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Managing Technical Debt in Embedded systems

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Abstract

Context: Today, software is contributing a substantial part of new functionalities and innovations of the embedded industry. With the size and the complexity of the software is increasing with time, additional challenges arises, including implicit assumptions of technical debt. Technical debt refers to situations where shortcuts are taken in technical decisions. Technical debt has been identified as one of the key reasons to software system projects failures. Accumulation of technical debt may reduce the dependability and maintainability of the embedded systems.

Objective: The goal of this study is to compare existing research on technical debt, and embedded systems, with the insights and experiences of traditional software and embedded system practitioners from the industry. We will explore and understand the causes of technical debt, as well as how it is managed in embedded systems.

Research Method: Four different companies with one participant from each, were interviewed. Two of them works with traditional software development, while the last two works with embedded system development. All of them had different positions.

Results: The results consists of the knowledge similar to the technical debt research. There are many similarities between the causes and management practices of technical debt. Results show that technical debt is mostly formed as a result of intentional decisions to reach deadlines. However, embedded system has more control over technical debt than traditional software. The results also revealed that neither of the participants had any specific management plan for reducing technical debt but several practices were identified. The results may also help companies to understand the existing practices of technical debt management and use it to improve their own processes.

Preface

This report has been written during autumn 2015, as a part of the course TDT4501, Specializion Project for Software Engineering, at Norwegian University of Science and Technology. This study can be seen as a pre study for the upcoming Master's Thesis in the spring 2016.

This work has been supervised by Carl-Fredrik Sørensen. I would especially like to thank him for providing insightful input and valuable feedback during the period. He also helped us with providing names of potential candiates in Trondheim along with their contact details.

At last, I would like to thank all the four participants who participated in the interviews.

Trondheim, December 16, 2015

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CHAPTER 1 INTRODUCTION

1.1 Motivation and Background

The field of embedded systems is growing rapidly based on the evolution in electronics and widespread use of sensors and actuators. From consumer electronics, automobiles, to satellites, embedded systems represent one of the largest segments of the software industry. The automotive domain is going through a major transition where all car manufacturers are working towards the development of self-driving cars. Internet of Things describes the concept of interconnecting the virtual world of computers with the real world of physical artifacts [5]. This leads to a distributed network of devices communicating with other devices as well as humans. Gartner [1] have estimated that in 2020, 25 billion connected "things" will be in use. Our society has come to depend on such systems for its day-to-day operation. Embedded systems is forecasted to grow exponentially in the next 10 years [6]

Software plays an important role in the development of embedded systems [7]. Embedded software is the primary driving force for implementing different functionalities of today's embedded systems. The software is specialized for one particular type of hardware, and may therefore have hardware specific run-time constraints. As the complexity of embedded system grows, the ability to maintain the required quality of such systems becomes more difficult. Traditional software development technologies do not take into account the specific needs of embedded systems development [6].

Moreover, many companies are forced to think about their time-to-market strategy to keep up with the increased competition. Companies need to decide what kind of shortcuts they will have to take in the development process. Such compromises causes the creation of a financial overhead in the future maintenance activities, usually termed as Technical Debt (TD) [8]. As the amount of TD accumulated in the developed embedded systems grows continuously, companies need to manage the overall debt while keeping the system flexible and extensible. Defects can cause life-threatening situations, delays can create hugs costs, and insufficient productivity can impact an entire company [7]. Pacemakers are a good example of how embedded software helps millions of person live a better live. Yet between 1990 and 2000, software errors accounted for about 40% of half million devices recalled [7]. If the companies could catch software defects earlier in the system design process, their income would be saved. It is necessary for companies to find out how to make decisions so future maintenance and evolution has as low cost as possible.

According to Gartner [9], the cost of dealing with TD threatens to grow to $1 trillion globally by 2015. That is the double of the amount of TD in 2010. IT management teams must measure the level of TD in their products, and develop a strategy to deal with TD.

Table 1.1: Internet of Things Units Installed Base by Category [1]

Category	**2013**	**2014**	**2015**	**2020**
Automotive	96.0	189.6	372.3	3,511.1
Consumer	1,842.1	2,244.5	2,874.9	13,172.5
Generic Business	395.2	479.4	623.9	5,158.6
Vertical Business	698.7	836.5	1,009.4	3,164.4
Grand Total	**3,032.0**	**3,750.0**	**4,880.6**	**25,006.6**

1.2 Research Questions

The main objective of this research is to increase the knowledge of TD by looking at the significant sources, and practices for managing the debt. The reason for this is that embedded systems usually has long lifetime, and it is important to find out how such systems are managed because the architecture and design decisions are usually made long time ago and the decision makers might not be available anymore.

The research questions in this research will be:

- **RQ1**: What practices and tools exists for managing technical debt? How are they used?
- **RQ2**: What are the most significant sources of technical debt?
- **RQ3**: When should a technical debt be paid?
- **RQ4**: Who is responsible for deciding whether to incur, or pay off technical debt?

1.3 Research Method

The most relevant research methodologies in software engineering are illustrated in Figure 1.1. Throughout this research, the research process illustrated in the model will be used as a basis for the elaboration of how to conduct the research in the upcoming master thesis.

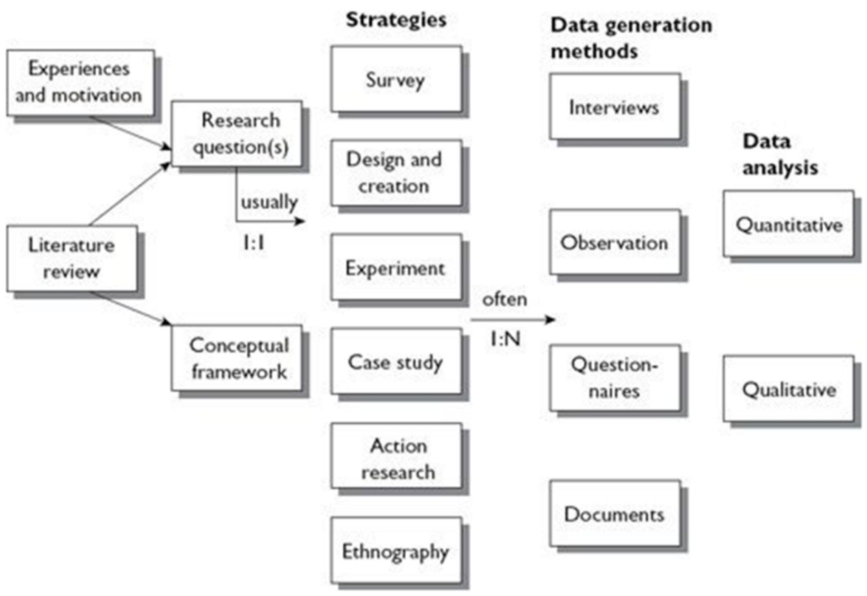


Figure 1.1: Model of research process [2]

To define the research questions, it is necessary to get an overview of the research field by conducting a review of published research within the selected area of study, providing a conceptual framework. Moreover, researchers can use their experiences and motivations. A research strategy is needed to answer the research questions. Oates [2] presents six different research strategies: survey, design and creation, experiment, case study, action research, and ethnography. A data collection method is needed to produce empirical data or evidence. Furthermore, Oates [2] presents four different data collection methods: interviews, observations, questionnaire, and documents. Research data can either be quantitative or qualitative.

1.4 Project Structure

The report is structured into several chapters:

- **Chapter 1** introduces the problem and motivation behind this project along with the search questions.
- **Chapter 2** provides a state-of-art within the field of TD, embedded systems, and software engineering.
- **Chapter 3** presents the research method, and the procedures that was used behind the method.
- **Chapter 4** provides an overview of the results acquired from the research method.
- **Chapter 5** presents a discussion of the relevant topics related to the research questions.

- **Chapter 6** concludes the report and provides some points to future work.

CHAPTER 2 STATE-OF-THE-ART

This chapter presents topics which are relevant to this project.

Section 2.1 Section 2.2 Section 2.4 Section 2.3 Section 2.5 Section 2.6 Section 2.7 Section 2.8 Section 2.9

2.1 Technical Debt

The concept of TD as first introduced by Ward Cunningham in 1992 to communicate technical problems with non-technical stakeholders [8]. The concept was used to describe the system design trade-offs that are made everyday. To deliver business functionality as quickly as possible, *'quick and dirty'* decisions had to be made, which affected the future development activities. Furthermore, Cunningham describes TD as *"shipping first time code is like going into debt. A little debt speeds development as long as it is paid back promptly with a rewrite"*. As the time goes, TD accumulates *interest* leading increased costs of a software system [10, 11]. Li et al. [12] defines interest as *the extra effort needed to modify the part of the software system that contains technical debt.* However, not all debts are necessarily bad. A small portion of debt may help developers speed up the development process, resulting short-term benefits [10].

Figure 2.1 illustrates the effects of TD growth in a system.

2.1.1 Definitions of Technical Debt

McConnell [13] describes TD as *a design or construction approach that is expedient in the short term but that creates a technical context in which the same work will cost more to do later than it would cost to do now (including the increased cost over time).* He splits the term into two categories based on how they are incurred; TD that is incurred *intentionally*,

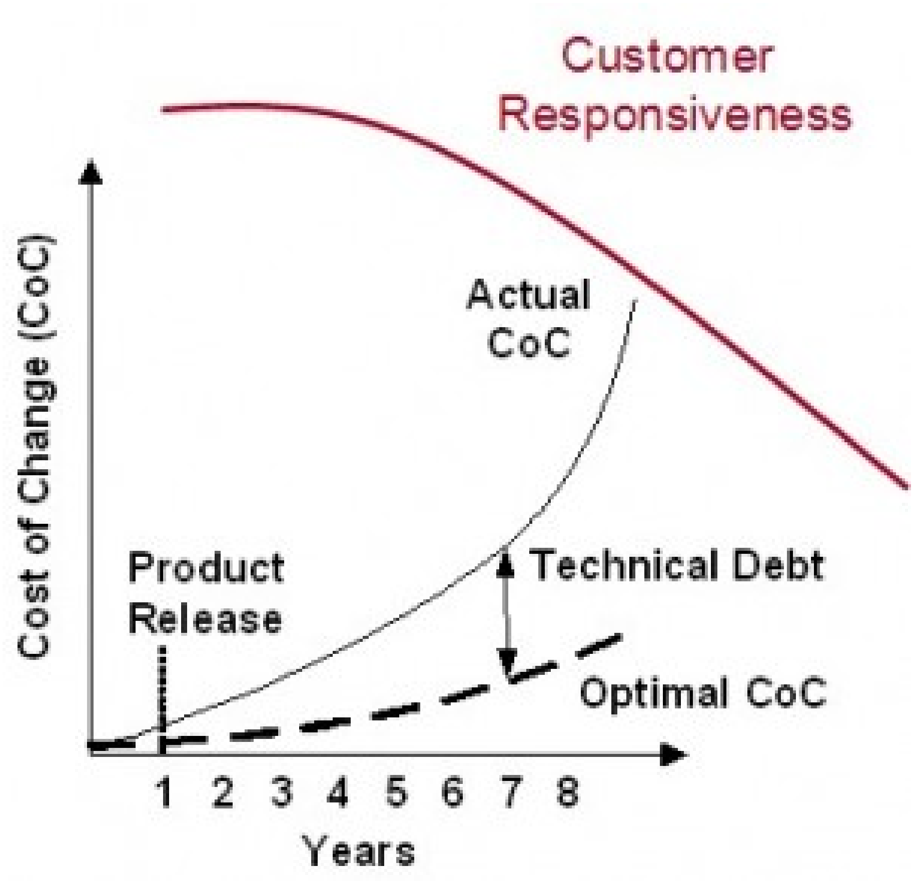


Figure 2.1: The TD Curve [3]

and TD that is incurred *unintentionally*. For instance, unintentional debt accumulates when a junior software developer writes low quality code due to lack of knowledge and experience. Intentional debt commonly occurs when an organization makes a decision to optimize for the present rather than the future. For instance, intentional debt is incurred when the project must be delivered on time. These type of decisions leads to shortcuts being taken to solve a problem.

Fowler [14] presents a more formal explanation of how TD can occur. He categories TD into a quadrant with two dimensions, which he calls the *"Technical Debt Quadrant"*. As seen in the Figure 2.2, the debt is grouped into four categories:

- **Reckless/Deliberate debt**: The team feels time pressure, and takes shortcuts intentionally without any thoughts on how to address the consequences in the future.
- **Reckless/Inadvertent debt**: Best practices when it comes to code and design is ignored, and a big mess in the code base is made.
- **Prudent/Deliberate debt**: : The value of taking shortcuts is worth the cost of incurring debt in order to meet a deadline. The team is aware of the consequences, and has a plan in place to address them in the future.
- **Prudent/Inadvertent debt**: Software development process is as much learning as

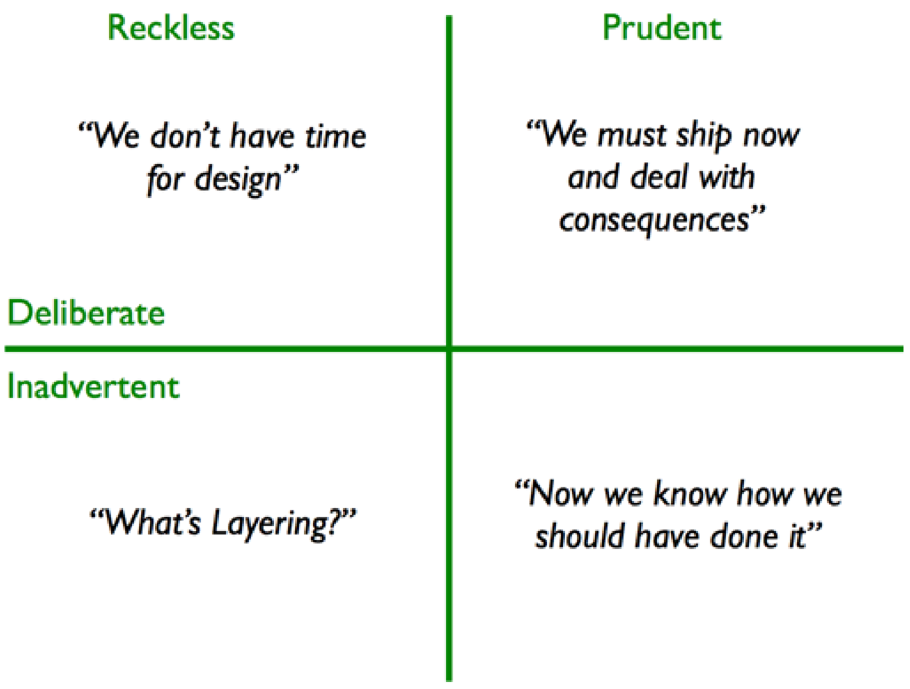

Reckless
Prudent
"We don't have time for design"
"We must ship now and deal with consequences"
Deliberate
Inadvertent
"What's Layering?"
"Now we know how we should have done it"

Figure 2.2: Fowler's TD Quadrant

it is coding. The team can deliver a valuable software with clean code, but in the end they might realize that the design could have been better.

Krutchen et al. [15]. divides TD into two categories: *Visible debt* that is visible for everyone. It contains elements such as new functionality to add, and defects to fix. *Invisible debt* is the other category, debt that is only visible to software developers. Figure 2.3 illustrates a map of the *"TD Landscape"*, in which distinguish visible and invisible elements. On the left side of Figure 2.3, TD mostly affects evolvability of the software system, while on the right side, TD mainly affects maintainability.

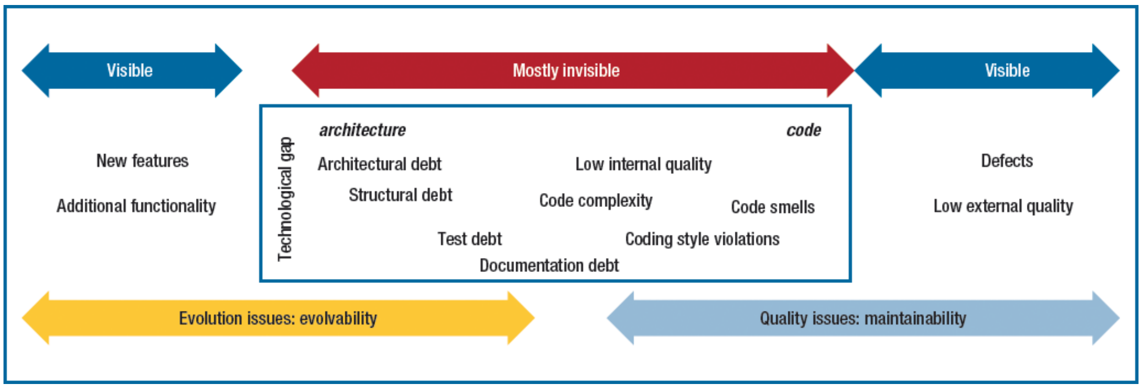


Figure 2.3: TD Landscape

2.1.2 Comparison with Financial Debt

TD has many similarities to financial debt [16, 17]:

- You take a loan that has to be repaid later

- You usually repay the loan with interest
- If you can not pay back, a very high cost will follow. For example, you can loose your house or car.

Like financial debt, TD accrues interest over time which comes in the form of extra effort that has to be dedicated in future development [10,11]. Stakeholders can choose to continue paying the interest, or pay down the debt by refactoring the problem into something better which reduces the interest payments in the future [14].

However, if the debt is not repaid, the development may slow down, resulting in software project failure or bankruptcy [16]. Moreover, there are some differences between financial debt and TD. The debt has to be repaid eventually, but not on any fixed schedule [16]. This means that some debts may never have to be paid back, which depends on the interest and the cost of paying back the debt [18]. Some examples on interests can be be lower pace of development, low competitiveness, security flaws on the system, loss of developers and their expertise, poor internal collaboration environment, dissatisfied customers, and loss of market share [16].

2.1.3 Causes and Effects of Technical Debt

Multiple studies have tried to analyze the reason for companies to incur TD.

Klinger et al. [11] conducted an industrial case study at IBM where four technical architects with different backgrounds were interviewed. The goal was to examine how decisions to incur debt were taken, and the extent to which the debt provided leverage [11]. The study revealed that the company failed to assess the impact of intentionally incurring debt on projects. Decisions regarding TD were rarely quantified. The study also revealed big organizational gaps among the business, operational, and technical stakeholders, which incurred debt. When the project team felt pressure from the stakeholders, TD decisions were made without quantifications of possible impacts.

Lim et al. [19] pointed out that TD is not always the result of poor developer disciplines, or sloppy programming. It can also include intentional decisions to trade off competing concerns during business pressure. Furthermore, Li et al. explains that TD can be used in short term to capture market share and to collect customers feedback early. In the long term, TD tended to be negative. These trade-offs included increased complexity, reduced performance, low maintainability, and fragile code. This led to bad customer satisfaction and extra working hours. In many cases, the short term benefits of TD outweighed the future costs.

Guo et al. [20] studied the effects of TD by tracking a single delayed maintenance task in a real software project throughout its life-cycle, and simulated how managing TD can impact the project result. The results showed that delaying the maintenance task would have almost tripled the costs, if it had been done later.

Siebra et al. [21] carried out an industrial case study where they analyzed documents, emails, and code files. Additionally, they interviewed multiple developers and project managers. The case study revealed that TD were mainly taken by strategic decisions. Siebra et. al also found out that using a unique specialist could lead the development team to solutions that the specialist wanted and believe were correct, leading the team to incur debt. The study also identified that TD can both increase and decrease the amount of working hours.

Zazworka et al. [22] studied the effects of god classes and TD on software quality. God classes are examples on bad coding, and therefore includes a possibility for refactoring [17]. The results indicated that god classes require more maintenance effort including bug fixing and changes to software that are considered as a cost to software project. In other words, if developers desire higher software quality, then TD needs to be addressed closely in the development process.

Buschmann [23] explained three different stories of TD effects. In the first case, TD accumulated in a platform started had growth to a point where development, testing, and maintenance costs started to increase dramatically. Additionally, the components were hardly usable. In the second case, developers started to use shortcuts to increase the development speed. This resulted in significant performance issues because an improper software modularization reflected organizational structures instead of the system domains. It ended up turning in to economic consequences. In the last case, an existing software product experienced increased maintenance cost due to architectural erosion. However, management analyzed that re-engineering the whole software would cost more than doing nothing. Management decided not to do anything to TD, because it was cheaper from a business point-of-view.

Codabux et al. [24] carried out an industrial case study where the topic was agile development focusing on TD. They observed and interviewed developers to understand how TD is characterized, addressed, prioritized, and how decisions led to TD. Two subcategories of TD were commonly described in this case study; infrastructure and automation debt.

These studies indicates that the causes and effects of TD are not always caused by technical reasons. TD can be the result of intentional decisions made by the different stakeholders. Incurring TD may have short-term positive effects such as time-to-market benefits. Not paying down TD can result economic consequences, or quality issues in the long-run. The allowance of TD can facilitate product development for a period, but decreases the product maintainability in the long-term. However, there are some times where short-term benefits overweight long-term costs [20].

These studies reveals that several types of TD are related to software life-cycle phases. The effects of taking shortcuts can happen in several stages of software life-cycle. Table 2.1 lists the types of TD that has been identified in the literature.

Table 2.1: Types of TD

Subcategory	**Definition**
Architectural debt [12, 18, 24]	Architectural decisions that make compromises in some of the quality attributes, such as modifiability.
Code debt [12, 18, 25]	Poorly written code that violates best coding practices and guidelines, such as code duplication.
Defect debt [12, 25]	Defect, failures, or bugs in the software.
Design debt [12, 17, 18]	Technical shortcuts that are taken in design.
Documentation debt [12, 18, 26]	Refers to insufficient, incomplete, or outdated documentation in any aspect of software development.
Infrastructure debt [12, 24, 25]	Refers to sub-optimal configuration of development-related processes, technologies, and supporting tools. An example is lack of continuous integration.
Requirements debt [12, 26]	Refers to the requirements that are not fully implemented, or the distance between actual requirements and implemented requirements.
Test debt [12, 18, 26]	Refers to shortcuts taken in testing. An example is lack of unit tests, and integration tests.

2.1.4 Current Strategies and Practices for Managing Technical Debt

Managing TD compromises the actions of identifying the debt and making decisions about which debt should be repaid [13, 15, 18]. This section examines some proposed methods that has been proposed by several authors.

Brown et al. [18] proposed open research questions to understand the need to manage TD. The questions includes refactoring opportunities, architectural issues, identifying dominant sources of technical debt, and identifying issues that arise when measuring TD.

Lim et al. [19] suggested four strategies for managing TD. The first strategy is to do nothing because the TD may never be visible to the customer. The second strategy is to use a risk management approach to evaluate and prioritize TDs cost and value by allocating 5-10% of each release cycle to address TD. The third strategy is to include the customers and non-technical stakeholders to TD decisions. Finally, the last strategy suggests to track TD items using tools like a Wiki, or a backlog.

Codabux et al. [24] suggested best practices such as refactoring, repackaging, re-engineering, and developing unit tests to manage TD. Moreover, they also propose that having dedicated teams with the purpose of reducing TD, while the product development team devote 20% of their effort toward TD reduction.

Guo et al. [10] suggested using of portfolio management for TD management. This approach collects TD items to a *"TD List"* (TDL). TDL is used to pay the TD back based on its cost and value. Three activities support the TDL. The first activity is TD Identification. TD Identification uses several tools to identify TD items which are then automatically placed in the TDL. The second activity is TD Estimation. Each item in the list is assigned the estimates for the debt principal, and the interest. The third activity, Decision Making, is used to determine which debts should be addressed first, and when they should be addressed.

Nugraho et al. [27] proposed an approach to quantify TD and its interest by using a software quality assessment method. This method rates the technical quality of a system in terms of the quality characteristics of ISO/IEC 9126.

Krutchen et al. [15] suggested listing debt-related tasks in a common backlog during release and iteration planning. Figure 2.4 illustrates how these elements can be organized in a backlog. Moreover, Krutchen mentioned that project backlogs often contain the green elements. The rest are seen rarely, especially the black elements, they are nowhere to be found.

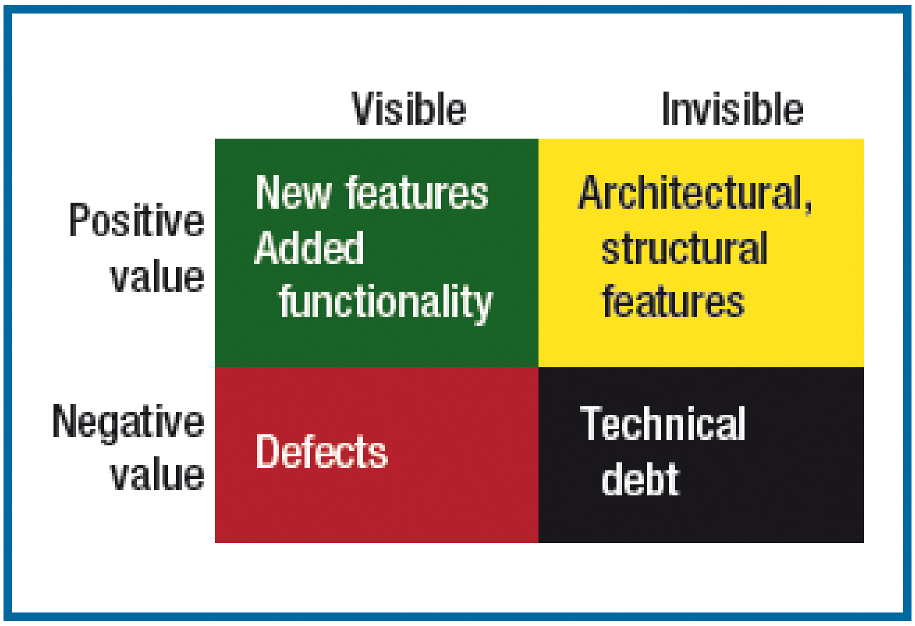

Visible
Invisible
Positive value
Negative value
New features Added functionality
Architectural, structural features
Defects
Technical debt

Figure 2.4: The Colors Reconcile Four Types of Possible Improvements.

SonarQube is an open source application for quality management [28]. It manages results of various code analysis tools, and is used to analyze and measure a projects technical quality. The TD is computed based on the SQALE (Software Quality Assessment based on Life-cycle Expectations) methodology [29]. SQALE is a method for assessing TD in a project. It is based on tools that analyze the source code of the project, looking at different types of errors such as mismatched indentation, and different naming conventions. Each error is assigned a score based on how much work it would take to fix that error. The analysis gives a total sum of TD for the entire project.

To conclude, despite the fact that many practices and tools have been for managing TD, the accumulation of technical debt in software systems keeps growing [9].

2.2 Software Quality

Software Quality (SQ) is defined as *an effective software process applied in a manner that creates a useful product that provides measurable value for those who produce it and those who use it* [30]. ISO/IEC 9126-2001 is an international standard for the evaluation of software [31]. It is currently one of the most widespread quality standards [32]. The standard defines quality as *the totality of characteristics of an entity that bear on its ability to satisfy stated and implied needs*. Additionally, ISO/IEC 9126-2001 offers a valuable conceptual framework for SQ, where it makes a distinction between *"quality in use"*, *"external quality"*, and *"internal quality"* [31, 32]. *Quality in use* is the users view of the quality of a system. *External quality* reflects the dynamic aspect of a software application, and is subdivided into six quality characteristics. *Internal quality* is reflected by a subdivision of the six external quality characteristics into internal quality attributes.

Table 2.2 describes the quality attributes, and their sub-characteristics (criteria).

Table 2.2: The Sub-Characteristics Adopted by ISO/IEC 9126-2001

Quality Attribute	**Criteria**	**Description**
Functionality	Suitability, Accuracy, Interoperability, Security, Functionality compliance	Ability of the system to do work for which it was intended.
Reliability	Maturity, Fault tolerance, Recoverability, Reliability compliance	Ability of the system to keep operating over time under certain conditions.
Usability	Understandability, Learnability, Operability, Attractiveness, Usability compliance	The capability of the software product to be understood, learned, and used by users.
Efficiency	Time behavior, Resource utilization, Efficiency compliance	The capability of the software product to provide appropriate performance, relative to the amount of resources used, under stated conditions.
Maintainability	Analyzeability, Changeability, Stability, Testability, Maintainability compliance	The capability of the software product to be modified in the future.
Portability	Adaptability, Installability, Co-existence, Replaceability, Portability compliance	The capability of the software product to be transferred from one environment to another.

2.3 Software Architecture

Bass et al. [33] defines software architecture as following:

The software architecture of a system is the set of structures needed to reason about the system, which compromise software elements, relations among them, and properties of both.

The architecture of a software is one of the most important artifacts within the systems life cycle [33,34]. Architectural design decisions that are made during the design phase, affect the systems ability to accept changes and to adapt to changing market requirements in the future. As the design decisions are made early, it will directly affect the evolution and maintenance phase [30], activities that consumes a big part of the systems lifespan [4]. The problem of software architecture has long been a concern for those building and evolving large software systems [35].

Software architecture can be seen from two standpoints [36]; prescriptive and descriptive architecture. The prescriptive architecture of a system captures the design decisions made prior to the construction. This is normally called as-conceived software architecture. Descriptive architecture describes how the system has actually been build, called for as-implemented software architecture.

As the system evolves, it is ideal that the prescriptive architecture is modified first. In practice, the system - the descriptive architecture - is often directly modified [33]. This can be due to developers sloppiness, short deadlines, or lack of documented prescriptive architecture. These principles introduces two new concepts; architectural drift and architectural erosion [33]. Architectural drift occurs when the documents are updated according to the implementation. The software architecture ends up as an architecture without vision and direction. Architectural erosion occurs when the implementation drifts away from the planned architecture.

System requirements can be categorized as *functional requirements*, *quality attribute requirements* (QA requirements), and *constraints* [33]. *Functional requirements* states what a system must do. *QA* are the non-functional requirements of a system. *Constraints* is a design decision with zero degrees of freedom. Moreover, long-term responsiveness of a system can be achieved by providing a solution of a system that would enable and achieve systems driving QA.

As a final step in the architecture design phase, more and more organizations are evaluating their design decisions using Architecture Trade-off Analysis Model [33, 37]. The goal of the ATAM is to understand the consequences of architectural decisions with respect to the quality attribute requirements of the system.

2.4 Software Life-cycle

A Software Life-Cycle (SLC) is the phases a software product goes through between its convenient, to when its no longer available for use [38]. According to *IEEE Standard for*

Developing SLC Processes [38], there are five general groups of related activities in the SLC:

1. The first group is project management. Every software life-cycle starts with the project initiation. Project planning, and project monitoring and control are two other, necessary activities withing this group for each project iteration.
2. The second group is pre-development. This group consists of activities that needs to be performed before the software development phase. Concept exploration is a good example of such activity.
3. The third group is the development itself. It includes the activities that must be performed during the development.
4. The fourth group is post-development. It includes activities to be performed after development to enhance the software project. The retirement activity involves removal of the existing system from its active support by ceasing its operation or support, or replacing it with a new system or an upgraded version of the existing system.
5. The final group is called integral. This group consists of activities that are necessary to ensure successful completion of a project. These activities are seen as support activities rather than activities that are directly oriented to the development effort.

2.4.1 Software Development Life Cycle and Methodologies

A software development process or a software development life-cycle (SDLC) is defined as the process by which user needs are translated into a software product [39]. The process involves translating user needs into requirements, transforming requirements into design, implementing design into code, testing the code, and sometimes, installing and checking out the software for operational use.

A software development methodology is defined as a framework to structure, plan, and control the software development process. Many software development methodologies exists, and the basic life-cycle activities are included in all life-cycle models, often in different orders. The difference is in terms of time to release, risk management, and quality. The models can be of different types, but they are usually defined as traditional and agile software development methodologies.

Traditional Software Development

Traditional software development methodologies are based on a sequential series of steps. They usually starts with elicitation and documentation of a complete set of requirements, followed by architecture and high level design, development, testing, and deployment. The most well-known of these traditional software development methodologies is the Waterfall method, the oldest software development process model. The Waterfall Model divides the software development life-cycle into five distinct and linear stages [4]; requirements engineering, design, implementation, testing, and maintenance. There are many risks associated with the use of Waterfall model [40]:

- **Continuous requirements change**: Requirements are specified at the beginning of the software development process, and the remaining software development activities have to follow the initial requirements. This kind of model is not appropriate to use for software where technology and business requirements always change.
- **No overlapping between stages**: Each stage in the Waterfall model needs to be completed entirely before proceeding into the next phase.
- **Poor quality assurance**: Lack of quality assurance during the different phases is another source of risk. Testing the system is the last stage in the development process. Thus, all problems, bugs, and risk are discovered too late.
- **Relatively long stages**: Long stages in the development process makes it difficult to estimate time and cost. Additionally, there is no working product until late in the development process.

Using sequential design processes such as Waterfall model in software development processes to build complex, intensive systems is often a failure [16]. According to the Standish Group, CHAOS Report of 2015, 29% of all projects using Waterfall method tends to fail, with no useful software deployed[1].

Agile Methods

To address the challenges posed by traditional methods, agile methods were developed as a set of lightweight methods [40]. Agile methods try to deal with collaboration in a way that promotes adaptive planning, early delivery, and continuous improvement, making the development phase faster and more flexible regarding changes [41]. Agile Manifesto describes four values that defines agile software development [42]:

- Individuals and interactions over processes and tools
- Working software over comprehensive documentation
- Customer collaboration over contract negotiation
- Responding to change over following a plan

Scrum is one of the most popular agile software development methodologies [4,30,43]. It is an iterative and incremental software development model. An advantage with iterative procedures is that parts of a system is developed early on, and can be tested before

[1]Standish Group 2015 Chaos Report - Q&A with Jennifer Lynch, http://www.infoq.com/articles/standish-chaos-2015

implementation of other parts. This reduces the risk of having long stages [44]. The idea with Scrum is to divide the development into short periods, called sprints. Unlike the approach in the Waterfall model, the team can estimate how long it will take to implement tasks which can be accomplished during each sprint. To implement the requirements step by step, a product backlog is kept containing the features that have yet to be implemented. The product backlog is not static as it changes to the needs of the project, with new features being added, and obsolete ones being removed. Sprint backlog is items from the backlog that a team works on during a sprint.

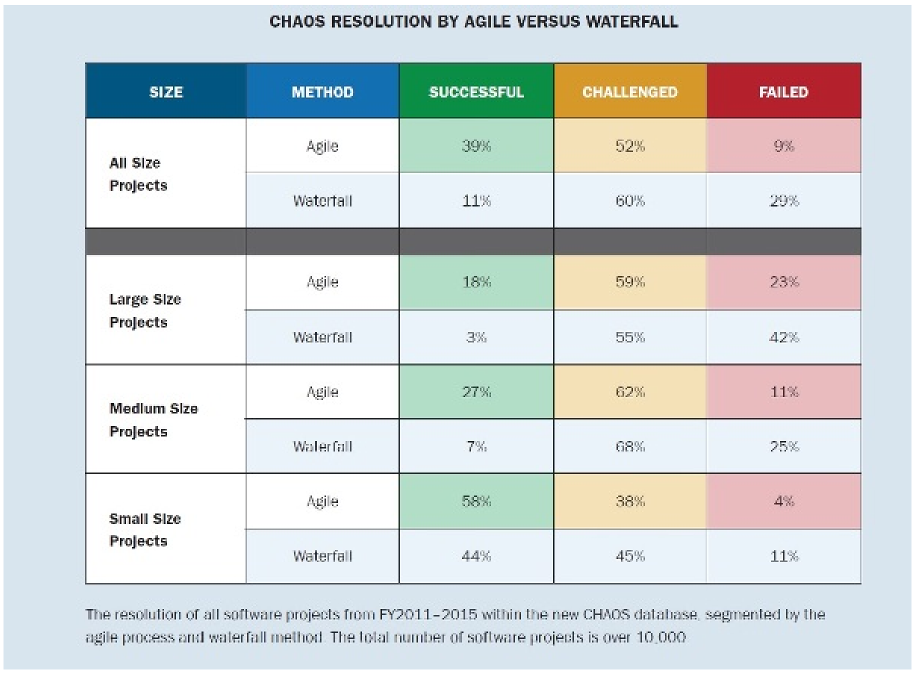
Lean Development adapts the concepts and principles of Toyota Product Development System, to the practice of developing software [45]. It is seen as a key component in building a change tolerant business [46]. The seven lean principles that is applied to software development are summarized as *eliminate waste, build quality in, create knowledge, defer commitment, deliver fast, respect people, and optimize the whole* [30, 45].

Despite the fact that agile methods addressed the challenges posed by traditional methods, there are many risks associated with agile methodologies [40]:

- **Very large software system**: Developing large, complex software systems results in large increments. This increase the time span between increments, and thus require a higher cost to deal with changes and bugs if discovered.
- **Large development team**: Having large teams results in difficulties in managing communication between team members.
- **High reliance on human factor**: Agile methodologies relies on the development team, and their abilities to communicate with the customers.
- **Inappropriate customer representative**: This factor can influence the development process and the team members.
- **Distributed development environment**: Agile methodologies requires close interaction between the development team. Having a distributed development environment might challenge the communication between team members due to different time zones.
- **Scope creep**: With minimal planning conducted, developers can be easily distracted from the project main objectives.

2.5 Software Evolution

Increasingly, more and more software developers are employed to maintain and evolve existing systems instead of developing new systems from scratch [43]. Software evolution is a process that usually takes place when the initial development of a software project is done and was successful [47]. The goal of software evolution is to incorporate new


CHAOS RESOLUTION BY AGILE VERSUS WATERFALL

SIZE	METHOD	SUCCESSFUL	CHALLENGED	FAILED
All Size Projects	Agile	39%	52%	9%
	Waterfall	11%	60%	29%
Large Size Projects	Agile	18%	59%	23%
	Waterfall	3%	55%	42%
Medium Size Projects	Agile	27%	62%	11%
	Waterfall	7%	68%	25%
Small Size Projects	Agile	58%	38%	4%
	Waterfall	44%	45%	11%

The resolution of all software projects from FY2011–2015 within the new CHAOS database, segmented by the agile process and waterfall method. The total number of software projects is over 10,000.

Figure 2.5: Agile implementation Success Rate by The Standish Group

user requirements in the application, and adapt it to the existing application. Software evolution is important because it takes up to 85-90% of organizational software costs [43]. Software evolution is also important because technology tend to change rapidly.

Rajlich et al. [47] proposed a view of the software lifespan, as shown in Figure 2.6. This view divides the software lifespan into five stages with initial development as the first stage. The key contribution is to separate the maintenance phase into an evolution stage, followed by a service stage, and at last the phase-out stage.

Initial development produces the first version of the software from scratch.

Evolution is the phase where significant changes to the software may be made. This could be addition of new features, correct previous mistakes, or adjust the software to new business requirements or technologies. Each change introduces a new feature or some other new property into the software.

Servicing is the stage where relatively small, essential changes are allowed. The company considers how the software can be replaced. Legacy software is a term to describe software in this stage.

Phase-out is the phase where software may still be used, but no further changes are being implemented. Users must work around any problems that they discover, or replace the software with something else.

Close-down is when the managers or customers completely withdraw the system from production.

A variation of this process is the versioned stage model, as shown in Figure 2.7. When a

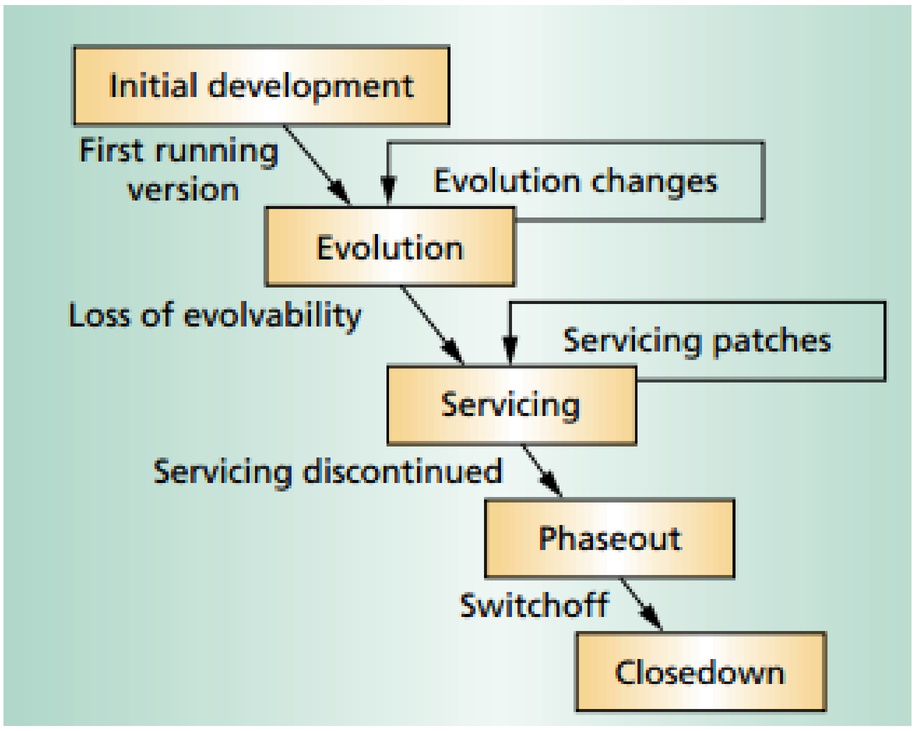


Figure 2.6: Software evolution process

software version is completed and released to the customer, the evolution continues with the company eventually releasing another version and only servicing the previous version.

2.5.1 Evolution Processes

Software evolution usually starts with change proposals, which may be new requirements, existing requirements that have not been implemented, or bug reports from stakeholders. The process of implementing a change goes through these stages [43] as shown in Figure 2.8.

The process starts with a set of proposed change requests. The cost and impact of the change is analyzed to decide whether to accept or deny the proposed changes. If the proposed changes are accepted, a new release of the system is planned. During release planning, all proposed changes such as fault repair, adaptation, and new functionality, are considered, to decide which changes to implement in the next version of the system. The changes are implemented and validated, and a new version of the system is released. The process ends with a new iteration with a set of proposed change requests for the next release.

Sometimes, the need of urgent changes may appear, such as a serious system fault that must be repaired to allow normal operation. In these cases, the usual process will not be beneficial as it takes time. An emergency fix is usually made to solve the problem. A developer choose a quick and workable solution rather than the best solution. The trade-off is that the the requirements, the software design, and the code become inconsistent.

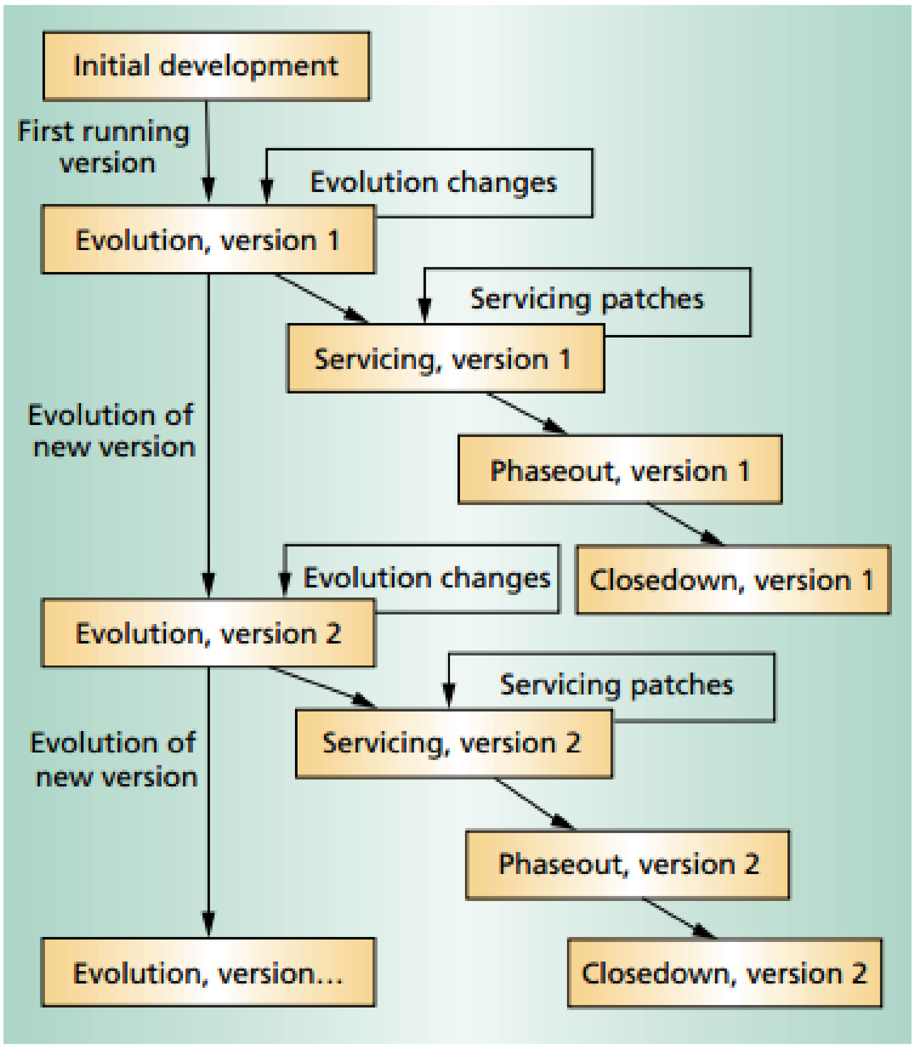


Figure 2.7: Software lifespan

As a system changes over time, it will have impact on the systems internal structure and complexity. Software evolution might cause poor SQ and erosion of software architecture over time [33].

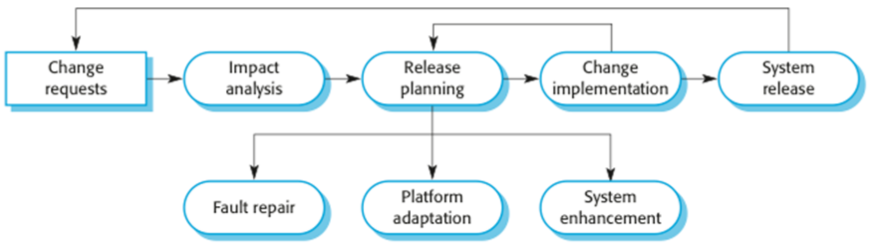


Figure 2.8: Software evolution process

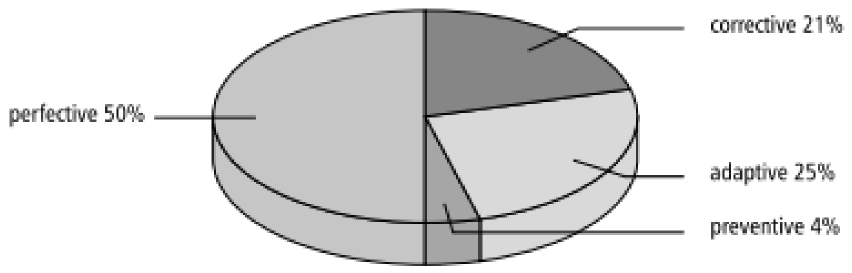


Figure 2.9: Distribution of maintenance activities [4]

2.5.2 Software Maintenance

IEEE 1219 defines software maintenance as follows [48]:

> Modification of a software after delivery to correct faults, to improve performance or other attributes, or to adapt the product to a modified environment.

Maintenance can be classified into four types [47, 48].

- Adaptive: Modification of a software product performed after delivery to keep a computer program usable in a changed or changing environment.
- Perfective: Modification of a software product after delivery to improve performance or maintainability.
- Corrective: Reactive modification of a software product performed after delivery to correct discovered faults.
- Preventive: Maintenance performed for the purpose of preventing problems before they occur.

According to van Vliet, the real maintenance activity is corrective maintenance [4]. 50% of the total software maintenance is spent on perfective, 25% on adaptive maintenance, and 4% on preventive maintenance. This leads to that 21% of the total maintenance activity is corrective maintenance, the 'real' maintenance [4]. This has not changed since the 1980s when Lientz and and Swanson conducted a study on software maintenance [49]. Their study found out that most severe maintenance problems were caused by poor documentation, demand from users for changes, poor meeting scheduled, and problems training new hires. Some other problem areas were lack of user understanding, user training, and that customers did not understand how the system worked.

2.6 Software Reuse

Software reuse is the process of using existing software artifacts, or knowledge, to create new software, rather than building it from scratch. Software reuse is a key method for improving software quality [50]. Software reuse can be specified in two directions, development *for* reuse, and development *with* reuse [51]. Development for reuse is related to components for reuse or system generalization. Development with reuse is related to how existing components can be reused in new system.

Table 2.3 lists several assets from a software project that can be reused [50].

Table 2.3: Reusable assets in software projects

1. architectures	6. estimates
2. source code	7. human interfaces
3. data	8. plans
4. designs	9. requirements
5. documentation	10. test cases

Slyngstad et al. [51] conducted an empirical study in Statoil ASA where they investigated developers views on software reuse. The results showed that reuse include lower costs, shorter development time, higher quality of the reusable components, and a standardized architecture. These findings are very similar to the key benefits of reuse that Lim has described [52]. The quality of software artifacts increases every time the item is reused, because errors are discovered more frequently, making it easier to keep the artifact more stable [53].

Additionally, there can be problems associated with software reuse. A case study on a selected feature from self-driving miniature car development revealed that reuse of legacy, third party, or open source code, was one of the root causes for the accumulation of technical debt [54]. Morisio et al. [55] identified three main causes of software reuse failure; not introducing reuse-specific processes, not modifying non-reuse processes, and not considering human factors, combined with lack of commitment by top management.

2.7 Refactoring

Design debt, a specific type of technical debt, accumulates as developers write code [17]. This type of debt can be reduced by refactoring. Fowler defines refactoring as means of adjusting the design and architecture towards new requirements without changing the external behavior of a program in order to improve the quality of the system [56]. It is an act of improving the design of an existing system [4]. Most of the time in spent on reducing design debt is on refactoring activities itself. These activities includes planning the design and architecture, rewriting the code, and adjusting documentation [30]. It is believed that refactoring improves software quality and developer productivity, by making it easier to understand and maintain software codes [57], thus a way to manage the technical debt of a system.

Table 2.4 lists the software artifacts that can be refactored [58].

Table 2.4: Types of Software Artifacts that can be refactored.

Programs	Refactoring at the source code or program level. For example, extracting methods, and encapsulating fields.
Designs	Refactoring at design level, for example in the form of UML models. Design patterns, software architecture, and database schemas, are some examples on artifacts that can be refactored at this level.
Software Requirements	Refactoring at the level of requirements specification. For example, decomposing requirements into a structure of viewpoints.

2.8 Configuration Management

Systems always change to cope with bugs and introduce new features. A new version of a system is created when changes are made [59]. Dart [60] defines configuration management (CM) as a discipline for controlling the evolution of software systems. CM identifies every component in a project and has an overview of every suggestions and changes from day one to the end of the product. CM involves four related activities [43]:

Change management is intended to ensure that the evolution of a system is a managed process, and to prioritize changes. Costs and benefits has to be analyzed to approve changes and track what components have been changed. The process starts with an actor submitting a change request. The request is checked for validity. If it is valid, the costs to this change are analyzed. The change request is passed to the change control board if it is not minor. The impact of the change from a strategic and organizational standpoint is considered, and if it is accepted, it is passed on. There are some important factors in the decision making process [43]:
a) The consequences of not making the change *b*) The benefits of the change *c*) The number of users affected by the change *d*) The costs of making the change *e*) The product release cycle

Version management is the process of keeping track of different and multiple versions of system components and ensuring that changes made to components by different developers do not interfere with each other. This is often done with version management tools, which provide features like
a) version and release identification; *b*) storage management; *c*) change history recording; *d*) independent development; or *e*) project support

System building creates an executable system by compiling and linking the program components, data, and libraries. The build process involves checking out component versions from the repository managed by the version management system, so it is necessary for system build tools and version management tools to communicate. There are many system build tools available, which provides features like *a*) build script generation; *b*) version management system integration; *c*) executable system creation; *d*) test automation; or *e*) document generation.

Release management prepares the software for external release and keeps track of the system versions that have been released for customer use. Managing releases is a complex process as a release needs documentation such as configuration files, data files, and an installation program. Some factors that influences release planning are *a*) the technical quality of the system; *b*) platform changes; *c*) Lehman's fifth law; *d*) competitions; *e*) market requirements; or *f*) customer change proposals.

There are some challenges related to development of embedded systems [61]:

- **Complex file sets**: Embedded systems consists of multiple diverse components, both hardware and software. This makes the system complex. Embedded system may also have different adjustable components for a specific platform, making it easier to sell a product by tweaking some parameters. Dealing with these variates is a major challenge. Another challenge is that a product requires correct version of a component. Ensuring the consistency between components and their dependents files is a challenge as well.

- **Distributed teams**: Components may be developed in different places in our world. Two team might for example work on the same components, especially when development are being outsourced. Such collaboration needs every developer to access each others work. The challenge is keep the team synchronized.

- **Management and versioning of intellectual property**: Embedded systems, or software generally might use third-party technologies. It is important that those technologies are up-to-date, and maintained. These updates needs to be traceable such that each components has the right, compatible and stable version of its software. If something is not outsourced, it might be a challenge for developers to contribute and trace their changes.

Software Configuration Management (SCM) is the task of tracking and controlling changes in the software through reliable version selection and version control. SCM is a part of CM. Some examples on SCM that is widely used is Git, SVN, and Adele. Choosing a robust SCM system makes it possible to deal with big and complex files. It also supports distributed development. The right combination of SCM system and best practices makes it possible for embedded development projects to progress fast and efficiently.

2.9 Embedded Systems

Embedded systems are special-purpose computer systems designed to perform certain dedicated functions under certain constraints. For instance, an embedded system in an automobile provides specific functions as a subsystem for the car itself [62]. According to Crnkovic [63], the various types of embedded systems share common requirements such as: *real-time requirements, resource consumption, dependability, and life-cycle properties.* Moreover, embedded systems are known as safety-critical and real-time systems due to their operational environment characteristics and common requirements [62, 64]. Properties such as response time and worst case execution time, are important design concerns [65]: *When the break pedal is pressed, the computer should initiate the breaking action within one millisecond.* Embedded systems are expected to be failure-free [66], but these requirements may hinder embedded systems to deliver reliable service given a disturbance to its services [67]. Additionally, it is expected that embedded systems has long life time [64].

2.9.1 Embedded Software

In modern embedded systems, there is always a software element. The *IEEE Standard Glossary of Software Engineering Terminologies* defines embedded systems software as *a part of a larger system which performs some of the requirements of that system* [39]. By 2010, premium class vehicles are expected to contain one gigabyte on-board software [7,68]. Current BMW 7 series implements about 270+ functions that a user interacts with, deployed over up to 67 embedded platforms [68]. Software constitutes only one part in embedded systems. Integration of these subsystems is always a challenging task for complex systems [68]. Additionally, other issues that needs to be addressed includes unstable requirements, technology changes, location of software errors, and inadequate documentation [69]. According to Ebert, in 2008, there were about 30 embedded microprocessors per person in developed countries with at least 2.5 million function points of embedded software. The volume of embedded software is increasing at 10 to 20% per year depending on the domain [7]. Embedded software developers face many challenges in their work like conflicts in the requirements placed on them. For instance, low memory usage while ensuring high availability [70]. Consider that the role of embedded systems is often critical, the importance of managing software quality is therefore necessary to deliver software in a useful, safe, and reliable way.

Embedded Software Quality

Embedded software has many common characteristics with traditional computer-software. However, compared to traditional computer-software development, embedded software development has been proven to be more difficult [7, 37]. Sherman [37] points out that is important that embedded systems not only meet the functional requirements of 'what' they should do, but also the non-functional or 'quality' requirements expected of them. Non-functional requirements have come to be referred to as software quality attributes. Ebert et al. [7] states that quality is difficult to measure in embedded systems. Concerning the design of embedded systems, often discussed behaviors are related to run-time qualities depending on the system domain. For instance, reliability and safety qualities are important in automotive domain [68], while performance and reliability qualities are important in mission critical systems [32]. However, other important design-time qualities directly related to business goals, such as maintainability and usability, are often compromised compared to run-time qualities.

Graaf et al. [6] studied seven European firms to determine the state of the practice in embedded software engineering. One of the key findings in the study was that system engineering was mostly driven by hardware constraints. Software development did not start until the project hit a phase where hardware development changes would be expensive. This led to suboptimal solutions in terms of software architecture, because the system architecture was more or less fixed. Existing software development technologies do not consider the specific needs of embedded systems development.

Risks and malfunctions in embedded software are much higher than in traditional application software. Security rapidly grows in relevance as embedded software communicates autonomously with other computing devices [7]. In the automotive industry, more and more vehicles are getting connected to the cyber-infrastructure [68]. This has resulted in attacks carried out via this cyber-infrastructure. For instance, earlier in 2015, two research discovered the possibility to start Tesla Model S using a laptop[2]. Despite the growth of embedded systems, research has revealed that many embedded system projects do not start from scratch [6, 68]. Several authors have pointed out that software reuse is applied a lot in the embedded system industry. According to Graaf et al. [6], software reuse is rather ad hoc. Most of the products that is developed today is based on previous products. Reuse artifacts, such as requirements and code, are therefore reused by copying them. Furthermore, Pretschner et al. [68] states that the difference between functionality changes from one vehicle generation to the next is relatively small. Most of the old functionality remains and can be found in a new car generation. Functionality differs mostly not more than 10%. However, more than 10% of the software is re-written.

Given the lack of focus on design-time aspects of SQ, the amount of TD accumulated in embedded systems grows continuously. This happens because of several factors, and especially because the current level of technical debt is not visible to the developers and managers. According to Graaf et al. [6] and Ebert et al. [7], insufficient requirements and testing are two major cost drivers in embedded software development. 40% of all software defects in embedded systems results from insufficient requirements, especially

[2]Researchers Hacked a Model S, But Tesla's Already Released a Patch: http://www.wired.com/2015/08/researchers-hacked-model-s-teslas-already/

non-functional requirements [6,7,44]. Furthermore, testing after code completion consumes 30 to 40% of embedded development resources, and depending on the project life cycle, testing requires a lead time of 15-50% of total project duration [7]. Moreover, time pressure from the management has been identified as a negative impact on embedded projects, which usually leads to suboptimal solutions.

CHAPTER 3

RESEARCH METHOD

This chapters presents the main empirical strategies used in this research.

3.1 Empirical Strategies

Empirical studies follows two types of research paradigms; the qualitative, and the quantitative paradigm [71]. Qualitative research is concerned with studying objects in their natural setting [71]. Its data include non-numeric data found in sources as interview tapes, documents, or developers' models [2]. Quantitative research is concerned with quantifying a relationship or to compare two or more groups [71]. It is based on collecting numerical data [2].

Oates [2] presents six different research strategies; survey, design and creation, case study, experimentation, action research, and ethnography.

Survey focuses on collection data from a sample of individuals through their responses to questions. The primary means of gathering qualitative or quantitative data are interviews or questionnaires. The results are then analyzed using patterns to derive descriptive, explorative and explanatory conclusions. *Design and creation* focuses on developing new IT products, or artifacts. It can be a computer-based system, new model, or a new method. *Case study* focuses on monitoring one single 'thing'; an organization, a project, an information system, or a software developer. The goal is to obtain rich, and detailed data. *Experimentation* are normally done in laboratory environment, which provides a high level of control. The goal is to investigate cause and effect relationships, testing hypotheses, and to prove or disprove the link between a factor and an observed outcome. *Action research* focuses on solving a real-world problem while reflecting on the learning outcomes. *Ethnography* is used to understand culture and ways of seeing of a particular group of people. The researcher spends time in the field by participating rather than observing.

3.1.1 Choice of Methods

Out of the six research strategies presented by Oates [2], survey was chosen as a strategy for this research. As mentioned before, questionnaires and interviews are two common means for data collection [71]. The method chosen is usually based on type of results researches are looking for. There are three types of interviews [2]:

- Structured interviews: The use of pre-determined, standardized, identical questions for every interviewee. Structured interviews are very similar to questionnaires.
- Semi-structured interviews: A list of themes and questions is prepared. However, the interviewer has the possibility to ask additional questions that is not included in the list.
- Unstructured interviews: The topic is introduced by the interviewer, and the participants talks freely about related events, behavior, or beliefs. The researcher has less control.

In this research, semi-structured interviews will be conducted as the supporting research method for qualitative data collections. Some advantages of using interviews are best trade-off between usage of time, and its ability to provide detailed textual description for the research questions. Most of the questions were formulated in an open fashion way, which allowed the participants to speak with more detail on the issue with their experiences and viewpoints [2, 71], hence resulting in qualitative and flexible answers.

3.1.2 Data collection

This research was performed by collecting data through a series of interviews with companies in the electronics and software business. The interviews focused around how companies encountered technical debt, how they are addressing it, what they are doing to handle it through the development and software evolution. In total, four interviews were conducted with four different companies, two of them working with embedded system development, and the last two working with traditional software business.

The companies to interview were chosen by the author and the supervisor of this project. The interviews were mainly conducted in Trondheim, because the companies could easily be interviewed in person. A proper request for participation for an interview were sent out to companies through e-mail. The participant were chosen by the company, but the type of person needed for the interview were given by the author.

The interviews were conducted in a semistructured manner. The benefit of using a semistructured approach is that the interviewer are able to change the order of questions depending on the flow of the conversation, and to probe deeper into a subject by asking additional questions the interviewer had not prepared for [2].

The interview questions were created by the author with the assistance of the supervisor. These questions were used as a guideline to get an overview over the subjects to be asked, and appropriate follow-up questions were asked to gain in-depth understanding about the subject. The interviewer took notes while the interview was in progress.

A certain degree of structure in the interviews also provides a basis for comparing the interviews afterwards. Covering the same main topics makes it possible to extract common trends and differences in the answers. After the interviews were conducted, it analyzed by arranging the interview data in tables containing the most relevant characteristics, and conclusions were drawn from analyzing it.

CHAPTER 4 RESULTS

This chapter presents the results of this study. The first section presents the participants. The main findings are presented in Section 4.2, 4.3, 4.4, and 4.5. Section 4.2 focuses the term TD and causes related to it. Section 4.3 reveals the causes of TD. Section 4.4 takes a further look at how TD is addressed and prioritized in organizations. Section 4.5 reveals the way TD is managed.

4.1 Introduction of participants

Table 4.1: The Participants

ID	Role	Academical degree	Experience
P1	Software Developer	Bachelor	Over 10 years
P2	ICT Security and Quality Manager	Master	Over 10 years
P3	Research and Developer Manager	Doctoral	Over 10 years
P4	Project Manager	Doctoral	Over 10 years

The participants are from the Trondheim area in Norway. They had various background within software development field, and had experience with different computer systems. Two of them works with embedded system field, and the last two works with traditional software development. Table 4.1 summarizes their background.

The interview began by asking the participants about their responsibilities, type of product they develop, size of the product, size of the team working on the product, and software development methodology used. Table 4.2 summarizes their responses.

Table 4.2: Some info

ID	System type	Responsibilities	Size of the solution (lines)	Process	Team size
P1	Web application	Working on an API, integrates multiple systems	101k - 1m	Scrum	5 to 10
P2	ERP solution, SAP project	Maintains and manages systems	More than 10m	Lean, Scrum	More than 20
P3	Embedded systems	Creates products by integrating other products with their own core product	101k - 1m	Lean, Scrum	11 to 20
P4	Embedded systems	Project leader, creates COTS solutions	101k - 1m	Scrum	More than 20

4.2 Definition of Technical Debt

To get an understanding of what the participants meant when they talked about TD, they were asked to define the term.

> *Technical debt is resolving things in a way so that there will be need of refactoring the solution later, either intentionally or unintentionally. It may be due to external assumptions that were not taken into account when designing the system. You can have the perfect payment system, but if you change the currency, the system may fail* - P1.

P2 defines TD as follows:

> *If we have systems or software that lays under the level we have set as requirement, like systems out-of-support, then we have incurred technical debt as the system operates with bigger risk than what we want. [...] We do not want to run the latest version of a software, but a version less because someone has run it before and fixed the bugs.*

The definition of TD given by P3 is:

> *A product where components are not available, operating system is outdated and is not supported with updates anymore. It is expensive to maintain the product, and people with the competence might not be available anymore.*

P4 defines TD as *things that needs to be changed before you can add new functionality.*

Why TD is a problem

The literature stated that TD is not always bad [10]. With respect to that, the participants were asked why they consider TD as a problem. Both P2 and P3 explained that incurring

TD creates long-term risks.

> *"Technical debt is a problem because all the products we deliver, will incur technical debt, if developers do not care to maintain the product, and remove unhealthy dependencies along the way that you quickly get as a result of technical debt. Another problem is that people are afraid to bring up this subject. I talked with a guy from the oil sector who told me that some of their systems has 40 years of technical debt. I think that it is time for an upgrade. The world has changed radically over the past decade and will change in the future"* - P3.

P2 expressed that their organization have many legacy equipments, and systems. Additionally, their systems are using legacy technologies. Legacy solutions creates troubles in the long-run. *"An example of a system we have running on Windows 95, cannot be upgraded or replaced due to compatibility problems. You cannot install Windows 95 on a new PC, because Windows 95 will not understand the drivers that the new PC needs. There are many organizations that keeps buying systems without having a plan for how to manage it later* - P2. Furthermore, he commented that their goal is to run a stable version on a system rather than the latest version.

P4 explained that there is always a possibility of refactoring the solution. *Our code base is almost 10 years old, and big parts of the architecture is still the same as it was 10 years ago. I am pretty sure that there are some parts of the system that can be improved* - P4.

P1 commented that TD is now always bad.

> *If you create systems that does not incur technical debt, there would not be so much for developers to do later. This is the reason for agile methods being used, you create visible technical debt. Your boss might give you a task to build a house without a roof. The house looks very nice, but the day it snows, things will go bad* - P1.

4.3 Causes of Technical Debt

To identify the causes of TD, the participants were asked the reasons for TD accumulation in their project.

4.3.1 Time Pressure

Time pressure was frequently mentioned as a motivation for incurring technical debt. For example, P1 and P4 mentioned that if they did not incur technical debt, it ran the risk of not being able to deliver the solution at all.

> *Sometimes, we need to take shortcuts in order to meet a deadline. We do not take shortcuts in terms of bad code, but rather to complete functionality and*

> *integrate them into our solution. Less important tasks can be postponed* - P4.

P2 explained that lack of time and resources is why technical debt keeps growing in their systems. He explained that the resources they are given by the management, are mostly used to implement new functionality, or to fix critical errors. They do not have the time to upgrade their existing systems.

> *We cannot prioritize upgrading existing systems. The resources that are given to us, are used to implement new functionality, or to fix critical errors such as system crashes. It is not certain that technical debt is behind a system crash, but it is something we need to prioritize. Additionally, we get new projects all the time, which makes software evolution a challenge* - P2.

Moreover, P2 provided an example of a situation where they had to incur technical debt due to lack of resources. One of their systems did not work properly after upgrading the operating system it was running on. Given the lack of resources to pay down TD, they eventually had to isolate the problem by workarounds.

System Size

Another cause that was mentioned was the size of the system. Despite the fact that the system complexity keeps increasing, the system also becomes harder to change. Increased system complexity makes it easier and cheaper to incur TD in short-run. P4 explained that many developers did not know their system well enough, so change requests made by developers may not fit with the intended design.

Architectural Decisions

P1 explained a situation where an architectural decision were the reason for TD accumulation. The solution looked good to begin with, but the effects of the outcome was not optimal. The architecture design was a debt itself.

Technology Choices

P1, P2, and P3 explained that technology and framework choices, may be a source of technical debt. Both technologies and frameworks gradually become obsolete by other solutions, resulting in legacy. P3 described a situation where the core part of their the product they developed, accumulated technical debt over time. The reason was that the core part used lots of legacy solutions from external suppliers. Replacing these was expensive because it would require changes at the infrastructure level of the system. However, at some point, the project team decided to manage the technical debt by upgrading the solution using open-source solutions.

4.4 Prioritizing Technical Debt

To investigate how the different companies prioritize technical debt, the participants were asked about the current status of technical debt in the project they are currently working on, and how it impacted their projects. The responses were different, both in a positive and negative way. Both P1 and P2 revealed that requirements from the management or customers are the dominant factor in determining if the available resources should be used to address technical debt, while deadlines are the dominant factor for P4.

> *There are some visible and some invisible technical debt. Our project does have some, mostly visible that should have been fixed. The reason for it is that the product is relatively new and young, which makes it important to deliver functionality.* - P1

P2 explained that they have lots of technical debt in their system, both known and unknown. Their systems consists of solutions from external suppliers, and many of these are out-of-support. They usually fix errors by workarounds, which results in architecture violations. Legacy components are hard to change. Another problem that was mentioned is that there is no documentation or knowledge about the components, hence making it difficult to change the internal structure of the solutions.

The project P3 is currently working on has little technical debt, because their project is relatively new. The previous product he worked on had lots of technical debt, and they decided to replace that product with a new product using open-source solutions. Moreover, shortcuts are taken sometimes, but they always makes a plan to address it in the future. Test-driven development is used a lot thorough the development, making sure that problems that arise are addressed.

P4 explained that they have some technical debt in their systems, but not more than they can manage. Most of the technical debt they have accumulated are related to integration and system tests. Most of the solutions they use are developed by themselves, such as frameworks. The testing framework they are using in the current project, has not been changed lately. This has resulted in workaround in the test code. P4 also mentioned that technical debt is not bad, sometimes you need to incur some debt to meet the business goals. *"You can take a loan from the bank to buy a house, as long as you are able to pay it back"* - - P4.

Short-term vs. long-term effects

The interviews revealed that technical debt can affect the software development in the short-term. Incurring technical debts by taking shortcuts, is used to save development time and deliver a solution faster to the customers. P4 explained that technical debt is not the result of poor programming skills, but as a result of intentional decisions to trade off competing concerns during development. P1, P2, and P4 mentioned that such desicions resulted in taking shortcuts in development in reaction to business pressure. Another short-term effect of technical debt that was identified is the customer satisfaction. The customers are interested in getting the product on time. They do not care about the technical details of implementation as long as it does not directly affect the product quality. *"The customers does not care how they get electricity from the wall, they just want electricity" - P2.* Moreover, P4 mentioned that sometimes short-term solutions might outweight the future costs, depending on the implementation method.

The negative effects tended to be on the longer term, such as poor performance, increased complexity, and low maintainability. P3 brought up example where one of their systems that used legacy technologies, crashed during a scaling test. P2 mentioned that some of their systems are still running on Windows 95, and they do not have enough resources to upgrade the systems.

Incurring Technical Debt

Some of the participants revealed that TD is incurred intentionally to a certain extent. P1 explained that both developers and the management makes such decisions.

> *"Developers tries simple solution to understand the exact problem. They usually hard code some parts of the code that could have been coded dynamically. However, hard coding results in short-term benefits, but it causes long-time problems." - P1*

Both P1 and P2 mentioned that TD is also incurred intentionally. Management and the customers often comes with requirements that needs to be prioritized.

> *"Lets say that we have two systems with technical debt. If we have resources to refactor one of them, the other system needs to be postponed. These types of situations occurs frequently, and the total technical debt keeps increasing." - P2*

Moreover, P3 reveals that they do not incur technical debt intentionally. He explains technical debt is incurred intentionally based on third-party solutions that is chosen. *"If an external supplier who provides third-party solutions decides to stop supporting solutions you are dependent on, then you incur technical debt."* - P3.

Business and Software Quality

Another aspect with software development we found interesting is how business decisions affects the development team and the overall software quality. With regards to that, the participants were asked about to what extent the company invest enough resources to measure the quality of the system, and how taks from management affects technical debt.

Both P1 and P2 mentioned that business decisions do have effect on the amount of technical debt.

> *Customer specified functionality have to be prioritized for business purposes. Such decisions often causes architectural erosion. The software may work, but the solution is dirty.* - P1

> *The management is not willing to see what people are doing during work, and how much time it takes to finish a task. This leads to problems in distribution of resources.* - P2

P1 further mentioned that there is a communication gap between the team and the management . *Not everyone from the management is known with the term technical debt. If something works, do not touch it - P1.* Moreover, he mentioned that we have try convincing the management by explaining the consequences.

P2 explained that the management is interested in the risks behind technical debt issues. Management does not care about the consequences if the risk is low, as long as it does not have any big impacts for the business. If the risk high, the management invests resources on technical debt issues.

P4 remarked that the quality on their product is good, maybe too good. He states that it is hard to measure the quality of their product, so they use feedbacks and reviews from the customers as a way to measure the quality. P4 also pointed out that he wish that the team had more time to deal with technical debt. Some of their solutions could have solved in a different way.

4.5 Management of Technical Debt

Another important aspect regarding TDis how it is managed. The participants were asked how important it is to reduce TD, how what kind of tools and techniques they use to manage the overall TD. Most of the responses involved some form of communication within the development team, and with management. It included approaches such as risk management, and use of backlogs. Some of the participants also pointed out that TD can be controlled by the customer, based on the needs.

Importance of reducing TD

A common response regarding the importance of reducing TD is the products ability to remain stable.

> *Managing technical debt by upgrading the software is not necessary a goal, it is more important to use a version of the software that is stable. A small change in the software may affect many people. [...] It is important to finish a task*

> *early as possible, and to clean up the mess before you end up with too much dependencies* - P1

However, reducing TD is a challenge itself. P3 commented that the challenge is to get attention of the project leader. *"Sometimes, there is need of refactoring technical debt. Postponing technical debt problems create long-term issues. It is a challenge to get an approval from the project maanger to address technical debt. It is important to fix technical debt problems while it is fresh. Keep the code agile."* - P3.

The participants were also asked how much time the development team spend on reducing TD. P3 and P4 remarked that fixing software bugs are something they work on all the time. It takes a lot of time, but both wants an overview of all software bugs before the product is shipped to the customers. P4 stated further than bugs are not considered as TD. TD is code that needs refactoring. P1 and P2 addresses TD in parallel with development of new functionalities. Both of them spend around 25% to 30% each sprint on maintenance and evolution.

Tools and techniques

The participants stated different ways to handle TD. rRefactoring and re-engineering were commonly mentioned. P3 had to re-engineer the core of their product using open-source software. Additionally, various tools are used to keep track of the TD. The most common mentioned tools was Jira, and issue trackers. However, one of the participants commented that they do not have any special tools for TD management.

> *We do not use any special tools or techniques to manage TD. We do have a system- and a service catalog. These catalogs gives an overview over all the systems we are working with. It displays information such as hardware and software version that is used, and age of the system. Administrators use these catalogs to create tasks for the different projects that are on-going. If some software or hardware is very old, the issues are addressed by risk management* - P2.

P3 considers TD issues all the time thorough the development. By using test driven development, they are able to address TD issues relatively fast. However, issues are raised if it is something important. Their goal is to fix it the next release.

The participants were asked how they would like to manage TD. P1 mentioned that encapsulating the code might help in the short-term. Software architecture does not get affected by encapsulation. Raise an issue, and put it on the backlog. Fix it the next sprint. Both P2 and P3 would like to use a fixed budget for managing TD. Using the budget, they would prioritize the tasks based on what effects it has for the customer. *"Systems are getting older and older each day, and the quality is getting worse. You should think about replacing it" - P3.* P4 would like to spend more time on managing TD on each sprint.

Ideally, 20% of the time on each sprint.

CHAPTER 5 DISCUSSION

The purpose of this study was to do a broader review of how TD in embedded systems.

5.1 Definitions of Technical Debt

The definitions of TD given by the participants have many similarities with the literature. TD was defined in terms of code refactoring, which matches Cunningham's definition of TD [8]. Furthermore, TD was also defined in terms of using legacy solutions. McConnell classifies TD as intentional and unintentional debt [13]. By looking at the material from the interviews, it is possible to see that TD was mostly associated with intentional debt. TD was incurred intentionally based on business decisions, such as faster time-to-market. Li et al. [12] defines interest as *the extra effort needed to modify the part of the software system that contains TD*. This kind of interest is also possible to find in issues uncovered in the interviews. One example was that developers experimented different solutions to a problem by hard-coding. Solving problems by hard-coding results in short-term benefits, but refactoring is needed at a later point. Moreover, the interview data revealed that TD is not always bad. In some situations, intentional debt brought success in terms of reaching goals, such as delivering products quickly to customers. However, on the other hand, TD was incurred unintentionally. Such decisions affects the overall software quality, creating risks, e.g. poor performance.

Workaround is not something that has been mentioned by the literature, but it is enough to describe as some of the symptoms of TD. Workarounds are related to code design which is not obvious and easy to understand. It can be used to bypass difficult points in the code which may result in TD. Moreover, workarounds can be taken in other phases in software development, which makes the concept much closer to TD. As described in one of the interviews, workarounds were often taken in legacy systems.

5.2 Causes of Technical Debt

P1 and P2 revealed that requirements from the management or customers are the dominant factor in determining if the available resources should be used to address TD, while deadlines are the dominant factor.

Time pressure was revealed as a common cause for TD accumulation. Issues with time has been present in multiple articles as a reason for incurring TD [8, 16, 18, 19, 22, 24]. Moreover, Ebert et al. [7] states that companies compress schedules to a point that makes engineers compromise design-time qualities to run-time qualities. Time issues ultimately comes from business realities that needs to be met based on customer needs and market situations.

Time issues may lead to communication problems within the team, thus incurring TD intentionally. Fowler defines this situation as reckless and deliberate TD [14]. This could be due to stress or lack of knowledge. As the project moves along, the debt will eventually surface, and when it does it will suddenly need to be repaid. Nevertheless, the findings revealed that time pressure was manageable.

Furthermore, the research identified that TD is connected with many different aspects in the software development life cycle. Table 2.1 lists the subcategories of TD. We clearly see that there many similarities between. When the problem of TD is divided into subcategories, it is easier to become aware of the problems of TD. An architectural solution resulted in bad outcomes. This is very similar to architectural debt, and unintentional debt. Software architecture is one of the artifacts that is hard to change, and therefore the debt becomes much higher. Code refactoring is needed before new functionalities could be added. This is very similar to code debt [12]. The interviews also revealed some lack of tests, and that shortcuts were also taken in test code. This is known as test debt [12]. Use of older technologies and framework are related to infrastructure debt [12]. The findings also revealed lack of documentation in some of the third-party solutions, known as documentation debt [12]. By dividing TD problems into categories based on where and why they occur, the actual problem would become more specific and this easier to grasp. This makes it easier to allocate respectability for making sure that debt is correctly managed.

Poor choices of technologies and third-party solutions from external suppliers can be considered as a debt generating activity. The participants expressed how TD accumulates when suppliers are going out of business, or are unable to support the product with updates. It is very rare for companies to select a poor implementation intentionally, to get short term benefits. However, poor technology choices will eventually surface as the system grows and its bottlenecks are discovered. It is something that cannot be planned for, and requires time and effort to fix one discovered. When choosing technologies or third-party solutions from external suppliers, it is important that developers has the competence to use the technologies, or that enough documentation follows the solutions that is bought from external suppliers. One of the participants mentioned that lack of documentation led to major workarounds later on.

5.3 Incurring Technical Debt

Observations from the interviews suggests that there is a difference on incurring TD between developers and management. Project managers were more likely to incur TD, because they realized that they needed to meet their business goals, without any plans on paying it back. How they met their business goals was not important. It also revealed that if something is working, it should not be touched. Moreover, from the developer perspective, the management remains largely unaware of TD, and they cannot see the value behind TD management. It makes it hard to convince the management. This reveals that the technical communication gap between the business and development departments is high. Klinger et al. [11] found similar causes in their IBM study. Based on this, we believe that larger companies has more challenges dealing with TD issues due to complex communication structure. We believe that management with no knowledge about TD is responsible for TD accumulation in this research. Development teams may incur small amount of TD, but not more than what they are able to handle.

In particular, the participants had to not only evaluate the technical implications before making a choice, but also the impact on the delivered business value. For example, such trade-offs included release of the product in time to capture the market share.

Several studies argue that the short-term effect of time-to-market is a good thing about TD [19, 21]. The interviews revealed similar situations, where TD were used to deliver a solution faster to the customer, resulting in customer satisfaction. We believe that the customer and management will demand more over time, causing accumulation of TD, leaving them unhandled. Moreover, the long-term effects of TD tends to have more negative effects [19, 21, 23]. The findings revealed that TD in the long-term started to generate extra working hours, performance issues, scalability errors, and system failures. By taking TD, things might turn into a problem later if they are not paid back. This might be a reason for why the amount of TD has doubled since 2010 [9]. Business people often thinks that TD is something that can be incurred to reach a deadline, and just fix it later. This is very similar to reckless and deliberate debt [14].

The findings also pointed out difficulties with ongoing projects, where each project has low amount of available resources. It seems like the participants have problems on balancing TD in parallel with development of new functionality. Many of their systems does not get updated, which creates problems in the long-term.

5.4 Management of Technical Debt

The findings from the interviews revealed that even though TD is not considered in the different projects, it is still managed thorough the development and evolution by using different practices. One of the practices that was mentioned is very similar to managing risks. Like risk management, TD management is a balancing act that aims to achieve a level of good quality while mitigating its failures. This requires involvement of all the stakeholders. The impact and consequence of TD can be used to convince the stakeholders to agree upon the same strategy for managing TD. A similar strategy has been defined in the literature [19, 72]. The author believe that closing the communication gap between technical and non-technical stakeholders is important to increase the visibility of TD.

It was evident from the interviews that communication within the team played a big part in achieving higher software quality. A common practice to handle TD issues that was expressed by the participants, is to make sure that the developers are aware of the TD issues. For example, if a company knows that there are some lack of tests, or that a system has performance issues, the debt would be less significant. The different development team used a backlog to collect TD issues and their risk in parallel with new functionalities to be implemented. TD issues can be taken into account when planning feature implementation, which lessens the impact of the debt. Similar strategy has been suggested by Krutchen et. al [15]. A portfolio management strategy has been proposed in other studies, where TD is stored to backlog and development team can use that for management of TD. This backlog strategy might be beneficial in the long-run when older TD is traceable, instead of of forgotten.

The use of test-driven development was identified as a way to manage TD thorough the development. Using test-driven development makes sure that bugs are discovered in the software. This improves the quality of the software.

A common approach to keep the debt from growing over time is to conduct refactoring and re-engineering. Both refactoring and re-engineer has mentioned by the interview participants, and the literature [24]. Code refactoring was applied by developers in parallel with development. Sometimes, developers spent evenings on code refactoring. The author believes that refactoring keeps the software quality stable, and mitigates TD issues.

Picking suitable technologies, frameworks, or solutions from external suppliers for implementation needs to be considered thoroughly. It was revealed that

Besides the use of practices that has been mentioned, it would be preferable to set apart a certain amount of time during each iteration, to address and manage TD. These measures may not have a big impact for the first few iterations, but we believe that one would be able to see improvements in quality and productivity over time.

It is interesting to see that the way the embedded system developers and traditional software developers handles TD is different. The studies revealed that TD in traditional

Table 5.1: My caption

RQ1: What practices and tools for managing TD? How are they used?	
Test-driven development	By implementing and automating tests, the overall softwa
Overview of the software and hardware versions	An overview of software and hardware versions may help
Refactoring and re-engineering	Nice bro
Backlog and issue tracker	Nice bro
Risk management	Nice bro
RQ2: What are the most significant sources of TD?	
Lack of time	Not good
Business decisions	Yes man
RQ3: When should a TD be paid?	
High risk	Because it is like that
RQ4: Who is responsible for deciding whether to incur, or pay off TD?	
Project leader	Because it is like that

software projects are much higher than the embedded system projects. One of the participants re-engineered their product, using open-source technologies. This reveals that TD is taken much more seriously by the embedded system developers. One reason for this is that their solutions cannot contain any errors. However, both of the embedded systems projects have some TD in their project, but nothing more than what they are able to handle. The most important thing is that the product is stable, and the quality is good. Using open-source solutions, or developing frameworks, gives lots of benefits. One thing is that the frameworks can be reused in other projects. There are some downsides with uThe downside of developing own frameworks is that there might be a possibility for developers to be blind of their own solution.

5.5 Research Questions

Table 5.1 summarizes the findings and how they are related to the research questions.

5.6 Threats to Validity

Validity is related to how much the results can be trusted [71]. Wohlin et al. [71] states that adequate validity refers to that the results should be valid for the population of interest. First of all, the results should not be valid for the population from which the sample is drawn. Secondly, it may be of interest to generalize the results to a broader population. Wohlin et al. [71] describes four types of validity threats; internal, external, construct, and conclusion validity.

5.6.1 Internal validity

Threats to internal validity refers to the possibility of having unwanted and unanticipated causal relationships between treatment and the outcome. The relevant threats for this research are: - Maturation: The participants may be affected negatively during the interview. They could be tired, or not motivated to answer some questions. This was not the case in our interviews. - Instrumentation: This effect is caused if the artifacts of the interview is badly designed. We do not think that the interviews were badly designed, and helped the participants with additional information if needed. - Selection:

5.6.2 External Validity

External validity is the degree to which the results of an experiment can be generalized outside the experiment setting. External validity is affected by the chosen experiment design, the objects in the experiment, and the subjects chosen. There are three main risks: people, place, and time. This research is concerned about people. Four people were able to participate in the interviews, and they are not possibly not representative for the larger population. In addition, only two of the participants were from the embedded system industry.

5.6.3 Construct Validity

Threats to construct validity refer to the extent to which the experiment setting actually reflects the construct under study. Questions that were asked during the interviews may have been misunderstood because they were improperly phased. The participants may therefore answer something else. After conducting and analyzing the interviews, we realized that some questions could have been better phrased to gain deeper information about the topic. The interview guide was reviewed by the supervisor, but we did not test the interview guide before the interviews.

5.6.4 Conclusion Validity

Threats to conclusion validity are concerned with factors that can affect the ability to draw the correct conclusion about relationships in the observations [71].

- Low statistical power: We only had four respondents, which makes the statistical power very low. This is something we are aware of, and more thorough studies need to be conducted to confirm if the results have more general applicability.
- Lack of creating interview guides and conducting interviews might be another problem.

CHAPTER 6 CONCLUSION

This study has revealed that TD is something that organizations are unable to avoid during software development projects. Technical debt is not always a bad thing to take. Organizations can use technical debt as a powerful tool to reach their customers faster and gain edge over the competition in the market. However, if technical debt is not paid back in time, it might generate economic consequences and quality issues to the software. It is necessary for organizations to create a strategy plan that includes practices and tools that decrese TD.

Empirical research has been performed to verify theories, or extend existing onces, and improve practice. This study is mainly used to gain understanding about technical debt accumulation in embedded systems with the goal to find the best practices for managing technical debt. This study reveals that the way traditional software developers and embedded system developer handle technical debt is different. The reason is that embedded system developers needs to deal with multiple constraints. We also found that the awareness of developers and managers is an important factor. When they are aware of the technical debt, it is less dangerous as it can be accounted for when planning for the future. Unknown and hidden debt is more dangerous. Having the ability to predict the long-term business outcomes of short-term technical decisions would help the software practitioners to choose the right kinds of technical debt to incur.

The results of the interview are presented. The literature study was used to provide a conceptual framework and understanding about the state-of-the-art, which defined the research questions.

6.1 Future work

A platform for managing technical debt? Make an app for crawling through your source code, visualize all modules and their dependices etc? Analysing tools like Git, Jira, find their weaknesses? Perform similar but bigger case studies in the Norwegian industry, or maybe another country?

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