Technical Debt: Identify, Measure and Monitor

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Abstract—Technical Debt is a term begat by Ward Cunningham to signify the measure of adjust required to put a software into that state which it ought to have had from the earliest starting point. Often organizations need to support continuous and fast delivery of customer value both in short and a long-term perspective and later have to compromise with the quality and productivity of the software. So, a simple solution could be to repay the debts as and when they are encountered to avoid maintainability cost and subsequent delays. Therefore, it has become inevitable to identify and come up with techniques so as to know when, what and how TD items to repay. This study aims to explore on how to identify, measure and monitor technical debt using SonarQube and PMD.

Index Terms—Technical Debt, SonarQube, CodePro, Eclipse, Code Smells

I. INTRODUCTION

The notion of “technical debt” was coined by Ward Cunningham at the OOPSLA conference in 1992. The original meaning as used by Cunningham was “all the not quite right code which we postpone making it right.” [1]. With this statement he was referring to the inner quality of the code. Later the term was extended to imply all that should belong to a properly developed software system, but which was purposely left out to remain in time or in budget, system features such as error handling routines, exception conditions, security checks and backup and recovery procedures and essential documents such as the architecture design, the user guide, the data model and the updated requirement specification. All of the many security and emergency features can be left out by the developer and the users will never notice it until a problem comes up. It is however very important to deal with this left debts. Here, technical debt management (TDM) comes into picture which involves various processes and tools to identify, represent, measure, prioritize and prevent Technical debt [2].

This paper focuses on conducting these aforementioned technical management activities mainly: Identification, Representation, Estimation, Monitoring, Repayment and Prevention on two projects - Core Java 8 and Booking Manager using tools - SonarQube and PMD. Through these tools, the paper analyses projects in depth and extracts out all the possible forms of technical debt, calculates the estimation effort required to fix it, tries to monitor evolution of debt with time using appropriate technique and even proposes ways of repaying and preventing the debt in limited time period. The two projects which we have taken for analysis have been described as follows.

Project 1: Core Java 8 - Java and XML based project with a total of 1.9k lines of code; Table I depicts the details with technology Stack.

| Table I | PROJECT 1 |
|---------|-----------|
| Java LOC | 1.7K |
| XML LOC | 200 |
| Total Lines of Code | 1948 |
| Lines | 2594 |
| Statements | 509 |
| Functions | 354 |
| Classes | 93 |

Project 2: Booking Manager - A web application with a total of 70k lines of code; Table II depicts the details with technology Stack.

| Table II | PROJECT 2 |
|---------|-----------|
| JavaScript LOC | 41K |
| CSS LOC | 17K |
| JSP LOC | 4.9K |
| Java LOC | 4.5K |
| HTML LOC | 2.9K |
| XML LOC | 350 |
| Total Lines of Code | 70K |
| Lines | 94417 |
| Statements | 24646 |
| Functions | 3703 |
| Classes | 66 |

The remainder of the paper is structured as follows. Section 2 discusses about the entire Technical Debt Management activities. In Section 3, we introduce a cost model for estimating technical debt principal and also cover a new tool for managing the debt followed by conclusion.

II. MANAGING TECHNICAL DEBT USING TOOLS

A. Quality Assessment

Len Bass defines Quality Attributes [QA] as measurable or testable property of a system that is used to indicate how well the system satisfies the needs of its stakeholders. They mainly adhere to non-functional requirements.
General quality attributes include Correctness, Reliability, Adequacy, Learnability, Robustness, Maintainability, Readability, Extensibility, Testability, Efficiency and Portability. SonarQube allows accessing of three main quality attributes - Reliability, Maintainability and Security.

We assess the above-mentioned attributes using SonarQube tool as follows:

- **Reliability**: It is measured as the probability of a system being fully functional for a specified period of time without fail [3].
- **Maintainability**: It measures how much capable the system is to bring any kind of change with ease. The change can be due to change of requirements, fixing of errors or implementation of new features [3].
- **Security**: It measures the capability of the system to withstand any sort of malicious actions and prevent loss of information [3].

**Project 1: Core Java 8**

- **Reliability**: Using SonarQube, it has been observed that there is at least one critical bug and overall, there are 2 bugs. It would take around 10 minutes (estimated time) to fix these reliability issues (shown in Fig. 2) [4]. Here the red coloured bubble indicates critical bug and green one indicates minor bug.
- **Security**: With respect to Security, there are 3 vulnerabilities observed out of which there one is a blocker vulnerability which can make the whole application unstable during production. It would take 45 minutes to fix all the vulnerability issues (depicted in Fig. 3) [4].
- **Maintainability**: As far as Maintainability is concerned, there are 148 smells with ratio between the cost to develop the software and the cost to fix it (i.e., the technical debt ratio) is 2.3% as depicted in Fig. 4. It would take 2 days and 6 hours to fix all the debts [4].

**Project 2: Booking Manager**

- **Reliability**: Using SonarQube, it has been observed that there are 153 bugs out of which 43 are blocker, 6 are critical, a are major and a are minor bugs. It would take around 1 day and 7 hours (estimated time) to fix these reliability issues (shown in Fig. 6) [4]. The red coloured bubbles are the worst bugs and there is 2 classes which are containing 1 of those bugs each.
- **Security**: With respect to Security, there are 165 vulnerabilities observed out of which there are 4 blocker
vulnerability which can make the whole application unstable during production and 161 minor ones. It would take 5 days and 7 hours to fix all the vulnerability issues (depicted in Fig. 7) [4].

**Maintainability:** As far as Maintainability is concerned, there are 723 smells with ratio between the cost to develop the software and the cost to fix it (i.e., the technical debt ratio) is 0.3% as depicted in Fig. 8. It would take 14 days to fix all the debts [4].

**B. Technical Debt Identification**

**Quality Assessment:** SonarQube provides a quality model which implements SQALE methodology (Software Quality Assessment based on Life cycle Expectations). This method mainly focuses on maintainability issues rather than other risks involved in the project. However, as far as our projects are concerned, we have observed that complexity of code and maintainability was good in all. So, we assessed quality on the basis of bugs and vulnerabilities each possessed. Our first project contains around 2 critical bugs and 3 blocker vulnerabilities. Whereas, second project contains 21 blocker bugs, 153 blocker bugs and 169 blocker bugs respectively. So, overall, ‘Booking Manager’ has been considered with the worst Quality.

**Project 1: Core Java 8**

- **Bugs:** Refer figure 9; depicts 1 critical and 1 minor debt.
• Vulnerabilities: Refer figure 10; depicts 3 minor debt.

Fig. 10. Project 1 - Vulnerabilities.

• Code Smells: Refer figure 11 and 12; depicts 4 critical, 2 blocker, 63 major and 1 minor debt.

Fig. 11. Project 1 - Code Smells.

Fig. 12. Project 1 - Code Smells.

• Security Hotspot: Refer figure 13; depicts 2 debt termed as security hotspot.

Fig. 13. Project 1 - Security Hotspot.

• Duplication: Refer figure 14 and 15; depicts duplication density throughout the project.

Fig. 14. Project 1 - Duplication.

Fig. 15. Project 1 - Duplication (Sample Class).

• Documentation: Refer figure 16; depicts documentation (comments) throughout the project.

Fig. 16. Project 1 - Comments.

Project 2: Booking Manager

• Bugs: Refer figure 17 and 18; depicts one critical, 43 blocker, 51 major and 1 minor debt.

• Vulnerabilities: Refer figure 18 and 19; depicts 4 blocker and 161 minor debt.

• Code Smells: Refer figure 20 and 21; depicts 64 critical, 6 blocker, 301 major and 331 minor debt.

• Security Hotspot: Refer figure 21 and 22; depicts 32
critical debt termed as security hotspot.

- Duplication: Refer figure 23 and 24; depicts duplication density throughout the project.
- Documentation: Refer figure 25; depicts documentation (comments) throughout the project.

**Mapping of TD Items and Dimensions:** TD items identified above have been mapped to their respective dimension; refer table III.
TABLE III

| Project            | TD Items                  | TD Dimension          |
|--------------------|---------------------------|-----------------------|
| Core Java 8        | Bugs                      | Code Debt             |
|                    | Vulnerabilities           | Code Debt             |
|                    | Code Smells               | Code Debt             |
|                    | Security Hotspot          | Code Debt             |
|                    | JUnit Test coverage       | Test Debt             |
|                    | Comments Completeness     | Documentation Debt    |
| Booking Manager    | Bugs                      | Code Debt             |
|                    | Vulnerabilities           | Code Debt             |
|                    | Code Smells               | Code Debt             |
|                    | Security Hotspot          | Code Debt             |
|                    | JUnit Test coverage       | Test Debt             |
|                    | Comments Completeness     | Documentation Debt    |

C. Technical Debt Representation

**Project 1: Core Java 8** Refer table 4, 5 and 6 for TD Representation.

**Project 2: Booking Manager** Refer table 7, 8, 9, 10 and 11 for TD Representation.

TABLE IV

| ID | TD REPRESENTATION                  |
|----|-----------------------------------|
| 1.1| Name: Bug                         |
|    | Location: src/.../optional/OrElseAndOrElseGet.java |
|    | Responsible/author: Not Assigned  |
|    | Dimension: Code Debt              |
|    | Date/time: Apr 14, 2019 15:43:18  |
|    | Context: Random objects should be reused |
|    | Propagation rule: May produce non accepted results; JDK dependent |
|    | Intentionality: N/A               |

TABLE V

| ID | TD REPRESENTATION                  |
|----|-----------------------------------|
| 1.2| Name: Code Smell                   |
|    | Location: src/.../AdderImpl.java  |
|    | Responsible/author: Not Assigned  |
|    | Dimension: Code Debt              |
|    | Date/time: Apr 14, 2019 15:23:18  |
|    | Context: Methods should not be empty |
|    | Propagation rule: Can cause unexpected behavior in production |
|    | Intentionality: No                |

TABLE VI

| ID | TD REPRESENTATION                  |
|----|-----------------------------------|
| 1.3| Name: Code Smell                   |
|    | Location: src/.../application/Application.java |
|    | Responsible/author: Not Assigned  |
|    | Dimension: Code Debt              |
|    | Date/time: Apr 14, 2019 15:37:18  |
|    | Context: Logging                  |
|    | Propagation rule: Useful for debugging |
|    | Intentionality: N/A               |

TABLE VII

| ID | TD REPRESENTATION                  |
|----|-----------------------------------|
| 2.1| Name: Bug                         |
|    | Location: src/.../wulian2front/DevicesJsonServlet.java |
|    | Responsible/author: Not Assigned  |
|    | Dimension: Code Debt              |
|    | Date/time: Apr 14, 2019 15:43:18  |
|    | Context: Failure to properly close resources |
|    | Propagation rule: This can lead to denial of service |
|    | Intentionality: No                |

TABLE VIII

| ID | TD REPRESENTATION                  |
|----|-----------------------------------|
| 2.2| Name: Bug                         |
|    | Location: src/.../DataTables-1.10.6/js/jquery.dataTables.js |
|    | Responsible/author: Not Assigned  |
|    | Dimension: Code Debt              |
|    | Date/time: Apr 14, 2019 15:23:18  |
|    | Context: Mixing up the order of operations |
|    | Propagation rule: May hamper the overall behaviour |
|    | Intentionality: No                |
TABLE IX
TD REPRESENTATION

| ID   | 2.3 |
|------|-----|
| Name | Bug |
| Location | src/.../action/GetRoomInfoAction.java |
| Responsible/author | Not Assigned |
| Dimension | Code Debt |
| Date/time | Apr 14, 2019 15:37:18 |
| Context | Non-serializable objects |
| Propagation rule | Objects in the session can throw error |
| Intentionality | No |

TABLE X
TD REPRESENTATION

| ID   | 2.4 |
|------|-----|
| Name | Security Hotspot |
| Location | src/.../wulian2front/DevicesJsonServlet.java |
| Responsible/author | Not Assigned |
| Dimension | Code Debt |
| Date/time | Apr 15, 2019 15:43:18 |
| Context | File Handling |
| Propagation rule | Exposing a file’s content is dangerous |
| Intentionality | No |

TABLE XI
TD REPRESENTATION

| ID   | 2.5 |
|------|-----|
| Name | Security Hotspot |
| Location | src/.../ccc/bm/wulian2front/DevicesJsonServlet.java |
| Responsible/author | Not Assigned |
| Dimension | Code Debt |
| Date/time | Apr 14, 2019 15:23:18 |
| Context | Dynamic Code Execution |
| Propagation rule | Dangerous to execute unknown code |
| Intentionality | No |

Please Note: For some TD items, Intentionality is N/A since the intentional debts observed are of documentation debt only. Also, for the propagation rules it’s only the blocker code smells that mainly affects the whole project so for the rest of the TD items it is assumed to be N/A. This has been followed in Appendix as well.

D. Technical debt estimation

Technical debt estimation basically implies the effort required to fix the identified debts. We here, use SonarQube to estimate the efforts required for each of the different TD items [3] [6].

Project 1: Core Java 8 Refer figure 28, 29 and 30 for the estimates.

Project 2: Booking Manager Refer figure 31, 32 and 33 for the estimates.

E. Technical Debt Monitoring

It is one of the Technical Debt management activity which controls the changes in the cost and benefit of the remaining debt items as the time passes by. There are various approaches to monitor TD:

Threshold-based approach: specify thresholds for TD related quality metrics, and issue warnings if these thresholds
### Technical Debt Repayment

Technical debt repayment is one of significant TD Management techniques because paying back the principal will keep technical debt under control. It also allows the programmer to focus on other issues such as developing the software or adding new features. In addition, it will prevent TD from being accumulated and keep paying the interest for a long time. There are several techniques to repay TD such as Refactoring, Rewriting, and Automation. After analyzing TD identified in each project, in this section, we proposed aforementioned techniques to repay the debt occurred in each project.

#### Project 1: Core Java
- Figure 36, 37, 38, 39, 40, and 41 shows TD item and refactoring techniques suggested by SonarQube.

#### Project 2: Booking Manager
- Figure 42, 43, 44, and 45 shows TD item and refactoring techniques suggested by SonarQube.
Technical debt prevention is one of the Technical Debt Management activity that prevents potential TD from being incurred. However, there is no such tool for TD prevention because it is mainly supported by software development process improvement. Nevertheless, there is a tool named Umple.
which helps to prevent TD by supporting model-oriented programming. There are four different approaches to prevent TD potentially:

**Development process improvement**: improve current development processes to prevent the occurrences of certain types of TD. Development process can notably be improved by adopting continuous integration in the software development process.

**Architecture decision-making support**: evaluate potential TD caused by different architecture design options, and then choose the option with less potential TD.

**Life Cycle cost planning**: develop cost-effective plans that look at the system throughout the life cycle to minimize overall TD of the system.

**Human factors analysis**: cultivate a culture that minimizes the unintentional TD caused by human factors (e.g., indifference and ignorance).

**H. Discussion**

Managing Technical Debt is a difficult and a subjective task. Each one would have a different approach. We here used SonarQube, PMD (at times) and Code Analytix to perform TD Management activities. We learned that no one tool can get us holistic view of all the activities. Also, different tools shows up different results. Hence, there is no clear set guidelines as to when and which tool one should go for. Issue wise, we had issues while running SonarQube due to incompatible Java version. Another issue we faced was with the projects analyzed. As we didn’t have much insights about the project, analyzing some TD items was difficult. Using tools in combination, we overcome the very first issue. Also, the choice of the tools is purely subjective and project dependent decision. Referring to official documentation of SonarQube and Java helped to resolve all the technical issues faced while installing and analyzing projects.

This study turned out to be interesting as we got an insight about how TDM activities are conducted in a company for one or more projects. We explored some tools and got an understanding of what and how each tool serves role in Technical debt management. Nevertheless, this project required a lot of research about the tools, lot of time was utilized in dealing with plugin based tools like PMD to get an overview of the TD items it caters since it lacks representation of the complete technical debt.

**III. PRINCIPAL CALCULATION MODEL & TOOLS**

**A. TD principal calculation model**

There are mainly three approaches that estimate Technical Debt Principal in a given system. out of these, we chose the method supported by SonarQube TD plugin. Our TD Principal focuses on the following based on the TD items we identified so far:

**Duplication** : Estimated effort required to remove duplicates from the code.

**Bugs** : Estimated effort to fix bug issues.

**Vulnerabilities** : Estimated time/effort to fix vulnerability issues.

**Code smells** : Effort to fix all maintainability issues.

**Comments** : Estimated effort associated with documenting the undocumented portions of the API.

**Coverage** : effort required to bring coverage from 0% to 80%.

**Complexity** : total estimated effort needed to split every method and every class (of those requiring such a split).

**Design** : estimated effort associated with cutting all existing
edges between files.
TD is summation of all the mentioned dimensions above.

Where,
Duplication = (cost to fix one block) * (duplicated blocks) *(US$ per hour)

Violations = (cost to fix high severity violations * number of high severity violations + cost to fix medium severity violation * number of medium severity violations + cost to fix low severity violations * number of low severity violations) * (US$ per hour)

Comments = (cost to comment one API) * (public undocumented API) * (US$ per hour)

Coverage = (cost to cover uncovered lines of code) * (uncovered lines) * (US$ per hour)

Design = (cost to cut an edge between two files * package edges weight) * (US$ per hour)

Complexity = (cost to split a method) * (function complexity distribution \( \geq 8 \)) + (cost to split a class) * (class complexity distribution \( \geq 60 \))

Here, we are considering two types of complexities - cyclomatic and cognitive complexity. While cyclomatic complexity determines the difficulty of testing your code, cognitive complexity determines the difficulty of reading and understanding the code.

Default Values for Parameters:

| Cost                                   | Default Value (in dollars) |
|----------------------------------------|----------------------------|
| cost to fix one block                  | 2                          |
| cost to fix high severity violations   | 0.5                        |
| cost to fix medium severity violations | 0.3                        |
| cost to fix low severity violations    | 0.1                        |
| cost to comment one API                | 0.2                        |
| cost to cover uncovered lines of code | 0.2                        |
| cost to cut an edge between two files  | 4                          |
| cost to split a method                 | 0.5                        |
| cost to split a class                  | 8                          |

B. More tools to manage Technical debt - CodePro Analytix

CodePro AnalytiX is a comprehensive automated software code quality and security analysis tool which is tightly integrated into Eclipse, it guarantees superior code quality, maximum developer productivity and Project maintainability by adding its potential features like code audit, metrics, testing and team collaboration while giving continuous quality improvement throughout the entire code development cycle. It is used by companies to save time, money and manage technical debts [7].

Features of CodePro Analytix: Dynamic, extensible tools that detect, report and repair instances of non-compliance with pre-defined coding standards and style conventions. It detects and corrects code quality issues automatically. It helps in distribution of quality standards across development team. It gives higher quality software product. CodePro Analytix contains 960+ audit rules and matrices and 350+ quick fixes. It also allows customization of rules, Metrics sets and rule sets. It provides dependency analysis and provides report for the same. It generates multiple report forms (HTML, XML, CSV). It contains Javadoc analysis and repair functionality. Dependency Analysis: Analyzes dependencies between projects, packages and classes [5] [7] [7].

Installation steps for CodePro Analytix in Eclipse:
Step 1: Open Eclipse IDE - Goto Help - Install new Software
Step 2: Enter the URL and then click on Add button. Select CodePro from the options
Step 3: Accept the terms and finish the installation.

Analysis of project by using CodePro Analytix:
Code analysis is very important feature of CodePro Analytix, which can be performed through the code auditing feature. There are over 770 java-based coding rules in more than 30 categories built into a tool. Audit run for this area
and determine the location where the code has a problem. Running code audit on all modules show some interesting code violations. The Audit View shows the explanation and recommendation for each violation as well [7].

Please note, there are no JUnit coverage in Project 2.

**CONCLUSION**

We studied SonarQube in detail and applied the tool on our chosen projects. To start with, we analyzed various quality attributes like reliability, maintainability and security. Next, we studied all the TD Management activities such as Identification, Measuring, Monitoring, Repayment and Prevention. We used SonarQube to perform each of this activity in depth. In addition to the given tools we also studied CodePro Analytix and gained more insights. Finally, the tools we used are found to be effective and give important information about technical debt. There are a lot of advantages of these tools but still there are few limitations. We can say no tool is perfect in finding all kinds of technical debts. Also, our work didn’t include environmental and requirement debts.
Fig. 52. Dependency Analysis - Project 1.

Fig. 53. Dependency Analysis - Project 2.

Fig. 54. Code Coverage - Project 1.
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APPENDIX

Technical Debt Identification

Project 1: Core Java 8 - Test Debt

Fig. 55. Project 1: Core Java 8 - Test Debt.

Fig. 56. Project 1: Core Java 8 - Violation Overview using PMD.

TABLE XIII
TD REPRESENTATION - PROJECT 1

| ID   | Name                  | Code Smell | Location                        | Responsible/author | Dimension | Date/time | Context | Intentionality |
|------|-----------------------|------------|---------------------------------|--------------------|-----------|-----------|---------|---------------|
| 1.4  | Core Java 8 (1)      |            | src/../doublecolon/ComputerUtils.java | Not Assigned        | Code Debt | Apr 14, 2019 15:37:18 | Utility classes should not have public constructors | Unintentional |

TABLE XIV
TD REPRESENTATION - PROJECT 1

| ID   | Name                  | Code Smell | Location                        | Responsible/author | Dimension | Date/time | Context | Intentionality |
|------|-----------------------|------------|---------------------------------|--------------------|-----------|-----------|---------|---------------|
| 1.5  | Core Java 8 (2)      |            | src/../doublecolon/MacbookPro.java | Not Assigned        | Code Debt | Apr 14, 2019 15:37:18 | ’Preconditions’ and logging arguments | Unintentional |

TABLE XV
TD REPRESENTATION - PROJECT 1

| ID   | Name                  | Code Smell | Location                        | Responsible/author | Dimension | Date/time | Context | Intentionality |
|------|-----------------------|------------|---------------------------------|--------------------|-----------|-----------|---------|---------------|
| 1.6  | Core Java 8 (3)      |            | src/.../LambdaExceptionWrappers.java | Not Assigned        | Code Debt | Apr 14, 2019 15:37:18 | Generic exceptions | Unintentional |