# THE EFFECTS OF TEST DRIVEN DEVELOPMENT ON SOFTWARE PRODUCTIVITY AND SOFTWARE QUALITY

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## ABSTRACT

## THE EFFECTS OF TEST DRIVEN DEVELOPMENT ON SOFTWARE PRODUCTIVITY AND SOFTWARE QUALITY

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In the 1990s, software projects became larger in size and more complicated in structure. The traditional development processes were not able to answer the needs of these growing projects. Comprehensive documentation in traditional methodologies made processes slow and discouraged the developers. Testing, after all code is written, was time consuming, too costly and made error correction and debugging much harder. Fixing the code at the end of the project also affects the internal quality of the software. Agile software development processes evolved to bring quick solutions to these existing problems of the projects. Test Driven Development (TDD) is a technique, used in many agile methodologies, that suggests minimizing documentation, writing automated tests before implementing the code and frequently run tests to get immediate feedback. The aim is to increase software productivity by shortening error correction duration and increase software quality by providing rapid feedback to the developer. In this thesis work, a software project is developed with TDD and compared with a control project developed using traditional development techniques in terms of software productivity and software quality. In addition, TDD project is compared with an early work in terms of product quality. The benefits and the challenges of TDD are also investigated during the whole process.

**Keywords:** Agile Software Development, Test Driven Development, Software Productivity, Software Quality.

# ÖZ

## SINAMAYA DAYALI GELİŞTİRMENİN YAZILIM ÜRETKENLİĞİ VE YAZILIM NİTELİĞİNE ETKİLERİ

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1990'larda, yazılım projeleri boyutça daha büyük ve yapıca daha karmaşık bir hale geldi. Geleneksel geliştirme süreçleri bu büyüyen projelerin ihtiyaçlarına cevap veremedi. Geleneksel metotlarda yapılan kapsamlı dokümantasyon, süreçleri yavaşlatıyor ve yazılım geliştiricileri isteksizleştiriyordu. Kod yazımından sonra testlerin yapılması fazla zaman alıyordu, çok masraflıydı ve hata düzeltme ile hata ayıklamayı zorlaştırıyordu. Kodun projenin sonunda düzeltilmesi de yazılımın içsel niteliğini etkiliyordu. Çevik yazılım geliştirme süreçleri bilinen bu problemlere hızlı çözümler getirebilmek için geliştirildi. Sınamaya Dayalı Geliştirme (SDG) birçok çevik metotta kullanılan, dokümantasyonun azaltılmasını, kod yazılmadan önce otomatik testlerin yazılmasını ve hızlı geri besleme alınması için testlerin sıkça koşturulmasını öneren bir tekniktir. Amaç, hata düzeltme zamanını kısaltarak yazılım üretkenliğini ve yazılım geliştiriciye hızlı geri beslemeler sağlayarak yazılım niteliğini arttırmaktır. Bu tezde, SDG tekniği ile bir proje geliştirildi ve geleneksel geliştirme tekniği ile geliştirilen bir kontrol projesi ile yazılım üretkenliği ve yazılım niteliği açısında karşılaştırıldı. Buna ek olarak, SDG projesi, daha önce geliştirilmiş olan bir projeyle ürün niteliği açısından karşılaştırıldı. SDG uygulanmasının yararları ve zorlukları da çalışma boyunca incelendi.

**Anahtar Kelimeler:** Sınamaya Dayalı Geliştirme, Çevik Yazılım Geliştirme, Yazılım Üretkenliği, Yazılım Niteliği

*To My Parents and To My Brother*

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| | |
|---|---|
| AFP | Adjusted Function Points |
| ARCHI-DIM | Architecturel Dimensions Based FSM |
| ASD | Adaptive Software Development |
| AUP | Agile Unified Process |
| BFC | Base Functional Component |
| CBO | Coupling Between Objects |
| CC | Cyclomatic Complexity |
| CMMI | Capability Maturity Model Integration |
| COSMIC | Common Software Measurement International Consortium |
| DIT | Depth of Inheritance Tree |
| DSDM | Dynamic Systems Development Method |
| EI | External Input |
| EIF | External Interface File |
| EO | External Output |
| EQ | External Inquiry |
| FDD | Feature Driven Development |
| FFP | Full Function Points |
| FP | Function Points |
| FPA | Function Point Analysis |
| FPC | Function Point Count |
| FSM | Functional Size Measurement |
| FUR | Functional User Requirements |
| GUI | Graphical User Interface |
| IBM | International Business Machines Corporation |
| IF | Information Flow |
| IFPUG | International Function Point Users Group |

| | |
|---|---|
| ILF | Internal Logical File |
| ISO | International Standards Organization |
| LCOM | Lack of Cohesion Of Methods |
| LOC | Lines Of Code |
| METU | Middle East Technical University |
| MSN | Microsoft Network |
| NESMA | The Netherlands Software Metrics Users Association |
| NOC | Number Of Children |
| OO | Object Oriented |
| RFC | Response For a Class |
| SDG | Sınamaya Dayalı Geliştirme |
| TDD | Test Driven Development |
| UFP | Unadjusted Function Points |
| VAF | Value Adjustment Factor |
| WMC | Weighted Methods per Class |
| XP | Extreme Programming |

# CHAPTER 1

# INTRODUCTION

In the 1990s, people started to figure out the weaknesses of the traditional software development processes [27]. The requirements need to be fixed during the process, but it is too costly to make changes after a certain point in traditional methodologies. Furthermore, these methods resist altering requirements, because changes lead to delays and delays break down the predicted schedule. Moreover, the aim in a project is that the outcome will not depend on the individuals but in reality, the project failures or successes heavily depend on the individuals involved. Consequently, new methodologies, having common values such as responding to change, interactions between individuals, working software and customer collaboration, were developed and they are all grouped as Agile Methodologies.

In many agile software development processes, Test Driven Development (TDD) technique is used. TDD is a style of development and can be summarized in five steps: Quickly add a test; run all tests and see the new one fail; write the necessary code; run all tests and see the new one pass; refactor code [2, 3].

Minute by minute testing in TDD provides instant feedback to the developer [6]. The features are divided into manageable tasks as a result of the iterative development [5]. Moreover, low level designs are made in each iteration, in the writing tests phase. Easy regression tests, achieved by automated tests, can be considered as another benefit of TDD.

On the other hand, there are some challenges of TDD. In the software development projects including database, network, embedded software and graphical user interface, it is mentioned that applying TDD may be not possible or useless [7, 8, 9]. In addition, lack of familiarity of the developers to TDD and insufficient tool support for the automation of tests can lead to serious delays in the project timeline.

In the literature, there is a debate about the effects of TDD on the software development process. There are some studies in industry and academy indicating that TDD leads to an increase in developer's productivity [5, 10] and software quality [4, 39]. There are also opposing ideas and studies [1, 4, 12]. These studies claim that TDD has no significant effect on software quality and that it also decreases the developers' productivity.

In this thesis study, we perform a case study to assess how TDD affects software productivity and software quality. To evaluate the effects of TDD, two software projects developed at Aselsan A.Ş., are considered. One of them is the control project and is developed using traditional Test-Last development technique; the second one is a similar project and is implemented using TDD. Software product metrics that are indicators of quality, and process metrics that measure productivity [13] are calculated for both projects and the evaluation results are compared to determine the differences between them in terms of productivity and quality.

The projects include graphical user interface and network applications. Besides assessing the effects of TDD, challenges of using TDD in a network and GUI application are also examined in the scope of this thesis.

In addition to comparison of the above mentioned projects, the TDD project is compared with an early work performed at Aselsan A.Ş in terms of product quality. This early work was developed using Test-Last development technique. It should be noted that the aim of the study is to present a case-based contribution to the arguments on the merits of TDD, rather than establishing a definitive conclusion, which would be much above and beyond the scope of this thesis.

The outline of the thesis is organized as follows: Chapter 2 provides background information about test driven development, a literature survey about software productivity and quality metrics and results available in the literature related with the subject of this thesis. Chapter 3 presents the overview and the results of the TDD project, Test-Last project and the early work. Finally in Chapter 4 the obtained results are compared and discussed; the overall development process is summarized and the study is concluded.

# CHAPTER 2

# TEST DRIVEN DEVELOPMENT

In this chapter, first, an overview of the literature on the subject of agile software development and test driven development (TDD) is given. Then, some TDD related studies are examined and possible benefits and some challenges of TDD are reviewed. In this context, the importance of software metrics is noted, and the possible measurements to assess the effects of TDD are also reviewed.

## 2.1 AGILE SOFTWARE DEVELOPMENT

During the 1990s a number of different people, who later formed the Agile Alliance [28], discovered that the challenges of modern software development can not be tackled by traditional processes [27]. Different methodologies, having common values and principles, have been established and gathered under the brand "Agile Methods". The Agile Alliance expressed 12 principles and four fundamental values [28]. The values declared in the Agile Manifesto are:

1. ***Individuals and interactions*** *over processes and tools*
2. ***Working software*** *over comprehensive documentation*
3. ***Customer collaboration*** *over contract negotiation*
4. ***Responding to change*** *over following a plan*

Some of the major agile methods are [27], [29]:

1. *Extreme Programming:* Extreme Programming (XP), the most popular agile software development methodology, was developed by Kent Beck. The five values of XP are: Communication, Simplicity, Feedback, Courage and Respect. These values denotes communicating with customer and within the team, keeping the design simple and clean, getting instant feedback by starting testing on day one, courageously responding to changing requirements and technology and responding fellow programmers and their work [35].

2. *Scrum:* Scrum is a lightweight methodology initially created by Ken Schwaber and Jeff Sutherland. Scrum method provides a project management framework including daily meetings for coordination and integration that do not last for more than 15 minutes and iterative development in 30 day periods (called a sprint cycle).

3. *Crystal Methods:* The crystal family of methodologies was developed by Alistair Cockburn who is a methodology archeologist. This is called crystal family because methodology differs according to the size of the team and the criticality of the project. The method focuses on people, interaction, collaboration, cooperation, skills, talents and communication as first order effects.

4. *Feature Driven Development (FDD):* FDD, developed by Jeff De Luca and Peter Coad, is composed of five sub-processes each defined with entry and exit criteria. These steps focuses on developing object models and sequence diagrams, building a feature list, planning by feature, iteratively designing by feature and building by feature respectively.

Besides the above methods, there are other agile methods such as Dynamic Systems Development Method (DSDM), Lean Development, Adaptive Software Development (ASD), Agile Modeling, Agile Unified Process (AUP).

## 2.2 INTRODUCTION TO TDD

Test Driven Development [2] is an approach, adopted in many agile software development techniques that involves writing automated tests before the implementation of the code and then coding in the guidance of the written tests. The developer executes these automated tests repeatedly so that he gets immediate feedback from failed or successful tests to judge progress.

TDD can be described mainly in five steps [2], [3]:

1. *Quickly add a test:* When a new functionality is to be implemented, the code that will test that the functionality works is written before implementing the functionality itself.

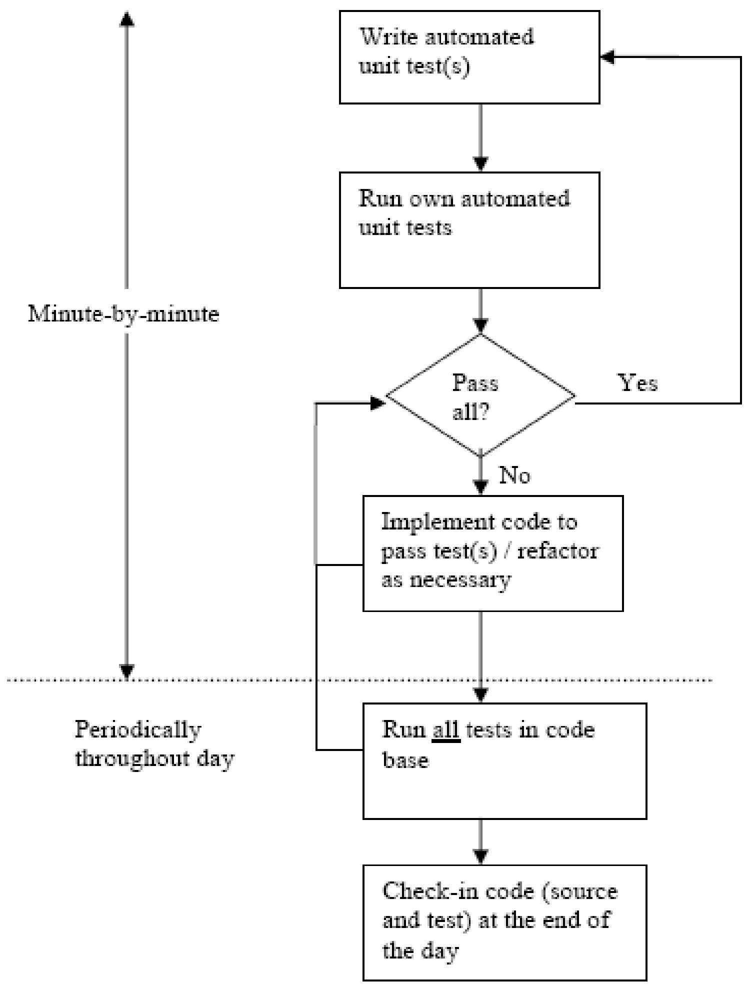
2. *Run all tests and see the new one fail:* Since the implementation of the new feature hasn't been done yet, the new test has to fail. This shows that the new test does not mistakenly pass without requiring any new code.

3. *Write some code:* In this step, the developer writes the simplest code that is only enough to pass the test. No more functionality should be implemented. The perfection of the code is not much important in this step.

4. *Run all tests and see the new one pass:* This validates that the newly added code satisfies the requirements of the new feature.

5. *Refactor:* Now, the perfection of the code can be considered. Refactoring means improving the quality of the working code without changing its external behavior. It can be done whenever we think that the code is poor but it must be done in case of duplications and ambiguity in code.

This cycle is repeated until the last feature is added to the software; that is, until the last requirement is satisfied. The step sizes can be smaller or larger. The developer can add a large feature in one cycle or split it into smaller testable steps. Running all tests in every cycle may be time consuming in some cases so instead of this, only newly added tests may be run in each cycle. The overall test execution can be done periodically throughout the day, as shown in Figure 2.1 [4].



Write automated unit test(s)
Run own automated unit tests
Minute-by-minute
Pass all?
Yes
No
Implement code to pass test(s) / refactor as necessary
Periodically throughout day
Run all tests in code base
Check-in code (source and test) at the end of the day

***Figure 2.1 – TDD Cycle [4]***

## 2.3 BENEFITS OF TDD

Main benefits of TDD can be outlined as follows [5], [6]:

1. *Rapid Feedback:* In traditional development processes, the gap between decision (designing and implementing) and feedback (functionality and performance obtained after testing) is longer when compared with TDD. The fine granularity of test-then-code cycle in TDD reduces this gap and gives instant feedback to the developer.

2. *Easy for regression tests:* Having up-to-date automated tests supplies a thorough regression test bed. It can be determined whether newly added code breaks anything in the working code or not by continuously running these automated tests. This also ensures a certain level of quality by removing defects without necessitating debugging or a patch.

3. *Task-orientation:* Development occurs iteratively and test-oriented in TDD so the feature to be added should be divided into manageable tasks. Each task is implemented in one cycle so that progress of coding a new feature can be measured by calculating finished number of tasks of that feature.

4. *Low-Level Design:* Low-level decisions are made during the generation of tests so that source codes are written without considering about what classes or methods will be added. After the execution of tests the compiler will tell if a class or method is missing [3]. Moreover, in TDD just what is needed is focused on, so irrelevant properties and methods are not implemented as in upfront designs.

## 2.4 CHALLENGES OF TDD

Some important challenges of TDD have been categorized as follows:

1. *Database Projects:* Applying Test Driven Development (TDD) to a project including network environment or database [7] is very difficult because the database and network environment may have not been developed before the beginning of the project. Thus, automated tests can not be processed till these environments are implemented. Preparation of mock objects for this purpose can also take too much time and effort.

2. *Developer's familiarity:* Since the developers are accustomed to use traditional Test-Last development techniques, getting familiar with writing tests first can be difficult for them.

3. *Overall Test Duration:* In main TDD cycle, all tests are repeatedly executed in case of a new test addition. If the overall test execution takes, for example an hour, the overall duration of the project significantly increases, proportionally the cost of the project increases and also the motivation of the developers decreases.

4. *Insufficient Tool Support:* As mentioned above overall test duration is a critical aspect for TDD. Hence, tool support for the automation of the unit tests becomes very important because utilization of a software tool to write automated unit tests significantly reduces the overall duration.

5. *Embedded Systems:* In the lowest level embedded systems [8], the resources for running test frameworks are limited such that these systems have no operating system and also there is no use of object oriented languages (C#, C++ or Java) in them. Moreover, direct interaction of software and hardware makes practicing TDD in embedded systems much

more difficult. Hardware functions must also be automated to be able to run unit tests in an automated fashion.

6. *GUI Applications:* Automating the tests for the Graphical User Interface (GUI) aspects of the system is very hard [9]. For example, writing automated unit tests for the code that implements a mouse action or gives a visual output is useless. Manual testing of complex GUI applications in TDD fashion (periodically run manual GUI tests with other automated unit tests) is also possible but time consuming; that is, expensive.

## 2.5 SOFTWARE METRICS

Recent development of software in organizations brings the necessity of improvement in the management of software development projects. To be able to improve something, first you have to know what the current situation is and to know that, you have to measure. As Lord Kelvin mentioned (http://www.qualitydigest.com/sept97/html/qmanage.html): "When you can measure what you are speaking about, and express it in numbers, you know something about it; but when you cannot measure it, when you cannot express it in numbers, your knowledge is of a meager and unsatisfactory kind; it may be the beginning of knowledge, but you have scarcely in your thoughts advanced to the state of Science". In literature, measurements of the properties such as, productivity, quality and reliability, of a software system are called software metrics. These metrics allow the organizations to quantify their schedule, work effort, product size, project status and quality performance [13]. Utilization of the recorded metrics in past projects also improves the future work estimates.

One set of software metrics are objectively measurable, code or any other kind of product metrics. These metrics are obtained by measuring any means of product at a particular point in time [23]. A second set of metrics, called process metrics, are related to concepts such as maintainability, comprehensibility and reliability and also involve people and the environment. Different from product metrics, process metrics measure the change during the whole process.

Product metrics are calculated by measuring the product at a specific time during the whole development cycle. This product can be the whole code, functions in the code, interactions between functions, classes or methods in classes. Many product metrics have been proposed in the literature (a comprehensive list of product metrics can be found in Appendix A). These metrics mainly measure the size of the project, functions and how functions interact, classes and how classes interact, methods and how methods interact and inheritance. Some of the product metrics used for measuring productivity and quality are examined in the following sub-sections in a more detailed way.

According to the Merriam-Webster online dictionary, a process is a series of actions or operations conducting to an end. Thus, the meaning of the process in business can be stated as "a structured set of activities that leads to the production of a product or a service for a particular customer or customers". The act of defining, planning, visualizing, measuring, controlling, reporting and improving these business processes called process management. Process management has become the main part of software quality management since 1970's [26].

Product metrics are measured at specific points of time and do not give information about the movement between these points. The whole process can not be understood from instantaneous calculations. The process has a time rate of change and the evaluation of this change can be made by using software process metrics [23].

Many process metrics have been defined and discussed in the literature. Some CMMI-based metrics are given in Table A.2 in Appendix A.

Besides product and process metrics classification, software metrics can also be classified according to what property they measure. In this study, two development projects are compared in terms of productivity and quality. Hence, in the next sub-section, software productivity and quality metrics will be discussed.

### 2.5.1 SOFTWARE PRODUCTIVITY METRICS

Productivity is measured as the ratio of units of output produced divided by units of input to the production process. Here, units of output denote the work done; units of input denote the effort spent to do that work. For software, work done can be expressed in terms of the source code produced (Lines of Code), function points and documentation pages. Effort spent is measured as the overall time spent on that project by the project team and it is calculated in staff-hours [14].

#### 2.5.1.1 LINES OF CODE (LOC)

LOC is the metric used to measure the size of the source code and is measured by counting the code lines. The source code lines can be calculated in two ways [20]:

1. *Physical LOC:* Physical LOC is measured by counting all lines in the code regardless of that the line consists of an instruction or not. The physical LOC metric can be automatically counted by the compilers or code generator tools and this metric can be used in a large number of software estimating tools. On the other hand, physical LOC metric does not exclude comments, blank lines and dead code which may be misleading for effort calculation. Also, there is no direct mathematical conversion of this metric to logical LOC or function points metric.

2. *Logical LOC:* Logical LOC is measured by counting the number of software instructions in each line. Explicitly, if a line includes two

instructions, that line is counted as two; if there is one instruction in two lines, that lines are counted as one. Logical LOC is also used in a number of software estimating tools, but calculation of it is not as easy as physical LOC. Since it is the count of instructions, it is not extensively automated for counting. Different from physical LOC, logical LOC does not include comments, blanks or dead code. Moreover, it can be converted into function point metrics.

In general, LOC metric is easy to calculate; more widely used in effort calculation and has tool support. Nevertheless, since it is measurement of size by only measuring the code lines, LOC metric is not appropriate for some visual languages and poor choice for full life-cycle studies. Furthermore, LOC metric is a programming language dependent metric [14], so can not be used in the comparison of software systems using different languages. Thus, if a software program is implemented using two languages such as C# and Java, LOC of each language shall be counted separately.

#### 2.5.1.2 FUNCTION POINTS (FP)

As an alternative to measuring simply the lines of code, Allan J. Albrecht originally suggested measuring the "function" that the software is performing [15]. The amount of the performed function is evaluated in terms of absorbed and produced data and it is quantified as function points.

In recent studies performed in METU on functional software measurement and effort estimation [30, 31], Gencel states that, after the development of Albrecht's original method, various new functional size measurement methods have been suggested and widely used. The methods found in the literature are given in Appendix B.

A need for the standardization of these methods was evolved to prevent the inconsistencies between them [30]. Thus, the common principles of these methods are established and published by the International Standards Organization (ISO). Four of the methods given in Appendix B; namely COSMIC Full Function Points, IFPUG Function Point Analysis, Mark II Function Point Analysis and NESMA Function Point Analysis, have been approved by this organization till now.

IFPUG Function Point Analysis is a relatively simple model of Function Point Analysis method based on weighting four types of functions, Input, Output, Inquiry and File, with an adjustment factor [15]. With the improvements in years [45], the "File" attribute has been divided into two as "the internal logical file" and "the external interface file". These five function types are named as External Input, External Output, External Inquiry, Internal Logical File and External Interface File and they are classified into two; data function and transactional function types [44].

Data function types are:

1. *Internal Logical File (ILF):* ILF is the data or control information internally stored and used in the boundary of the software application.

2. *External Interface File (EIF):* EIF is the data or control information stored in another application but used by the application through an interface. EIF must be an ILF of another application.

Transactional function types are:

1. *External Input (EI):* EI is the data or control information that comes from outside the software system.

2. *External Output (EO):* EO is the data or control information that is sent outside the software system.

3. *External Inquiry (EQ):* EQ is an input-output combination that results in data retrieval. Input data is formatted and sent outside the application without added value. No ILF is maintained during EQ processing.

All function types are shown in Figure 2.2.

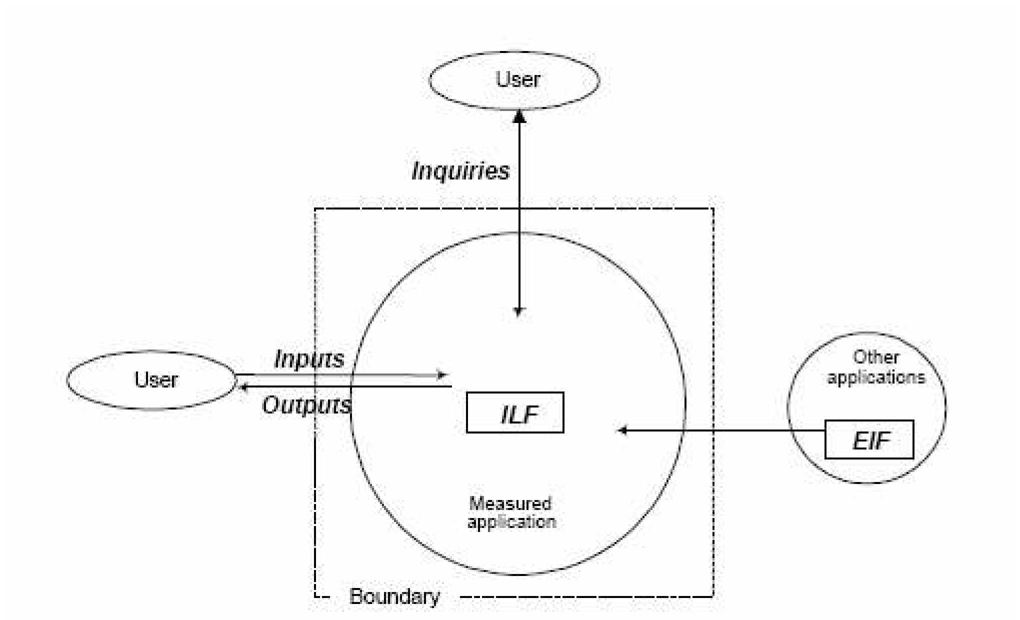


***Figure 2.2 – IFPUG Function Point Analysis Attributes [22]***

These characteristics are weighted consistent with their importance level as low, average and high [44]. Using predefined weights for these function types, unadjusted FP (UFP) can be computed. In the last step, the influence of fourteen general system characteristics is rated to assess the environment and process the complexity of the system as a whole. Value adjustment factor (VAF) is obtained with these rates that adjust the UFP to produce Adjusted Function Points (AFP).

Mark II Function Point Analysis (Mk II FPA) was proposed in 1988 by Charles Symons [40]. It is based on the assumption that the system size is determined by three components: Information processing size, technical complexity factor and environmental factors. Allan Albrecht's "Function Point Analysis" method is based on the first two of these components and the purpose of the proposed new approach is to overcome the weakness of regular FPA. The system is divided into logical transactions in Mark II FPA method [41]. Each logical transaction is composed of Input Data Element Types, Data Entity Types Referenced and Output Data Element Types and FP is calculated by counting these types. This method can be used mainly to improve estimation of development of computerized business information systems [40].

Nesma Function Point Analysis method is based on the principles of the IFPUG FPA [46]. The types of user functions used in NESMA FPA are same as the types in IFPUG: External Input, External Output, External Inquiry, Internal Logical File and External Interface File as in the IFPUG FPA. Different from the detailed function point count (FPC) in IFPUG, NESMA FPA additionally provides estimated function point count and the indicative function point count. The only difference in estimated FPC from the detailed FPC, is that the function complexities are evaluated by default. In the indicative FPC, function point is evaluated by using only ILFs and EIFs.

COSMIC Full Function Points (FFP) method presented by Alain Abran[41] was designed to measure functional size of real-time software in addition to the business application software. It provides higher level model of abstraction, richer functional size model and simpler measurement function than the previous methods. This measurement is based on the Functional User Requirements (FUR) of the system, which is a sub-set of user requirements including data transfer and data transformation; excluding quality and technical requirements [42]. COSMIC FFP is calculated by counting data movements; Entry, Exit, Read, and Write.

Besides the approved methods mentioned above, Ç. Gencel, in her PhD study in METU Informatics Institute [30], has proposed a new functional size measurement (FSM) method based on the findings of the literature reviews and the results of the case studies, called architectural dimensions based FSM (ARCHI-DIM) [30]. Development projects, enhancement projects and also applications can be measured by this method. The purpose and the boundaries of measurement are identified and so the FURs are chosen according to the measurement type, purpose and the boundaries of the measurement. After identifying these elementary processes, base functional components (BFCs) within the FURs, data groups, data element types, constituent parts of BFCs and BFC types of the Constituent Parts of BFCs are identified and measured to construct the Archi-Dim model and calculate Archi-Dim functional size of the project.

Archi-Dim uses vectors of measures instead of counting data elements and combining these counts. Functionality is evaluated by considering four types; Interface, Control Process, Algorithmic Process and Permanent Data Access/Storage. This functionality types provides measuring components of different application domains. One of the main contribution of Archi-Dim is that the effort for each functionality specified above can be measured independently. Measuring functionality separately allows user to represent the application domain of the software as data strong, control strong, etc. [30].

In general, FP is a language independent metric; that is, FP value of a software system is computed regardless of the programming language used in that system [20]. Moreover, besides coding, FP measures documentation activities, defects found in requirements, design or analysis stages. Thus, FP is a better choice than LOC for full life-cycle analysis. As LOC metric, FP has also tool support for software cost estimating. Since FP includes measurement of interactions of the system and files, it can be considered as a good choice for software reuse analysis.

It has also been argued in the literature that, in contrast to its advantages, FP has some weaknesses as well [20]: Function point calculation is a subjective calculation method and to be precise enough, counting requires function point specialists. It is not as easy as LOC calculation and automation is not possible in most of the cases, so FP can be time-consuming and expensive. Lastly, it has been claimed [20] that FP calculation is not suitable for small projects; projects below 15 function points in size.

#### 2.5.1.3 DOCUMENTATION PAGES

Document pages metric is the measurement of all documents that actively support the development or the usage of the product. Documents may be composed of hard copies, screen shots, texts and graphics used to carry information to people. In a software development project, typically measured documents are requirements specifications, architectural and design documents, test description and test plan documents, data definitions, user manuals, reference manuals, tutorials, training guides and installation and maintenance manuals. The documents that are not preserved but require a significant amount of effort to produce should also be evaluated. Proposals, schedules, budgets, project plans and reports are the examples of this kind of documents. There are three main aspects while counting documentation [14]:

1. *Document Page Count:* Total number of nonblank pages contained in a hard copy documentation or document screens in computer file documentation can be considered as document page count. It is an integer value and partially filled pages are counted as full pages.

2. *Document Page Size:* Edge-to-edge dimensions of hard copy documents shall be measured and specified in some units. Similarly, for electronically

displayed documents, screen width and screen height shall be measured. Average number of characters per line is measured as screen width; the number of lines per screen is measured as screen height.

3. *Document Token Count:* Three kinds of token shall be counted: words, ideograms, and graphics. Contractions, such as "can't", "won't", numerical values, such as 35, 32.45, acronyms, roman numerals and abbreviations are counted as a single word. Punctuation marks are ignored. Ideograms are the symbols representing ideas such as equations. Graphs, tables, figures, charts and pictures are considered as all graphics and counted in the graphic token count.

Documentation pages metric clearly measures and illustrates the documentation effort of the software development project and also can be used to estimate the functionality size of the project by looking at requirement specifications and design specifications documents. However, this metric is still very weak in the implementation effort calculation. Values for the coding part obtained using this metric are only the estimations from documentation. Thus, documentation pages metric is generally used as an associative metric to LOC metric or FP metric. Furthermore, as agile methods, in general, emphasize "people over documentation", TDD does not generally aim to increase the amount of documentation produced in a software project.

### 2.5.2 SOFTWARE QUALITY METRICS

Software quality is the evaluation of a software system in accordance with a desired and clearly defined set of attributes. Software quality metrics are the numerical interpretation of these quality attributes. The judgment of whether the quality requirements of a project are being met can be made by the use of software quality metrics. Furthermore, utilization of numerical values in the assessment and control of software quality reduces subjectivity by making the software quality attributes more noticeable [16].

In this section, seven most commonly used quality metrics will be described.

1. Cyclomatic Complexity (CC): The application of an algorithm is evaluated with the cyclomatic complexity metric. In contrast to the usual understanding of CC, it cannot be used to measure the complexity of a class [18]. Only CC of individual methods can be considered as a complexity evaluation criteria with the combination of other measures. CC mainly measures control flow complexity within a function [24]. Consider the flow chart in Figure 3.

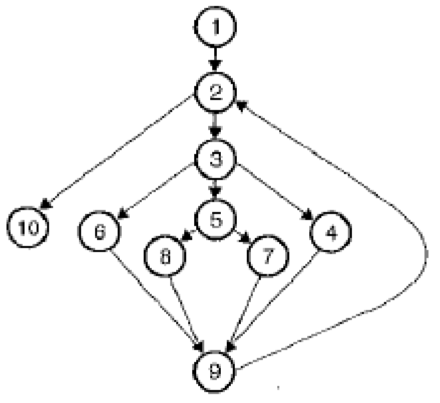


***Figure 2.3 – Flow Chart Example of a Function [24]***

Cyclomatic complexity of the given function is calculated by counting the number of enclosed regions and adding one to the result. In this example, there are four enclosed regions, so CC of the function is computed as five. This metric indicates how complicated the control flow chart is and so shows how many test cases are needed to perform functional path testing.

2. Weighted Methods per Class (WMC): WMC is a usability and reusability metric calculated simply by counting the methods implemented in a class or evaluating the sum of the complexities of all methods [18], [19]. Method

complexity can be measured by CC, as mentioned in the Cyclomatic Complexity sub-section. Both number of methods and sum of complexities are used for estimating how much time and effort is required to develop and maintain the class. Increasing WMC value of a class has a negative effect on inheriting classes and also increases the effort and time needed for testing and maintenance. Moreover, classes with high number of methods have low cohesion which limits the possibility of reuse.

3. Response for a Class (RFC): Response for a class is used for measuring complexity in terms of the amount of communication between the methods of the class with methods in the same class or other classes [19]. If the RFC value is high; that is, if the number of methods that can be invoked from a class through messages is high, debugging becomes much harder and the class turns into a less understandable one. Hence, usability and the testability of the class become more complicated.

4. Lack of Cohesion of Methods (LCOM): LCOM measures the cohesion of a class by evaluating inter-relatedness of the methods [18], [19]. There are two different ways of measuring cohesion.

- For each data field, calculate the percentage of the methods use that data field to all methods in a class. Greater percentages mean greater cohesion of data and methods in the class.
- Subtract the number of non-similar method pairs from the number of similar method pairs. The larger number of similar methods shows the more cohesiveness of the class.

Lack of cohesion increases complexity and is evidence for the necessity of dividing that class into two or more subclasses with increased cohesion.

5. Coupling between Objects (CBO): CBO is the count of the number of coupled classes to a class [19]. Smaller CBO values indicate that the class is more independent and it is easier to reuse the class in another application. Thus, CBO

values should be kept at minimum to improve modularity and provide encapsulation. Increase in the number of couples, increases the understandability of the class and also sensitivity of the class to changes. Therefore, debugging and maintenance become more difficult.

6. Depth of Inheritance Tree (DIT): The maximum length from the class node to the root of the tree is calculated as the depth of a class within the inheritance hierarchy [18]. With increasing DIT value, understandability of a class decreases and also tests become more complex because deeper trees have greater design complexity and they are composed of more methods and classes. Contrarily, the potential for reuse of inherited methods increases. In general, this metric relates to reusability, understandability and testability.

7. Number of Children (NOC): The number of children is the number of immediate subclasses inferior to another class in the hierarchy [18]. NOC metric primarily measures usability. The Greater the NOC value, the greater the reuse. On the contrary, increasing number of children, makes testing of that class more complex, thus testing time of the class increases. Hence, NOC can also be considered as an evaluation criteria for the design of the class.

In a recent study performed in METU, the effect of design patterns on object-oriented metrics and software error-pronenses was investigated [32]. Here, B. Aydınoz stated that the WMC, DIT, NOC, RFC and CBO indicates the complexities of the software classes and are important for software fault tolerance, whereas LCOM is a class cohesion metric which has a weak relation with fault-pronenses. In an empirical experiment conducted on eight medium sized school projects, the results show that these five metrics (WMC, DIT, NOC, RFC and CBO) are useful quality indicators for predicting error prone classes [34].

Since WMC shows the number of methods and the complexity of methods, increase in the WMC value makes the class hard to maintain and also hard to repair [32]. This shows that the class should be divided into two or more classes. It is also mentioned that the RFC is a good indicator for OO faults because it additionally counts the associations between objects and methods. While the higher DIT value makes the classes more error prone, the higher NOC value makes the classes less error prone [11]. This is explained by the greater attention given to the classes with high NOC during implementation [32]. Moreover, classes with high export coupling values are not more likely to be error prone [11, 32]. On the other hand high import coupling values are directly related with error proneness, so CBO metric should be considered while measuring quality in terms of error-proneness.

## 2.6 THE EFFECTS OF TDD ON SOFTWARE METRICS

The general belief about TDD is that TDD leads to an increase in developer's productivity and improves the internal quality of the software; but there are also counter ideas and studies.

Developer productivity in a software project is defined as code developed per unit time. There are a few comparison studies looking at whether TDD increases productivity or not. Two of them that have come from academia stated that Test-First development significantly increased the productivity of the developers. In one of them [10], it was observed that the Test-First team (the team using TDD) spent 57% less effort per feature than the Test-Last team. In another study [5], the conclusion was that TDD led to 21% - 28% increase in productivity.

On the contrary, the results coming from industry do not, in general, support the results from academia. In the research conducted by a group of experienced programmers [1], developer productivity was evaluated by comparing the efforts of the groups with the estimated effort provided by a group of industry experts. As compared to the estimated time, both projects took longer time, but when compared to each other there was no significant difference between them. The other study compared two case studies performed at Microsoft using TDD with the early comparable works at Microsoft using non-TDD [4]. In project A, which was carried out in Windows division, it was seen that TDD led to an increase in the order of 25-35% in development time. The development time increase in Project B, performed in MSN division, was 15%.

There are also contradicting results for internal quality measurements coming from both academia and industry.

In the industrial experiment [1], software quality was investigated by calculating the frequency of unplanned test failures. The frequency of unplanned test failures was evaluated both in developer/unit test level and customer/acceptance test level. As in developer productivity comparison mentioned above, there was no significant difference between test-first and test-last groups.

The studies performed at Microsoft [4], on the other hand, showed a significant increase in internal quality in terms of defect density. Defect databases were used to obtain an accurate measure of internal quality. Defects are measured when developed code is integrated into main build as shown in the figure 2.4. When compared with comparable projects carried out earlier, it was seen that TDD increased the quality by a factor of 2.6 in project A, and 4.2 in project B.

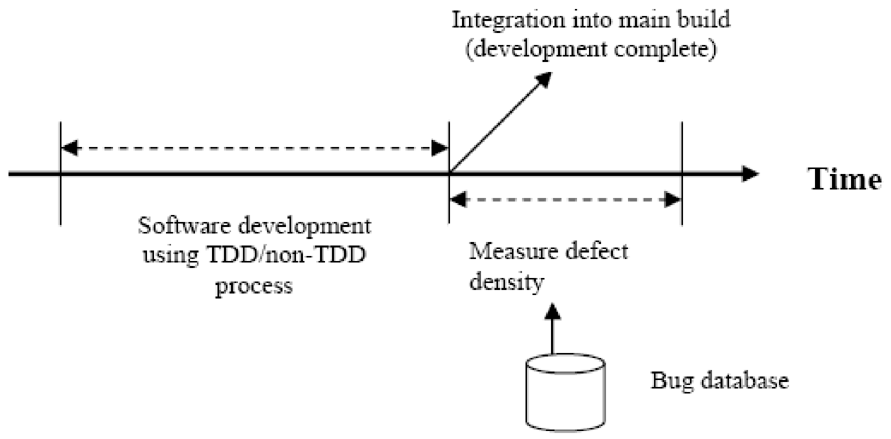

Integration into main build
(development complete)
Time
Software development using TDD/non-TDD process
Measure defect density
Bug database

***Figure 2.4 – Defect Density Measurement Process[39]***

In addition, in a case study run at IBM [39], a project developed in a traditional fashion was compared with a similar project developed using TDD in terms of defect density. An external testing group wrote and ran black-box functional verification tests after the completion of development. Results showed that 40% fewer defects were found in the TDD project. Obviously, the defects found during development (as a result of unit tests) are not considered in the defect density measurement.

Quite to the contrary, however, the results of an experiment conducted with undergraduate students in a software engineering course by D. Janzen and H.Saiedian [12] indicated that TDD has no positive significant effect on internal software quality. It was accepted in that study that measuring internal quality is somewhat subjective, so over twenty-five structural and object-oriented metrics were calculated for all software, to obtain a well-rounded evaluation. The metrics investigated included nested block depth, cyclomatic complexity, number of parameters, coupling between objects (CBO) and Information flow. According to these calculations, there were some warnings in the Test-First code shown in bold in Table 2.1.

*Table 2.1 – Internal Quality Metrics with Warnings [12]*

| | Nested Block Depth | | Cyclomatic Complexity | | Parameters | | CBO | | IF |
|---|---|---|---|---|---|---|---|---|---|
| Team | avg | max | avg | max | avg | max | avg | max | avg |
| Test-First | **2.02** | **6** | **2.33** | **13** | **0.62** | **6** | 4.58 | **20** | 2.56 |
| Test-First(no GUI) | **1.85** | **6** | **2.59** | **13** | 0.89 | 6 | 3.27 | 5 | 1.47 |
| No-Tests | **3.00** | **6** | **6.53** | **27** | 1.08 | 5 | 2.57 | 6 | 0.00 |
| Test-Last | 1.20 | 3 | 1.46 | 4 | 0.57 | 3 | 1.25 | 2 | 0.00 |

For example, CBO of GUI class in the Test-First code was 20 while maximum CBO of Test-Last code was 2. An additional evaluation performed within the scope of that experiment showed that these warnings arose from the part of code that is not covered by any automated unit tests. Overall representation of the related works is given in the Table 2.2.

*Table 2.2 – Related Works*

| | **Productivity** | **Quality** |
|---|---|---|
| **Academy1[10]** | Inc. 132% | No Difference |
| **Academy2[5]** | Inc. 21% - 28% | NA |
| **Industry[1]** | No Difference | No Difference |
| **Windows[4]** | Dec. 20% - 26% | Inc. by a factor of 2.6 |
| **MSN[4]** | Dec. 13% | Inc. by a factor of 4.2 |
| **IBM[39]** | NA | Inc. 40% |

In short, Test Driven Development is a relatively new development technique which gives rapid feedback, serves complete test bed for regression by automated tests, improves low-level design and encourages developer to decompose his work into manageable tasks. Using TDD in a software development project must be considered well before because projects including embedded systems, GUI, database and network applications may not be suitable for applying TDD.

However, the studies reviewed above show that there is not a definite answer for the questions: “Does TDD increase developer’s productivity?” and “Does TDD improve quality?”. The inconsistencies in the results from academia and industry may be due to experience level of the programmers or the projects considered. To be able to make a good judgment on these questions, more case studies on TDD must be carried out.

In the next chapter, the research carried out to assess the effects of TDD on the software productivity and software quality in the particular organization to which the author of this study belongs will be described.

# CHAPTER 3

# ASSESSMENT OF THE EFFECTS OF TDD

## 3.1 EXPERIMENTAL DESIGN

For the assessment of the effects of TDD on software development productivity and software quality, two similar software development projects were implemented in object-oriented manner by using two different development techniques; project A with Test Driven Development, project B with Test-Last development technique.

Project A is the development of a simulator program that will behave as the STRELETS unit and simulate all communication with the interfaces of this unit. STRELETS unit communicate with its interfaces using Serial Input/Output (SIO) and TCP/IP protocols. This simulator program was developed by using C# in the .NET 2003 platform.

Project B is also a simulator program that will behave as the LRF unit and simulate all communication with the interfaces of this unit. Moreover, this program was developed by using C# in the .NET 2003 platform to be able to make comparison between TDD and Test-Last development independent of the programming language and the development platform. As in STRELETS simulator in project A, LRF simulator communicate using Serial Input/Output (SIO) and TCP/IP protocols.

LOC produced per staff-hours is measured during the development processes in both projects and used for the evaluation of productivity. LOC metric is used for size measurement together with FP calculation because our aim is evaluating not only the size of code but also the interactions in the code.

Since TDD emphasizes working code over comprehensive documentation, documentation pages metric is not measured in this research. Instead of this metric, effort distribution percentage metrics for both processes are measured. These metrics show the proportion of the effort spent (in staff-hours) for documentation, testing and coding.

Defects found during implementation are also measured to assess the effects of TDD to the internal quality by means of defect density. Both defects found per unit time and defects found per KLOC are evaluated to be able to assess the rate change of defects with time and size. Moreover, some quality product metrics such as cyclomatic complexity, weighted methods per class, response for a class, lack of cohesion of methods, coupling between objects, depth of inheritance tree and number of children, are measured at the end of both projects for assessment of overall software quality. It is mentioned that the non-Object-Oriented metrics are ineffective for the assessment of OO software design because they have mathematical properties for the traditional function based software design and fail to display predictable behaviour of OO software [33]. Thus, WMC, DIT, NOC, RFC, CBO and LCOM metrics are chosen in this study because they are specifically for object-oriented systems [33] and also they are suitable and enough for the evaluation of coupling, cohesion and inheritance [18]. CC metric is used to measure the control flow complexity [24].

Besides the comparison of project A and project B, the TDD project is also compared with an early work, project C, performed at ASELSAN A.Ş. Project C is developed by using Test-Last development technique. Since project A and the early work are not similar in size, a productivity comparison would not be meaningful. Furthermore, defect density measurement for the project C is not available so these projects are compared only in terms of product quality by using the above mentioned software product quality metrics.

In short, the product metrics, Cyclomatic Complexity, Weighted Methods per Class, Response For a Class, Lack of Cohesion Of Methods, Coupling Between Objects, Depth of Inheritance and Number Of Children have been evaluated for projects A, B and C, and the process metrics, LOCs / Staff-Hours, FP / Staff-Hours, Defects Found / Staff-Hours, Defects Found / LOCs and Effort Percentage have been evaluated for projects A and B.

## 3.2 EXPERIMENT RESULTS

### 3.2.1 PROJECT A – RESULTS OF THE TDD PROJECT

STRELETS simulator program was developed by using TDD at ASELSAN A.Ş. Within the scope of this thesis, it is used for assessing the effects of TDD on software metrics. Further information about the STRELETS simulator program can be found in the Appendix G.

Automated unit tests are done with the NUnit 2.4.8 [36] program in the project. The increments in the project are planned and the workload is equally distributed between these iterations. In an iteration, first, new tests are added to the project by using NUnit framework. These tests are run and they are all failed. The necessary code is implemented till all the newly added tests are passed. After all code is implemented for that iteration, automated functional tests are added and also previously added functional tests are updated. Then all tests in the code base are run to see whether the previously implemented code is affected from the newly added code. This part is the integration of the new increment to the main build. The project was completed in eight iterations and the products obtained each iteration were given a new version number. Process metrics graphs were prepared by using these versions. Overall representation of the evaluated process metrics for each version can be found in the Appendix F.

As mentioned in the "Challenges of TDD" section automated GUI testing is a very hard process. In this project, user interface testing is done by checking GUI parameters whereas possible. When it is not possible, half-automated tests (requiring tester to declare pass/fail) are added to the GUI test steps which extend the overall test duration.

The LOCs versus staff hours graph is shown in Figure 3.1. In the second increment, the serial communication class is implemented. The methods necessary to open a serial communication make the sharp increase in this iteration. Besides second iteration, the LOC changes are very close to each other.

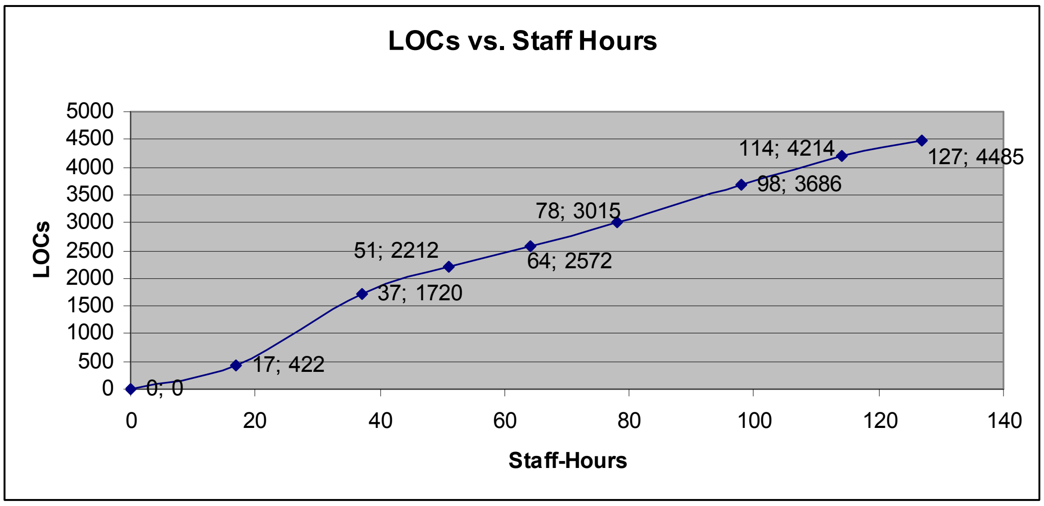


*Figure 3.1 – LOCs versus Staff-Hours for Project A*

Second process metric evaluated is the function points per staff hours. The equal distribution of workload between iterations can easily be seen in Figure 3.2. Here function points are calculated according to the IFPUG FPA and the calculation details are given in the Appendix H.

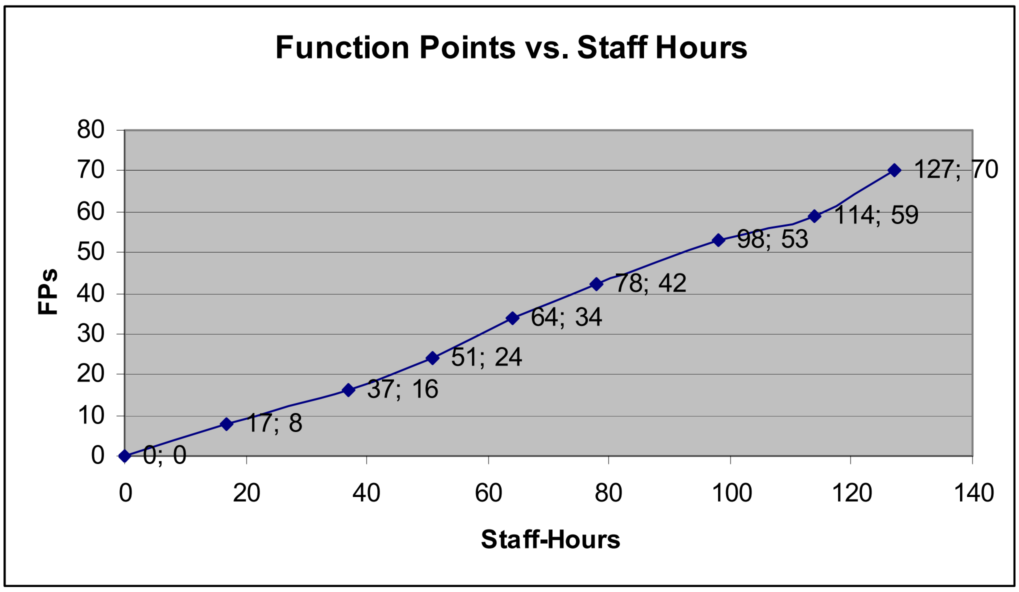


*Figure 3.2 – Function Points versus Staff-Hours for Project A*

In the project, the process quality is measured by means of defects density. As seen, defects are equally distributed all over the project.

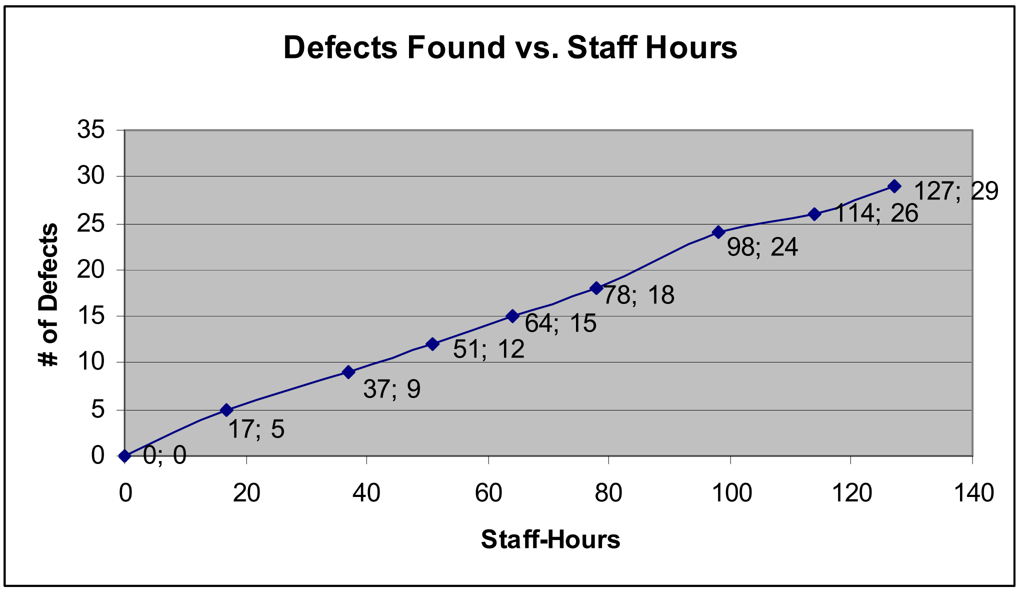


*Figure 3.3 –Defects Found versus Staff-Hours for Project A*

The slope of the defects density versus LOCs graph is higher in the first and sixth iterations. The defects in the first increment are originated from the disconnect method in the Ethernet client class. The complex algorithms in the Combat Mode class cause the increase in the sixth iteration.

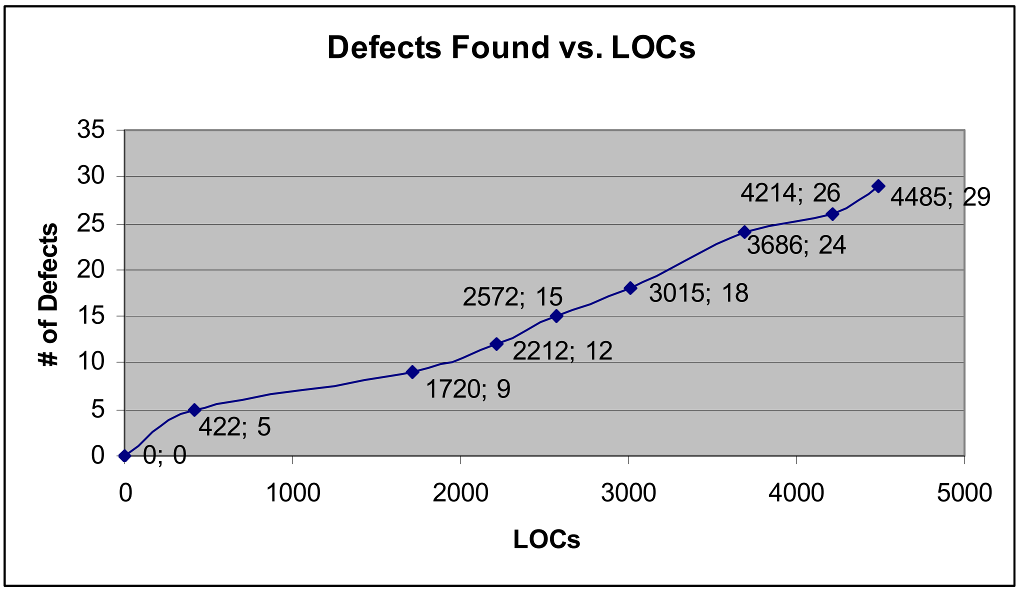


***Figure 3.4 –Defects Found versus Line of Codes for Project A***

29 total defects were found in the project A. These errors are including both defects found in automated unit tests and in automated functional tests. Separately, 12 defects were found by functional tests, where 17 defects were found by unit tests.

The effort percentage metric was measured to be able to see whether TDD decreases the time spent for documentation. The effects of TDD on testing time are also examined by this metric. In the projects, performed effort is divided into three as documentation, coding and testing. Here, documentation covers the time spent for SRS, software product specification, software version specification, test reports and also metric documentation. Instead of software description document (STD), automated unit tests are written. The effort distribution can be seen in Figure 3.5.

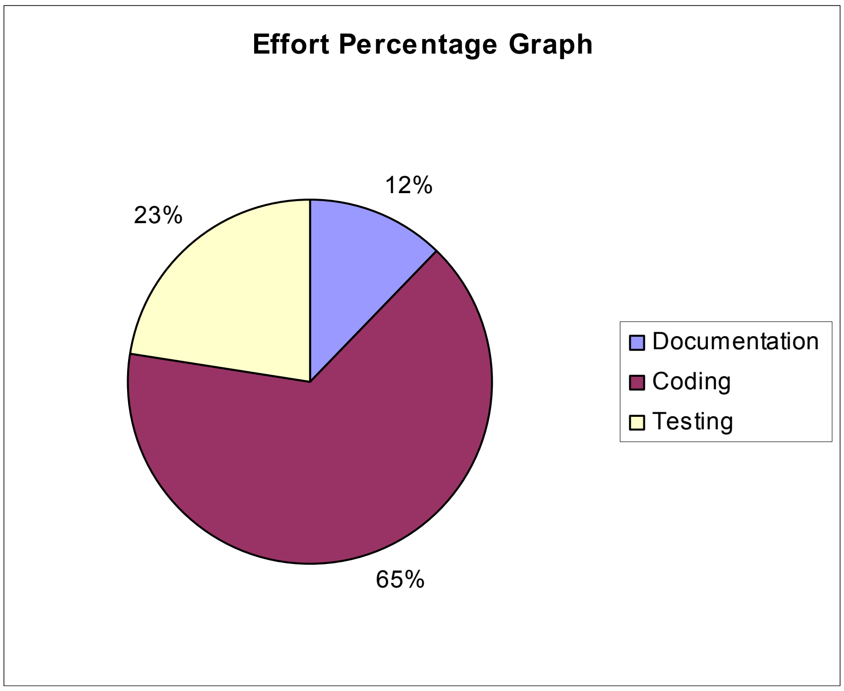


***Figure 3.5 –Effort Percentage Graph for Project A***

For the assessment of overall software product quality, cyclomatic complexity, weighted methods per class, response for a class, lack of cohesion of methods, coupling between objects, depth of inheritance tree and number of children metrics are evaluated at the end of the project. WMC, RFC, CBO, DIT and CC metrics are measured by using vil-Console 1.1 program [38]; LCOM metric is measured by using Visual NDepend 2.8.1 [37]. The obtained LCOM metric value is 1 – the first type mentioned in the 2.5.2 section. Therefore, when the percentage is great, the evaluated value approaches to 0. A high LCOM value indicates poorly cohesive class. The metrics evaluated with both programs are consistent with each other (WMC, DIT). All metrics are given in the table 3.1.

***Table 3.1 – Overall Quality Metrics of Project A***

| Class Name | Weighted Methods per Class | Response for Class | Lack of Cohesion of Methods | Coupling Between Objects | Depth in Tree |
|---|---|---|---|---|---|
| CombatMode | 56 | 16 | 0.72 | 3 | 1 |
| Communication | 22 | 29 | 0.76 | 4 | 1 |
| DataStorage | 19 | 24 | 0.57 | 0 | 1 |
| EthernetClient | 22 | 29 | 0.83 | 1 | 2 |
| MainGUI | 47 | 84 | 0.93 | 2 | 7 |
| Management | 9 | 26 | 0.54 | 7 | 1 |
| MessageOperations | 9 | 11 | NA | 0 | 1 |
| Missile | 7 | 5 | 0 | 1 | 1 |
| Seeker Head | 3 | 4 | 0.33 | 0 | 1 |
| SerialChannel | 85 | 62 | 0.79 | 9 | 1 |
| StandByMode | 25 | 12 | 0.53 | 2 | 1 |
| ULM | 7 | 9 | 0.47 | 1 | 1 |
| AVERAGE | 25.92 | 28.27 | 0.59 | 2.73 | 1.73 |

Besides the given metrics in the table, NOC metric is measured at the end of the project but NOC metric value for each class is 0. Thus, its value is not mentioned in the above table. Method based evaluation is done for the CC metric and the average of all methods has been calculated as 3,2. The maximum and minimum values are also evaluated for each metric and displayed in Table 3.2.

***Table 3.2 – Minimum and Maximum Values for the Product Metrics Evaluated for Project A***

| | WMC | RFC | LCOM | CBO | DIT | CC |
|---|---|---|---|---|---|---|
| **Minimum** | 3 | 4 | 0 | 0 | 1 | 1 |
| **Maximum** | 85 | 84 | 0,93 | 9 | 7 | 33 |

### 3.2.2 PROJECT B – RESULTS OF THE TEST-LAST PROJECT

LRF simulator program was developed at ASELSAN A.Ş. and used as a control project while assessing the effects of TDD on software metrics. Further information about the LRF simulator program can be found in the Appendix D.

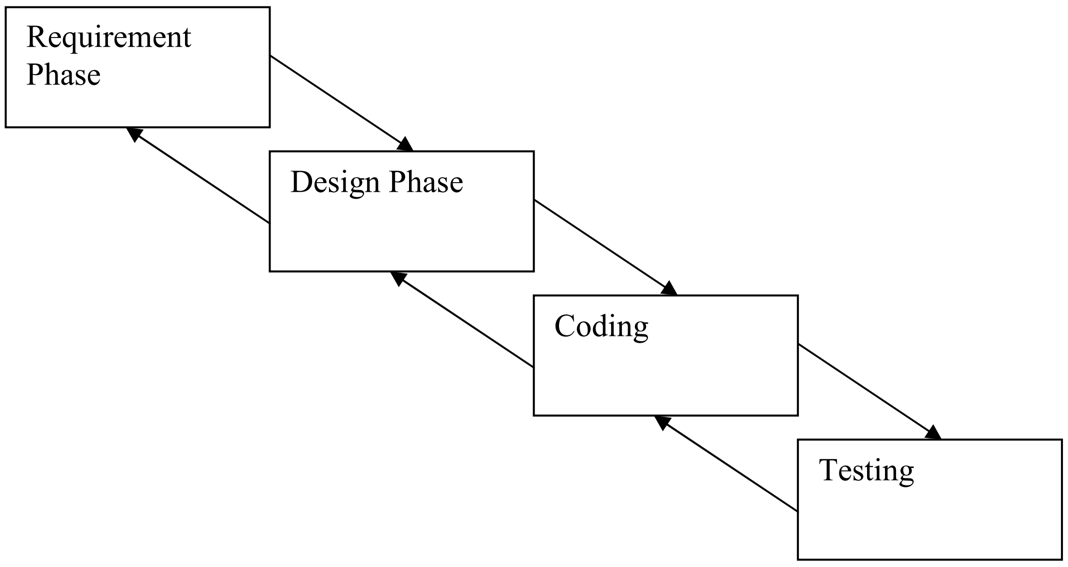


***Figure 3.6 –Waterfall Model***

A waterfall like development process was used during this development. The process is same as the waterfall method (shown in figure) till the coding and testing part. The implementation and testing of LRF simulator is done incrementally. The project was completed in six iterations and the products obtained each iteration was given a new version number. Process metrics were evaluated by using these versions.  Overall representation of the evaluated process metrics for each version can be found in the Appendix C.

The unit test process in this project was not automated and disciplined. Unit tests are done during development by the developer before formal and regression tests

(tests that are held after each iteration). Small applications implemented or debug prints were used for testing the methods and classes.

The iterations in the project were not planned so the work load was not separated equally between them. In the first and the second iterations, the communication base and the main GUI elements are implemented. Formal tests that are done with a STD document were not held after these iterations; the defects were found by the manual testing of the developer. The main functionality of the project was implemented in the third and the fifth iterations and the tests were done with the participation of customer after these steps. In the fourth and the sixth iterations, the errors found in their previous increments, were corrected. Some missing new functionality was also added in these iterations. Regression tests for the newly added parts and the corrected parts were performed after these iterations.

The first process metric evaluated for this project is line of codes per staff hours. The sharp increase in the first iteration results from the windows generated code and the generic functions of the communication classes. As mentioned above, fourth and sixth iterations cover mainly error correction; that is, little functionality was added in these iterations so the count of LOCs is slightly changes when compared with the other iterations.

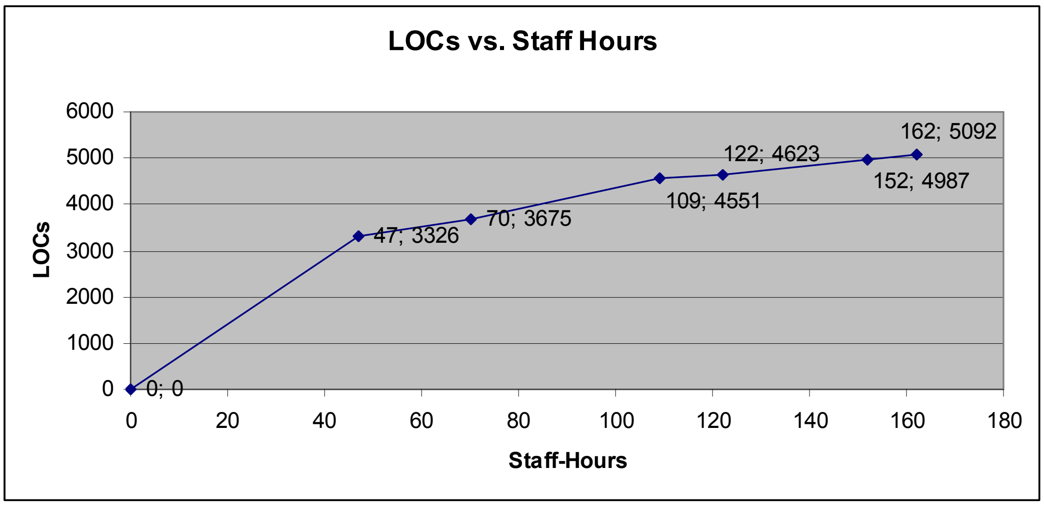


*Figure 3.7 – LOCs versus Staff-Hours for Project B*

The change in the size of the project including the functionality and interactions can be observed from the FP vs Staff-Hours graph. Function points are calculated according to the IFPUG FPA and the calculation details are given in the Appendix E.

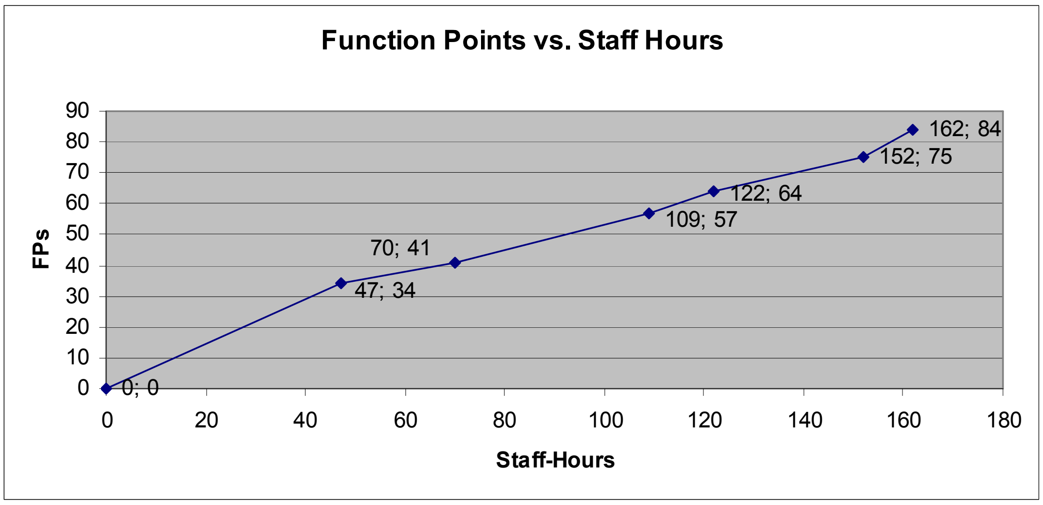


***Figure 3.8 – Function Points versus Staff-Hours for Project B***

As in the project A, the process quality is measured by means of defects density. The change rate of defect density per LOCs and Staff-Hours were both observed during the development process.

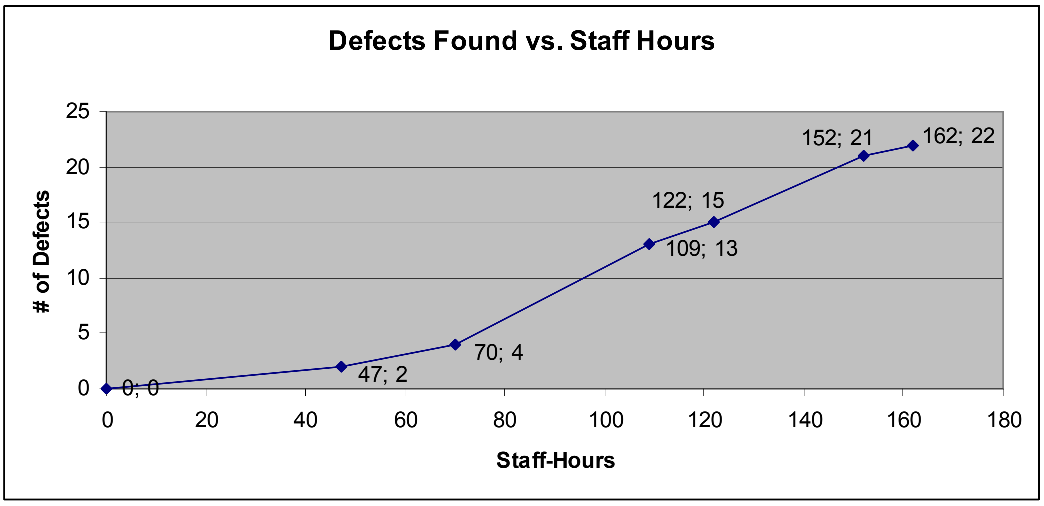


*Figure 3.9 – Defects Found versus Staff-Hours for Project B*

In a traditional waterfall process, since the testing phase is held at last, defects are expected to be found in the last phases of the implementation. In this project, because of the iterative coding and testing, defects were started to be found from the beginning but density is higher at last stages.

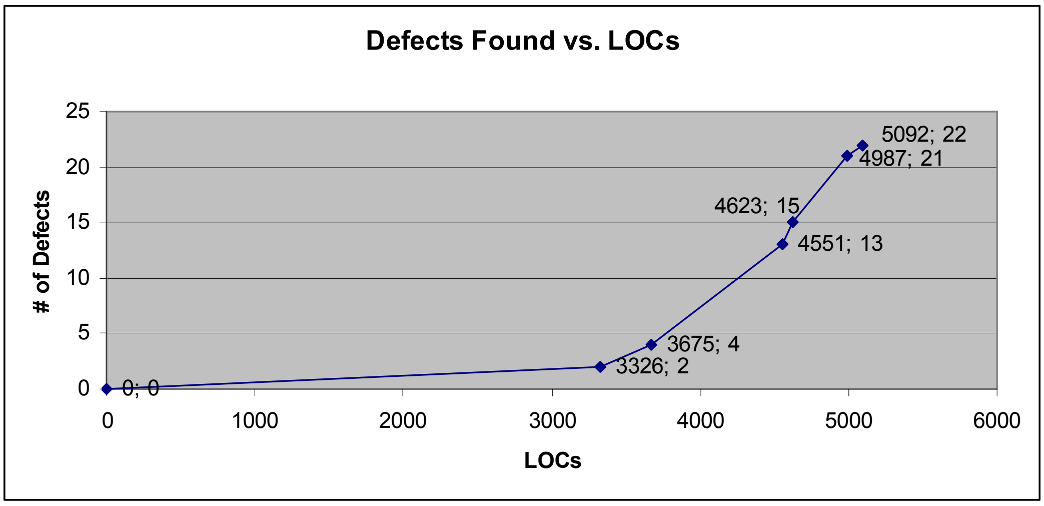


*Figure 3.10 – Defects Found versus LOCs for Project B*

In the test last project, in contrast to the TDD project, majority of the defects were found by the formal tests. 5 defects were discovered by the unit tests during development; 4 defects by regression tests and 13 defects by formal tests.

As in the project A, performed effort is divided into three as documentation, coding and testing. Here, documentation covers the time spent for SRS, STD, software product specification, software version specification, test reports and also metric documentation. Since this is a relatively small project in size, no other documentation (project plan, test plan, design document…) was prepared for this. The main difference with the TDD project in the documentation calculation is the STD. Unlike TDD, Software Test Description document is prepared in test last development.  The effort distribution can be seen Figure 3.11.

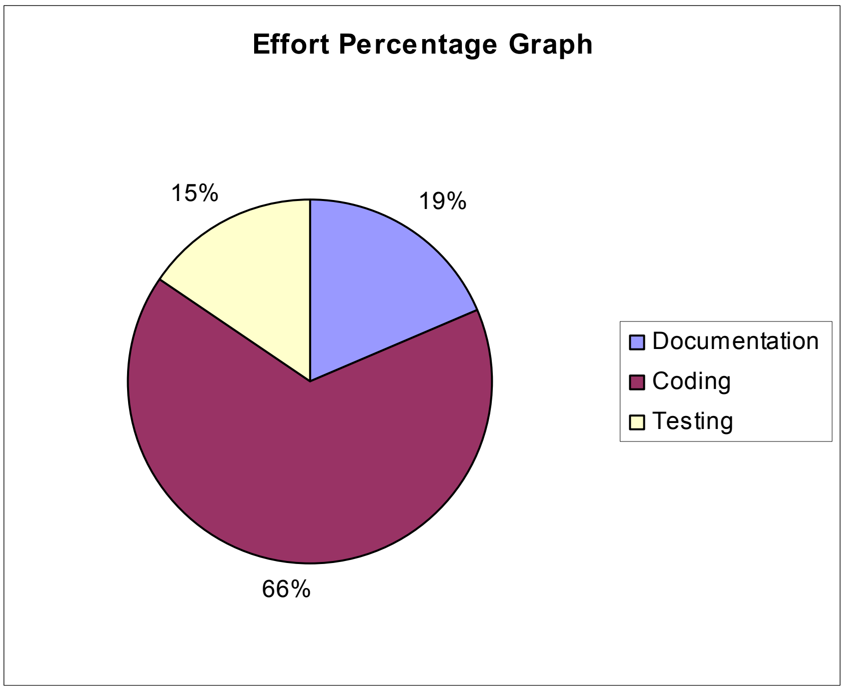


***Figure 3.11 – Effort Percentage Graph for Project B***

For the assessment of overall software product quality, cyclomatic complexity, weighted methods per class, response for a class, lack of cohesion of methods, coupling between objects, depth of inheritance tree and number of children metrics are evaluated at the end of the project. WMC, RFC, CBO, DIT, NOC and CC metrics are measured by using vil-Console 1.1 program; LCOM metric is measured by using Visual NDepend 2.8.1. The obtained LCOM metric value is the first type mentioned in the 2.5.2 section. The metrics evaluated with both programs are consistent with each other (WMC, DIT, NOC). All metrics are given in the Table 3.3.

***Table 3.3 – Overall Quality Metrics of Project B***

| **Name** | **Weighted Methods per Class** | **Response for Class** | **Lack of Cohesion of Methods** | **Coupling Between Objects** | **Depth in Tree** |
|---|---|---|---|---|---|
| Communication Management | 21 | 31 | 0,75 | 4 | 1 |
| DataStorage | 30 | 39 | 0,67 | 0 | 1 |
| EthernetClient | 30 | 40 | 0,87 | 1 | 2 |
| InitializationMode | 15 | 12 | 0,67 | 1 | 1 |
| MainForm | 39 | 94 | 0,90 | 2 | 7 |
| MessageOperations | 13 | 14 | NA | 1 | 1 |
| PulseRateError | 8 | 10 | 0,33 | 1 | 1 |
| SeriKanal | 134 | 94 | 0,89 | 11 | 1 |
| ServiceMode | 14 | 10 | 0,52 | 2 | 1 |
| SystemManagement | 42 | 45 | 0,55 | 9 | 1 |
| TransferMode | 56 | 21 | 0,73 | 1 | 1 |
| AVERAGE | 36,55 | 37,27 | 0,69 | 3 | 1,64 |

As in the project A, NOC metric for each class is measured as 0 and so this metric results are not given in the table. The average of the CC metric evaluated for all methods is 3,14. The maximum and minimum values of the quality product metrics for project B are shown in the table 3.4.

***Table 3.4 – Minimum and Maximum Values for the Product Metrics Evaluated for Project B***

| | **WMC** | **RFC** | **LCOM** | **CBO** | **DIT** | **CC** |
|---|---|---|---|---|---|---|
| **Minimum** | 8 | 10 | 0,33 | 0 | 1 | 1 |
| **Maximum** | 134 | 94 | 0,90 | 11 | 7 | 31 |

### 3.2.3 PROJECT C – EARLY WORK

Project C, namely SKN software, is developed using C# in Microsoft Visual Studio .NET platform and working compatible with Microsoft Windows XP. The project includes GUI classes and developed using waterfall development process. Since SKN is a GUI application like the project A and also it is similar to TDD project in terms of operating system and software language, a Test last – TDD comparison between project A and C is performed within the scope of this thesis. The final product of the project C is evaluated with object-oriented software quality product metrics by using a free tool Visual NDepend 2.8.1.

SKN software is developed consistent with 249 software requirements. The project is composed of 48 KLOCs so comparison of productivity becomes meaningless. Besides GUI classes, SKN has two communication interfaces via serial channel and also SKN projects includes database applications. SKN software is composed of 80 classes and 46 of these classes are form classes. The product metrics of all form classes are evaluated separately but Table 3.5, only their averages are displayed.

*Table 3.5 – Overall Quality Metrics of Project C*

| | WMC | RFC | LCOM | CBO | DIT |
|---|---|---|---|---|---|
| FormAverage | 38.45 | 22.65 | 0.82 | 3.25 | 7 |
| Icorthread | 11 | 17 | 0.84 | 2 | 1 |
| PingStatus | 90 | 71 | 0.87 | 3 | 3 |
| SCevreBirimleriYonetici | 71 | 38 | 0.79 | 6 | 1 |
| SEMesajFiltreAyarlari | 2 | 3 | 0.65 | 1 | 1 |
| SEMesajKaydi | 4 | 5 | 0.85 | 1 | 1 |
| SGDPKontrol | 56 | 43 | 0.83 | 3 | 1 |
| SHataYonetici | 3 | 3 | 0.44 | 3 | 1 |
| SKonsolCalismaBilgileri | 1 | 1 | 0.80 | 3 | 1 |
| SKullaniciYonetici | 77 | 52 | 0.83 | 4 | 1 |
| SOturumYonetici | 52 | 48 | 0.87 | 7 | 1 |
| SServisSaglayici | 93 | 72 | 0.68 | 10 | 1 |
| SSistemAyarlariYonetici | 142 | 101 | 0.97 | 5 | 1 |
| SSistemSaatTarih | 3 | 5 | 0.76 | 1 | 1 |
| SSKNAnaSinif | 46 | 32 | 0.81 | 22 | 1 |
| SSKNIletisimYeni | 82 | 68 | 0.87 | 9 | 1 |
| STekrarOynatmaYonetici | 35 | 22 | 0.85 | 2 | 1 |
| SUzakHaberlesme | 36 | 21 | 0.93 | 2 | 2 |
| SToolTipAyarlayici | 7 | 8 | 0.65 | 1 | 1 |
| SVDAktifPlan | 28 | 22 | 0.86 | 1 | 1 |
| SVDKullaniciBilgisi | 26 | 15 | 0.87 | 1 | 1 |
| SVeriIndirgemeYonetici | 29 | 18 | 0.86 | 3 | 1 |
| SVeriTabaniYonetici | 33 | 32 | 0.79 | 5 | 1 |
| SVeriYonetici | 143 | 97 | 0.95 | 3 | 1 |
| SVIKaydiDosyaBilgisi | 3 | 2 | 0.64 | 1 | 1 |
| SVTBakim | 16 | 18 | 0.77 | 1 | 1 |
| SVTYedegiDosyaBilgisi | 3 | 2 | 0.66 | 1 | 1 |
| Swin32KlavyeFiltresi | 9 | 12 | 0.66 | 2 | 1 |
| Swin32WindowsMesajFiltresi | 10 | 5 | 0.25 | 0 | 1 |
| SWinKapat | 28 | 26 | 0.78 | 3 | 1 |
| UyariciToolTip | 4 | 7 | 0.60 | 0 | 1 |
| Average | 38.3 | 25.39 | 0.80 | 3.36 | 4.4 |

Here, WMC, RFC, LCOM, CBO and DIT metrics are evaluated with NDepend tool. The classes included in the project have no children at all so NOC metric is not given in the above table. Method based evaluation is done for the CC metric and the average of all methods is 4,18. Moreover the maximum and minimum values for each metric is measured and displayed in Table 3.6.

***Table 3.6 – Minimum and Maximum Values for the Product Metrics Evaluated for Project C***

| | WMC | RFC | LCOM | CBO | DIT | CC |
|---|---|---|---|---|---|---|
| **Minimum** | 1 | 1 | 0.25 | 1 | 1 | 1 |
| **Maximum** | 326 | 172 | 0.97 | 22 | 7 | 34 |

# CHAPTER 4

# DISCUSSION AND CONCLUSION

## 4.1 RESULTS COMPARISON AND DISCUSSION

First comparison will be made on productivity metrics, i.e. line of codes developed versus staff hours and function points versus staff hours.

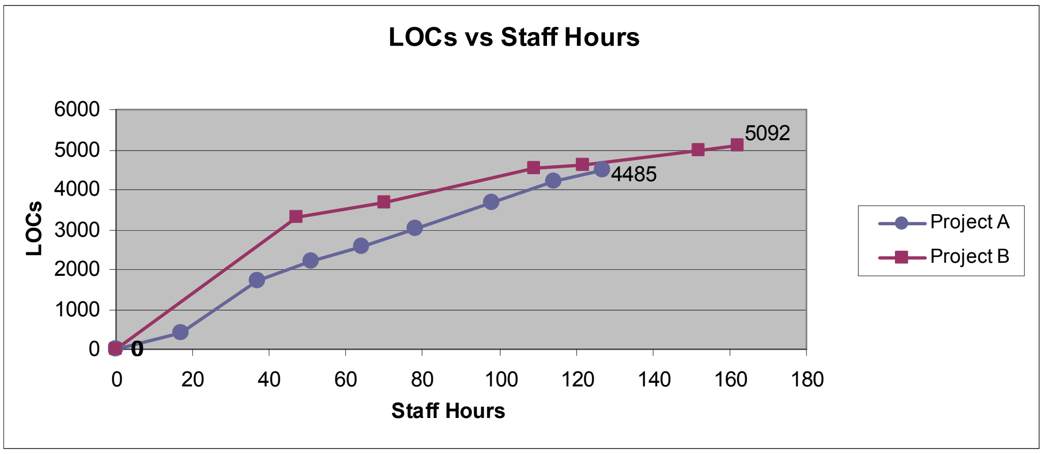


*Figure 4.1 – LOCs versus Staff-Hours for Projects A and B*

When we look at the figure 4.1, we can see that the lines of code produced per staff hour for TDD project is calculated as 35,31 LOCs, where this number is 31,43 for the Test-Last project. Overall, TDD has lead to an increase of 12% in lines of code produced per staff hours. As seen from the figure 4.1, the decrease in the slope of project B causes this difference; that is, in the later stages of Test-Last project the productivity in terms of line of code decreases. It should be noted, however, that to make a good judgment on productivity of the projects, the functionality of the code and interactions in the code must be taken into account.

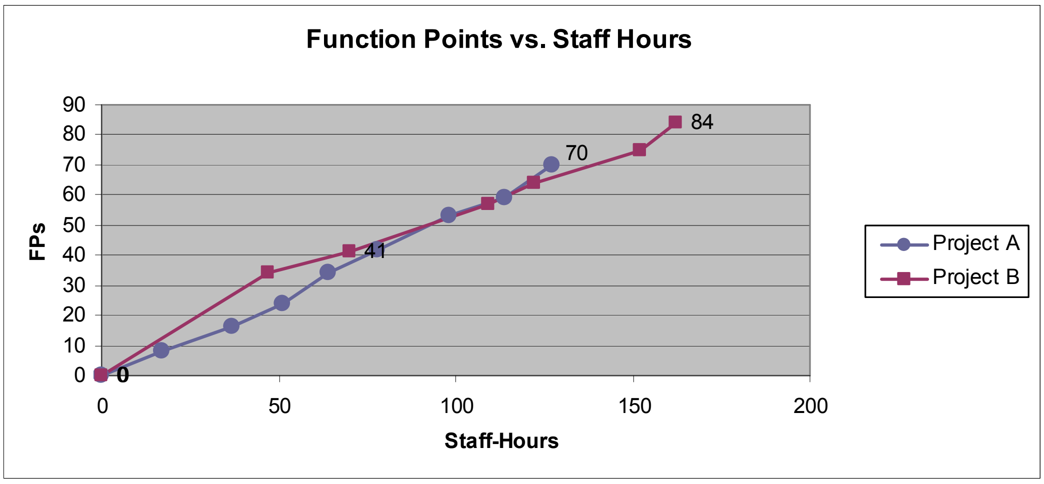


***Figure 4.2 – Function Points versus Staff-Hours for Projects A and B***

Figure 4.2 gives the function points accumulation in the projects A and B in time. The sharp increase in the last stages of project B shows that the complex part of the code is implemented in these stages. Developing the challenging parts in a short time in last iterations seems to be increasing the productivity but it also affects the quality of the code which will be discussed later.

When the overall process is considered, the time needed to implement 1 FP code for project A is evaluated 1,81 staff hours, where 1,93 staff hours for project B. Here, the difference is smaller than the difference in LOCs vs. Staff-Hours metric measurement. When these two metrics are taken into account, it can be concluded that TDD has no significant effect on productivity in this study. The main reason for this may be the inexperience of the developer in test driven development. Since writing tests before implementation and designing the code using these tests can be time consuming, an experienced developer can get better results by using TDD.

Second comparison will be made on software quality in terms of defect density.

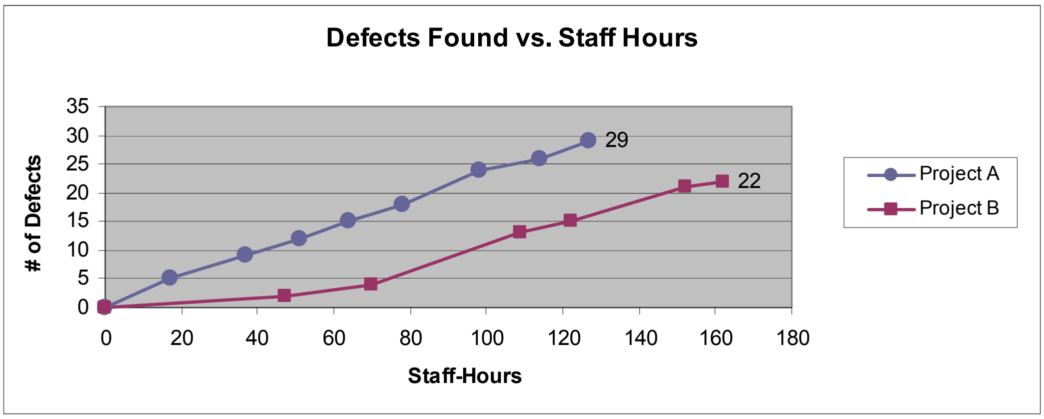


*Figure 4.3 – Defects Found versus Staff-Hours for Projects A and B*

Figure 4.3 shows the change of the number of defects found in time. Because of the periodically testing throughout the day, in TDD project, defects found rate is nearly constant all over the process. Moreover; although project B is greater in size in terms of both LOCs and FPs, more defects were found in the project A. The defects found rate for the first project is 1 defect / 4,38 hours. In the test last development approximately 7,36 hours needed to find a defect. That is, in this experiment, 1.68 times more defects have been found per unit time with TDD in comparison to the test last approach.

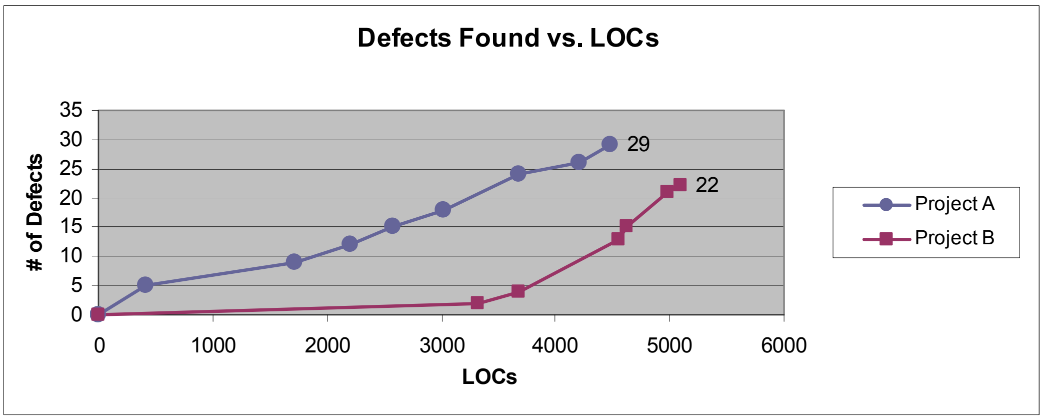


*Figure 4.4 – Defects Found versus LOCs for Projects A and B*

The total number of defects found change with the size of the code is displayed in the figure 4.4. This figure clearly shows that the errors are started to be found after half of the implementation is completed in project B. Thus, changes made to correct these errors affect the design and quality of the project more than the TDD project.

As shown in the figure 4.4, more defects were found in TDD project; although its size is smaller than the project B. However, for the meaningful assessment of defect density, the defects found during integration, formal and regression tests must be taken into account. The defects found by the unit tests were part of the development, so they are not included in the defect density measurement as in the early works at Microsoft and IBM [4, 39]. Thus, 12 defects were found by the functional tests in the project A; where 17 defects were located by formal and regression tests in the project B. When the size of the codes are considered, defect density evaluated for project A is 1 defect per 374 LOCs; for project B is 1 defect per 300 LOCs. This measurement shows that within the context of this experiment, the TDD has increased the quality by 25% percent in terms of defect density.

Moreover, two defects that were found in TDD project also exist in the Test-Last project, but can not be discovered. In the project B, only sample inputs are tested. Since every possible input can be tested by automated unit tests in TDD, these unexpected defects were found.

When the effort percentage graphs of both project A and B are examined, it is noticed that the coding percentage in the projects are nearly same (Table 4.1).

***Table 4.1 – Effort Percentages of Projects A and B***

| | **Documentation** | **Testing** | **Coding** |
|---|---|---|---|
| **Project A** | 12% | 23% | 65% |
| **Project B** | 19% | 15% | 66% |

The time spent for testing increases, while documentation time decreases, in the TDD project. The main reason for the increase in testing time is obviously the time spent for writing automated unit tests. Automated tests are written instead of Software Test Description document; so documentation time decreases.

One more reason for the increase in testing time is the testing of GUI classes. Some of the GUI tests can be done automated by checking the parameters of the user interface class. However, there are requirements that require visual testing. In these cases, user control is needed while running tests. Thus, execution of automated tests for each periodic test run increases. To reduce the effects of GUI testing, these test steps are implemented at the last stages of the project.

In addition, testing of communication interfaces also slightly increases the testing time. Since testing of serial channel and Ethernet communication requires hardware, application must be waited till the data transfer is completed. For example, in a serial channel message receive test, the program must be suspended after message is sent from the other channel. Both projects require communication interfaces, but because of the multiple tests run in each iteration, TDD project is much more affected than the Test-Last project.

As mentioned in the "Quality Metrics" section, coupling, complexity, cohesion and communication between classes are the quality aspects that provides understandability, testability and reusability to the classes. The object oriented metrics evaluated for all three projects, to assess these features, are given in Table 4.2.

***Table 4.2 – Overall Quality Metrics of Projects A, B and C***

| | WMC (Max) | RFC (Max) | LCOM (Max) | CBO (Max) | DIT (Max) | CC (Max) |
|---|---|---|---|---|---|---|
| Project A | 25,92 (85) | 28,27 (84) | 0,59 (0,93) | 2,73 (9) | 1,73 (7) | 3,2 (33) |
| Project B | 36,55 (134) | 37,27 (94) | 0,69 (0,9) | 3 (11) | 1,64 (7) | 3,14 (31) |
| Project C | 38,3 (326) | 25,39 (172) | 0,8 (0,97) | 3,36 (22) | 4,4 (7) | 4,18 (34) |

Weighted methods per class metric is lower in TDD project than the other projects. This makes projects B and C hard to test, less understandable and less reusable. FormSKNAna class in project C has a very high WMC value and also RFC and LCOM values which show that the class is not understandable and must be divided. Moreover, when project A and B's metrics are examined, it is observed that the maximum WMC valued classes are the classes with similar responsibilities. Both of the classes were implemented to provide serial channel connection and message transfer using serial channel. In TDD project, the irrelevant parts, which were not noticed during test last development, were not implemented. As a result, the code size decreases and the quality increases in TDD; but functionality is still the same.

RFC metric measures the communication density between the methods of the classes. As in the WMC metric result, RFC value of project A is lower than the test last project; but, a little higher than the early work average. This makes testing and debugging harder for project B.

For LCOM metric, the values greater than 0,8 point lack of cohesion [37]. Although MainGUI class of project A has a LCOM value of 0,93, TDD project's classes are more cohesive than the others. In project B, poorly cohesive classes are GUI class and communication classes. The connection of communication classes with lower layers may lead to increase in cohesion, but the similar classes in project A have lower LCOM values. Exclusion of irrelevant parts from the code increases cohesiveness of the classes. In project C, half of the classes are not cohesive enough and need to be splited to increase cohesion.

There is no significant difference between CBO values of the projects. TDD project has low coupling than the others on the average.

Larger DIT values make classes less understandable; on the contrary larger DIT values indicate potential for reuse of inherited methods. When DIT values of project A and B are examined, no effect of TDD on depth of inheritance can be seen. DIT value in project is great because 46 of 80 classes included in project C are form classes which has a DIT value of 7.

Control flow complexity is evaluated with cyclomatic complexity metric. Average CC of methods of projects A and B are nearly same. Project C has a greater average complexity which can be caused from the larger size of the project.

## 4.2 CONCLUSION

In this study, a software project was developed using test driven development technique and compared in terms of software productivity and software quality with two software projects developed using the traditional Test-Last technique. Both process and the final product comparisons are made by measuring relevant software metrics. Furthermore, throughout the development process, benefits and challenges of TDD are also examined.

There were contradicting results in the literature about the effects of TDD to developers' productivity. In our study, productivity is measured by calculating the change of size with the time. Obtained results given in the previous section show that, in the context of the experiment performed, the effect of TDD on productivity was insignificant. It should, however, be mentioned that the unfamiliarity of the developer with TDD may have caused this outcome.

Quality assessment of the projects is achieved by measuring seven product quality metrics and also by examining the change of the total number of defects found with both size and time. The defects found during unit tests are considered as the part of development so they are excluded in defect density calculation. By observing the results, it can be concluded that the quality is improved in TDD project in terms of class complexity and defect density. It is observed that more cohesive and less complex classes are obtained by using TDD technique. Since defects are found at the later stages of the project, the architecture of the code is much more corrupted in the Test-Last approach. In fact, the higher defect density values measured in the Test-Last project may, in turn, be a result of complexity and lack of cohesive classes.

On the other hand, again, in the context of this experiment, the test driven technique has had a little positive effect on coupling. The developed projects consist of few classes and so, small coupling values are observed. Coupling comparison in larger projects may give more meaningful results. Similarly, effect of TDD on inheritance could not be observed in this study. There was no need for inheritance usage in the developed projects and depth of inheritance values are constituted by the form classes.

As mentioned in Chapter 2, there seems to be a consensus in the literature on the fact that using test driven development in projects involving network communication and GUI has some challenges. Both challenges lead to an increase in testing time. The results of this increase were not serious in this study; mainly high testing duration was caused by the automated unit tests. However, network testing and GUI testing may lead to devastating delays in projects including more complicated networks and too many GUI classes.

Further work in this area may consist of studies on projects in different domains, and projects with a wide range of sizes. A limitation of the current experiment was that only three projects were compared. If the aim of establishing a definitive assessment of TDD on productivity and product quality is adopted, much more extensive studies in terms of software types, including a diversity of domains, software sizes and also organization sizes and characteristics such as development maturity, as assessed by techniques such as CMMI, must be considered.

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# APPENDIX A

# SOFTWARE METRICS

*Table A.1 – Software Product Metrics [18]*

| | METRIC | STRUCTURE |
|---|---|---|
| ACM | attribute complexity metric | Class |
| CBO | coupling between object classes | Coupling |
| CC | McCabe's cyclomatic complexity | Method |
| CC | class complexity | Coupling |
| CC2 | progeny count | Class |
| CC3 | parent count | Class |
| CCM | class coupling metric | Coupling |
| CCO | class cohesion | Class |
| CCP | class coupling | Coupling |
| CM | cohesion metric | Class |
| DAC | data abstraction coupling | Class |
| DIT | depth of inheritance tree | Inheritance |
| FAN | fan-in | Class |
| FFU | friend function | Class |
| FOC | function- oriented code | Class |
| GUS | global usage | Class |
| HNL | hierarchy nesting level | Inheritance |
| IVU | instance variable usage | Class |
| LCOM | lack of cohesion of methods | Class |
| LOC | lines of code | Method |
| MCX | method complexity | Method |
| MPC | message passing coupling | Coupling |
| MUI | multiple inheritance | Inheritance |
| NCM | number of class methods | Class |
| NCV | number of class variables | Class |
| NIM | number of instance methods | Class |
| NIV | number of instance variables | Class |
| NMA | number of methods added | Inheritance |
| NMI | number of methods inherited | Inheritance |
| NMO | number of methods overridden | Inheritance |
| NOC | number of children | Inheritance |
| NOM | number of message sends | Method |
| NOM | number of local methods | Class |

| | METRIC | STRUCTURE |
|---|---|---|
| NOT | number of tramps | Coupling |
| OACM | operation argument complexity metric | Class |
| OCM | operation coupling metric | Coupling |
| OXM | operation complexity metric | Class |
| PIM | number of public instance methods | Class |
| PPM | parameters per methods | Class |
| RFC | raw function counts | Class |
| RFC | response for a class | Class |
| SIX | specialization index | Inheritance |
| SIZE1 | language dependent delimiter | Method |
| SIZE2 | number of attributes + number of local methods | Class |
| SSM | Halstead software science metrics | Method |
| VOD | violations of the Law of Demeter | Coupling |
| WAC | weighted attributes per class | Class |
| WMC | weighted methods per class | Class |

*Table A.2 – Software Process Metrics [26]*

| **Metric** | **Equation** |
|---|---|
| Schedule Variance | (Actual duration- Planned duration) /Planned duration |
| Effort Variance | (Actual effort - Planned effort)/Planned effort |
| Size Variance | (Planned size - Actual size)/Planned size |
| Requirement stability Index | Number of requirements changed, added or deleted / Total no. of requirements |
| Defect density | Total Number of defects detected / size |
| Residual defect density | Number of defects found after system testing / Size in KLOC |
| Productivity | LOC per person-day (Software size / Total effort) |
| **Effort distribution (%)** | |
| SRS | Effort for SRS/Total project effort |
| Design | Effort for Design/Total project effort |
| Code | Effort for Code/Total project effort Code |
| Testing | Effort for Testing/Total project effort |
| PM | Effort for Project Management SRS/Total project effort |
| QA | Effort for Quality Assurance/ Total project effort |
| Training | Effort for Training/ Total project effort |
| CM | Effort for Configuration Management/Total project effort |
| Support | Effort for Support/ Total project effort |
| Others | Effort for any other project activities/ Total project effort |
| **Defect distribution (%)** | |
| Analysis | No. of Requirements category defects / Total No. of defects |
| Design | No. of Design category defects / Total No. of defects |
| Code | No. of Code category defects / Total No. of defects |
| Document | No. of Doc category defects / Total No. of defects |
| Others | No. of Others category defects / Total No. of defects |
| **Process efficiency (%)** | |
| SRS review efficiency | No. of Requirements category defects detected by SRS review/ Total No. of Requirements category defects |
| Design review efficiency | No. of Design category defects detected by design review/Total No. of Design category defects |
| Efficiency of Code review and Unit test | No. of Code category defects detected by code review and Unit test/Total no. of Code category defects |
| Test efficiency | No. of bugs found up to and including system testing/No. of bugs found during and after testing |
| Defect Removal Efficiency | No. of defects found until and including system testing/total no. of defects |

# APPENDIX B

## SOFTWARE SIZE MEASUREMENT METHODS [30]

*Table B – Software Size Measurement Methods [30]*

| Year | Method | ISO Certification | Developer |
|---|---|---|---|
| 1979 | Albrecht / IFPUG FPA | √ | Albrecht, IBM (Albrecht et al. 1983; IFPUG, 1999) |
| 1982 | DeMarco's Bang Metrics | | DeMarco (DeMarco, 1982) |
| 1986 | Feature Points | | Jones, SPR (Jones, 1987) |
| 1988 | Mark II FPA | √ | Symons (Symons, 1988; UKSMA, 1998) |
| 1990 | NESMA FPA | √ | The Netherlands Software Metrics Users Association (NESMA, 1997) |
| 1990 | ASSET - R | | Reifer (Reifer, 1990) |
| 1992 | 3 - D Function Points | | Boeing (Whitmire, 1992) |
| 1994 | Object Points | | Bankeri Kauffman, and Kumar (Banker et al., 1994; Kauffman and Kumar, 1997) |
| 1994 | FP by Matson, Barret and Mellichamp | | Matson, Barret and Mellichamp (Matson et al., 1994) |
| 1997 | Full Function Points | | Unicersity of Quebec in coop. with the Software Eng. Laboratory in Applied Metrics (Abran et al., 1998) |
| 1997 | Early FPA | | Meli (Meli, 1997a; 1997b; Conte et al., 2004) |
| 1998 | Object Oriented Function Points | | Caldiera, Antoniol, Fiutem, and Lokan (Caldiera et al., 1998) |
| 1999 | Predictive Object Points | | Teologlou (Teologlou, 1999) |
| 1999 | COSMIC Full FP | √ | COSMIC (Abran, 1999) |
| 2000 | Early & Quick COSMIC FFP | | Meli, Abran, Ho, Oligny (Meli et al., 2000; Conte et al., 2004) |
| 2001 | Object Oriented Method FP | | Pastor and his colleagues (Pastor and Abrahao, 2001) |
| 2000 | Kammelar's Component Object Points. | | Kammelar (Kammelar, 2000) |
| 2004 | FİSMA FSM | | The Finish Software Metrics Association (Forselius, 2004) |

# APPENDIX C

## OVERALL REPRESENTATION OF PROCESS METRICS EVALUATED FOR PROJECT B

*Table C – Project B Process Metrics*

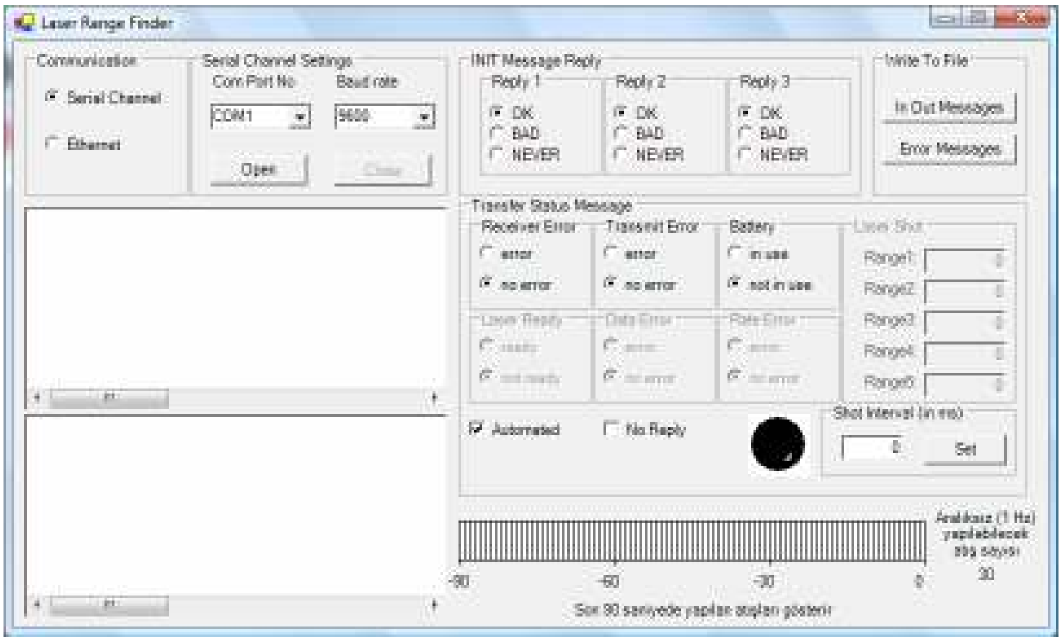
| | LOC per classes | LOC Total | Total Staff Hours | Total # of Defects | FPs |
|---|---|---|---|---|---|
| **Version 1.1** | MainForm.cs : 459 LOC | 3326 | 47 Staff Hours | 2 | 34 |
| | SystemManagement.cs : 81 LOC | | | | |
| | CommunicationManagement.cs : 154 LOC | | | | |
| | EthernetClient.cs : 465 LOC | | | | |
| | SeriKanal.cs : 1611 LOC | | | | |
| | MessageOperations.cs : 80 LOC | | | | |
| | DataStorage.cs : 476 LOC | | | | |
| **Version 1.2** | MainForm.cs : 620 LOC | 3675 | 70 Staff Hours | 4 | 41 |
| | SystemManagement.cs : 141 LOC | | | | |
| | CommunicationManagement.cs : 154 LOC | | | | |
| | EthernetClient.cs : 465 LOC | | | | |
| | SeriKanal.cs : 1611 LOC | | | | |
| | MessageOperations.cs : 102 LOC | | | | |
| | DataStorage.cs : 476 LOC | | | | |
| | InitializationMode.cs : 106 LOC | | | | |
| **Version 1.3** | MainForm.cs : 1090 LOC | 4551 | 109 Staff Hours | 13 | 57 |
| | SystemManagement.cs : 221 LOC | | | | |
| | CommunicationManagement.cs : 154 LOC | | | | |
| | EthernetClient.cs : 465 LOC | | | | |
| | SeriKanal.cs : 1611 LOC | | | | |
| | MessageOperations.cs : 102 LOC | | | | |
| | DataStorage.cs : 476 LOC | | | | |
| | InitializationMode.cs : 106 LOC | | | | |
| | TransferMode.cs : 326 LOC | | | | |
| **Version 1.4** | MainForm.cs : 1090 LOC | 4623 | 122 Staff Hours | 15 | 64 |
| | SystemManagement.cs : 238 LOC | | | | |
| | CommunicationManagement.cs : 154 LOC | | | | |

| | | | | | |
|---|---|---|---|---|---|
| | EthernetClient.cs : 465 LOC | | | | |
| | SeriKanal.cs : 1611 LOC | | | | |
| | MessageOperations.cs : 102 LOC | | | | |
| | DataStorage.cs : 476 LOC | | | | |
| | InitializationMode.cs : 106 LOC | | | | |
| | TransferMode.cs : 381 LOC | | | | |
| **Version 1.5** | MainForm.cs : 1253 LOC | 4987 | 152 Staff Hours | 21 | 75 |
| | SystemManagement.cs : 249 LOC | | | | |
| | CommunicationManagement.cs : 154 LOC | | | | |
| | EthernetClient.cs : 465 LOC | | | | |
| | SeriKanal.cs : 1611 LOC | | | | |
| | MessageOperations.cs : 102 LOC | | | | |
| | DataStorage.cs : 476 LOC | | | | |
| | InitializationMode.cs : 106 LOC | | | | |
| | TransferMode.cs : 390 LOC | | | | |
| | ServiceMode.cs : 103 LOC | | | | |
| | PulseRateError.cs : 78 LOC | | | | |
| **Version 1.6** | MainForm.cs : 1304 LOC | 5092 LOCs | 162 Staff Hours | 22 | 84 |
| | SystemManagement.cs : 249 LOC | | | | |
| | CommunicationManagement.cs : 154 LOC | | | | |
| | EthernetClient.cs : 465 LOC | | | | |
| | SeriKanal.cs : 1611 LOC | | | | |
| | MessageOperations.cs : 102 LOC | | | | |
| | DataStorage.cs : 516 LOC | | | | |
| | InitializationMode.cs : 106 LOC | | | | |
| | TransferMode.cs : 404 LOC | | | | |
| | ServiceMode.cs : 103 LOC | | | | |
| | PulseRateError.cs : 78 LOC | | | | |

# APPENDIX D

## LRF SIMULATOR – PROJECT B

LRF Simulator software is developed consistent with 53 software requirements. It can read all the messages coming to real LRF unit and can answer these messages appropriately. The user can also create error conditions by using the graphical user interface of the simulator program. All messaging and the operations done can be observed from the user interface. The screenshot of the GUI of the LRF is given below.



Communication: [✓ Serial Channel] Ethernet

Com Port No: COM1

Baud rate: 9600

Reply 1: [✓ OK] BAD NEVER

Reply 2: [✓ OK] BAD NEVER

Reply 3: [✓ OK] BAD NEVER

Receiver Error: error [✓ no error]

Transmit Error: error [✓ no error]

Battery: in use [✓ not in use]

Laser Ready: ready [✓ not ready]

Data Error: error [✓ no error]

Rate Error: error [✓ no error]

Range1: 0

Range2: 0

Range3: 0

Range4: 0

Range5: 0

[✓ Automated] No Reply

Shot Interval (in ms): 0

Aralıksız (1 Hz) yapılabilecek atış sayısı: 30

*Figure D – GUI of the LRF*

The GUI of the LRF simulator can be examined in three sub-topics:

**1. Communication Part:**

LRF can either communicate from serial channel or Ethernet at the same time. The selection of the communication protocol can be done from the user interface and only selected protocol's settings are become visible.

**2. Messaging Part:**

- **Initialization Message:** The settings of the initialization message reply are done in this part of the user interface. The first three initialization message reply can be set to;
  - **i.** Initialization is successful (INIT_OK),
  - **ii.** Initialization is unsuccessful (INIT_BAD),
  - **iii.** No reply message,

  respectively.
- **Transfer Message:** The settings of the transfer message reply are done in this part of the user interface. The transfer message settings are given below:
  - **i.** Receiver Error can be set or reset.
  - **ii.** Transmit error can be set or reset.
  - **iii.** Whether the battery is in use or not in use can be set.
  - **iv.** Laser can be set to ready or not ready.
  - **v.** Data Error can be set or reset.
  - **vi.** Rate error can be set or reset.
  - **vii.** 5 measurement results can be set. If the simulator is in automated mode measurement results that are read from "Ranges.txt" file are used. The laser shot part in user interface becomes disabled.

**3. General Settings:**

- User interface has two logging screens; the first one is to show messaging and the second one is to show errors and warnings.

- The simulator can react incoming messages in three ways; reply automatically, reply manually and no reply. This setting can be done by using “Automated” and “No Reply” checkboxes.
- The user interface displays the laser shot state of simulator in the last 90 seconds.
- The user interface displays the led state. If “open led” message is received, led color will turn to red. Led is black when it is off.

The LRF simulator is composed of 11 classes. Their brief explanations are given below:

**MainForm.cs:** It is graphical user interface class. It delivers the messages coming from user interface to the “SystemManagement.cs” and applies the messages coming from “SystemManagement.cs” to the user interface.

**SystemManagement.cs:** This class manages all of the operations done in the program. It delivers the messages to the appropriate classes and transfers the reply messages to the “CommunicationManagement.cs”.

**CommunicationManagement.cs:** This class manages the all communication operations in the program. It constitutes the incoming message and delivers it to the “SystemManagement.cs”. It also sends messages coming from “SystemManagement.cs” using selected protocol.

**SeriKanal.cs:** This class includes the necessary methods for serial channel communication.

**EthernetClient.cs:** This class includes the necessary methods for Ethernet communication.

**DataStorage.cs:** This class stores the all incoming and outgoing messages with time stamps. It also stores the error and warning messages. All messages stored in this class can be written in a file by the user.

**InitializationMode.cs:** Initialization message operations are done and message reply is formed in this class.

**TransferMode.cs:** Transfer message operations are done and message reply is formed in this class.

**ServiceMode.cs:** Service message operations are done and message reply is formed in this class.

**MessageOperations.cs:** It is static class. The other classes use the methods of this class for algorithmic operations.

**PulseRateError.cs:** This class keeps the history of laser shots done for 90 seconds. It gives the necessary information to the GUI class to display laser shot state for the past 90 seconds.

# APPENDIX E

## FUNCTION POINTS CALCULATION DETAILS FOR PROJECT B

*Table E – FP Tables of all Versions for Project B*

| **Version 1.1** | **Name** | **Weighting Factor** |
|---|---|---|
| **External Inputs** | Ethernet Connection | Average |
| | Ethernet Disconnection | Average |
| | Serial Port Open | Average |
| | Serial Port Close | Average |
| **External Outputs** | Message Log | Simple |
| | Error&Warning Log | Simple |
| **Internal Logical File** | Data Storage File | Average |

| | **Weighting Factor** | | | |
|---|---|---|---|---|
| **Measurement Parameter** | **Simple** | **Average** | **Complex** | **Total** |
| External Inputs | **0***3= | **4***4= | **0***6= | **16** |
| External Outputs | **2***4= | **0***5= | **0***7= | **8** |
| File Storage | **0***7= | **1***10= | **0***15= | **10** |
| External SW Interfaces | **0***5= | **0***7= | **0***10= | **0** |
| Number of User Inquiries | **0***3= | **0***4= | **0***6= | **0** |
| **Count Total** | | | | **34** |

| Version 1.2 | Name | Weighting Factor |
|---|---|---|
| **External Inputs** | Ethernet Connection | Average |
| | Ethernet Disconnection | Average |
| | Serial Port Open | Average |
| | Serial Port Close | Average |
| | Initialization Message | Simple |
| **External Outputs** | Message Log | Simple |
| | Error&Warning Log | Simple |
| | Initialization Status | Simple |
| **Internal Logical File** | Data Storage File | Average |

| | Weighting Factor | | | |
|---|---|---|---|---|
| **Measurement Parameter** | **Simple** | **Average** | **Complex** | **Total** |
| External Inputs | **1***3= | **4***4= | **0***6= | **19** |
| External Outputs | **3***4= | **0***5= | **0***7= | **12** |
| File Storage | **0***7= | **1***10= | **0***15= | **10** |
| External SW Interfaces | **0***5= | **0***7= | **0***10= | **0** |
| Number of User Inquiries | **0***3= | **0***4= | **0***6= | **0** |
| **Count Total** | | | | **41** |

| Version 1.3 | Name | Weighting Factor |
|---|---|---|
| **External Inputs** | Ethernet Connection | Average |
| | Ethernet Disconnection | Average |
| | Serial Port Open | Average |
| | Serial Port Close | Average |
| | Initialization Message | Simple |
| | Transfer Message | Complex |
| | Interval Adjustment | Simple |
| **External Outputs** | Message Log | Simple |
| | Error&Warning Log | Simple |
| | Initialization Status | Simple |
| | Transfer Status | Complex |
| **Internal Logical File** | Data Storage File | Average |

| | Weighting Factor | | | |
|---|---|---|---|---|
| **Measurement Parameter** | **Simple** | **Average** | **Complex** | **Total** |
| External Inputs | **2***3= | **4***4= | **1***6= | **28** |
| External Outputs | **3***4= | **0***5= | **1***7= | **19** |
| File Storage | **0***7= | **1***10= | **0***15= | **10** |
| External SW Interfaces | **0***5= | **0***7= | **0***10= | **0** |
| Number of User Inquiries | **0***3= | **0***4= | **0***6= | **0** |
| **Count Total** | | | | **57** |

| **Version 1.4** | **Name** | **Weighting Factor** |
|---|---|---|
| **External Inputs** | Ethernet Connection | Average |
| | Ethernet Disconnection | Average |
| | Serial Port Open | Average |
| | Serial Port Close | Average |
| | Initialization Message | Simple |
| | Transfer Message | Complex |
| | Interval Adjustment | Simple |
| | Service Message | Simple |
| **External Outputs** | Message Log | Simple |
| | Error&Warning Log | Simple |
| | Initialization Status | Simple |
| | Transfer Status | Complex |
| | Service Status | Simple |
| **Internal Logical File** | Data Storage File | Average |

| | Weighting Factor | | | |
|---|---|---|---|---|
| **Measurement Parameter** | **Simple** | **Average** | **Complex** | **Total** |
| External Inputs | **3***3= | **4***4= | **1***6= | **31** |
| External Outputs | **4***4= | **0***5= | **1***7= | **23** |
| File Storage | **0***7= | **1***10= | **0***15= | **10** |
| External SW Interfaces | **0***5= | **0***7= | **0***10= | **0** |
| Number of User Inquiries | **0***3= | **0***4= | **0***6= | **0** |
| **Count Total** | | | | **64** |

| **Version 1.5** | **Name** | **Weighting Factor** |
|---|---|---|
| **External Inputs** | Ethernet Connection | Average |
| | Ethernet Disconnection | Average |
| | Serial Port Open | Average |
| | Serial Port Close | Average |
| | Initialization Message | Simple |
| | Transfer Message | Complex |
| | Interval Adjustment | Simple |
| | Service Message | Simple |
| **External Outputs** | Message Log | Simple |
| | Error&Warning Log | Simple |
| | Initialization Status | Simple |
| | Transfer Status | Complex |
| | Service Status | Simple |
| | Aiming Led | Simple |
| | Shot Rate | Complex |
| **Internal Logical File** | Data Storage File | Average |

| | **Weighting Factor** | | | |
|---|---|---|---|---|
| **Measurement Parameter** | **Simple** | **Average** | **Complex** | **Total** |
| External Inputs | **3***3= | **4***4= | **1***6= | **31** |
| External Outputs | **5***4= | **0***5= | **2***7= | **34** |
| File Storage | **0***7= | **1***10= | **0***15= | **10** |
| External SW Interfaces | **0***5= | **0***7= | **0***10= | **0** |
| Number of User Inquiries | **0***3= | **0***4= | **0***6= | **0** |
| **Count Total** | | | | **75** |

| **Version 1.6** | **Name** | **Weighting Factor** |
|---|---|---|
| **External Inputs** | Ethernet Connection | Average |
| | Ethernet Disconnection | Average |
| | Serial Port Open | Average |
| | Serial Port Close | Average |
| | Initialization Message | Simple |
| | Transfer Message | Complex |
| | Interval Adjustment | Simple |
| | Service Message | Simple |
| | Write To File | Average |
| **External Outputs** | Message Log | Simple |
| | Error&Warning Log | Simple |
| | Initialization Status | Simple |
| | Transfer Status | Complex |
| | Service Status | Simple |
| | Aiming Led | Simple |
| | Shot Rate | Complex |
| | Output File | Average |
| **Internal Logical File** | Data Storage File | Average |

| | **Weighting Factor** | | | |
|---|---|---|---|---|
| **Measurement Parameter** | **Simple** | **Average** | **Complex** | **Total** |
| External Inputs | **3***3= | **5***4= | **1***6= | **35** |
| External Outputs | **5***4= | **1***5= | **2***7= | **39** |
| File Storage | **0***7= | **1***10= | **0***15= | **10** |
| External SW Interfaces | **0***5= | **0***7= | **0***10= | **0** |
| Number of User Inquiries | **0***3= | **0***4= | **0***6= | **0** |
| **Count Total** | | | | **84** |

## APPENDIX F

## OVERALL REPRESENTATION OF PROCESS METRICS EVALUATED FOR PROJECT A

*Table F – Project A Process Metrics*

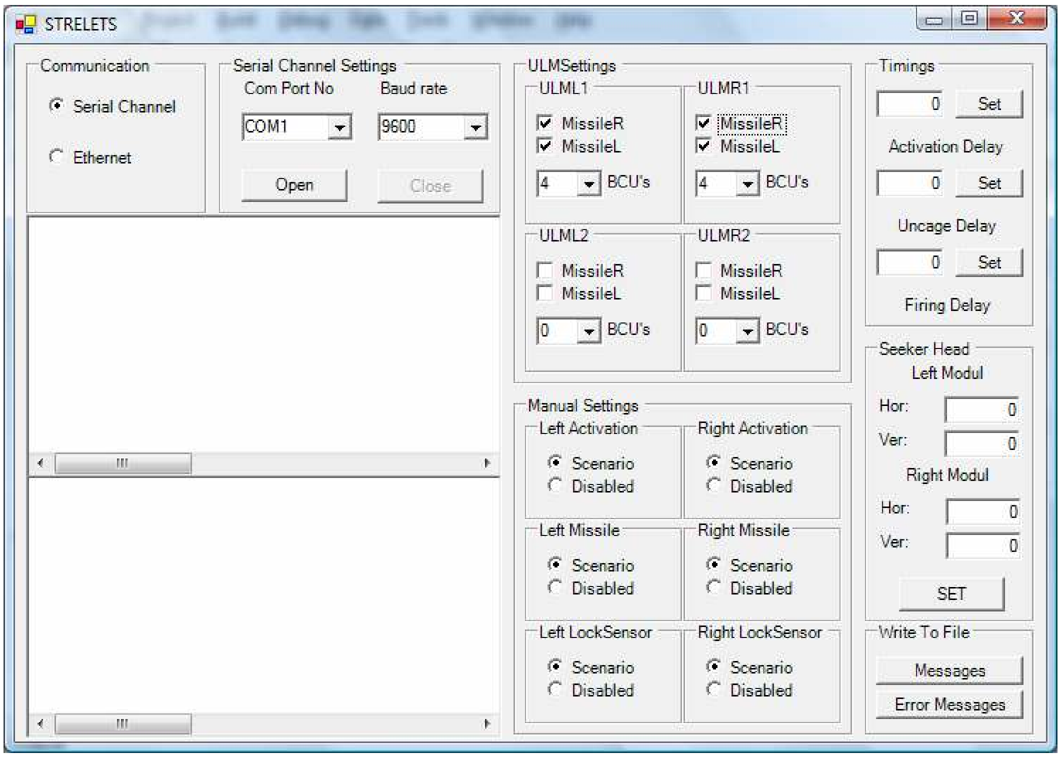
| | LOC per classes | LOC Total | Total Staff Hours | Total # of Defects | FPs |
|---|---|---|---|---|---|
| **Version 1.1** | MainGUI.cs : 86 | 422 | 17 | 5 | 8 |
| | Management.cs : 24 | | | | |
| | Communication.cs : 28 | | | | |
| | EthernetClient.cs : 284 | | | | |
| **Version 1.2** | MainGUI.cs : 86 | 1720 | 37 | 9 | 16 |
| | Management.cs : 24 | | | | |
| | Communication.cs : 28 | | | | |
| | EthernetClient.cs : 284 | | | | |
| | SerialChannel.cs : 1298 | | | | |
| **Version 1.3** | MainGUI.cs : 449 | 2212 | 51 | 12 | 24 |
| | Management.cs : 29 | | | | |
| | Communication.cs : 152 | | | | |
| | EthernetClient.cs : 282 | | | | |
| | SerialChannel.cs : 1300 | | | | |
| **Version 1.4** | MainGUI.cs : 449 | 2572 | 64 | 15 | 34 |
| | Management.cs : 29 | | | | |
| | Communication.cs : 152 | | | | |
| | EthernetClient.cs : 282 | | | | |
| | SerialChannel.cs : 1300 | | | | |
| | MessageOperations.cs : 59 | | | | |
| | DataStorage.cs : 301 | | | | |
| **Version 1.5** | MainGUI.cs : 744 | 3015 | 78 | 18 | 42 |
| | Management.cs : 74 | | | | |
| | Communication.cs : 152 | | | | |
| | EthernetClient.cs : 282 | | | | |
| | SerialChannel.cs : 1300 | | | | |
| | MessageOperations.cs : 70 | | | | |
| | DataStorage.cs : 301 | | | | |
| | StandByMode.cs : 92 | | | | |

| | | | | | |
|---|---|---|---|---|---|
| **Version 1.6** | MainGUI.cs : 744 | 3686 | 98 | 24 | 53 |
| | Management.cs : 111 | | | | |
| | Communication.cs : 152 | | | | |
| | EthernetClient.cs : 282 | | | | |
| | SerialChannel.cs : 1300 | | | | |
| | MessageOperations.cs : 70 | | | | |
| | DataStorage.cs : 301 | | | | |
| | StandByMode.cs : 114 | | | | |
| | CombatMode.cs : 484 | | | | |
| | ULM.cs : 67 | | | | |
| | Missile.cs : 61 | | | | |
| **Version 1.7** | MainGUI.cs : 1207 | 4214 | 114 | 26 | 59 |
| | Management.cs : 111 | | | | |
| | Communication.cs : 152 | | | | |
| | EthernetClient.cs : 282 | | | | |
| | SerialChannel.cs : 1300 | | | | |
| | MessageOperations.cs : 70 | | | | |
| | DataStorage.cs : 301 | | | | |
| | StandByMode.cs : 114 | | | | |
| | CombatMode.cs : 549 | | | | |
| | ULM.cs : 67 | | | | |
| | Missile.cs : 61 | | | | |
| **Version 1.8** | MainGUI.cs : 1405 | 4485 | 127 | 29 | 70 |
| | Management.cs : 111 | | | | |
| | Communication.cs : 152 | | | | |
| | EthernetClient.cs : 282 | | | | |
| | SerialChannel.cs : 1300 | | | | |
| | MessageOperations.cs : 70 | | | | |
| | DataStorage.cs : 328 | | | | |
| | StandByMode.cs : 114 | | | | |
| | CombatMode.cs : 553 | | | | |
| | ULM.cs : 67 | | | | |
| | Missile.cs : 61 | | | | |
| | SeekerHead.cs : 42 | | | | |

# APPENDIX G

## STRELETS SIMULATOR – PROJECT A

STRELETS Simulator software is developed consistent with 44 software requirements. It can read and parse all the messages coming to real STRELETS unit and can answer these messages appropriately. Manuel settings of the unit can be done from the user interface of the simulator and also error conditions can be created. All messaging, errors and warnings can be observed from the GUI. The screenshot of the GUI of the STRELETS is given below.



STRELETS

Communication: [✓ Serial Channel] Ethernet

Serial Channel Settings: Com Port No: COM1; Baud rate: 9600; Open; Close

ULMSettings
- ULML1: [✓ MissileR] [✓ MissileL] 4 BCU's
- ULMR1: [✓ MissileR] [✓ MissileL] 4 BCU's
- ULML2: MissileR, MissileL, 0 BCU's
- ULMR2: MissileR, MissileL, 0 BCU's

Manual Settings
- Left Activation: [✓ Scenario] Disabled
- Right Activation: [✓ Scenario] Disabled
- Left Missile: [✓ Scenario] Disabled
- Right Missile: [✓ Scenario] Disabled
- Left LockSensor: [✓ Scenario] Disabled
- Right LockSensor: [✓ Scenario] Disabled

Timings
- Activation Delay: 0 Set
- Uncage Delay: 0 Set
- Firing Delay: 0 Set

Seeker Head
- Left Modul: Hor: 0; Ver: 0
- Right Modul: Hor: 0; Ver: 0
- SET

Write To File: Messages; Error Messages

*Figure G – GUI of the STRELETS*

The GUI of the STRELETS simulator can be examined in three sub-topics:

1. **Communication Part:**

STRELETS simulator can either communicate from serial channel or Ethernet at the same time. The selection of the communication protocol can be done from the user interface and only selected protocol's settings are become visible.

2. **Message Settings Part:**

- **ULM Settings:** ULMs are the missile launcher units in the system. From the user interface of the simulator, the user can add or take out missiles to the system and set the number of gas tubes (BCUs).
- **Manuel Settings:** The user can change the activation, uncaging and launching scenarios by manually disable these controls. This part is used to create unexpected behaviors and to see whether an error condition occurs or not.
- **Timings:** The user can adjust delays before responding a command message. This setting is used to make simulator acts as if in the system.
- **Seeker Head:** Seeker Head setting is used to adjust the position of the seeker head manually. Seeker head symbol appears in the screen during uncage state and launch state.

3. **Storing Messages Part:**

Messages and errors are displayed in the listboxes with timestamps. They can also be written in a text based file by the buttons in the user interface.

The STRELETS simulator is composed of 12 classes. Their brief explanations are given below:

**MainGUI.cs:** It is the graphical user interface class. It delivers the user commands given from the interface to the management class. It is only accessible from Management and StandByMode classes.

**Management.cs:** This class manages all of the operations done in the program. It takes messages from Communication class and user commands from MainGUI class. Management class parses the messages and delivers the commands to the inner classes. It applies the responds to the user interface and sends the appropriate reply message using the Communication class.

**Communication.cs:** This class manages the all communication operations in the program. It constitutes the incoming message and delivers it to the Management class. It also sends messages coming from Management class using selected protocol.

**EthernetClient.cs:** This class includes the necessary methods for Ethernet communication.

**SerialChannel.cs:** This class includes the necessary methods for serial channel communication.

**MessageOperations.cs:** It is a static class. The other classes use the methods of this class for general message operations.

**DataStorage.cs:** This class stores the all incoming and outgoing messages with time stamps. It also stores the error and warning messages. All messages stored in this class can be written in a file by a user command.

**StandByMode.cs:** This class gets the ULM settings from the user interface and prepares the missile status of the simulator to be sent as a reply to missile status enquiry message.

**CombatMode.cs:** All missile activation, uncaging and launching operations are done in this class. Combat mode reply message is constituted in this class.

**ULM.cs:** ULM class simulates the ULM unit in the system. It is used by CombatMode class.

**Missile.cs:** Missile class holds the state of a missile. It is used by ULM class.

**SeekerHead.cs:** This class gets the seeker head position from the user interface and fills the related part in the combat mode reply message.

# APPENDIX H

# FUNCTION POINTS CALCULATION DETAILS FOR PROJECT A

*Table H – FP Tables of all Versions for Project A*

| **Version 1.1** | **Name** | **Weighting Factor** |
|---|---|---|
| **External Inputs** | Ethernet Connection | Average |
| | Ethernet Disconnection | Average |

| | **Weighting Factor** | | | |
|---|---|---|---|---|
| **Measurement Parameter** | **Simple** | **Average** | **Complex** | **Total** |
| External Inputs | **0***3= | **2***4= | **0***6= | **8** |
| External Outputs | **0***4= | **0***5= | **0***7= | **0** |
| File Storage | **0***7= | **0***10= | **0***15= | **0** |
| External SW Interfaces | **0***5= | **0***7= | **0***10= | **0** |
| Number of User Inquiries | **0***3= | **0***4= | **0***6= | **0** |
| **Count Total** | | | | **8** |

| **Version 1.2** | **Name** | **Weighting Factor** |
|---|---|---|
| **External Inputs** | Ethernet Connection | Average |
| | Ethernet Disconnection | Average |
| | Serial Port Open | Average |
| | Serial Port Close | Average |

| | Weighting Factor | | | |
|---|---|---|---|---|
| **Measurement Parameter** | **Simple** | **Average** | **Complex** | **Total** |
| External Inputs | **0***3= | **4***4= | **0***6= | **16** |
| External Outputs | **0***4= | **0***5= | **0***7= | **0** |
| File Storage | **0***7= | **0***10= | **0***15= | **0** |
| External SW Interfaces | **0***5= | **0***7= | **0***10= | **0** |
| Number of User Inquiries | **0***3= | **0***4= | **0***6= | **0** |
| **Count Total** | | | | **16** |

| **Version 1.3** | **Name** | **Weighting Factor** |
|---|---|---|
| **External Inputs** | Ethernet Connection | Average |
| | Ethernet Disconnection | Average |
| | Serial Port Open | Average |
| | Serial Port Close | Average |
| **External Outputs** | Message Log | Simple |
| | Error&Warning Log | Simple |

| | Weighting Factor | | | |
|---|---|---|---|---|
| **Measurement Parameter** | **Simple** | **Average** | **Complex** | **Total** |
| External Inputs | **0***3= | **4***4= | **0***6= | **16** |
| External Outputs | **2***4= | **0***5= | **0***7= | **8** |
| File Storage | **0***7= | **0***10= | **0***15= | **0** |
| External SW Interfaces | **0***5= | **0***7= | **0***10= | **0** |
| Number of User Inquiries | **0***3= | **0***4= | **0***6= | **0** |
| **Count Total** | | | | **24** |

| **Version 1.4** | **Name** | **Weighting Factor** |
|---|---|---|
| **External Inputs** | Ethernet Connection | Average |
| | Ethernet Disconnection | Average |
| | Serial Port Open | Average |
| | Serial Port Close | Average |
| **External Outputs** | Message Log | Simple |
| | Error&Warning Log | Simple |
| **Internal Logical File** | Data Storage File | Average |

| | **Weighting Factor** | | | |
|---|---|---|---|---|
| **Measurement Parameter** | **Simple** | **Average** | **Complex** | **Total** |
| External Inputs | **0***3= | **4***4= | **0***6= | **16** |
| External Outputs | **2***4= | **0***5= | **0***7= | **8** |
| File Storage | **0***7= | **1***10= | **0***15= | **10** |
| External SW Interfaces | **0***5= | **0***7= | **0***10= | **0** |
| Number of User Inquiries | **0***3= | **0***4= | **0***6= | **0** |
| **Count Total** | | | | **34** |

| **Version 1.5** | **Name** | **Weighting Factor** |
|---|---|---|
| **External Inputs** | Ethernet Connection | Average |
| | Ethernet Disconnection | Average |
| | Serial Port Open | Average |
| | Serial Port Close | Average |
| | Stand-By Message | Simple |
| **External Outputs** | Message Log | Simple |
| | Error&Warning Log | Simple |
| | Stand-By Reply | Average |
| **Internal Logical File** | Data Storage File | Average |

| | Weighting Factor | | | |
|---|---|---|---|---|
| **Measurement Parameter** | **Simple** | **Average** | **Complex** | **Total** |
| External Inputs | **1***3= | **4***4= | **0***6= | **19** |
| External Outputs | **2***4= | **1***5= | **0***7= | **13** |
| File Storage | **0***7= | **1***10= | **0***15= | **10** |
| External SW Interfaces | **0***5= | **0***7= | **0***10= | **0** |
| Number of User Inquiries | **0***3= | **0***4= | **0***6= | **0** |
| **Count Total** | | | | **42** |

| **Version 1.6** | **Name** | **Weighting Factor** |
|---|---|---|
| **External Inputs** | Ethernet Connection | Average |
| | Ethernet Disconnection | Average |
| | Serial Port Open | Average |
| | Serial Port Close | Average |
| | Stand-By Message | Simple |
| | Combat Message | Complex |
| **External Outputs** | Message Log | Simple |
| | Error&Warning Log | Simple |
| | Stand-By Reply | Average |
| | Combat Reply | Average |
| **Internal Logical File** | Data Storage File | Average |

| | Weighting Factor | | | |
|---|---|---|---|---|
| **Measurement Parameter** | **Simple** | **Average** | **Complex** | **Total** |
| External Inputs | **1***3= | **4***4= | **1***6= | **25** |
| External Outputs | **2***4= | **2***5= | **0***7= | **18** |
| File Storage | **0***7= | **1***10= | **0***15= | **10** |
| External SW Interfaces | **0***5= | **0***7= | **0***10= | **0** |
| Number of User Inquiries | **0***3= | **0***4= | **0***6= | **0** |
| **Count Total** | | | | **53** |

| **Version 1.7** | **Name** | **Weighting Factor** |
|---|---|---|
| **External Inputs** | Ethernet Connection | Average |
| | Ethernet Disconnection | Average |
| | Serial Port Open | Average |
| | Serial Port Close | Average |
| | Stand-By Message | Simple |
| | Combat Message | Complex |
| | Set Timings | Average |
| **External Outputs** | Message Log | Simple |
| | Error&Warning Log | Simple |
| | Stand-By Reply | Average |
| | Combat Reply | Complex |
| **Internal Logical File** | Data Storage File | Average |

| | **Weighting Factor** | | | |
|---|---|---|---|---|
| **Measurement Parameter** | **Simple** | **Average** | **Complex** | **Total** |
| External Inputs | **1***3= | **5***4= | **1***6= | **29** |
| External Outputs | **2***4= | **1***5= | **1***7= | **20** |
| File Storage | **0***7= | **1***10= | **0***15= | **10** |
| External SW Interfaces | **0***5= | **0***7= | **0***10= | **0** |
| Number of User Inquiries | **0***3= | **0***4= | **0***6= | **0** |
| **Count Total** | | | | **59** |

| **Version 1.8** | **Name** | **Weighting Factor** |
|---|---|---|
| **External Inputs** | Ethernet Connection | Average |
| | Ethernet Disconnection | Average |
| | Serial Port Open | Average |
| | Serial Port Close | Average |
| | Stand-By Message | Simple |
| | Combat Message | Complex |
| | Set Timings | Average |
| | Write To File | Simple |
| **External Outputs** | Message Log | Simple |
| | Error&Warning Log | Simple |
| | Stand-By Reply | Average |
| | Combat Reply | Complex |
| | Output File | Simple |
| | Seeker Head Position | Simple |
| **Internal Logical File** | Data Storage File | Average |

|  | **Weighting Factor** |  |  |  |
|---|---|---|---|---|
| **Measurement Parameter** | **Simple** | **Average** | **Complex** | **Total** |
| External Inputs | **2***3= | **5***4= | **1***6= | **32** |
| External Outputs | **4***4= | **1***5= | **1***7= | **28** |
| File Storage | **0***7= | **1***10= | **0***15= | **10** |
| External SW Interfaces | **0***5= | **0***7= | **0***10= | **0** |
| Number of User Inquiries | **0***3= | **0***4= | **0***6= | **0** |
| **Count Total** |  |  |  | **70** |