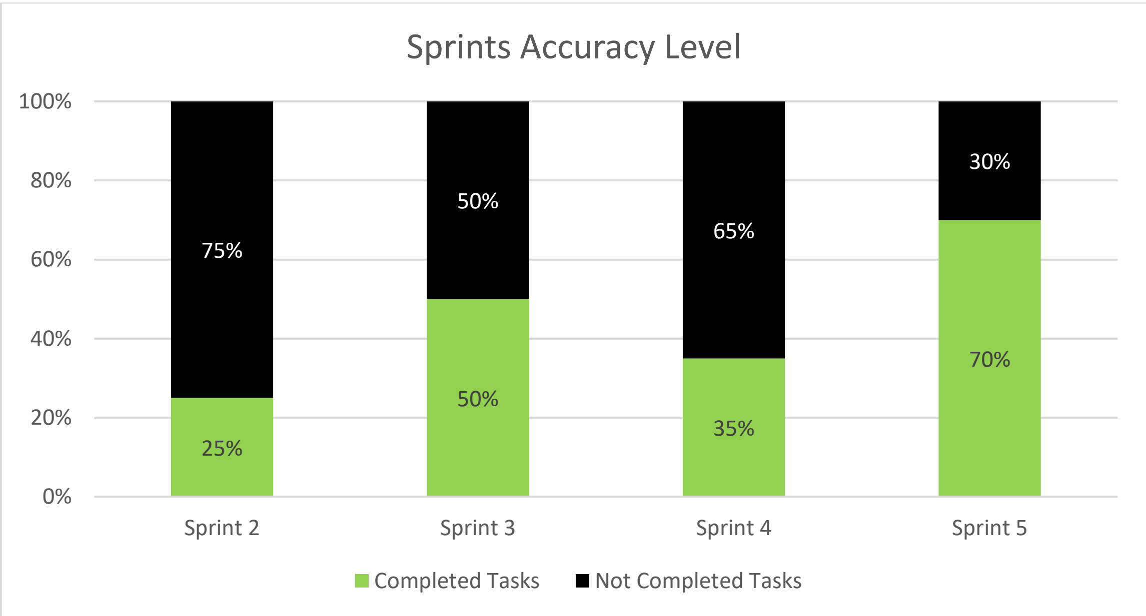


Figure 78: Sprint accuracy for the last four sprints in Company C

9.4. The concept of the Pair-estimation technique

The pair-estimation technique encourages the team members to talk to each other. The technique helps the team overcome disorganised discussions that led to misleading estimation values from nonspecialists. The proposed 'pair estimation' technique allows pair professionals to exchange their opinions, experience and understanding about the user story specification to achieve a highly accurate prediction. The Pair-estimation concept originated from the Pair-programming practice from eXtreme Programming that increases the quality of the decision outcomes from the pair developers (Beck & Fowler, 2000). The survey from this study in 7.2.3, in addition, supported the Pair-programming concept in mobile application development in terms of sharing knowledge and designing a good UI-UX for mobile apps. As a result, the concept of Pair-programming was applied in the first case study to be used in effort estimation as well to obtain a good accuracy of estimation. The Pair-estimation technique is supported with a checklist concept that facilitates the pair-estimation process and decision making as occurred in case study A in section 9.1. The checklist technique was described in more detail in section 7.4.

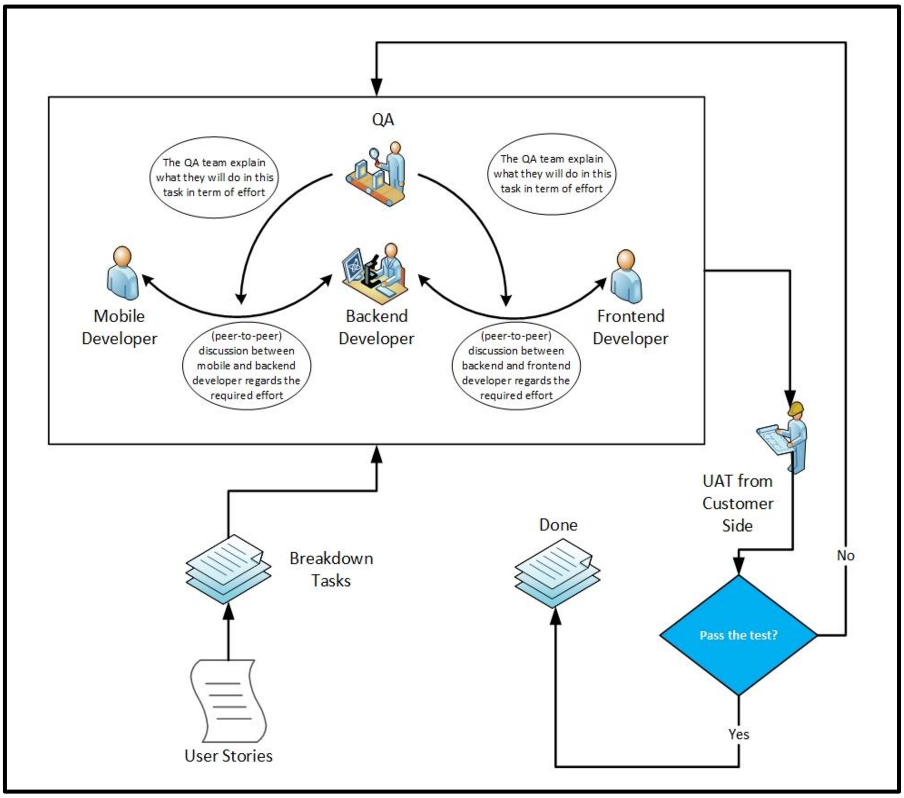


Figure 79: Pair-estimation technique

9.5. Limitations of the Research

In terms of conducting the case studies, the researcher experienced some difficulties and challenges in obtaining and recording information on the development teams' performance and sprint velocity. Some companies were reluctant to share their data and feared losing clients, which could affect their reputation. However, the researcher observed and recorded important information to evaluate and validate the proposed estimation technique. For each case study, there were various types of information; therefore, every case study had a different type of analysis. There was possibility that the participants from the three case studies could changed their behaviour in response to their awareness of being studied, watched or observed for any reason, and this situation known as the Hawthorne effect. In order to mitigate this risk; however, the researcher handled the Hawthorne effect by understanding and following the suggested protocols from (Oswald et al., 2014) that encourage building trust, good communication, friendly relationship and relaxing with the participants and wearing casual dress. The researcher had direct contact with the project managers in order to acquire the required data while the development team not feeling they have been observed. Also, the research ask the project manager to confirm the observed data to make sure the data has been collected properly.

9.6. Summary

In this chapter, the proposed effort estimation technique of 'pair estimation' was validated in three companies, resulting in an improvement in estimation accuracy. Company A had used an EJ technique that allowed one expert from the development team to take control of estimation for all user stories in the sprint. Sometimes the team used a self-estimation technique, whereby the developer who is to do the task is responsible for assigning the effort value to that task. Company A allowed the researcher to undertake more investigation into the sprint and conduct focus groups to understand the challenges during the estimation process. The result of the proposed technique, pair estimation, was enhanced delivery of the user story and its quality in terms of the numbers of defects/bugs. In Company B, the researcher was able to obtain detailed information on the sprint due the small size of the company. The company applied pair estimation and the results showed a positive impact by the proposed technique.

Most of the companies preferred self-estimation to avoid the complexity of the estimation process and wanted commitment from developers regarding estimates. Companies A and B concluded that PP technique was not working properly for them due to unrelated members of the team being involved in the estimation of a task that is not their specialty, resulting in inaccurate estimation. PP took a long time during sprint planning. In Company C, the development team suffered from the organisational structure and hierarchy, and the researcher had limited access to the sprint data due to the sensitivity of the clients and the company's reputation. The researcher contacted the two project managers and PMO department directly to investigate the estimation challenges, and the pair-estimation technique enhanced the project's estimation accuracy, to some extent.

Chapter 10: Conclusions and Future Work

This chapter summarises and concludes the present study, which is derived from the results of the research questions, methods, findings and analysis. In this chapter, the main conclusions of this study are provided in section 10.1. Following this, the main contributions are discussed in section 10.2. At the end of this chapter, the possible direction of this study and future work are provided in section 10.3.

10.1. Conclusions

This study presented and evaluated the current state of practice of effort estimation techniques for mobile app development using Agile processes. The aim was to investigate the efficiency of estimation techniques in the industrial fields and evaluate their effectiveness in terms of Agile processes. The study aimed to propose a technique devised and designed by several Agile practitioners in multiple organisations to improve the accuracy of estimation.

10.1.1. Systematic literature Review

This study first presented a Systematic Literature Review (SLR) on effort estimation in mobile apps that use the ASD method. The initial search phase returned 701 results, only 21 of which were selected for the primary study. Various information was extracted from these studies, such as estimation techniques, cost drivers, domain and type of dataset and estimation accuracy techniques. Then, the research gaps were identified. The research aim and objectives are concerned with the identification of the effort estimation factors for mobile app development, and these have been stated, along with investigating the applicability of the Agile process to mobile app development. After that, this study presented the research methodology regarding the data that were collected, and the research strategy, design and approach adopted. The Table 62 below presents an overview of the SLR's aim and objectives of this study.

Table 62: A summary of the Systematic Literature Review objectives

Chapter	Research Method	Aim	Objectives
4 and 5	Systematic Literature Review	Provide the current state of art of the effort estimation methods of mobile app development in Agile process	Identify the estimation techniques used in mobile app development from exited studies
			Identify and investigate the factors and predictors of effort estimation in mobile app
			Identify the effort estimation factors for Agile process
			Investigate the suitability of Agile process in mobile app development

10.1.2. Survey Method

Prior to specifying data collection through interviews, the author had prepared likely techniques. The interview aimed to evaluate the effective factors in enhancing the accuracy of development teams' estimates. The interview questions, in addition, aimed to explore the estimation techniques and processes used in the development of mobile apps and investigate its validity and efficiency in the context of Agile processes. The author conducted interviews with 20 experts from 18 different organisations, then the data collected from the survey and interviews were analysed quantitatively and qualitatively. The interview included a wide diversity of participants that involved project managers, mobile developers, backend developers, frontend developers and QA.

Survey result: The interviews revealed that the EJ technique of effort estimation is the one most commonly used in the development of mobile apps. Development teams tend to use non-formal models that rely on judgement; however, these techniques suffer from low accuracy for mobile app development, according to the interviews, and for software in general from previous studies in the literature. The survey's results concluded that the experts preferred to undertake estimation on an individual basis, so each task should be assigned to one member of the development team. Group-based estimation, such as PP, leads to inaccuracy due to the varying level of developers' experience, knowledge, capability and other factors. The survey, moreover, evaluated the list of comprehensive factors that influence the accuracy of the effort estimation. At the start, the interviews evaluated 48 effective factors. Then, the experts provided 20 further factors and explained more extensively how these could affect the estimation values. The quantitative analysis of the results showed a relationship between these factors and the opinions of project managers, developers and QAs.

Preliminary of proposed technique: At the end of Chapter 7 there was a discussion on formal and non-formal estimation techniques that included the debate between Magne Jørgensen and Barry Boehm (Jørgensen et al., 2009; Jørgensen & Grimstad, 2010) and other researchers and specialists from the SLR, such as Mahnič and Hovelja (2012), Tanveer, Guzmán and Engel (2017) and M. Usman et al. (2015). The results revealed that, while the experts usually rely on non-formal techniques such as PP and EJ, there is a need for improvement in their current techniques. A proposed technique was initiated by the experts' discussions and evolved into the checklist method of estimation.

The Table 63 summarised the aim and objectives of the survey methods, and provided an overview of the survey method purpose.

Table 63: A summary of the survey method's aim and objectives

Chapter	Research Method	Aim	Objectives
7.1.2 **7.1.3**	Structured Interview	To investigate and understand the current state of practice of effort estimation in mobile app development using Agile from the industrial fields	To investigate the effort estimation techniques that used for mobile app development in industries
7.1.4 **7.1.5**			To investigate and evaluate the effort estimation factors and predictors that influence on the estimation accuracy
7.2.1 **7.3.1** **7.3.3**	Semi-structured interview		To investigate, understand and evaluate the existed estimation process that used in the IT companies
			To investigate the most used estimation techniques for mobile app development in the industrial fields
7.2			To understand the challenges and drawbacks of the current estimation techniques and process
7.2.2 **7.3.2**			To gain more additional factors and predictors that play critical factors to influence on the estimation accuracy
7.1.5			To understand the estimation accuracy of the exited estimation techniques
7.4		To improve the existed estimation technique	Enhance the most used existing estimation techniques
			Ask for feedback and opinions about the preliminary proposed technique

10.1.3. Case Study Method

The case-study method was planned and designed in detail in Chapter 8, which includes the aim and objectives of the case study. The research scope of the case study and questions were defined prior to the start of the study. The case study involved three companies that produce software products including mobile apps.

Case study A: The first case study was in Company A, which involved seven specialists including mobile developers, QA, a backend developer, frontend developer and project manager. Focus group discussions and observations were conducted to evaluate the current estimation process and design the proposed estimation technique. Pair estimation was proposed, and was applied and evaluated in two sprints, then an evaluation process compared its efficiency to the existing technique. The result revealed an improvement in delivering a user story within the planned time over previous sprints in the same project. The correlation test was applied to compare the estimation efficiency before and after the proposed technique, and concluded that there was a strong relationship between the estimated and actual effort when the pair-estimation technique was applied. The improvement was not only on delivering the story points and tasks within the planned time; the number of bugs was reduced by 60 to 70%. The pair-estimation technique not only improves estimates; it encourages strong communication with the client and reduces wasted time in negotiation with irrelevant people, compared to the PP technique.

Case study B: The second case study validated the results from the first. The pair-estimation technique was applied at Company B and focus group discussions were held with the relevant team members to discuss the proposed estimation before applying it to a sprint. Pair estimation was used in Sprint 13, and the accuracy level of estimation improved from 76% in Sprint 11 to 85% in Sprint 13. Moreover, from the group discussion, the development team felt more confident than in the previous sprints, due to the clarity of the planned tasks and user stories.

Case study C: There were stringent limits on access to data about the development team and the performance of and information about the sprint. The company did not wish to risk its reputation and feared sharing the data with others. Therefore, there was limited access to raw data, but the company shared some analysed data and was willing to improve its estimation accuracy. The accuracy of effort estimation in a selected project was between 30 and 50%. The error ratio was very high compared to the average in earlier case studies and the survey of experts. The reason was the multiple levels of management on this project and the existing estimation process. The type of the project was unique, and the details of the project requirements were not mature. Nonetheless, the accuracy of the estimation improved to 70% after using the proposed estimation technique of pair estimation by making the development team aware of the influence of the effort estimation factors and predictors of the estimation accuracy, and encouraging them to delve deeper into the project requirement details.

The Table 64 below provided the summary of the case study method from this study.

Table 64: A summary of the case study objectives

Chapter	Research Method	Objectives
8 and 9	Action Method / Case Study	To propose an enhanced technique for the most used estimation techniques from the industrial fields
		To confirm the proposed estimation technique efficiency and validity
		To evaluate the efficiency of the effort estimation factors / predictors
		To evaluate the accuracy of the proposed estimation technique

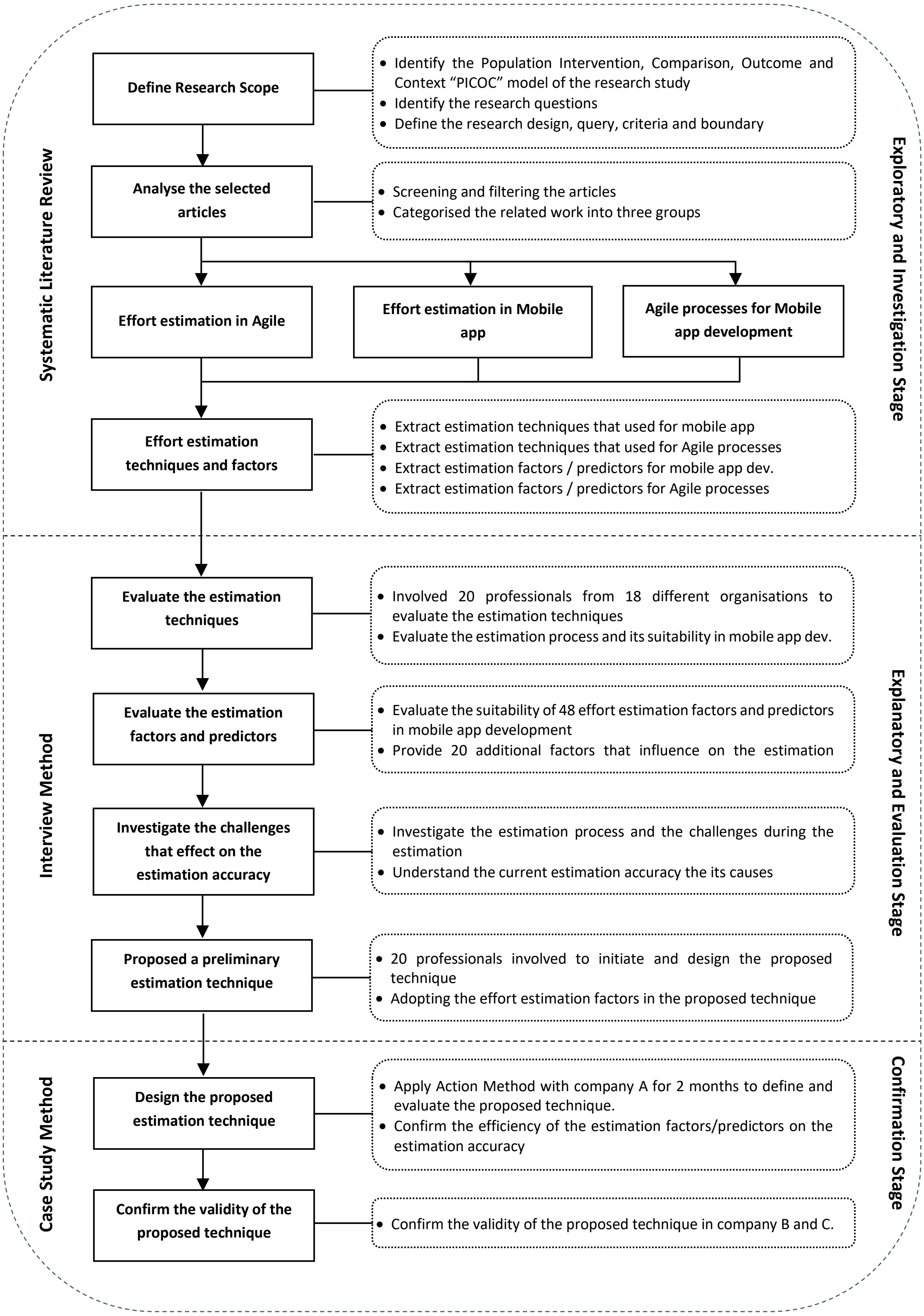


Figure 80: Overview of the study methods and process

10.2. Contributions of the Research

The aim of the study and its objectives and contributions were shaped and designed clearly in Chapter 3. The study stated four research questions that have been investigated in the SLR in Chapter 4. Several research gaps were identified and explained at the end of Chapter 5 after the research questions and the literature review were discussed. Therefore, in this section, the main contributions of this research study are recapped and listed below:

- To investigate the current state of the practice of effort estimation techniques used in mobile app development using Agile processes.
- To evaluate the most used estimation techniques in Agile processes, Poker Planning and Expert Judgment, in the industrial fields for mobile app development.
- To identify the main challenges of current estimation processes and its techniques from the industry's perspectives.
- To identify and evaluate a comprehensive list of effort estimation factors and predictors for mobile app development in the Agile context.
- To measure the effect of effort estimation factors and predictors on estimation techniques.
- To propose an estimation technique with the collaboration of professionals from various organisations, and to validate and evaluate its efficiency and accuracy in Agile mobile app development.

Taking these together, this research identified 68 validated factors that support the Agile development team to assign the estimated effort for a task. This research designed and examined the proposed Pair-estimation technique to perform the estimation process during the sprint in Agile process. The research contribution, in addition, has validated the most used estimation techniques, Planning Poker and Expert Judgment, and measured their effectiveness in the Agile process for Mobile app development. There is no best estimation technique in Agile processes; however, the Pair-estimation technique provided promising results that have been validated empirically across multiple companies.

10.3. Future Work

Several research gaps were identified from the SLR results and discussions. Some were discussed and covered in this study and others were not. In addition, this study investigated the current state of practice in 18 organisations and proposed estimation factors that improved existing estimation techniques. However, more gaps have arisen during the investigation. In this section, therefore, possible future works and directions are highlighted.

One possible future work direction is to meet the need to examine suitable Agile approaches for mobile app development. This study investigated and validated the effort estimation of mobile app development in Agile process. Part of this study provided feedback on the Agile process in mobile app development, as this is within its scope. There are proposed Agile approaches, such as Mobile-D and MASAM, in mobile app development that should be examined and validated empirically.

Since this study applied its case studies in three companies in the Kingdom of Saudi Arabia in cities; further companies, countries and places need to be involved, in future work, to investigate the current state of practice in activities there and provide more feedback on existing estimation techniques and the proposed technique. This study, in addition, provided feedback on one of the most well-known techniques in Agile, PP, from an IT-sector perspective. The result revealed that PP suffered from challenges mentioned extensively in Chapter 9. However, this study is the only research to have given empirical feedback on PP for mobile app development using Agile processes (Altaleb & Gravell, 2018; Britto et al., 2014; Kaur & Kaur, 2018; M. Usman et al., 2015), alongside the few works that examine PP activities empirically for Agile process in general. Therefore, there is a potential direction to investigate the PP technique in mobile app development for Agile processes.

This study provided a comprehensive list of factors from interviews and other research, and then validated its suitability for mobile app development. There is potential future work to validate these factors using a greater number of professionals across companies and countries. Another work could investigate the effort estimation factors for a specific mobile app platform, either IOS or Android. This study initiated a search for comprehensive factors across mobile app platforms in general, out of concern at the diversity of mobile platforms, and a continued investigation could focus on a specific platform to investigate deeper within API's complexity, tools and UI-UX features of a mobile platform.

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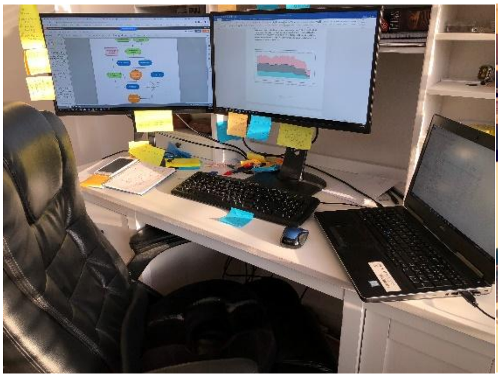
Appendix A

About the Author

Abdullah Altaleb is a PhD candidate specialising in Software Engineering at the University of Southampton, United Kingdom. The author accomplished his master's degree in software engineering at Southern Methodist University in Dallas, Texas in the United States. The author worked at the GOSI and NIC organisation as a software and application developer for four years, with a focus on the Java EE platform. He also worked at MRN Inc. as a software architect in San Jose, California. Abdullah is certified in CABA, which is associated with the business analysis profession, and in Scrum Master.




Cross-platform Frameworks and Tools Background

- PhoneGap: an open-source framework from Adobe considered to be one of the most popular hybrid cross-platform framework for mobile app development. Apache Cordova is the engine that powers PhoneGap, which acts as a container or wrapper for web technologies such as HTML, JavaScript and CSS in a mobile app ('PhoneGap,' n.d.). Thus, the framework does not convert the HTML and JavaScript into native code; however, it allows access to native device functionality (APIs) and lets the web technologies execute within a wrapper targeted on each platform (Android, IOS, etc.).
- Ionic: a powerful HTML5 open-source framework that helps to build native-style mobile user interface for hybrid mobile app development. It require a native wrapper, such as PhoneGap, to run as a native app ('Ionic Framework,' n.d.). Ionic uses a lot of functionality of AngularJS; however, it provides additional components for mobile app development.
- Xamarin: a cross-platform framework from Microsoft that promises to build native app for multiple platform (IOS, Android and Windows) using a single code C# language, which means the application has all the native features. The Xamarin platform consists of the Mono .Net framework, which provides cross-platform implementation features.

- Appcelerator Titanium: an open-source framework that allow a developer to build a cross-platform native mobile app using JavaScript APIs. Titanium SDK consist of a set of Nodejs services and other supporting tools that work alongside with native SDK tool chains ('Appcelerator Titanium,' n.d.). Hyperloop is a compiler that turns the JavaScript into native code and have direct access to native APIs.
- Angularjs: is a client-side JavaScript framework to build a dynamic web app, single page application and support MVC concept.
- Nodejs: is an open-source JavaScript runtime environment that allows JavaScript code to be executed on the server-side.
- Smartface: a framework to develop a native IOS and Android mobile app. Smartface uses a standard JavaScript OS engine such as V8 for Android and JavaScript Core for IOS. This framework offers What You See Is What You Gets (WYSIWYG) editor for native UI development. Moreover, it supports a single code base, which avoids designing UI separately for each target environment. That means developing and designing just one app interface and deploying on various device OS. Smartface is the only cross-platform to support IOS development on Windows OS.
- jQuery-Mobile: a framework designed for cross-platform mobile web apps integrated with HTML5, CSS, jQuery and jQuery UI. This framework offers Ajax navigation for page transition and supports several touch-event UI widgets. This framework is not considered as either a hybrid or an interpreted approach, but as a web application approach (Latif et al., 2016; ('jQuery-Mobile website,' n.d.).
- React-native: an open-source framework from Facebook for building a mobile app using ReactJS and JavaScript.

Appendix B

SLR Query Schema

Table 65: Query schema

Query ID	Command Query	Query Category	Results	Validity/comments
IEEE: Search by documents title				
IEEE (Search query 1)	("Document Title":effort OR "Document Title":cost OR "Document Title":size) AND ("Document Title":estimation OR "Document Title":estimate OR "Document Title":estimating OR "Document Title":predict* OR "Document Title":prediction OR "Document Title":assess* OR "Document Title":assessment OR "Document Title":calculation OR "Document Title":calculating OR "Document Title":calculate) AND ("Document Title":mobile OR "Document Title":*phone* OR "Document Title":touchscreen OR "Document Title":smartphone)	Normal	23	This query was designed to obtain all of the published articles related to effort estimation with mobiles. I ignored the Agile SD on this query.
IEEE (Search query 2)	("Document Title":effort OR "Document Title":cost OR "Document Title":size) AND ("Document Title":estimation OR "Document Title":estimate OR "Document Title":estimating OR "Document Title":predict* OR "Document Title":prediction OR "Document Title":assess* OR "Document Title":assessment OR "Document Title":calculation OR "Document Title":calculating OR	Very Important	Zero	When I added the Agile or all the synonymous words to the previous search query, there was no result. The indication was very good for this paper, thus meaning that no previous publication exists concerning this topic.

Query ID	Command Query	Query Category	Results	Validity/comments
	"Document Title":calculate) AND ("Document Title":mobile OR "Document Title":*phone* OR "Document Title":touchscreen OR "Document Title":smartphone) AND ("Document Title":agile OR "Document Title":"software development" OR "Document Title":scrum OR "Document Title":XP OR "Document Title":"extreme programming" OR "Document Title":crystal OR "Document Title":DSDM OR "Document Title":"dynamic system development method" OR "Document Title":lean)			
IEEE (Search query 3)	("Document Title":effort OR "Document Title":cost OR "Document Title":size) AND ("Document Title":estimation OR "Document Title":estimate OR "Document Title":estimating OR "Document Title":predict* OR "Document Title":prediction OR "Document Title":assess* OR "Document Title":assessment OR "Document Title":calculation OR "Document Title":calculating OR "Document Title":calculate) AND ("Document Title":mobile OR "Document Title":*phone* OR "Document Title":touchscreen OR "Document Title":smartphone) AND ("Document Title":app OR "Document Title":apps OR	Very Important	6	I used the (search query 1) and added the “application” and its synonym. There were only four results related to this query. This result was similar to those of the papers shown in query 1. I will focus on and read these papers in more detail. Updated 11-9-2017 All the results in this document were included in Search query 3. As such, the results in this file were ignored.

Query ID	Command Query	Query Category	Results	Validity/comments
	"Document Title":application OR "Document Title":applications OR "Document Title":software OR "Document Title":program OR "Document Title":programs)			
IEEE (Search query 14)	("Document Title":mobile OR "Document Title":*phone* OR "Document Title":touchscreen OR "Document Title":smartphone) AND ("Document Title":app OR "Document Title":apps OR "Document Title":application OR "Document Title":applications OR "Document Title":software OR "Document Title":program OR "Document Title":programs) AND ("Document Title":agile OR "Document Title":"software development" OR "Document Title":scrum OR "Document Title":"extreme programming" OR "Document Title":crystal OR "Document Title":DSDM OR "Document Title":"dynamic system development method")	Normal	32	This query was designed to obtain all the relevant articles concerning the mobile application software development process, regardless of the field of study.
IEEE: Search by index terms				
IEEE (Search query 4)	("Index Terms":effort* OR "Index Terms":efforts OR "Index Terms":cost OR "Index Terms":size) AND ("Index Terms":estimation OR "Index Terms":estimate OR "Index Terms":estimating OR "Index Terms":predict* OR "Index Terms":prediction OR "Index Terms":predicting OR "Index Terms":measure OR	Very Important	17	This query was fairly different from the previous ones. It covered all the research topic terms and these papers should be read in more detail to establish whether the questions have been answered. Updated 14-11-2017 About half of the query's results were duplicates.

Query ID	Command Query	Query Category	Results	Validity/comments
	"Index Terms":measurement) AND ("Index Terms":mobile OR "Index Terms":phone OR "Index Terms":smartphone OR "Index Terms":touchscreen OR "Index Terms":*phone*) AND ("Index Terms":app OR "Index Terms":apps OR "Index Terms":application OR "Index Terms":applications OR "Index Terms":software OR "Index Terms":project OR "Index Terms":projects) AND ("Index Terms":agile OR "Index Terms":“software development” OR "Index Terms":scrum OR "Index Terms":XP OR "Index Terms":“extreme programming” OR "Index Terms":crystal OR "Index Terms":DSDM OR "Index Terms":“dynamic system development method”)			
IEEE: Search by abstract				
IEEE (Search query 5)	("Abstract":effort* OR "Abstract":efforts OR "Abstract":cost) AND ("Abstract":estimation OR "Abstract":estimate OR "Abstract":estimating OR "Abstract":predict* OR "Abstract":prediction OR "Abstract":predicting OR "Abstract":measure OR "Abstract":measurement) AND ("Abstract":mobile OR	Normal	48	

Query ID	Command Query	Query Category	Results	Validity/comments
	"Abstract":phone OR "Abstract":smartphone OR "Abstract":touchscreen OR "Abstract":*phone* OR "Abstract":apple OR "Abstract":android) AND ("Abstract":app OR "Abstract":apps OR "Abstract":application OR "Abstract":applications OR "Abstract":software OR "Abstract":project OR "Abstract":projects) AND ("Abstract":agile OR "Abstract":"software development" OR "Abstract":scrum OR "Abstract":XP OR "Abstract":"extreme programming" OR "Abstract":crystal OR "Abstract":DSDM OR "Abstract":"dynamic system development method")			
ACM: Search by title and term index				
ACM (Search query 6)	acmdlTitle:(+(effort efforts cost size) +(estimate estimation estimating prediction predicting predict measure measurement) +(mobile mobiles phone phones smartphone apple android "screen touch" screentouch touchphone "touch phone"))		7	Three of these papers were included and duplicated in query 7.
ACM: Search by abstract				
ACM (Search query 7)	recordAbstract:(+(effort efforts cost costs) +(estimate estimation estimating prediction predicting predict measure measurement) +(mobile mobiles phone phones smartphone apple android "screen touch" screentouch touchphone	Not Important	293	The result was huge. I obtained many results that were not related to my topic, such as energy consumption, network, malware detection and so on. As such, it is my

Query ID	Command Query	Query Category	Results	Validity/comments
	"touch phone") +(apps app application applications software project projects program))			feeling that I must conduct another filter to emphasise the most important articles which have discussed my topic.
ACM (Search query 8)	recordAbstract:(+(effort efforts cost costs) +(estimate estimation estimating prediction predicting predict measure measurement) +(mobile mobiles phone phones smartphone apple android "screen touch" screentouch touchphone "touch phone") +(apps app application applications software project projects program programs) +(agile "software development" scrum XP "extreme programming" crystal DSDM "dynamic system development method" lean)) AND I combined the previous query with the following one : acmdlTitle:(+(mobile mobiles phone phones smartphone apple android "screen touch" screentouch touchphone "touch phone") +(apps app application applications software project projects program) +(agile "software development" scrum XP "extreme programming" crystal DSDM "dynamic system development method" lean))	Very Important	8	This query yielded only six articles. Some of them were included in Search query 6, thus meaning that a great deal of attention will be paid to these research matches or those relevant to my topic. Updated 11-10-2017 All the research results were duplicates and were included in query 7. As such, I will focus on the duplicated ones.
Inspec And WebOfScience: Search by topic				
Inspec (Search query 9)	(TS=((effort OR efforts OR cost OR size) AND (estimation OR estimating OR estimate OR prediction OR predicting OR predict OR assess OR assessment OR calculate Or calculation OR measure OR measuring) AND (mobile OR smartphone OR "screen touch" OR phone OR apple OR android OR IOS) AND (app OR apps OR application OR applications OR software OR	Normal	123	TS = Topic that covers all abstract and topic field terms. Many studies are duplicated on IEEE.

Query ID	Command Query	Query Category	Results	Validity/comments
	program OR programs) AND (agile OR "software development" OR scrum OR XP OR extreme programming OR Crystal OR DSDM OR "dynamic system development method" OR lean))) AND LANGUAGE: (English) Indexes=Inspec Timespan=2008-2017			
Inspec And WebOfScience: Search by title without Agile terms				
Inspec (Search query 10)	(TI=((effort OR efforts OR cost OR size) AND (estimation OR estimating OR estimate OR prediction OR predicting OR predict OR assess OR assessment OR calculate OR calculation OR measure OR measuring) AND (mobile OR smartphone OR screen touch OR phone OR apple OR android OR IOS) AND (app OR apps OR application OR applications OR software OR program OR programs))) AND LANGUAGE: (English) Indexes=Inspec Timespan=2008-2017	Normal	11	TI = Title of the topic. Only 11 studies. There was no result when I added the Agile terms on this query. Updated: all queries' results were duplicated on other different queries.
Inspec And WebOfScience: Search by title with Agile terms				
Inspec (Search query 11)	(TI=((effort OR efforts OR cost OR size OR performance) AND (estimation OR estimating OR estimate OR prediction OR predicting OR predict OR assess OR assessment OR calculate Or calculation OR measure OR measuring) AND (mobile OR smartphone OR screen touch OR phone OR apple OR android OR IOS) AND (app OR apps OR application OR applications OR software OR program OR programs) AND (agile OR "software development" OR scrum OR XP OR "extreme programming" OR Crystal OR	Very Important	Zero	There was no result for this query when I added the Agile terms. No work has been published on this topic.

Query ID	Command Query	Query Category	Results	Validity/comments
	DSDM OR “dynamic system development method” OR lean))) AND LANGUAGE: (English) Indexes=Inspec Timespan=2008-2017			
SCOPUS And Compendex: Search by abstract				
SCOPUS & Compendex (Search query 12)	ABS((effort OR efforts OR cost OR size) AND (estimation OR estimating OR estimate OR prediction OR predicting OR predict OR assess OR assessment OR calculate Or calculation OR measure OR measuring) AND (mobile OR smartphone OR "touch screen" OR phone OR apple OR android OR IOS) AND (app OR apps OR application OR applications OR software OR program OR programs) AND (agile OR "software development" OR scrum OR XP OR "extreme programming" OR Crystal OR DSDM OR "dynamic system development method" OR lean))	Not Important	76	
SCOPUS And Compendex: Search by title without Agile terms				
SCOPUS & Compendex (Search query 13)	TITLE-ABS((effort OR efforts OR cost OR size) AND (estimation OR estimating OR estimate OR prediction OR predicting OR predict OR assess OR assessment OR calculate Or calculation OR measure OR measuring) AND (mobile OR smartphone OR "touch screen" OR phone OR apple OR android OR IOS) AND (app OR apps OR application OR applications OR software OR program OR programs) AND (agile OR "software development" OR scrum OR XP OR "extreme programming" OR Crystal OR DSDM OR "dynamic system development method" OR lean))	Very Important	17	The search title with no added Agile terms yielded 17 results. With Agile terms the result was zero. Updated 14-11-2017 Most of the results were duplicated somewhere else in another query.
SCOPUS and Compendex	((mobile OR smartphone OR "touch screen" OR phone OR apple OR	Very Important	31	

Query ID	Command Query	Query Category	Results	Validity/comments
(Search Query 16)	android OR ios) AND (app OR apps OR application OR applications OR software OR program OR programs) AND (agile))			
OpenDOAR/Google Scholar: search manually by using the query criteria				
OpenDOAR & Google Scholar (Search query 15)	(effort OR efforts OR cost) AND (estimation OR estimating OR estimate OR prediction OR predicting OR predict) AND (mobile OR smartphone OR screen touch OR phone) AND (app OR apps OR application OR software) AND (agile OR “software development” OR scrum)	Normal	9	This search was conducted manually because OpenDOAR has many repositories and I had to use some of those which were related to my topic and obtain all topics pertaining to my research.

Appendix C

Interview Questions

Structured, Semi-structured and in-depth Questions

The total number of questions is 25, 12 of these questions are open-ended questions.

A. Structured questions:

1) Demographics and basic information about the practitioner:

Question	Answer
Work experience countries	
Years software development experience in general	
Years of software development experience in mobile apps	
Current positions/role in your employment	
Previous positions/role in your employment history	
Name/Nature Of organisation you work with (Telecom/Manufactory/etc.)	
Mobile development platform: Native, web-based or hybrid	
Name of the mobile platforms and technologies that you have been used	

2) Effort Estimation model:

- Select the estimation methods/techniques and size metrics that you have been used in a software project?

Estimation method	Select
Planning poker	☐
Expert-judgment	☐
COCOMO	☐
Delphi	☐
Analogy	☐
Use case point method UCP	☐
Regression based	☐
Other ………………………	

- Rank the importance of the estimation factors/predictors that you were used or rely on during your estimation process?

B. Semi-Structured and In-depth investigation:

- How do you estimate the effort of your mobile app development? And why you choose this technique?
- From the previous estimation factors list, is there any additional factors you used?
- What are the main challenges that may face you to estimate the effort for a mobile app project?
- How accurate your estimation method? Why (is/is not) accurate in your opinion? How much time you spent to estimate (ex:5 min)?
  - Underestimate (0-5%, 6-10 %, 11-15%, 16-20%, more than)
  - Overestimate (0-5%, 6-10 %, 11-15%, 16-20%, more than)

  How do you know?
- Do you concern about the length and duration of the estimation process? Why?

Agile software development method in mobile app:

- Have you applied agile process in your mobile project?
- If yes,
  - Which methodology you have applied (XP, Scrum, Crystal, Lean, other ………)?
  - How was the process working with you, and what do you think about Mobile-D process?
  - What is the optimal length of the sprint/iteration (1,2,3 or 4 weeks)? Why?
  - What is the optimal number of development team (3,4,5,6,7,8,9 people)? Why?
  - What is the advantage and disadvantage of using agile?
- If no, what is the process you used? Explain?
- How did you apply the effort estimation in your development process?
- "Explain suggested framework (Checklist), and ask them about their opinion"

Figure 81: Example of survey questions

Interview Information

Table 66: Expert's information

Expert ID	Expert Name	Main Job's Role	Position Role (current/previous)	Worked at Company ID	Year of Experience
A	Anonymous	Project Manager	IT Director, software analyst, junior developer	CO_2, CO_3, CO_8	4
B	Anonymous	Software Developer	Senior developer, junior dev	CO_2, CO_3, CO_9	4
C	Anonymous	Software Developer	Sales, senior developer, freelancer	CO_1, CO_4, CO_13	9
D	Anonymous	Software Developer	Team leader, senior developer	CO_1, CO_3, CO_10	5
E	Anonymous	Software Developer	Senior dev, junior developer	CO_4, CO_11	6
F	Anonymous	Software Developer	Senior developer, freelancer	CO_3, CO_7	4
G	Anonymous	Software Developer	Senior dev, integration dev	CO_2, CO_3, CO_10	6
H	Anonymous	Software Developer	team leader, senior dev, senior soft engineer	CO_4, CO_17	9
I	Anonymous	Project Manager	Project manager	CO_4, CO_15	9
J	Anonymous	Project Manager	Senior Project manager, Agile coach	CO_1, CO_4, CO_5	7
K	Anonymous	Project Manager	Project manager, Pre-Sale, Teacher assistant	CO_14, CO_18	4
L	Anonymous	Software Developer	senior dev, junior developer	CO_3, CO_13	5
M	Anonymous	Software Developer	Senior dev, junior developer	CO_1, CO_2, CO_3	6
N	Anonymous	Quality Assurance	Assistant project manager, software tester	CO_4	7
O	Anonymous	Quality Assurance	Quality assurance	CO_4	6
P	Anonymous	Quality Assurance	Quality assurance leader	CO_7, CO_11, CO_12	5.5
Q	Anonymous	Quality Assurance	Quality assurance	CO_4	4
R	Anonymous	Project Manager	Project manager, junior developer	CO_3, CO_6, CO_16	6
S	Anonymous	Quality Assurance	Quality assurance	CO_4	5
T	Anonymous	Software Developer	junior developer	CO_1	2

Table 67: Job role distributed by the country work

			Country				
			Saudi Arabia	USA	Bahrain	India	Total
Job Role	project manager	Count	5	3	0	0	5
	software developer	Count	12	2	1	0	12
	QA	Count	5	0	1	1	5
	freelancer	Count	4	0	1	0	4
	team leader	Count	3	0	0	0	3
	sale	Count	2	1	0	0	2
	IT director	Count	1	1	0	0	1
Total		Count	20	3	2	1	20

Table 68: Companies details for the interview

company ID	company name	category	location	employee size
CO_01	Anonymous	Telecom	Saudi Arabia	17000
CO_02	Anonymous	IT Co.	Saudi Arabia	300
CO_03	Anonymous	Social Org	Saudi Arabia	1200
CO_04	Anonymous	IT Co.	Saudi Arabia	1600
CO_05	Anonymous	Bank	Saudi Arabia	13077
CO_06	Anonymous	Government	Saudi Arabia	3500
CO_07	Anonymous	Telecom	Bahrain	6200
CO_08	Anonymous	University	USA	3700
CO_09	Anonymous	Social Co.	Saudi Arabia	15
CO_10	Anonymous	IT Co.	Saudi Arabia	450
CO_11	Anonymous	Consultation Co.	India	20000
CO_12	Anonymous	IT Co.	Saudi Arabia	250
CO_13	Anonymous	Security Co.	Saudi Arabia	100
CO_14	Anonymous	University	USA	800
CO_15	Anonymous	Gov	Saudi Arabia	1800
CO_16	Anonymous	IT Co.	USA	20
CO_17	Anonymous	IT Co.	Saudi Arabia	150
CO_18	Anonymous	Consultation Co.	USA	3000

Table 69: Experts' estimation technique in detail

Expert ID	Effort Estimation Technique	Expert ID	Effort Estimation Technique
A	PP & Expert Judgment	K	Expert Judgment
B	Planning Poker	L	Expert Judgment
C	Planning Poker	M	Planning Poker
D	Expert Judgment	N	Expert Judgment
E	Expert Judgment	O	expert judgment
F	Planning Poker & Expert Judgment	P	Planning Poker & Expert Judgment
G	Planning Poker & Expert Judgment	Q	Expert Judgment
H	Planning Poker	R	Planning Poker
I	Expert Judgment	S	Expert Judgment
J	Planning Poker & Expert Judgment & COCOMO	T	expert judgment

Quantitative Analysis

Table 70: Effort estimation factors description

Factor name	Factor description
Backend system availability and Server Config. Flexibility	Include a remote database to store the data and manipulate data into backend side
Backlog items complexity	User story or task complexity of a project in the product backlog "user requirements"
Battery & Power Optimisation	It is a non-functional feature that preserve and maintain the power consumptions of the mobile battery by reducing number the processing procedures in the app
Booking and reservation	It is a functional feature that allow a user to make a reservation transaction in the app, for example book a ticket
Budget for the project	The total amount of the budget of the app
Calendar and Time	It is a functional feature that provide a calendar and time services to the user
Comment feature	It is a functional feature that allow a user to write up some comments text in the application
Communication process	The communication process and method between the development team members

Factor name	Factor description
Compatibility with Previous Version	Support previous version of the mobile app.
Connection (Wirless,Bluetooth,3G,etc)	The mobile connection method, if there any restriction on the connection
Data Storage and Memory Opt. Complexity	Local or remote storage of the data, and following the memory optimisation instruction of the mobile device to maintain the memory space
Deadline date	The delivery date of the app that given from the client
Dependency between backlog items	The dependency between the user stories or tasks in a project requirement
Developer estimation experience	Number of years practicing the effort estimation process for user stories or tasks
Developer implementation experience	Number of years practicing the development of mobile app
Developer knowledge of backlog item	Level of understanding the requirement and needs from a user story or a task
Development type (New or enhanced app)	Whether the application is new or already exists
Dynamicity of screen	Number of dynamic pages in the app, and is the page static or dynamic. For example, the page view change based on the role of the user
File upload	It is a functional feature that allow a user to upload a file into the app.
Geographical of the development team	The physical location of the development team member
Hardware access	Complexity of accessing to the hardware components of the mobile device through API
Interrupt handling	The user can return to an application after he quit from the app or switching from app to another
Item priority	the importance level of a user story to be delivered as soon as possible
Language and culture differences	The culture and language differences between the development team members
Localisation & tracking	It is a functional feature that allow the app use GPS service to track and localise the movement of the user
Managerial skills	The skills of the leader and his ability to manage the project recourses

Factor name	Factor description
Map view	It is a functional feature that allow a user to access to map service
Media support	It is a functional feature that allow a user to use, watch the media in the app
Messaging	It is functional feature that allow the user to communicate between each other
Multi-languages support	It is a feature that allow the user to select an appropriate language of the app
Navigation	The structure of the user position in the app. The user needs to know where to go, how to get any point in the app and where he is in the app
Number of API party	Total number of third-party application and APIs that used to integrate the application with other services
Number of Screen	Total number of screen (UI) that used in the application
Payment process	It is a feature that could be provided to the user to make a payment transaction
Platform type (native, hybrid)	Whether the application use native or hybrid framework, such as swift framework for native or Ionic framework for hybrid
Push Notification	It is a feature that is available in the mobile app to present a pop up message in the mobile screen
Registration & login	It is a function feature that allow the user to access the application.
Searching contents	It is a functional feature that allow a user to look up for a content entire the application
Security Support	The information security level of the user data in the app
Sharing	It is a functional feature that allow a user to share the app content to another user or other social network, for example share your location to someone else
Support Code reusability	The development team member builds reusable code to be used again for any purpose
Supported device (phone, tablet, smartwatch)	Does the app support multiple mobile devices
Supported Platform type (IOS/Android./Win./etc.)	Is the app support multiple operating system of mobile device
Team process experience	The knowledge of the development team about the Agile process and development process
Team size	Number of the development team member

Factor name	Factor description
Third-party authentication	Login or register through social media services such as Facebook
User Interface quality and complexity	The level of details on the user interface (UI) of the mobile app
Work pressure (workload)	heavy work needs to be submitted on short time (limited time)

Table 71: Effort estimation frequencies

Estimation factor	Very important	important	Neutral	Less important	Very less important	Total
Sharing	0%	10%	15%	25%	50%	100%
Registration & login	45%	40%	10%	0%	5%	100%
Payment process	65%	25%	10%	0%	0%	100%
Booking and reservation	20%	40%	35%	5%	0%	100%
File upload	25%	30%	40%	5%	0%	100%
Comment feature	5%	45%	15%	25%	10%	100%
Navigation	10%	20%	35%	10%	25%	100%
Map view	50%	30%	5%	10%	5%	100%
Localisation & tracking	50%	30%	20%	0%	0%	100%
Searching contents	20%	15%	50%	15%	0%	100%
Messaging	30%	60%	5%	0%	5%	100%
Calendar and time	5%	0%	5%	25%	65%	100%
Multi-languages support	40%	45%	5%	0%	10%	100%
Media support	30%	30%	25%	15%	0%	100%
Third-party authentication	35%	40%	15%	10%	0%	100%
Number of screens	50%	35%	15%	0%	0%	100%
Push notification	20%	30%	30%	15%	5%	100%
User Interface quality and complexity	75%	20%	5%	0%	0%	100%
Number of API party	30%	50%	15%	5%	0%	100%
Support Code reusability	35%	30%	25%	5%	5%	100%
Data storage and memory opt. Complexity	10%	35%	35%	10%	10%	100%

Estimation factor	Very important	important	Neutral	Less important	Very less important	Total
Interrupt handling	5%	15%	30%	25%	25%	100%
Hardware access	20%	25%	30%	15%	10%	100%
Battery & power optimisation	10%	20%	35%	20%	15%	100%
Connection (Wireless, **Bluetooth, 3G, etc.**)	5%	15%	30%	30%	20%	100%
Compatibility with previous version	10%	40%	35%	10%	5%	100%
Security support	45%	40%	10%	0%	5%	100%
Dynamicity of screen	15%	60%	15%	0%	10%	100%
Backend system availability and Server Config. Flexibility	45%	40%	15%	0%	0%	100%
Supported platform type (IOS/android./Win./etc.)	85%	15%	0%	0%	0%	100%
Supported device (phone, tablet, smartwatch)	55%	20%	20%	5%	0%	100%
Platform type (native, hybrid)	90%	5%	5%	0%	0%	100%
Communication process	65%	30%	5%	0%	0%	100%
Team process experience	50%	30%	20%	0%	0%	100%
Team size	30%	50%	15%	5%	0%	100%
Backlog items complexity	70%	20%	10%	0%	0%	100%
Dependency between backlog items	45%	45%	0%	0%	10%	100%
Developer implementation experience	65%	25%	10%	0%	0%	100%
Developer knowledge of backlog item	60%	25%	10%	5%	0%	100%
Developer estimation experience	55%	35%	5%	5%	0%	100%
Language and culture differences	10%	15%	40%	25%	10%	100%
Geographical of the development team	35%	35%	10%	15%	5%	100%

Estimation factor	Very important	important	Neutral	Less important	Very less important	Total
Item priority	50%	10%	15%	25%	0%	100%
Deadline date	55%	35%	5%	5%	0%	100%
Budget for the project	20%	5%	15%	55%	5%	100%
Development type (New or enhanced app)	55%	25%	10%	10%	0%	100%
Managerial skills	20%	35%	30%	15%	0%	100%
Work pressure (workload)	50%	30%	10%	10%	0%	100%

Table 72: Normality test for the estimation factors

Factor	Job Role	Kolmogorov-Smirnov[a]			Shapiro-Wilk		
		Statistic	df	Sig.	Statistic	df	Sig.
Sharing	Software Developer	.240	10	.107	.886	10	.152
	Project Manager/Director	.221	5	.200*	.902	5	.421
	QA	.	5	.	.	5	.
Registration & amp; login	Software Developer	.305	10	.009	.781	10	.008
	Project Manager/Director	.201	5	.200*	.881	5	.314
	QA	.367	5	.026	.684	5	.006
Payment process	Software Developer	.422	10	.000	.628	10	.000
	Project Manager/Director	.367	5	.026	.684	5	.006
	QA	.367	5	.026	.684	5	.006
Booking and reservation	Software Developer	.245	10	.091	.820	10	.025
	Project Manager/Director	.237	5	.200*	.961	5	.814
	QA	.231	5	.200*	.881	5	.314
File upload	Software Developer	.248	10	.082	.805	10	.017
	Project Manager/Director	.231	5	.200*	.881	5	.314
	QA	.300	5	.161	.883	5	.325
Comment feature	Software Developer	.293	10	.015	.810	10	.019
	Project Manager/Director	.237	5	.200*	.961	5	.814
	QA	.273	5	.200*	.852	5	.201
Navigation	Software Developer	.231	10	.139	.924	10	.392
	Project Manager/Director	.136	5	.200*	.987	5	.967
	QA	.273	5	.200*	.852	5	.201
Map view	Software Developer	.333	10	.002	.693	10	.001
	Project Manager/Director	.367	5	.026	.684	5	.006
	QA	.221	5	.200*	.902	5	.421
Localisation & amp; tracking	Software Developer	.362	10	.001	.717	10	.001
	Project Manager/Director	.231	5	.200*	.881	5	.314
	QA	.231	5	.200*	.881	5	.314
Searching contents	Software Developer	.416	10	.000	.650	10	.000
	Project Manager/Director	.367	5	.026	.684	5	.006
	QA	.349	5	.046	.771	5	.046
Messaging	Software Developer	.324	10	.004	.794	10	.012
	Project Manager/Director	.367	5	.026	.684	5	.006
	QA	.404	5	.008	.768	5	.044
Calendar and Time	Software Developer	.335	10	.002	.662	10	.000

Factor	Job Role	Kolmogorov-Smirnov[a]			Shapiro-Wilk		
		Statistic	df	Sig.	Statistic	df	Sig.
	Project Manager/Director	.349	5	.046	.771	5	.046
	QA	.	5	.	.	5	.
Multi-languages support	Software Developer	.380	10	.000	.728	10	.002
	Project Manager/Director	.231	5	.200*	.881	5	.314
	QA	.367	5	.026	.684	5	.006
Media support	Software Developer	.181	10	.200*	.895	10	.191
	Project Manager/Director	.221	5	.200*	.902	5	.421
	QA	.237	5	.200*	.961	5	.814
Third-party authentication	Software Developer	.224	10	.168	.911	10	.287
	Project Manager/Director	.367	5	.026	.684	5	.006
	QA	.300	5	.161	.833	5	.146
Number of Screen	Software Developer	.248	10	.082	.805	10	.017
	Project Manager/Director	.367	5	.026	.684	5	.006
	QA	.367	5	.026	.684	5	.006
Push Notification	Software Developer	.324	10	.004	.849	10	.056
	Project Manager/Director	.241	5	.200*	.821	5	.119
	QA	.367	5	.026	.684	5	.006
User Interface quality and complexity	Software Developer	.482	10	.000	.509	10	.000
	Project Manager/Director	.	5	.	.	5	.
	QA	.231	5	.200*	.881	5	.314
Number of API party	Software Developer	.254	10	.067	.833	10	.036
	Project Manager/Director	.300	5	.161	.883	5	.325
	QA	.300	5	.161	.833	5	.146
Support Code reusability	Software Developer	.305	10	.009	.781	10	.008
	Project Manager/Director	.367	5	.026	.684	5	.006
	QA	.221	5	.200*	.902	5	.421
Data Storage and Memory Opt. Complexity	Software Developer	.286	10	.020	.885	10	.149
	Project Manager/Director	.367	5	.026	.684	5	.006
	QA	.241	5	.200*	.821	5	.119
Interrupt handling	Software Developer	.240	10	.107	.886	10	.152
	Project Manager/Director	.330	5	.079	.735	5	.021
	QA	.241	5	.200*	.821	5	.119
Hardware access	Software Developer	.236	10	.123	.841	10	.046
	Project Manager/Director	.367	5	.026	.684	5	.006
	QA	.221	5	.200*	.902	5	.421
Battery & amp; Power Optimisation	Software Developer	.200	10	.200*	.932	10	.466
	Project Manager/Director	.473	5	.001	.552	5	.000
	QA	.231	5	.200*	.881	5	.314

Factor	Job Role	Kolmogorov-Smirnov[a]			Shapiro-Wilk		
		Statistic	df	Sig.	Statistic	df	Sig.
Connection (Wirless,Bluetooth,3G,etc)	Software Developer	.282	10	.023	.890	10	.172
	Project Manager/Director	.237	5	.200*	.961	5	.814
	QA	.243	5	.200*	.894	5	.377
Compatibility with Previous Version	Software Developer	.342	10	.002	.841	10	.045
	Project Manager/Director	.	5	.	.	5	.
	QA	.287	5	.200*	.914	5	.490
Security Support	Software Developer	.416	10	.000	.650	10	.000
	Project Manager/Director	.231	5	.200*	.881	5	.314
	QA	.473	5	.001	.552	5	.000
Dynamicity of screen	Software Developer	.333	10	.002	.778	10	.008
	Project Manager/Director	.473	5	.001	.552	5	.000
	QA	.367	5	.026	.684	5	.006
Backend system availability and Server Config. Flexibility	Software Developer	.360	10	.001	.731	10	.002
	Project Manager/Director	.231	5	.200*	.881	5	.314
	QA	.367	5	.026	.684	5	.006
Supported Platform type (IOS/Android./Win./etc.)	Software Developer	.524	10	.000	.366	10	.000
	Project Manager/Director	.473	5	.001	.552	5	.000
	QA	.473	5	.001	.552	5	.000
Supported device (phone, tablet, smartwatch)	Software Developer	.362	10	.001	.717	10	.001
	Project Manager/Director	.231	5	.200*	.881	5	.314
	QA	.473	5	.001	.552	5	.000
Platform type (native, hybrid)	Software Developer	.524	10	.000	.366	10	.000
	Project Manager/Director	.473	5	.001	.552	5	.000
	QA	.	5	.	.	5	.
Communication process	Software Developer	.433	10	.000	.594	10	.000
	Project Manager/Director	.367	5	.026	.684	5	.006
	QA	.473	5	.001	.552	5	.000
Team process experience	Software Developer	.362	10	.001	.717	10	.001
	Project Manager/Director	.231	5	.200*	.881	5	.314
	QA	.231	5	.200*	.881	5	.314
Team size	Software Developer	.254	10	.067	.833	10	.036
	Project Manager/Director	.367	5	.026	.684	5	.006
	QA	.372	5	.022	.828	5	.135
Backlog items complexity	Software Developer	.362	10	.001	.717	10	.001
	Project Manager/Director	.473	5	.001	.552	5	.000
	QA	.473	5	.001	.552	5	.000
Dependency between backlog items	Software Developer	.325	10	.004	.694	10	.001

Factor	Job Role	Kolmogorov-Smirnov[a]			Shapiro-Wilk		
		Statistic	df	Sig.	Statistic	df	Sig.
	Project Manager/Director	.367	5	.026	.684	5	.006
	QA	.367	5	.026	.684	5	.006
Developer implementation experience	Software Developer	.422	10	.000	.628	10	.000
	Project Manager/Director	.367	5	.026	.684	5	.006
	QA	.473	5	.001	.552	5	.000
Developer knowledge of backlog item	Software Developer	.362	10	.001	.717	10	.001
	Project Manager/Director	.367	5	.026	.684	5	.006
	QA	.473	5	.001	.552	5	.000
Developer estimation experience	Software Developer	.346	10	.001	.730	10	.002
	Project Manager/Director	.367	5	.026	.684	5	.006
	QA	.367	5	.026	.684	5	.006
Language and culture differences	Software Developer	.200	10	.200*	.953	10	.703
	Project Manager/Director	.237	5	.200*	.961	5	.814
	QA	.300	5	.161	.833	5	.146
Geographical of the development team	Software Developer	.324	10	.004	.849	10	.056
	Project Manager/Director	.300	5	.161	.833	5	.146
	QA	.360	5	.033	.767	5	.042
Item priority	Software Developer	.308	10	.008	.703	10	.001
	Project Manager/Director	.221	5	.200*	.902	5	.421
	QA	.367	5	.026	.684	5	.006
Deadline date	Software Developer	.333	10	.002	.678	10	.000
	Project Manager/Director	.367	5	.026	.684	5	.006
	QA	.231	5	.200*	.881	5	.314
Budget for the project	Software Developer	.268	10	.040	.752	10	.004
	Project Manager/Director	.473	5	.001	.552	5	.000
	QA	.300	5	.161	.883	5	.325
Development type (New or enhanced app)	Software Developer	.360	10	.001	.731	10	.002
	Project Manager/Director	.221	5	.200*	.902	5	.421
	QA	.330	5	.079	.735	5	.021
Managerial skills	Software Developer	.178	10	.200*	.907	10	.258
	Project Manager/Director	.231	5	.200*	.881	5	.314
	QA	.237	5	.200*	.961	5	.814
Work pressure (workload)	Software Developer	.302	10	.010	.781	10	.008
	Project Manager/Director	.254	5	.200*	.803	5	.086
	QA	.367	5	.026	.684	5	.006

Table 73: Mann-Whitney ranks for software developer and project managers

Factor	Job Role	N	Mean Rank	Sum of Ranks
Sharing	Software Developer	10	7.95	79.50
	Project Manager/Director	5	8.10	40.50
	Total	15		
Registration & amp; login	Software Developer	10	8.65	86.50
	Project Manager/Director	5	6.70	33.50
	Total	15		
Payment process	Software Developer	10	8.05	80.50
	Project Manager/Director	5	7.90	39.50
	Total	15		
Booking and reservation	Software Developer	10	8.20	82.00
	Project Manager/Director	5	7.60	38.00
	Total	15		
File upload	Software Developer	10	7.50	75.00
	Project Manager/Director	5	9.00	45.00
	Total	15		
Comment feature	Software Developer	10	7.40	74.00
	Project Manager/Director	5	9.20	46.00
	Total	15		
Navigation	Software Developer	10	7.90	79.00
	Project Manager/Director	5	8.20	41.00
	Total	15		
Map view	Software Developer	10	8.20	82.00
	Project Manager/Director	5	7.60	38.00
	Total	15		
Localisation & tracking	Software Developer	10	8.40	84.00
	Project Manager/Director	5	7.20	36.00
	Total	15		
Searching contents	Software Developer	10	6.95	69.50
	Project Manager/Director	5	10.10	50.50
	Total	15		
Messaging	Software Developer	10	7.60	76.00
	Project Manager/Director	5	8.80	44.00
	Total	15		
Calendar and time	Software Developer	10	8.15	81.50
	Project Manager/Director	5	7.70	38.50
	Total	15		
Multi-languages support	Software Developer	10	7.70	77.00
	Project Manager/Director	5	8.60	43.00

Factor	Job Role	N	Mean Rank	Sum of Ranks
	Total	15		
Media support	Software Developer	10	7.95	79.50
	Project Manager/Director	5	8.10	40.50
	Total	15		
Third-party authentication	Software Developer	10	6.60	66.00
	Project Manager/Director	5	10.80	54.00
	Total	15		
Number of screens	Software Developer	10	7.20	72.00
	Project Manager/Director	5	9.60	48.00
	Total	15		
Push notification	Software Developer	10	7.65	76.50
	Project Manager/Director	5	8.70	43.50
	Total	15		
User Interface quality and complexity	Software Developer	10	7.50	75.00
	Project Manager/Director	5	9.00	45.00
	Total	15		
Number of API party	Software Developer	10	8.20	82.00
	Project Manager/Director	5	7.60	38.00
	Total	15		
Support Code reusability	Software Developer	10	8.85	88.50
	Project Manager/Director	5	6.30	31.50
	Total	15		
Data storage and memory opt. Complexity.	Software Developer	10	8.80	88.00
	Project Manager/Director	5	6.40	32.00
	Total	15		
Interrupt handling	Software Developer	10	9.55	95.50
	Project Manager/Director	5	4.90	24.50
	Total	15		
Hardware access	Software Developer	10	8.60	86.00
	Project Manager/Director	5	6.80	34.00
	Total	15		
Battery & power optimisation	Software Developer	10	8.25	82.50
	Project Manager/Director	5	7.50	37.50
	Total	15		
Connection (Wirless,Bluetooth,3G,etc)	Software Developer	10	7.65	76.50
	Project Manager/Director	5	8.70	43.50
	Total	15		
Compatibility with previous version	Software Developer	10	9.50	95.00
	Project Manager/Director	5	5.00	25.00
	Total	15		

Factor	Job Role	N	Mean Rank	Sum of Ranks
Security support	Software Developer	10	8.75	87.50
	Project Manager/Director	5	6.50	32.50
	Total	15		
Dynamicity of screen	Software Developer	10	8.65	86.50
	Project Manager/Director	5	6.70	33.50
	Total	15		
Backend system availability and Server Config. Flexibility	Software Developer	10	9.20	92.00
	Project Manager/Director	5	5.60	28.00
	Total	15		
Supported platform type (IOS/android./Win./etc.)	Software Developer	10	8.25	82.50
	Project Manager/Director	5	7.50	37.50
	Total	15		
Supported device (phone, tablet, smartwatch)	Software Developer	10	9.00	90.00
	Project Manager/Director	5	6.00	30.00
	Total	15		
Platform type (native, hybrid)	Software Developer	10	8.20	82.00
	Project Manager/Director	5	7.60	38.00
	Total	15		
Communication process	Software Developer	10	8.75	87.50
	Project Manager/Director	5	6.50	32.50
	Total	15		
Team process experience	Software Developer	10	8.40	84.00
	Project Manager/Director	5	7.20	36.00
	Total	15		
Team size	Software Developer	10	6.70	67.00
	Project Manager/Director	5	10.60	53.00
	Total	15		
Backlog items complexity	Software Developer	10	7.40	74.00
	Project Manager/Director	5	9.20	46.00
	Total	15		
Dependency between backlog items	Software Developer	10	7.95	79.50
	Project Manager/Director	5	8.10	40.50
	Total	15		
Developer implementation experience	Software Developer	10	8.45	84.50
	Project Manager/Director	5	7.10	35.50
	Total	15		
Developer knowledge of backlog item	Software Developer	10	8.20	82.00
	Project Manager/Director	5	7.60	38.00
	Total	15		
	Software Developer	10	7.80	78.00

Factor	Job Role	N	Mean Rank	Sum of Ranks
Developer estimation experience	Project Manager/Director	5	8.40	42.00
	Total	15		
Language and culture differences	Software Developer	10	8.45	84.50
	Project Manager/Director	5	7.10	35.50
	Total	15		
Geographical of the development team	Software Developer	10	7.45	74.50
	Project Manager/Director	5	9.10	45.50
	Total	15		
Item priority	Software Developer	10	7.95	79.50
	Project Manager/Director	5	8.10	40.50
	Total	15		
Deadline date	Software Developer	10	7.90	79.00
	Project Manager/Director	5	8.20	41.00
	Total	15		
Budget for the project	Software Developer	10	9.10	91.00
	Project Manager/Director	5	5.80	29.00
	Total	15		
Development type (New or enhanced app)	Software Developer	10	8.80	88.00
	Project Manager/Director	5	6.40	32.00
	Total	15		
Managerial skills	Software Developer	10	7.60	76.00
	Project Manager/Director	5	8.80	44.00
	Total	15		
Work pressure (workload)	Software Developer	10	8.65	86.50
	Project Manager/Director	5	6.70	33.50
	Total	15		

Table 74: Mann-Whitney ranks for software developer and QA's

Factor	Job Role	N	Mean Rank	Sum of Ranks
Sharing	Software Developer	10	9.75	97.50
	QA	5	4.50	22.50
	Total	15		
Registration & amp; login	Software Developer	10	8.10	81.00
	QA	5	7.80	39.00
	Total	15		
Payment process	Software Developer	10	8.05	80.50
	QA	5	7.90	39.50
	Total	15		
Booking and reservation	Software Developer	10	8.00	80.00
	QA	5	8.00	40.00
	Total	15		
File upload	Software Developer	10	9.35	93.50
	QA	5	5.30	26.50
	Total	15		
Comment feature	Software Developer	10	8.55	85.50
	QA	5	6.90	34.50
	Total	15		
Navigation	Software Developer	10	8.50	85.00
	QA	5	7.00	35.00
	Total	15		
Map view	Software Developer	10	8.45	84.50
	QA	5	7.10	35.50
	Total	15		
Localisation & amp; tracking	Software Developer	10	8.40	84.00
	QA	5	7.20	36.00
	Total	15		
Searching contents	Software Developer	10	9.35	93.50
	QA	5	5.30	26.50
	Total	15		
Messaging	Software Developer	10	8.45	84.50
	QA	5	7.10	35.50
	Total	15		
Calendar and time	Software Developer	10	9.25	92.50
	QA	5	5.50	27.50
	Total	15		
Multi-languages support	Software Developer	10	7.05	70.50
	QA	5	9.90	49.50

Factor	Job Role	N	Mean Rank	Sum of Ranks
	Total	15		
Media support	Software Developer	10	8.25	82.50
	QA	5	7.50	37.50
	Total	15		
Third-party authentication	Software Developer	10	7.45	74.50
	QA	5	9.10	45.50
	Total	15		
Number of screens	Software Developer	10	7.20	72.00
	QA	5	9.60	48.00
	Total	15		
Push notification	Software Developer	10	9.45	94.50
	QA	5	5.10	25.50
	Total	15		
User Interface quality and complexity	Software Developer	10	9.10	91.00
	QA	5	5.80	29.00
	Total	15		
Number of API party	Software Developer	10	7.90	79.00
	QA	5	8.20	41.00
	Total	15		
Support Code reusability	Software Developer	10	9.85	98.50
	QA	5	4.30	21.50
	Total	15		
Data Storage and Memory Opt. Complexity.	Software Developer	10	10.05	100.50
	QA	5	3.90	19.50
	Total	15		
Interrupt handling	Software Developer	10	9.35	93.50
	QA	5	5.30	26.50
	Total	15		
Hardware access	Software Developer	10	9.60	96.00
	QA	5	4.80	24.00
	Total	15		
Battery & amp; power optimisation	Software Developer	10	9.60	96.00
	QA	5	4.80	24.00
	Total	15		
Connection (Wirless,Bluetooth,3G,etc)	Software Developer	10	7.70	77.00
	QA	5	8.60	43.00
	Total	15		
Compatibility with previous version	Software Developer	10	8.30	83.00
	QA	5	7.40	37.00
	Total	15		

Factor	Job Role	N	Mean Rank	Sum of Ranks
Security support	Software Developer	10	9.70	97.00
	QA	5	4.60	23.00
	Total	15		
Dynamicity of screen	Software Developer	10	8.85	88.50
	QA	5	6.30	31.50
	Total	15		
Backend system availability and Server Config. Flexibility	Software Developer	10	8.35	83.50
	QA	5	7.30	36.50
	Total	15		
Supported platform type (IOS/android./Win./etc.)	Software Developer	10	8.25	82.50
	QA	5	7.50	37.50
	Total	15		
Supported device (phone, tablet, smartwatch)	Software Developer	10	7.70	77.00
	QA	5	8.60	43.00
	Total	15		
Platform type (native, hybrid)	Software Developer	10	7.75	77.50
	QA	5	8.50	42.50
	Total	15		
Communication process	Software Developer	10	7.90	79.00
	QA	5	8.20	41.00
	Total	15		
Team process experience	Software Developer	10	8.40	84.00
	QA	5	7.20	36.00
	Total	15		
Team size	Software Developer	10	7.95	79.50
	QA	5	8.10	40.50
	Total	15		
Backlog items complexity	Software Developer	10	7.40	74.00
	QA	5	9.20	46.00
	Total	15		
Dependency between backlog items	Software Developer	10	7.95	79.50
	QA	5	8.10	40.50
	Total	15		
Developer implementation experience	Software Developer	10	7.65	76.50
	QA	5	8.70	43.50
	Total	15		
Developer knowledge of backlog item	Software Developer	10	7.70	77.00
	QA	5	8.60	43.00
	Total	15		
	Software Developer	10	8.20	82.00

Factor	Job Role	N	Mean Rank	Sum of Ranks
Developer estimation experience	QA	5	7.60	38.00
	Total	15		
Language and culture differences	Software Developer	10	8.15	81.50
	QA	5	7.70	38.50
	Total	15		
Geographical of the development team	Software Developer	10	7.40	74.00
	QA	5	9.20	46.00
	Total	15		
Item priority	Software Developer	10	7.45	74.50
	QA	5	9.10	45.50
	Total	15		
Deadline date	Software Developer	10	8.50	85.00
	QA	5	7.00	35.00
	Total	15		
Budget for the project	Software Developer	10	9.40	94.00
	QA	5	5.20	26.00
	Total	15		
Development type (New or enhanced app)	Software Developer	10	8.15	81.50
	QA	5	7.70	38.50
	Total	15		
Managerial skills	Software Developer	10	7.85	78.50
	QA	5	8.30	41.50
	Total	15		
Work pressure (workload)	Software Developer	10	7.55	75.50
	QA	5	8.90	44.50
	Total	15		

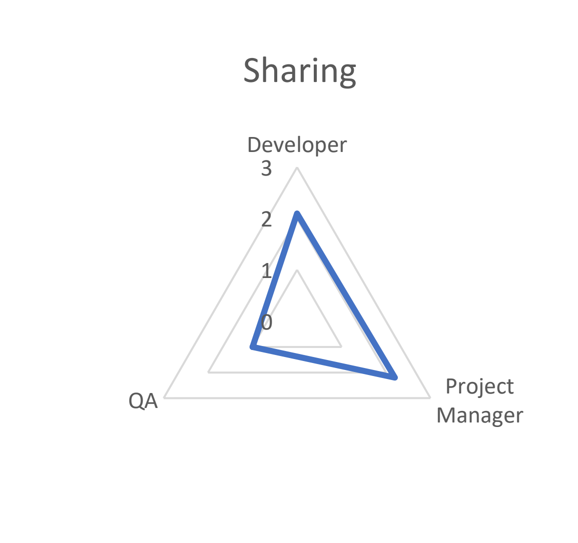
Table 75: Mann-Whitney ranks for project managers and QA's

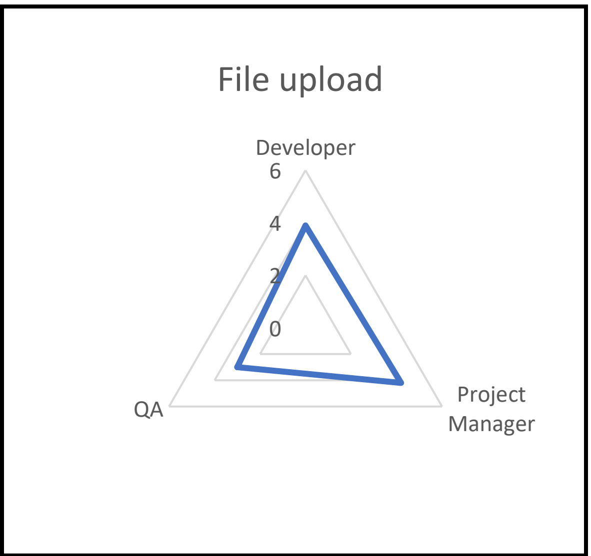
Factor	Job Role	N	Mean Rank	Sum of Ranks
Sharing	Project Manager/Director	5	7.00	35.00
	QA	5	4.00	20.00
	Total	10		
Registration & amp; login	Project Manager/Director	5	4.90	24.50
	QA	5	6.10	30.50
	Total	10		
Payment process	Project Manager/Director	5	5.50	27.50
	QA	5	5.50	27.50
	Total	10		
Booking and reservation	Project Manager/Director	5	5.30	26.50
	QA	5	5.70	28.50
	Total	10		
File upload	Project Manager/Director	5	7.30	36.50
	QA	5	3.70	18.50
	Total	10		
Comment feature	Project Manager/Director	5	6.60	33.00
	QA	5	4.40	22.00
	Total	10		
Navigation	Project Manager/Director	5	6.10	30.50
	QA	5	4.90	24.50
	Total	10		
Map view	Project Manager/Director	5	6.10	30.50
	QA	5	4.90	24.50
	Total	10		
Localisation & amp; tracking	Project Manager/Director	5	5.50	27.50
	QA	5	5.50	27.50
	Total	10		
Searching contents	Project Manager/Director	5	7.40	37.00
	QA	5	3.60	18.00
	Total	10		
Messaging	Project Manager/Director	5	6.30	31.50
	QA	5	4.70	23.50
	Total	10		
Calendar and time	Project Manager/Director	5	6.50	32.50
	QA	5	4.50	22.50
	Total	10		
Multi-languages support	Project Manager/Director	5	4.80	24.00
	QA	5	6.20	31.00

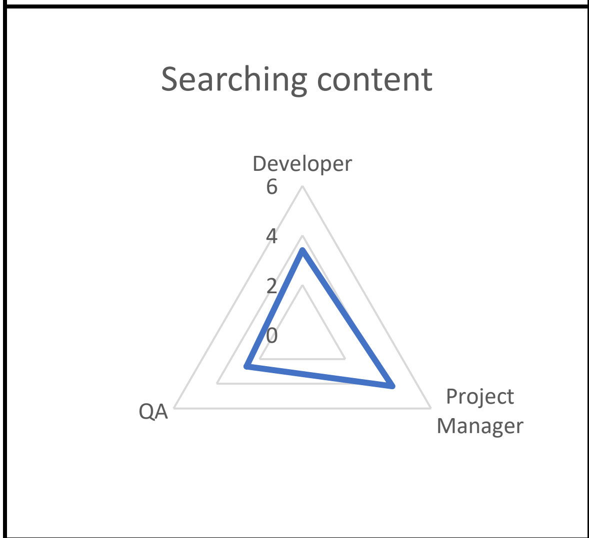
Factor	Job Role	N	Mean Rank	Sum of Ranks
	Total	10		
Media support	Project Manager/Director	5	5.80	29.00
	QA	5	5.20	26.00
	Total	10		
Third-party authentication	Project Manager/Director	5	6.20	31.00
	QA	5	4.80	24.00
	Total	10		
Number of screens	Project Manager/Director	5	5.50	27.50
	QA	5	5.50	27.50
	Total	10		
Push notification	Project Manager/Director	5	7.40	37.00
	QA	5	3.60	18.00
	Total	10		
User Interface quality and complexity	Project Manager/Director	5	7.00	35.00
	QA	5	4.00	20.00
	Total	10		
Number of API party	Project Manager/Director	5	5.20	26.00
	QA	5	5.80	29.00
	Total	10		
Support Code reusability	Project Manager/Director	5	6.50	32.50
	QA	5	4.50	22.50
	Total	10		
Data storage and memory opt. Complexity.	Project Manager/Director	5	7.40	37.00
	QA	5	3.60	18.00
	Total	10		
Interrupt handling	Project Manager/Director	5	5.10	25.50
	QA	5	5.90	29.50
	Total	10		
Hardware access	Project Manager/Director	5	6.90	34.50
	QA	5	4.10	20.50
	Total	10		
Battery & amp; power optimisation	Project Manager/Director	5	7.60	38.00
	QA	5	3.40	17.00
	Total	10		
Connection (Wirless,Bluetooth,3G,etc)	Project Manager/Director	5	5.30	26.50
	QA	5	5.70	28.50
	Total	10		
Compatibility with previous version	Project Manager/Director	5	5.00	25.00
	QA	5	6.00	30.00
	Total	10		

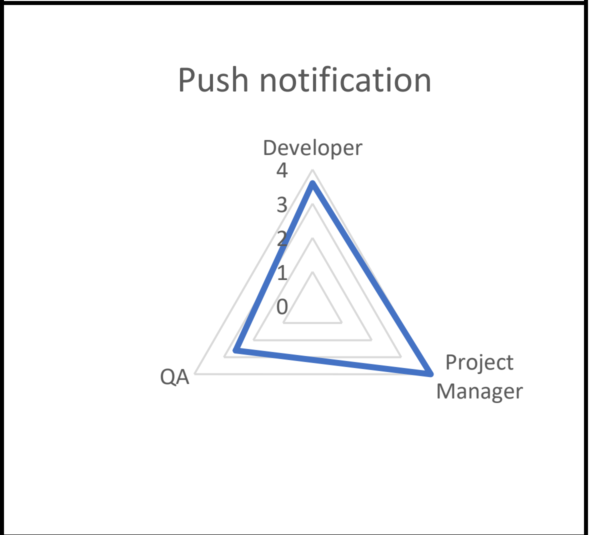
Factor	Job Role	N	Mean Rank	Sum of Ranks
Security support	Project Manager/Director	5	6.40	32.00
	QA	5	4.60	23.00
	Total	10		
Dynamicity of screen	Project Manager/Director	5	5.80	29.00
	QA	5	5.20	26.00
	Total	10		
Backend system availability and Server Config. Flexibility	Project Manager/Director	5	4.40	22.00
	QA	5	6.60	33.00
	Total	10		
Supported Platform type (IOS/Android./Win./etc.)	Project Manager/Director	5	5.50	27.50
	QA	5	5.50	27.50
	Total	10		
Supported device (phone, tablet, smartwatch)	Project Manager/Director	5	4.40	22.00
	QA	5	6.60	33.00
	Total	10		
Platform type (native, hybrid)	Project Manager/Director	5	5.00	25.00
	QA	5	6.00	30.00
	Total	10		
Communication process	Project Manager/Director	5	4.80	24.00
	QA	5	6.20	31.00
	Total	10		
Team process experience	Project Manager/Director	5	5.50	27.50
	QA	5	5.50	27.50
	Total	10		
Team size	Project Manager/Director	5	6.70	33.50
	QA	5	4.30	21.50
	Total	10		
Backlog items complexity	Project Manager/Director	5	5.50	27.50
	QA	5	5.50	27.50
	Total	10		
Dependency between backlog items	Project Manager/Director	5	5.50	27.50
	QA	5	5.50	27.50
	Total	10		
Developer implementation experience	Project Manager/Director	5	4.50	22.50
	QA	5	6.50	32.50
	Total	10		
Developer knowledge of backlog item	Project Manager/Director	5	4.80	24.00
	QA	5	6.20	31.00
	Total	10		
	Project Manager/Director	5	6.00	30.00

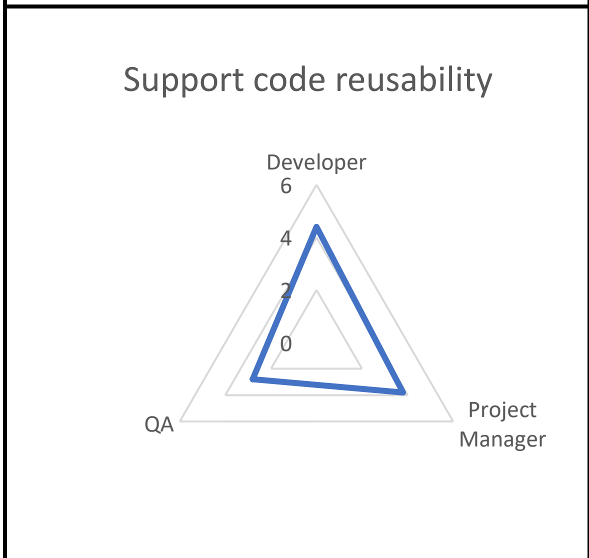
Factor	Job Role	N	Mean Rank	Sum of Ranks
Developer estimation experience	QA	5	5.00	25.00
	Total	10		
Language and culture differences	Project Manager/Director	5	5.20	26.00
	QA	5	5.80	29.00
	Total	10		
Geographical of the development team	Project Manager/Director	5	5.30	26.50
	QA	5	5.70	28.50
	Total	10		
Item priority	Project Manager/Director	5	5.00	25.00
	QA	5	6.00	30.00
	Total	10		
Deadline date	Project Manager/Director	5	6.20	31.00
	QA	5	4.80	24.00
	Total	10		
Budget for the project	Project Manager/Director	5	6.00	30.00
	QA	5	5.00	25.00
	Total	10		
Development type (New or enhanced app)	Project Manager/Director	5	5.00	25.00
	QA	5	6.00	30.00
	Total	10		
Managerial skills	Project Manager/Director	5	5.70	28.50
	QA	5	5.30	26.50
	Total	10		
Work pressure (workload)	Project Manager/Director	5	4.60	23.00
	QA	5	6.40	32.00
	Total	10		

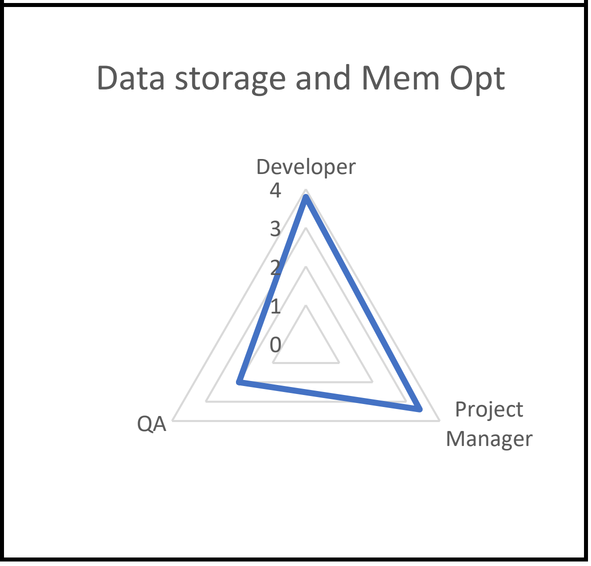

Sharing
Developer
3
2
1
0
QA
Project Manager


File upload
Developer
6
4
2
0
QA
Project Manager


Searching content
Developer
6
4
2
0
QA
Project Manager


Push notification
Developer
4
3
2
1
0
QA
Project Manager


Support code reusability
Developer
6
4
2
0
QA
Project Manager


Data storage and Mem Opt
Developer
4
3
2
1
0
QA
Project Manager

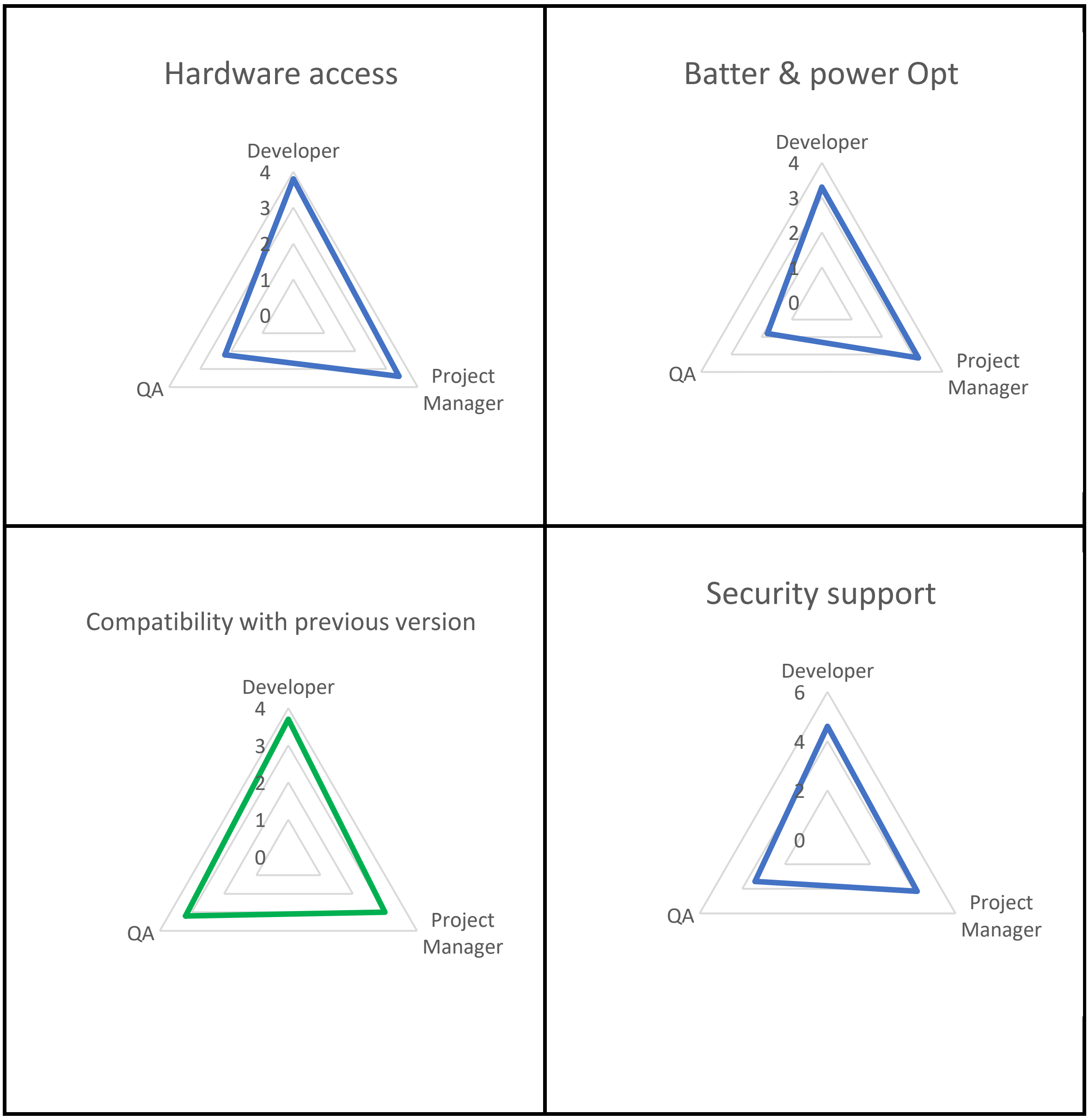


Figure 82 Mean differences values between factors as shown in Mann-Whitney test:

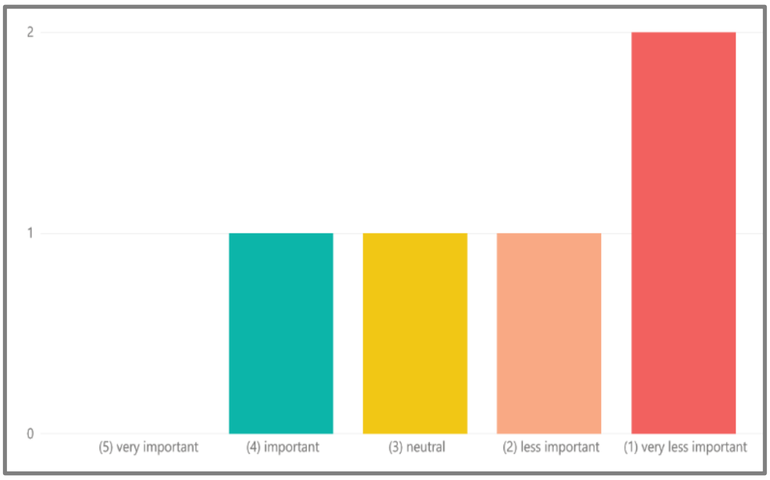


Figure 83 Project manager rank of Sharing factor

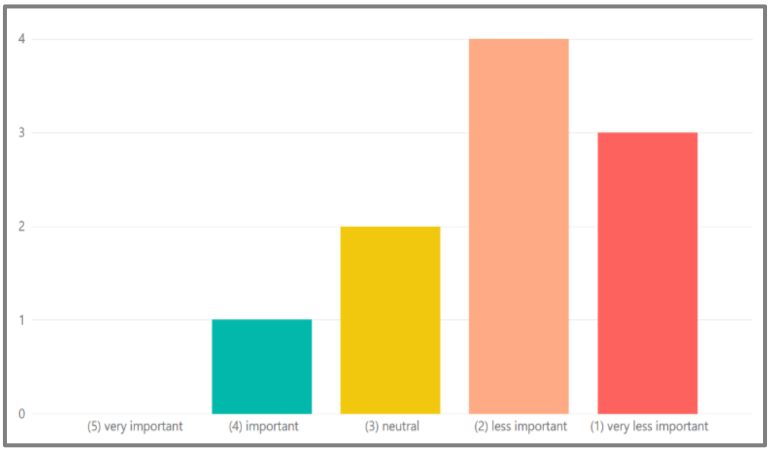


Figure 84 Software developer rank of Sharing factor

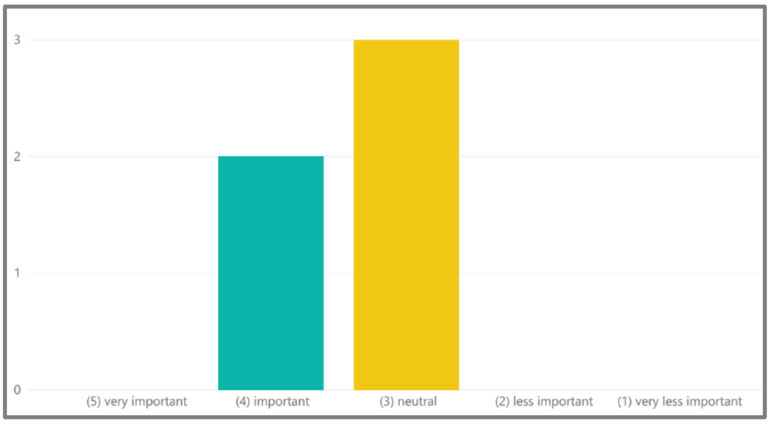


Figure 85 Project manager rank of Data storage & memory factor

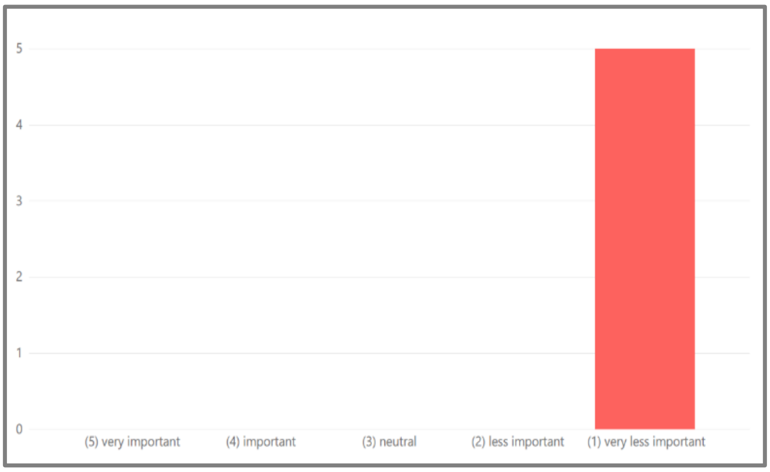


Figure 86 QA rank of Sharing factor

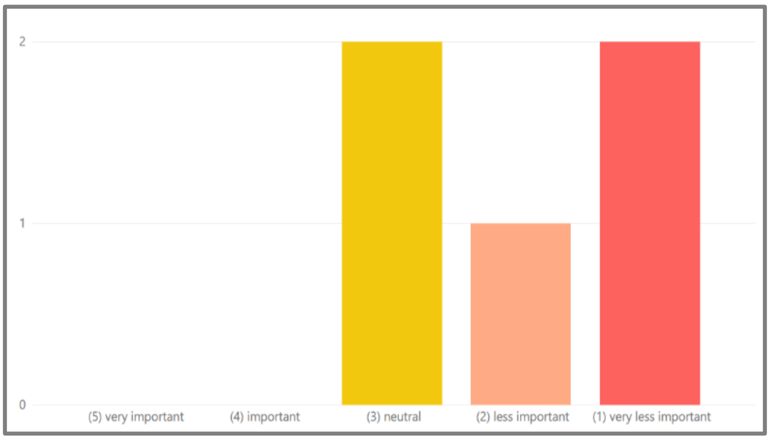


Figure 87 QA rank of Data storage & memory factor

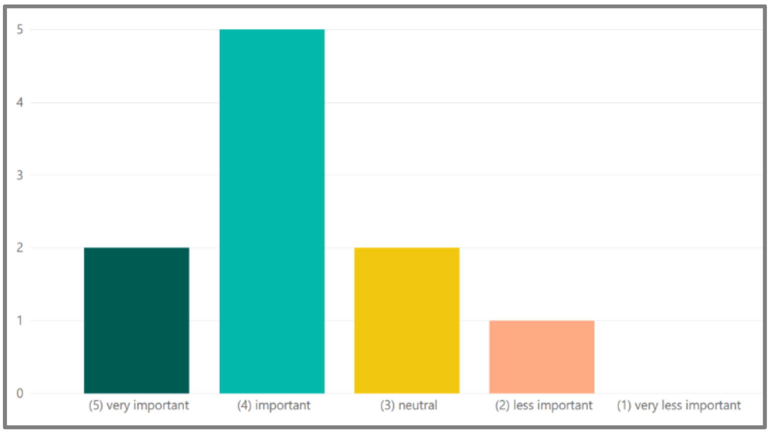


Figure 88 Software developer ranked of Data storage & memory factor

Table 76: One-way ANOVA test between all the experts job role and factors

		Sum of Squares	df	Mean Square	F	Sig.
Sharing	Between Groups	4.850	2	2.425	2.626	.101
	Within Groups	15.700	17	.924		
	Total	20.550	19			
Registration & login	Between Groups	2.400	2	1.200	1.214	.321
	Within Groups	16.800	17	.988		
	Total	19.200	19			
Payment process	Between Groups	.050	2	.025	.048	.953
	Within Groups	8.900	17	.524		
	Total	8.950	19			
Booking and reservation	Between Groups	.150	2	.075	.094	.911
	Within Groups	13.600	17	.800		
	Total	13.750	19			
File upload	Between Groups	4.050	2	2.025	2.942	.080
	Within Groups	11.700	17	.688		
	Total	15.750	19			
Comment feature	Between Groups	2.500	2	1.250	.912	.420
	Within Groups	23.300	17	1.371		
	Total	25.800	19			
Navigation	Between Groups	1.100	2	.550	.291	.751
	Within Groups	32.100	17	1.888		
	Total	33.200	19			
Map view	Between Groups	.900	2	.450	.284	.756
	Within Groups	26.900	17	1.582		
	Total	27.800	19			
Localisation & tracking	Between Groups	.200	2	.100	.142	.869
	Within Groups	12.000	17	.706		
	Total	12.200	19			
Searching contents	Between Groups	6.400	2	3.200	4.387	.029
	Within Groups	12.400	17	.729		
	Total	18.800	19			
Messaging	Between Groups	1.800	2	.900	1.093	.358
	Within Groups	14.000	17	.824		
	Total	15.800	19			
Calendar and time	Between Groups	2.150	2	1.075	1.088	.359
	Within Groups	16.800	17	.988		
	Total	18.950	19			
Multi-languages support	Between Groups	2.850	2	1.425	1.005	.387
	Within Groups	24.100	17	1.418		

		Sum of Squares	df	Mean Square	F	Sig.
	Total	26.950	19			
Media support	Between Groups	.150	2	.075	.059	.943
	Within Groups	21.600	17	1.271		
	Total	21.750	19			
Third-party authentication	Between Groups	2.700	2	1.350	1.500	.251
	Within Groups	15.300	17	.900		
	Total	18.000	19			
Number of screens	Between Groups	1.250	2	.625	1.142	.342
	Within Groups	9.300	17	.547		
	Total	10.550	19			
Push notification	Between Groups	5.350	2	2.675	2.320	.129
	Within Groups	19.600	17	1.153		
	Total	24.950	19			
User Interface quality and complexity	Between Groups	1.800	2	.900	3.477	.054
	Within Groups	4.400	17	.259		
	Total	6.200	19			
Number of API party	Between Groups	.050	2	.025	.033	.968
	Within Groups	12.900	17	.759		
	Total	12.950	19			
Support Code reusability	Between Groups	8.550	2	4.275	4.542	.026
	Within Groups	16.000	17	.941		
	Total	24.550	19			
Data Storage & Memory Opt. Complexity.	Between Groups	10.950	2	5.475	7.271	.005
	Within Groups	12.800	17	.753		
	Total	23.750	19			
Interrupt handling	Between Groups	7.300	2	3.650	3.150	.069
	Within Groups	19.700	17	1.159		
	Total	27.000	19			
Hardware access	Between Groups	8.600	2	4.300	3.384	.058
	Within Groups	21.600	17	1.271		
	Total	30.200	19			
Battery & amp; power optimisation	Between Groups	8.100	2	4.050	3.5	.050
	Within Groups	19.700	17	1.159		
	Total	27.800	19			
Connection (Wirless,Bluetooth,3G,etc)	Between Groups	.550	2	.275	.192	.827
	Within Groups	24.400	17	1.435		
	Total	24.950	19			
Compatibility with previous version	Between Groups	1.900	2	.950	.956	.404
	Within Groups	16.900	17	.994		
	Total	18.800	19			

		Sum of Squares	df	Mean Square	F	Sig.
Security Support	Between Groups	4.800	2	2.400	2.833	.087
	Within Groups	14.400	17	.847		
	Total	19.200	19			
Dynamicity of screen	Between Groups	.900	2	.450	.359	.703
	Within Groups	21.300	17	1.253		
	Total	22.200	19			
Backend system availability and Server Config. Flexibility	Between Groups	1.700	2	.850	1.700	.212
	Within Groups	8.500	17	.500		
	Total	10.200	19			
Supported platform type (IOS/android./Win./etc.)	Between Groups	.050	2	.025	.170	.845
	Within Groups	2.500	17	.147		
	Total	2.550	19			
Supported device (phone, tablet, smartwatch)	Between Groups	1.350	2	.675	.700	.510
	Within Groups	16.400	17	.965		
	Total	17.750	19			
Platform type (native, hybrid)	Between Groups	.150	2	.075	.290	.752
	Within Groups	4.400	17	.259		
	Total	4.550	19			
Communication process	Between Groups	.300	2	.150	.392	.681
	Within Groups	6.500	17	.382		
	Total	6.800	19			
Team process experience	Between Groups	.200	2	.100	.142	.869
	Within Groups	12.000	17	.706		
	Total	12.200	19			
Team size	Between Groups	2.050	2	1.025	1.599	.231
	Within Groups	10.900	17	.641		
	Total	12.950	19			
Backlog items complexity	Between Groups	.800	2	.400	.850	.445
	Within Groups	8.000	17	.471		
	Total	8.800	19			
Dependency between backlog items	Between Groups	1.250	2	.625	.420	.664
	Within Groups	25.300	17	1.488		
	Total	26.550	19			
Developer implementation experience	Between Groups	.450	2	.225	.450	.645
	Within Groups	8.500	17	.500		
	Total	8.950	19			
Developer knowledge of backlog item	Between Groups	.000	2	.000	.000	1.000
	Within Groups	14.800	17	.871		
	Total	14.800	19			
	Between Groups	.300	2	.150	.204	.817

		Sum of Squares	df	Mean Square	F	Sig.
Developer estimation experience	Within Groups	12.500	17	.735		
	Total	12.800	19			
Language and culture differences	Between Groups	.600	2	.300	.220	.805
	Within Groups	23.200	17	1.365		
	Total	23.800	19			
Geographical of the development team	Between Groups	.800	2	.400	.239	.790
	Within Groups	28.400	17	1.671		
	Total	29.200	19			
Item priority	Between Groups	.850	2	.425	.228	.799
	Within Groups	31.700	17	1.865		
	Total	32.550	19			
Deadline date	Between Groups	.400	2	.200	.274	.763
	Within Groups	12.400	17	.729		
	Total	12.800	19			
Budget for the project	Between Groups	7.600	2	3.800	2.737	.093
	Within Groups	23.600	17	1.388		
	Total	31.200	19			
Development type (New or enhanced app)	Between Groups	1.650	2	.825	.775	.476
	Within Groups	18.100	17	1.065		
	Total	19.750	19			
Managerial skills	Between Groups	.300	2	.150	.138	.872
	Within Groups	18.500	17	1.088		
	Total	18.800	19			
Work pressure (workload)	Between Groups	2.700	2	1.350	1.391	.276
	Within Groups	16.500	17	.971		
	Total	19.200	19			

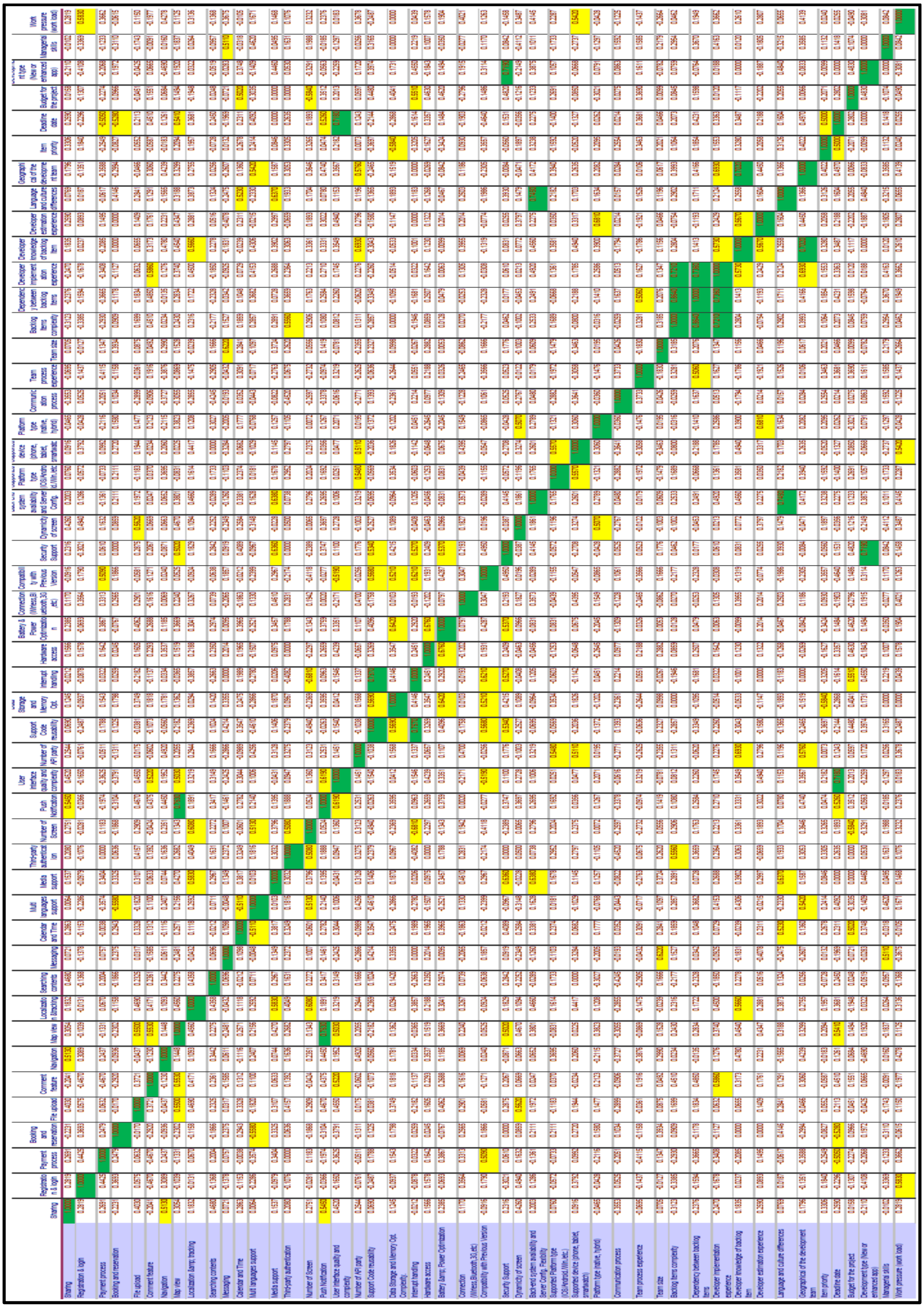


Figure 89: Correlation for all effort estimation factors

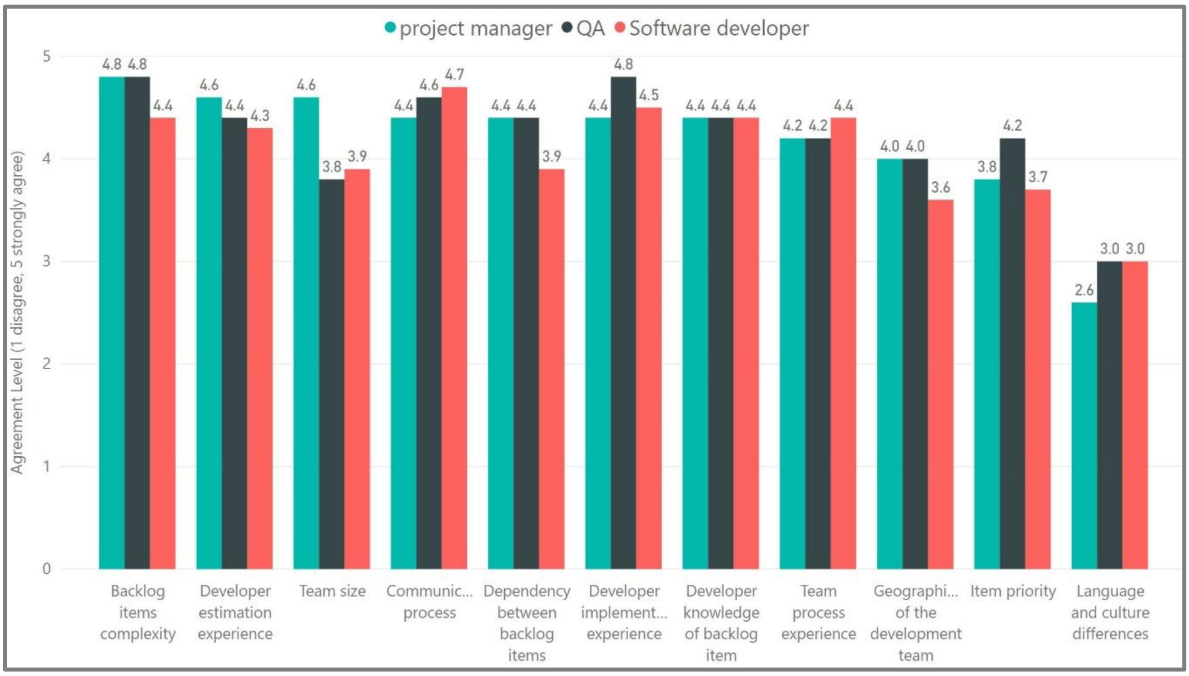


Figure 90 Agile estimation factors filtered by expert's job role

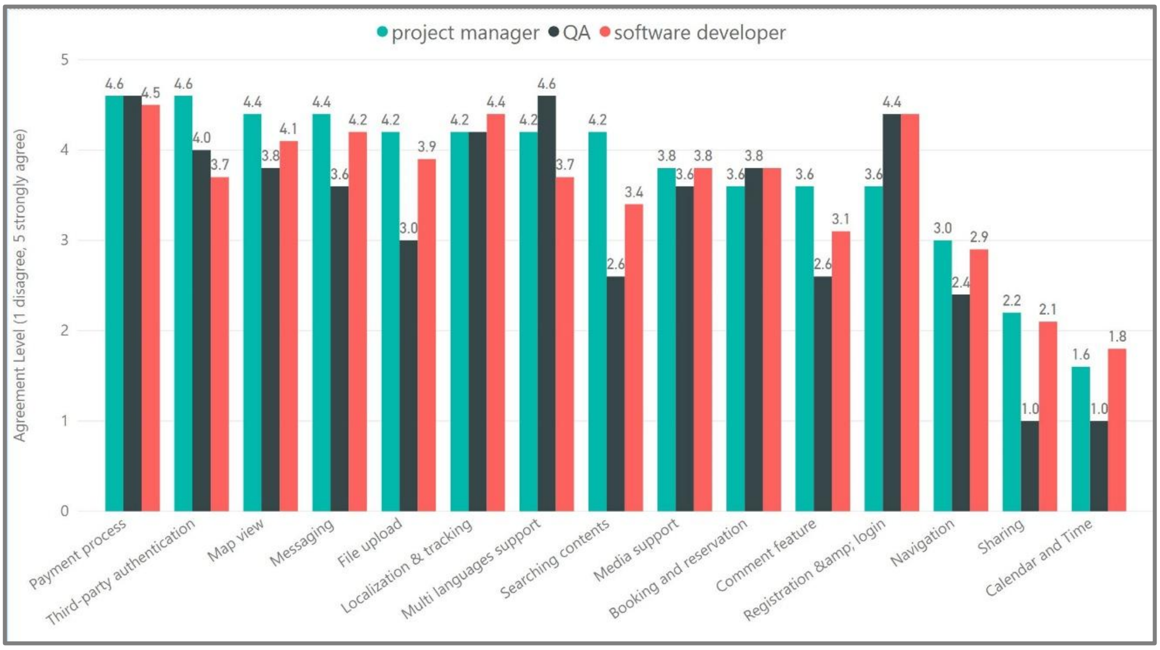


Figure 91 Functional estimation factors filtered by expert's job role

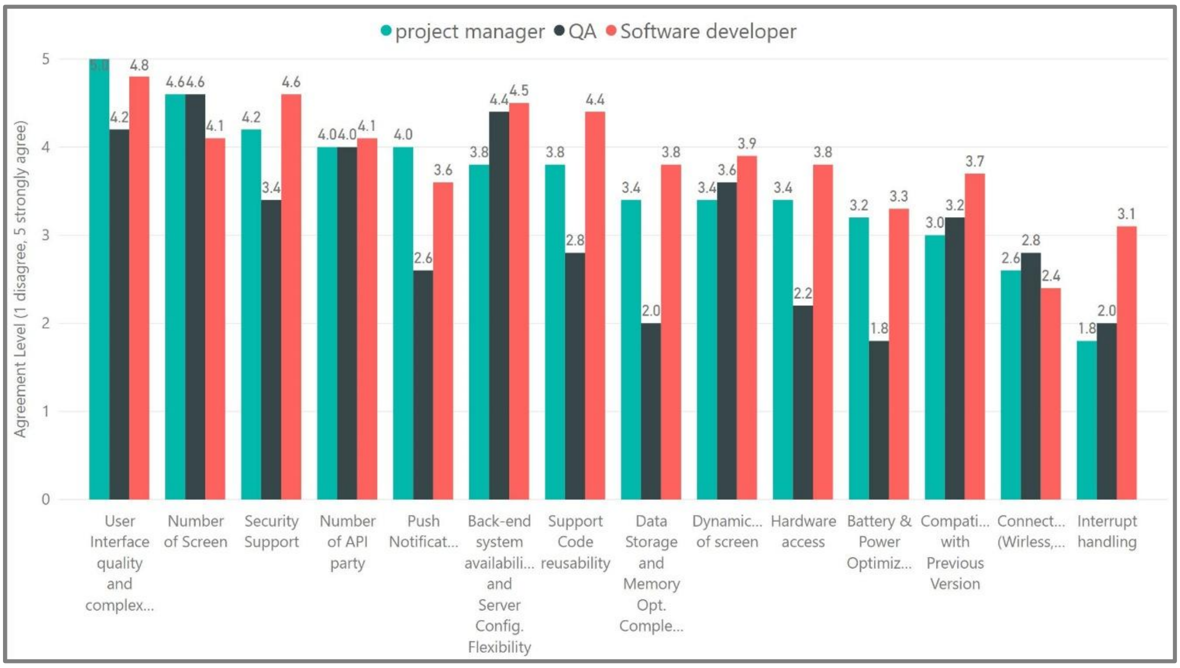


Figure 92 Non-functional estimation factors filtered by expert's job role

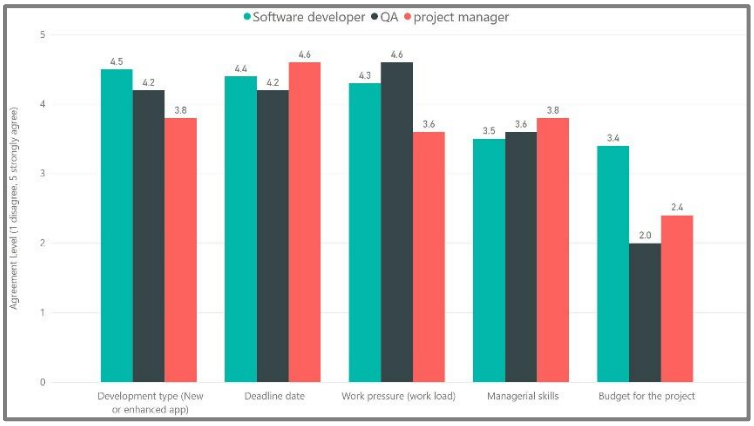


Figure 93: Project estimation factors filtered by expert's job role

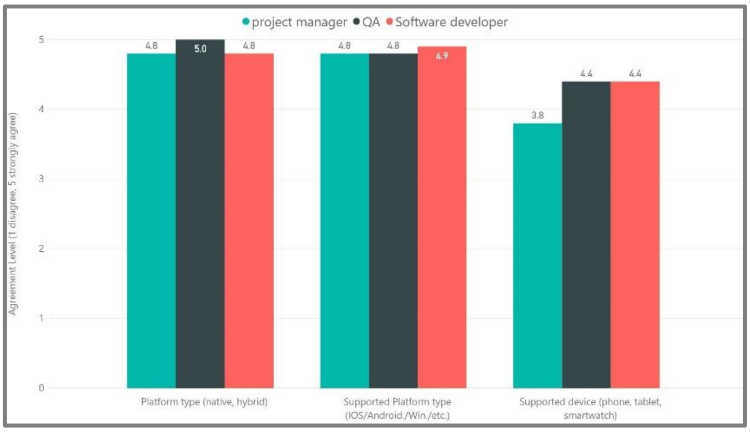
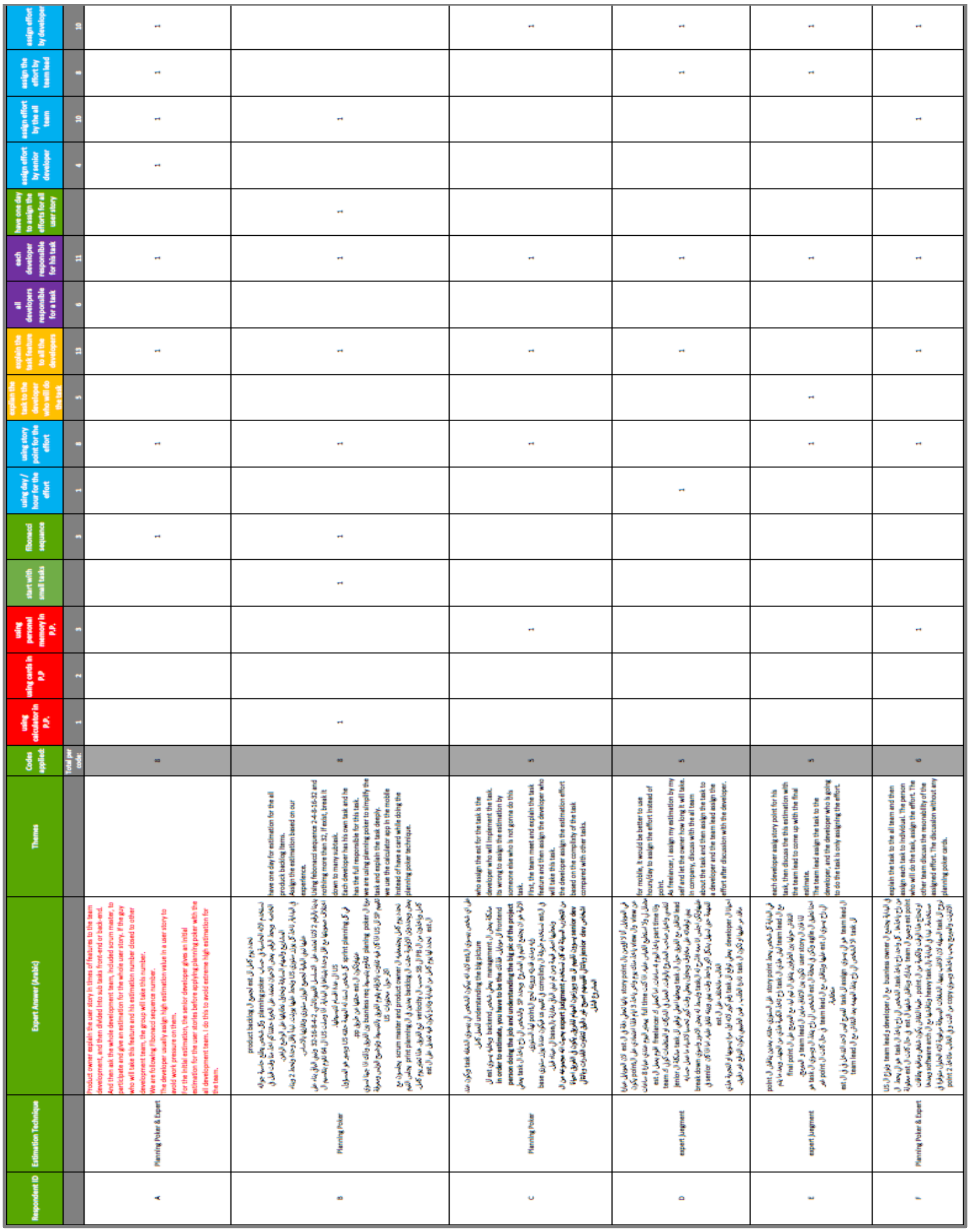


Figure 94: Mobile platform estimation factors filtered by expert's job role

Qualitative Analysis



Respondent ID	Estimation Technique	Expert Answer (Arabic)	Themes	Codes applied:	using calculator in P.P.	using cards in P.P	using personal memory in P.P.	start with small tasks	fibonacci sequance	using day / hour for the effort	using story point for the effort	explian the task to the developer who will do the task	explain the task feature to all the developers	all developers responsible for a task	each developer responsible for his task	have one day to assign the efforts for all user story	assign effort by senior developer	assign effort by the all team	assign the effort by team lead	assign effort by developer
				Total per code:	1	2	3		3	1	8	5	13	6	11		4	10	8	10
A	Planning Poker & Expert	Product owner explain the user story in times of features to the team development, and then divided into sub tasks front-end or back-end. And then ask the whole development team, included scrum master, to participate and give an estimation for the whole user story. If the guy who will take this feature and his estimation number closed to other development team, the group will take this number. We are following Fibonacci sequence number. The developer usually assign high estimation value in a user story to avoid work pressure on them. For the initial estimation, the senior developer gives an initial estimation for the user stories before applying planning poker with the all development team. I do this to avoid extreme high estimation for the team.		8					1		1		1		1		1	1	1	1
B	Planning Poker	[illegible]	have one day for estimation for the all produck backlog items. Assign the estimation based on our experience. Using febonacci sequence 2-4-8-16-32 and nothimg more than 32, if exist, break it down to many subtask. Each developer has his own task and he has the full responsible for this task. we are using planning poker to simplify the task and explain the task deeply. we use the calculator app in the mobile instead of have a card while doing the planning poker technique.	8	1			1	1		1		1		1	1		1		
C	Planning Poker	[illegible]	who assign the est for the task is the developer who will implement the task. Its wrong to assign the estimation by someone else who is not gonna do this task. First, the team meet and explain the task feature and then assign the developer who will take this task. the developer assign the estimation effort based on the complixty of the task compared with other tasks.	5			1				1		1		1					1
D	expert jusgment	[illegible]	for mobile, it would be better to use hours/day to assign the effort instead of point. As freelancer, I assign my estimation by my self and let the owner how long it will take. In company, discuss with the all team about the task and then assign the task to a developer and the team lead assign the effort after discussion with the developer.	5						1			1		1				1	1
E	expert jusgment	[illegible]	each developer assig story point for his task, then discuss the this estimation with the team lead to come up with the final estimate. The team lead assign the task to the developer, and the developer who is going to do the task is only assigning the effort.	5							1	1			1				1	1
F	Planning Poker & Expert	[illegible]	explain the task to the all team and then assign each task to individual. The person who will do the task, assign the effort. The other team discuss the resonability of the assigned effort. The discussion without any planning poker cards.	6			1				1		1		1			1		1

Figure 95: Example of thematic technique used to summarise and generate themes of the estimation process from the qualitative question

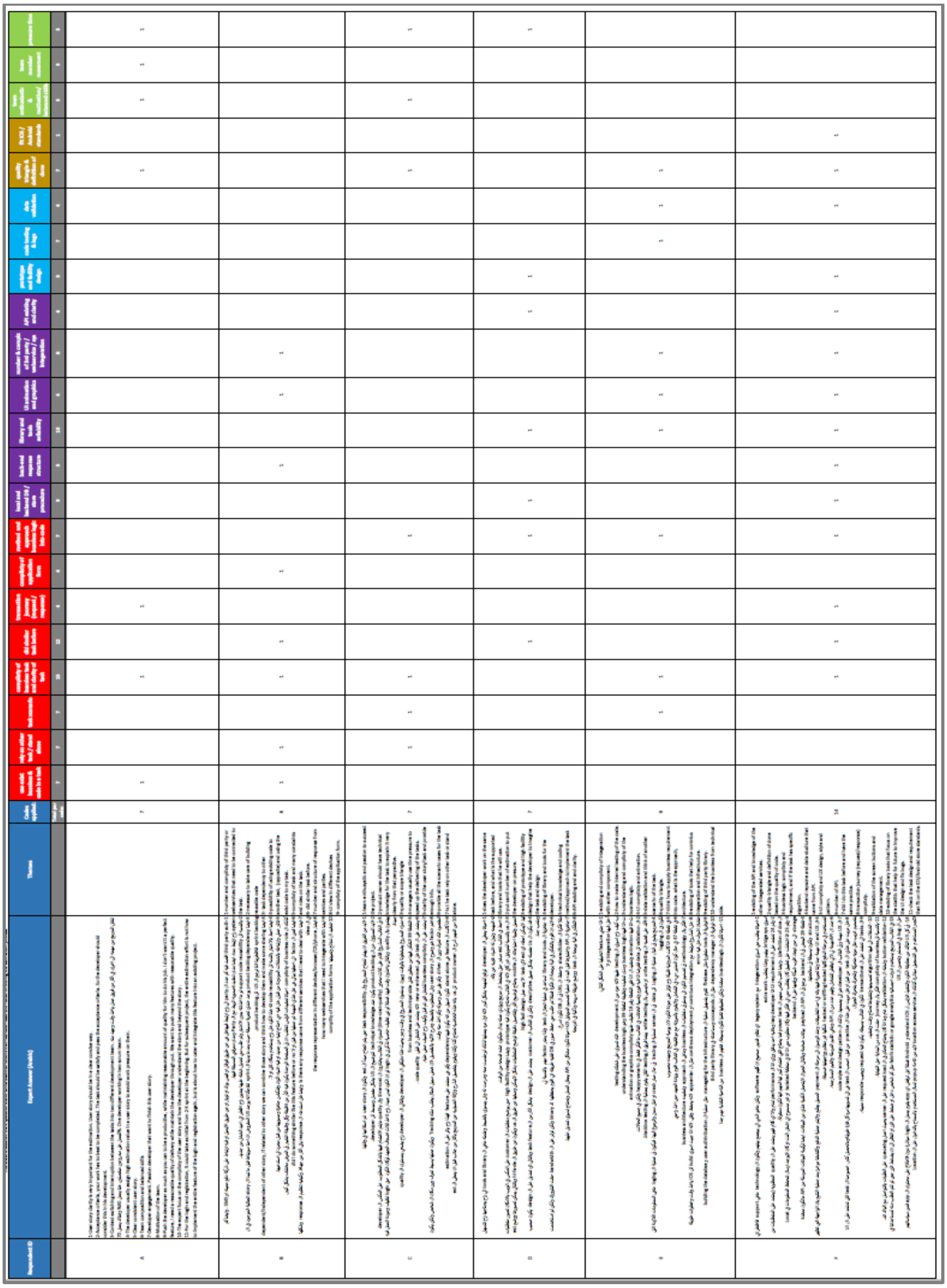


Figure 96 Example of thematic technique used to summarise and generate themes of additional estimation factors from the qualitative question

Appendix D

Case Study Method

Re: Summary of what happened during last two weeks at [redacted]

RA R[redacted]e>
[redacted]

To: Altaleb A. Cc: [redacted]

Dear Abdullah,

Thank you very much for your effort and the summary you have provided.
All comments we discussed and you mentioned are currently under monitoring,
I can see a clear enhancement in the way the team is breaking down their tasks and updating the board this week.
Also, I'm looking forward to our next planning session to clarify what is the estimation model that we will go for.

Thanks again and have a great week ahead.

Best regards,

Figure 97: Email message from the project manager after conducting a group discussion with the development team

---------- Forwarded message ---------
From: A[redacted].sa>
Date: Tue, Oct 15, 2019, 4:11 PM
Subject: appreciation letter
To: [redacted]sa>, R[redacted]t.me>, Y[redacted]
Cc: A[redacted]n.sa>

Dear all ,

On behalf of [redacted], I would like to extend our appreciation for the amazing work done by all the team on

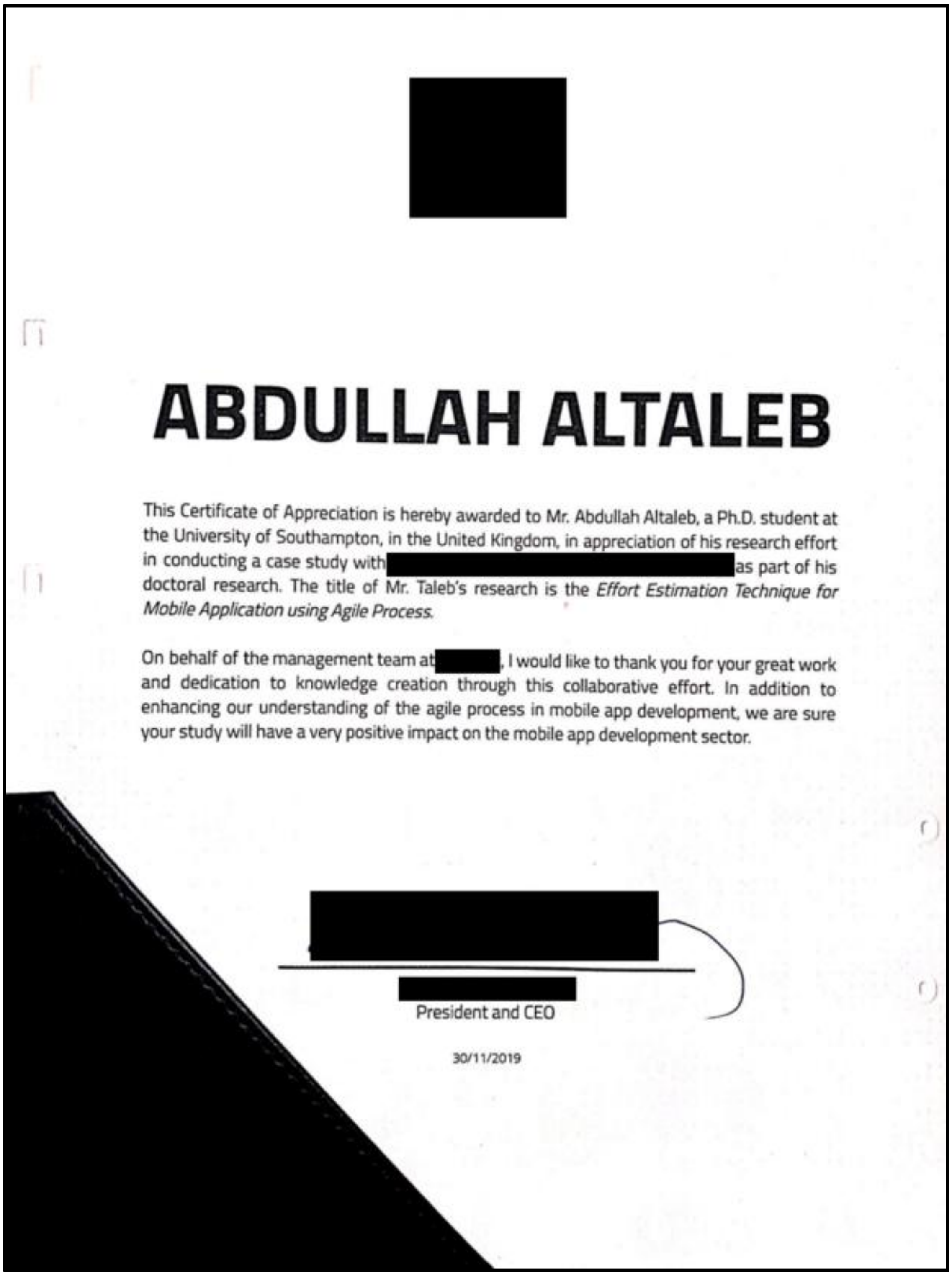
the [redacted] project last month . lately it was obvious our improvement , progress and the professionalism

that you have shown has impressed the client immensely.

Your diligence, self-motivation as well as eager to learn and improve have been a source of appreciation for the rest of the

team.

Figure 98: Email message of appreciation for the improvement from the client representative of Organisation T



[redacted]

ABDULLAH ALTALEB

This Certificate of Appreciation is hereby awarded to Mr. Abdullah Altaleb, a Ph.D. student at the University of Southampton, in the United Kingdom, in appreciation of his research effort in conducting a case study with [redacted] as part of his doctoral research. The title of Mr. Taleb's research is the *Effort Estimation Technique for Mobile Application using Agile Process.*

On behalf of the management team at [redacted], I would like to thank you for your great work and dedication to knowledge creation through this collaborative effort. In addition to enhancing our understanding of the agile process in mobile app development, we are sure your study will have a very positive impact on the mobile app development sector.

[redacted]

[redacted]

President and CEO

30/11/2019

Figure 99: Appreciation letter from the president and CEO of Company A for the positive results in Project X

Figure 100: Researcher being presented by the CEO at Company A with an award for the case study's successful results and feedback

Table 77: Development performance before the proposed estimation process

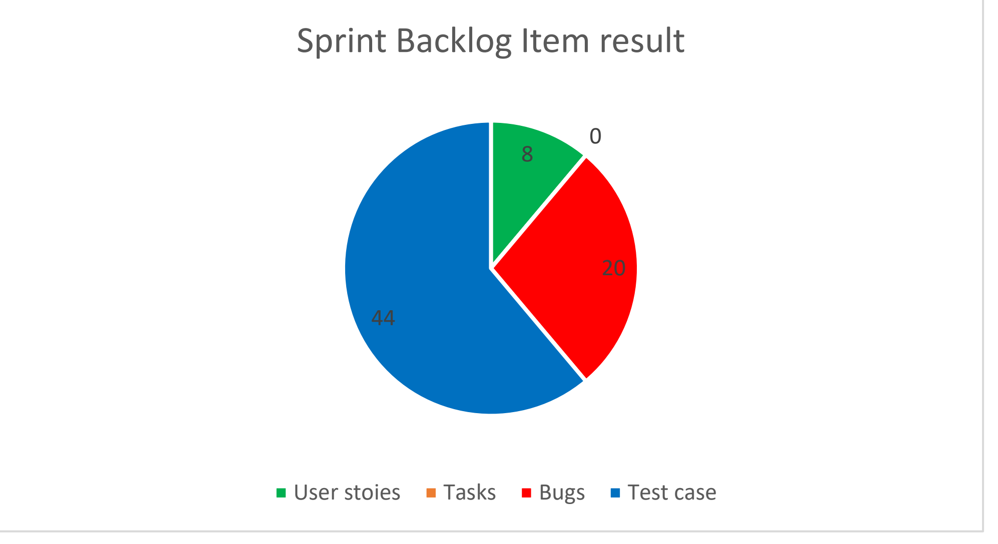
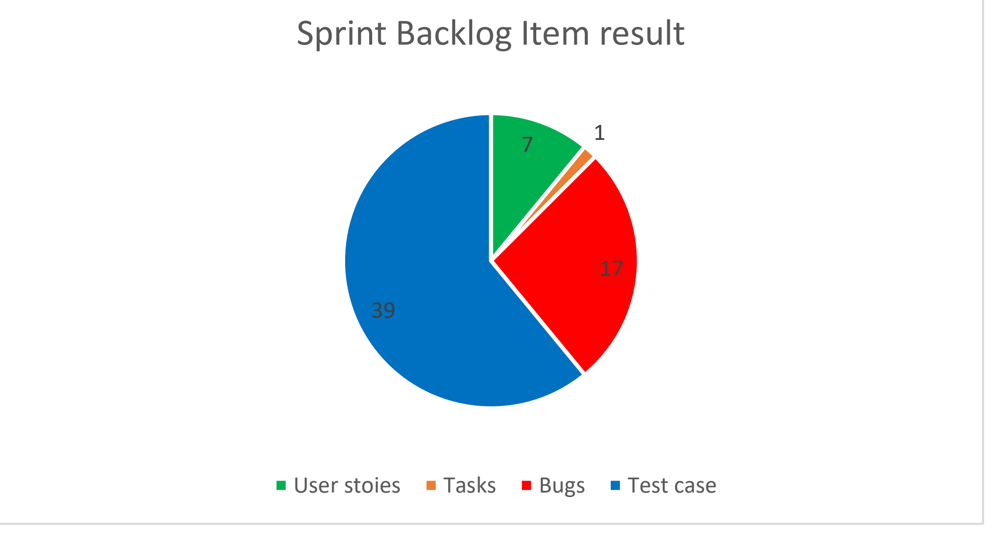
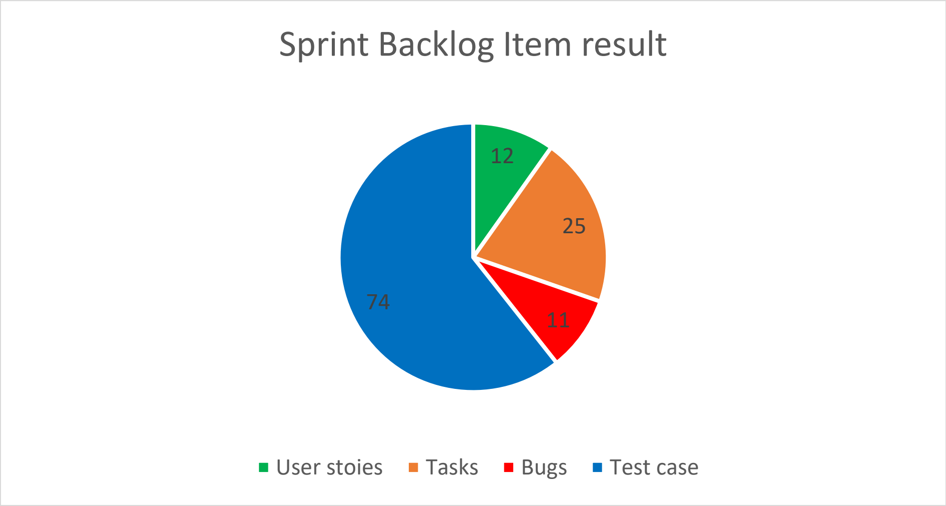
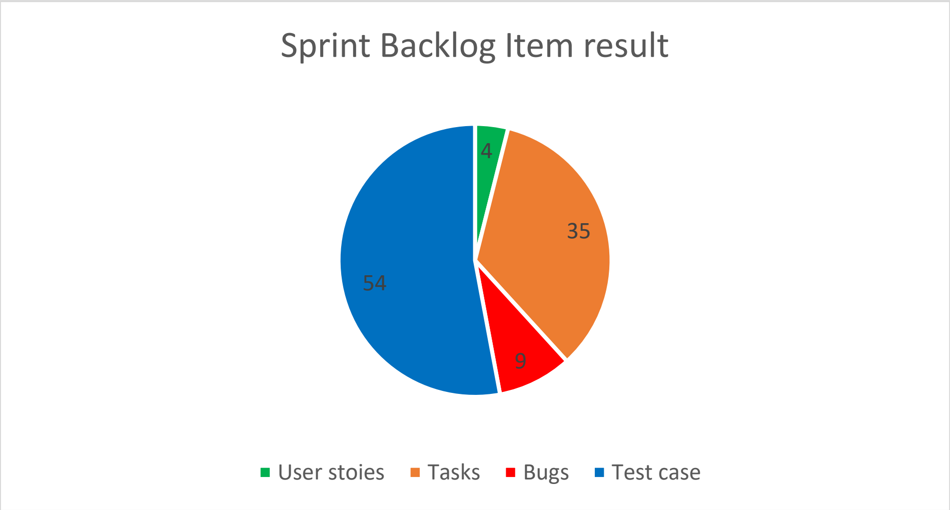
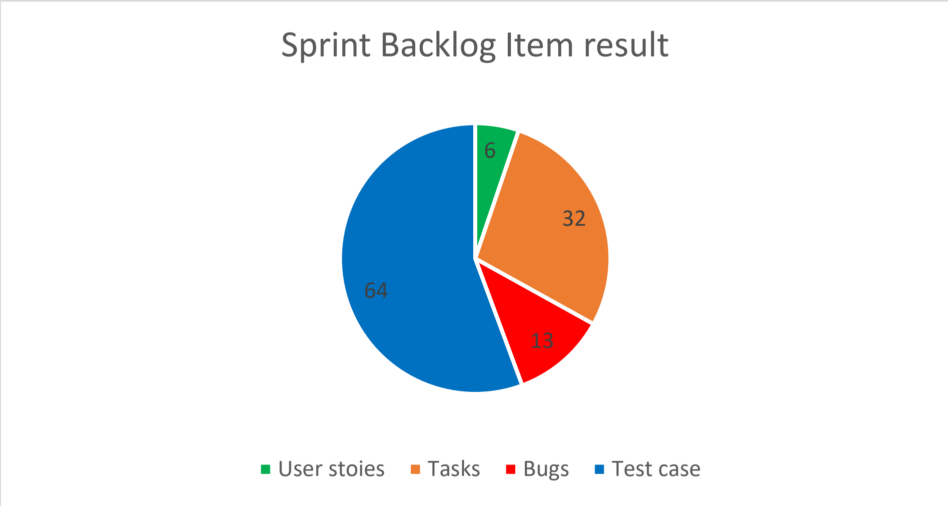
Sprint number	Sprint Performance before applying the proposed model
Sprint 4	
Sprint 5	

Table 78: Development performance after the proposed estimation process

Sprint number	Sprint Performance after applying the proposed model
Sprint 6	
Sprint 7	

Sprint number	Sprint Performance after applying the proposed model
Sprint 8	

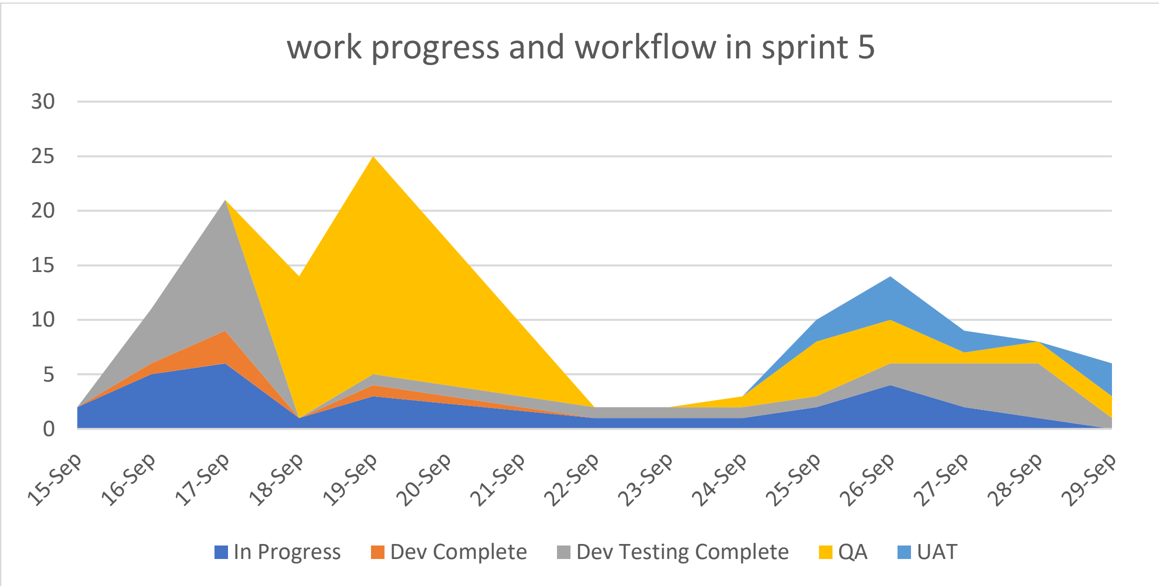


Figure 101: Distribution of the work progress on Sprint 5

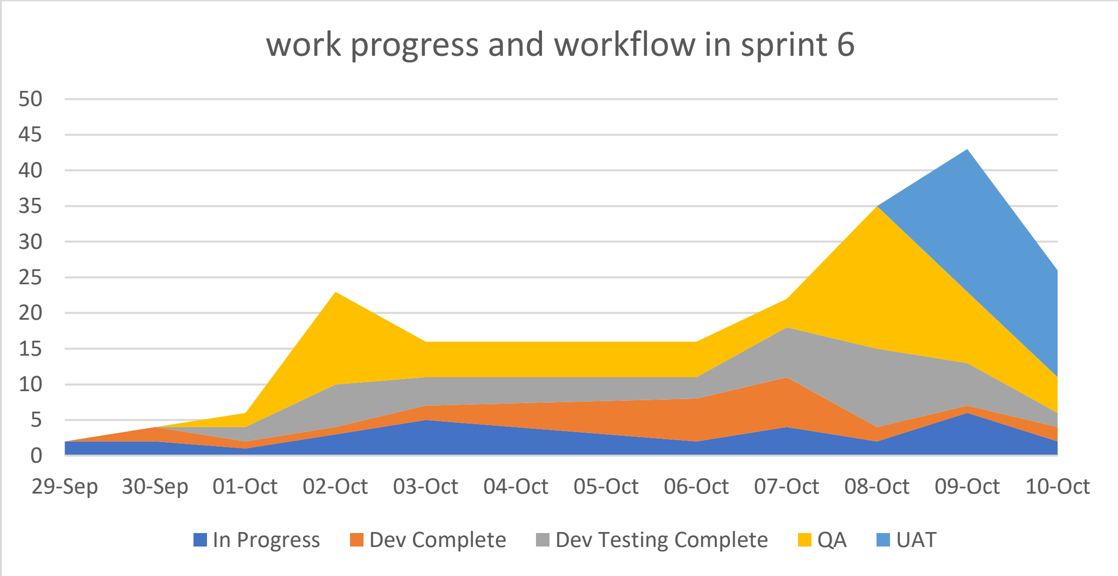


Figure 102: Distribution of the work progress on sprint 6

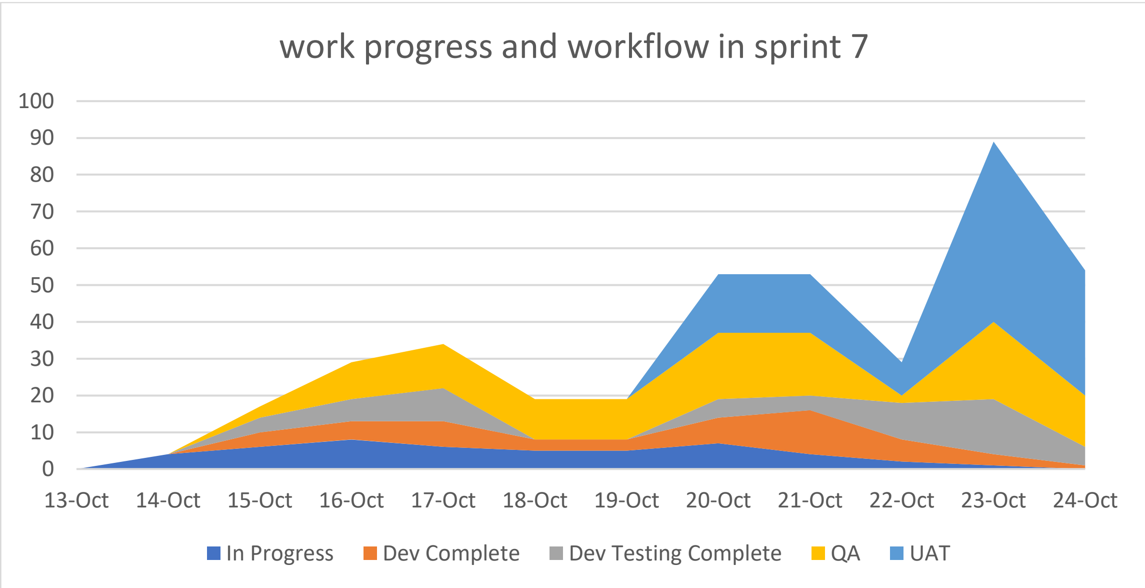


Figure 103: distribution of the work progress on sprint 7

Table 79: Example of breaking down the user story into small tasks

User story	Tasks	Acceptance testing
As an XXX Admin, I want to send a Push General Notification to all XXX app users.	Send notifications according to language XXX	C1: Check the reminder notification content
	Filter users upon conditions XXX XXX	C1: Check the reminder notification language if the user selects EN language - Android
	Connect backend to notification server XXX	C1: Check the reminder notification language if the user selects AR language - Android
	Save Rule in DB	C1: Check the reminder notification if the user did not select the language - Android
	Create an API for XXX to receive conditions	C1: Check when the user press on the notification he will be directed to home screen - IOS
	QA user behaviour notification	C1: Check when the user press on the notification he will be directed to home screen - Android
	IOS - case 1	C1: Check that the user will receive the usage reminder when he/she logout from the app - Android
	IOS - case 2	C1: Check that the user will receive the usage reminder when he/she logout from the app - IOS
	Android - case 1	C1: Verify the period time for usage reminder- IOS
	Android - case 2	C1: Verify the period time for usage reminder- Android
	QA on general notification	C1: Check the user will receive app notification when he/she did not use the app for 3 months - IOS
	Create API for frontend to send general notification XXX	C1: Check that the app user will receive app notification when he/she did not use the app for 3 months - Android
	Connect notification API to backend API XXX	C2: Check the registration notification language if the user selects EN language - Android
	Create API to send Arabic notification to only Arabic users XXX	C2: Check the registration notification language if the user selects AR language - Android
	Create API to send English notification to only English users	C2: Check the registration notification if the user did not select the language - Android

User story	Tasks	Acceptance testing
	Modify notification API to receive English and Arabic notifications	Confirmation message must appear to the Admin user before cancel the notification (General)
	Create API to take language of user from mobile app and save in db	C2: Check if the user updates the app will not receive register notification- IOS
	Create wireframe XXX	C2: Check the registration notification language if the user selects EN language-IOS
	Connection with API (General) XXX	C2: Check the registration notification language if the user selects AR language-IOS
	On submit validate fields (General)	C2: Check the registration notification if the user did not select the language- IOS
	Change fields depending on type (General) XXX	C2: Check the registration notification content
	Applying new design for create notification pop up (General) XXX	C2: Check when the user press on the notification he will be directed to home registered screen - Android
	Add Create Notification button XXX	C2: Check when the user press on the notification he will be directed to home registered screen - IOS
		C2: Check the user will be notified if he/she did not complete registration-Android
		C2: Check the user will be notified if he/she did not complete registration-IOS

XXX: means the data is private and hidden upon the case study ethics and regulation number 52598.

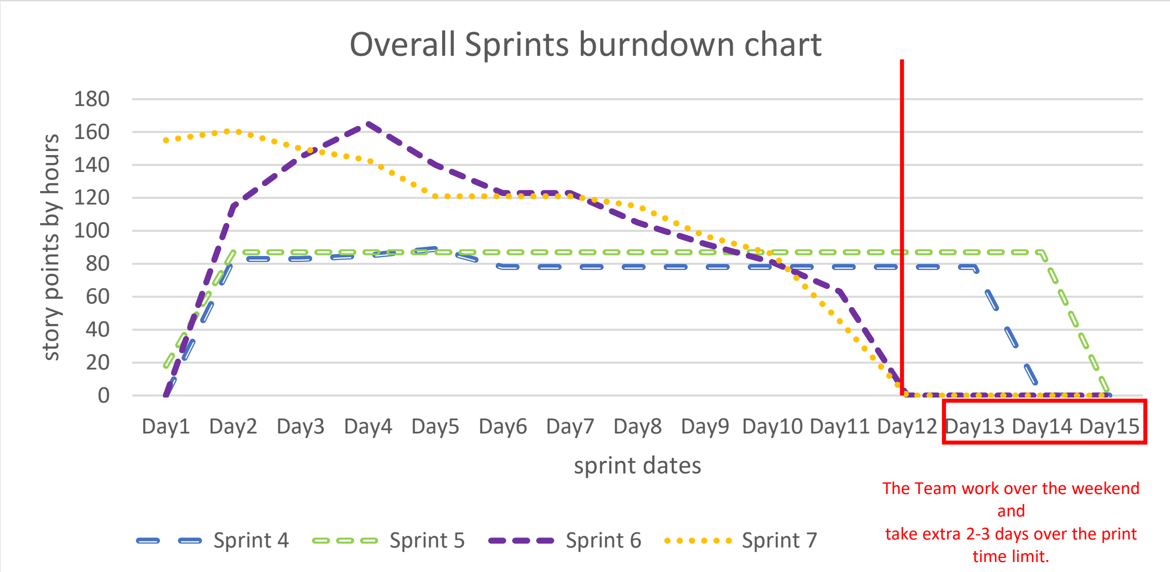


Figure 104: burn down chart of the development team from sprint 4 until sprint 7

Table 80: Details of user stories' information for Sprint 11 of case study C

ID	Group	Name	Planned Start Date	Planned End Date	Estimated Effort	Actual Effort	Delivered
234	US	N/A					
235	TSK	N/A	Sep 22, 2019	Sep 23, 2019	7	9	D
236	TSK	N/A	Sep 23, 2019	Sep 24, 2019	8	15	D
237	US	N/A					
238	TSK	N/A	Sep 24, 2019	Sep 25, 2019	4	8	D
239	TSK	N/A	Sep 24, 2019	Sep 25, 2019	8	16	D
240	TSK	N/A	Sep 25, 2019	Sep 26, 2019	10	17	D
241	US	N/A					
242	TSK	N/A	Sep 26, 2019	Sep 27, 2019	8	15	D
243	TSK	N/A	Sep 29, 2019	Sep 30, 2019	10	16	D
244	TSK	N/A	Sep 30, 2019	Oct 01, 2019	8	14	D
245	US	N/A					
246	TSK	N/A	Oct 01, 2019	Oct 02, 2019	12	19	D
247	US	N/A					

ID	Group	Name	Planned Start Date	Planned End Date	Estimated Effort	Actual Effort	Delivered
248	TSK	N/A	Oct 02, 2019	Oct 03, 2019	10	3 NC	ND
249	TSK	N/A	Oct 02, 2019	Oct 03, 2019	5	0	ND
250	TSK	N/A	Oct 03, 2019	Oct 04, 2019	8	0	ND

Table 81: Details of user stories' information for Sprint 13 of Case study C

ID	Group	Name	Planned Start Date	Planned End Date	Estimated Effort	Actual Effort	Delivered
269	US	N/A					
270	TSK	N/A	Oct 20, 2019	Oct 21, 2019	2	2	D
271	TSK	N/A	Oct 20, 2019	Oct 21, 2019	4	4	D
272	TSK	N/A	Oct 21, 2019	Oct 22, 2019	4	5	D
273	TSK	N/A	Oct 21, 2019	Oct 22, 2019	4	4	D
274	TSK	N/A	Oct 21, 2019	Oct 22, 2019	4	4	D
275	TSK	N/A	Oct 22, 2019	Oct 23, 2019	3	4	D
276		N/A					
277	TSK	N/A	Oct 22, 2019	Oct 23, 2019	5	6	D
278	TSK	N/A	Oct 22, 2019	Oct 23, 2019	4	4	D
279	TSK	N/A	Oct 23, 2019	Oct 24, 2019	3	4	D
280	TSK	N/A	Oct 23, 2019	Oct 24, 2019	2	2	D
281	TSK	N/A	Oct 23, 2019	Oct 24, 2019	4	5	D
282	TSK	N/A	Oct 24, 2019	Oct 25, 2019	4	5	D

ID	Group	Name	Planned Start Date	Planned End Date	Estimated Effort	Actual Effort	Delivered
283	TSK	N/A	Oct 24, 2019	Oct 25, 2019	3	5	D
284	TSK	N/A	Oct 24, 2019	Oct 25, 2019	5	5	D
285		N/A					
286	TSK	N/A	Oct 27, 2019	Oct 28, 2019	5	6	D
287	TSK	N/A	Oct 27, 2019	Oct 28, 2019	4	5	D
288	TSK	N/A	Oct 28, 2019	Oct 29, 2019	4	5	D
289	TSK	N/A	Oct 28, 2019	Oct 29, 2019	4	4	D
290	TSK	N/A	Oct 28, 2019	Oct 29, 2019	3	4	D
291		N/A					
292	TSK	N/A	Oct 29, 2019	Oct 30, 2019	2	3	D
293	TSK	N/A	Oct 29, 2019	Oct 30, 2019	3	3	D
294	TSK	N/A	Oct 29, 2019	Oct 30, 2019	2	3	D
295	TSK	N/A	Oct 30, 2019	Oct 31, 2019	4	5	D
296	TSK	N/A	Oct 30, 2019	Oct 31, 2019	4	5	D
297	TSK	N/A	Oct 31, 2019	Nov 01, 2019	3	5	D
298	TSK	N/A	Oct 31, 2019	Nov 01, 2019	4	4	D

Table 82: Summary of methods used for the 1st and 2nd research questions

Question	Method	Purpose	Chapter
What are the effort estimation factors and predictors that have been used in software estimation technique in Agile software development process?	Systematic Literature Review	To provide the estimation factors and predictors that influence on the effort estimation	4 and 5
	Structured interview	To evaluate the existed factors and predictors and measure its suitability for mobile app development	6 and 7
	Semi-structured interview	To provide additional factors from the industrial fields that influence on the accuracy of the effort estimation	6 and 7
What is the influence of the estimation factors on the estimation accuracy?	Case Study and Action Method	To examine the efficiency of the effort estimation factors and predictors in the development team from industrial fields	8 and 9

Table 83: Summary of methods used for the 3rd research question

Question	Method	Purpose	Chapter
What methods or technique have been used to estimate effort in mobile application development using Agile process?	Systematic Literature Review	To identify and investigate the current state of art of effort estimation techniques for mobile app in Agile context	4 and 5
	Structured interview	To identify the effort estimation techniques in the current state of practice	6 and 7
	Semi-structured interview	To understand the process of the effort estimation technique from the industrial fields	6 and 7
	Case Study and Action Method	To understand the existing estimation technique and measure its efficiency with the development team	8 and 9

Table 84: Summary of methods used for the 4th, 6th and 7th research questions

Question	Method	Purpose	Chapter
What is the accuracy level and efficiency of using Agile SD to estimate the effort of mobile application software projects?	Systematic Literature Review	To provide the current state of art of the effort estimation accuracy that used for mobile app development in Agile context	4 and 5
	Structured interview	To understand the current state of practice of the effort estimation accuracy in IT sector	6 and 7
	Case Study	To measure the accuracy level of the existed effort estimation technique and analyse the result	8 and 9
What is the main causes that effect on the accuracy of the effort estimation?	Semi-structured interview	To investigate the reasons of the effort estimation accuracy from the IT sector	6 and 7
What is the impact of using effort estimation factors/predictors on the accuracy level of the effort estimation?	Case Study and Action Method	To measure the effectiveness of the accuracy level of effort estimation on the development team performance	8 and 9