

**Using user-based activity logging and analysis to prioritise software maintenance**

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Dissertation submitted in fulfilment of the requirements for the degree *Master of Engineering in Computer and Electronic* *Engineering* at the North West University

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| Examination: | Nov 2023 |
| Student number: | 25899880 |

Abstract

Title: Using user-based activity logging and analysis to prioritise software maintenance

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Degree: Master of Engineering in Computer and Electronic Engineering

Keywords: Software maintenance, logging mechanism, user activities, system utili-sation, maintenance prioritisation, Web-based

Software maintenance is continuous and a form of the software development process. Re-search suggests that 15% of the total development cost should be allocated to implementing a maintenance model for a software system. Unused components or non-compliant software will increase over the project’s life cycle. The discontinuation of some systems may reduce the resources required to maintain the system. Deciding how many resources to allocate for maintenance for each subsystem can be challenging without a suitable software maintenance prioritisation method.

Software logging is crucial to improve software maintenance by troubleshooting. In extensive software systems, logging enables the development team to monitor specific events. A suit-able logging mechanism can identify the most used for each software system. In web-based applications, the user interactions with each software system can be determined by capturing user-based events.

Analysing logs can be challenging if the logging mechanism does not track the desired user-based events. Developing a method to track these events for a specific purpose is more efficient and reliable. Therefore, integrate the method to create a logging mechanism and create a log analysis for prioritisation of software maintenance.

The method for this study was split into two main functional parts, the logging mechanism and the log analysis. The logging mechanism captures any user activity on the software systems. The characteristics of these user-based events, user types, and user-based attributes are defined. The logging points in strategic locations in the software systems capture the log attributes. HTTP requests have more significant and relevant data about a specific event. Additional data from request parameters are obtained as metadata that can be used for system diagnostic purposes

For the log analysis for this study, log quality is monitored to ensure that event logs are con-sistent, reliable, and complete to create prioritisation recommendations for software mainte-nance. A test system validates the method’s work, making modifications where needed. The results of this method applied to case studies proved that the method can prioritise software maintenance. The results are evaluated and discussed, and positive and negative points are highlighted by implementing this method.

Acknowledgements

I want to express my heartfelt thanks to my parents, Albert and Mirriam Scheepers, for their unwavering support through all these years. Your love and encouragement have been my guiding light, and I couldn’t have done it without you. I also want to extend my gratitude to my brothers, Tyron and Danzel, and my sister, Claudia, for always being there with me on this journey.

I’m also deeply grateful to ETA-Operations (Pty) Ltd for granting me the opportunity to

pursue my master’s degree through an IPGIP-bursary under the guidance of Prof. E.H.

Mathews.

I want to extend my sincere appreciation to Dr. Jaco Pronsloo, my supervisor, and Dr.

Jano de Meyer, my mentor, who helped me during my most difficult times. Your unwavering

support and guidance were invaluable, and I am thankful for your mentorship. A special thanks also goes to my previous supervisors, Dr. Pieter Goosen and Dr. Jan Vosloo, for getting me started on my Master’s journey.

I would also like to express my gratitude to Megan Lowes for her meticulous proofreading of my work and her incredible patience with me. Your assistance was invaluable in the final

stages of my journey.

Lastly, I want to thank my colleagues and friends for their support and encouragement throughout this journey. Your friendship has made this experience even more memorable and meaningful

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Nomenclature

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
|  |  | Abbreviations |  |  |
|  |  |  | |  |
|  | Acronym | Full Form | | |
|  |  |  | |  |
|  |  |  | |  |
| AJAX | | Asynchronous JavaScript and XML | | |
|  |  |  |  |  |
| BI | | Business Intelligence |  |  |
|  |  |  |  |  |
| CPU | | Central Processing Unit |  |  |
|  |  |  |  |  |
| ENUM | | Enumeration |  |  |
|  |  |  |  |  |
| ERD | | Entity Relationship Diagram |  |  |
|  |  |  |  |  |
| F/R | | Functional Requirements |  |  |
|  |  |  | |  |
| HTML | | HyperText Markup Language | | |
|  |  |  | |  |
| IEEE | | Institute of Electrical and Electronics Engineers | | |
|  |  |  |  |  |
| I/O | | Input/Output |  |  |
|  |  |  |  |  |
| INT | | Integer |  |  |
|  |  |  |  |  |
| LCP | | Life-Cycle Phases |  |  |
|  |  |  |  |  |
| MVC | | Model-View-Controller |  |  |
|  |  |  |  |  |
| OSS | | Open-source software |  |  |
|  |  |  |  |  |
| PHP | | Hypertext Preprocessor |  |  |
|  |  |  | |  |
| SDLC | | Software Development Life Cycle | | |
|  |  |  |  |  |
| URI | | Uniform Resource Identifier |  |  |
|  |  |  |  |  |
| URL | | Uniform Resource Locator |  |  |
|  |  |  |  |  |
| VARCHAR | | Variable Character |  |  |
|  |  |  |  |  |
| JSON | | JavaScript Object Notation |  |  |
|  |  |  |  |  |
|  |  |  |  |  |
|  |  | Units: |  |  |
|  |  |  |  |  |
|  | Abbreviation | Name | Description | |
|  |  |  |  |  |
|  | kVAr | Kilovolt-ampere | Reactive power | |
|  |  |  |  |  |

Chapter 1

Introduction

A white number one on a white background

Description automatically generated

Using user-based activity logging and analysis to prioritise software maintenance

Cornelius Scheepers

1

Chapter 1. Introduction

1.1 Background

In the modern era, most businesses use digital products and services to maximise their profits [1]. This increases the need to create new, innovative software systems to meet the specific needs of users. Software projects can vary in size, type, and degree of difficulty of implementation. Therefore, the quality of software is crucial [2]. There are defined attributes and characteristics that software systems need to adhere to, which are termed software quality [2].

Using a System Development Life Cycle (SDLC)1 methodology, such as the Agile Software Development methodology, is crucial to making the software development process efficient and predictable. This enforces various degrees of discipline in the software development process to ensure that the quality of the software is acceptable for the user’s requirements [2, 3]. Table 1.1 lists the Life-Cycle Phases (LCP) of the SDLCs.

Table 1.1: System Development Life Cycle Phases [2]

|  |  |
| --- | --- |
| Life-Cycle phase | Description |
|  |  |
|  |  |
| Initiation | The sponsor identifies a need or an opportunity, creating a con- |
|  | cept proposal for the new opportunity. This new opportunity |
|  | will require a software solution to make the project successful |
|  | for all stakeholders. |
|  |  |
| System Concept De- | In this phase, the feasibility and suitability of the concept pro- |
| velopment Phase | posal are reviewed and need approval. The Systems Boundary |
|  | Document identifies the scope and requires additional approval |
|  | before implementing the planning phases. |
|  |  |
| Planning | The project management plan and other documents are created |
|  | in the planning phase. These documents define the available |
|  | budget, project resources, activities, schedules, tools, and re- |
|  | views. |
|  |  |
| Requirements Analy- | In this phase, user requirements are defined and analysed. The |
| sis | functional requirements are created with the Functional Re- |
|  | quirement Document. Non-functional requirements are also |
|  | defined to ensure that the software system operations will not |
|  | deviate from working within the non-functional specifications. |
|  | These nonfunctional requirements can be negative and costly |
|  | to the software system’s operations and potentially reduce its |
|  | usability or life cycle. |
|  |  |
| Design | In this stage, the detailed requirements are completed in the |
|  | System Design Document, which describes the detailed logic |
|  | specifications of the software system. |
|  |  |
|  |  |
|  | Continued on next page |

* System Development Life Cycle (SDLC) highlights certain procedures, practices and guidelines for software development. Refer to the source: DOJ, ”SDLC”, DOJ, Available: [https://www.justice.gov/](https://www.justice.gov/archive/jmd/irm/lifecycle/ch1.htm) [archive/jmd/irm/lifecycle/ch1.htm](https://www.justice.gov/archive/jmd/irm/lifecycle/ch1.htm) (visited on 2023-07-25)

Using user-based activity logging and analysis to prioritise software maintenance 2

|  |  |
| --- | --- |
|  | Chapter 1. Introduction |
|  |  |
|  | Table 1.1: (continued from previous page) |
|  |  |
| Life-Cycle phase | Description |
|  |  |
| Development | In this phase, the design specifications are converted into an |
|  | executable software system. This also includes acquiring other |
|  | third-party or internal software to install in certain software |
|  | environments, creating and testing databases, performing test |
|  | readiness reviews, and other software development activities. |
|  |  |
| Integration and Test | In this phase, the software systems are integrated and system- |
|  | atically tested to examine whether they meet all functional re- |
|  | quirements and other accreditation activities for the approval of |
|  | the test and the approval of the user using user tests. |
|  |  |
| Implementation | This phase is initiated after the software systems pass the test- |
|  | ing phase and are accepted by the users. This phase contains |
|  | the implementation of the software system in a production en- |
|  | vironment and the deployment of the production version of the |
|  | software. This phase continues until the software systems are |
|  | operational in a final production environment. |

Operations and Main- In this phase, the performance of the software system is contin-

|  |  |
| --- | --- |
| tenance | uously monitored according to the defined user requirements. |
|  | Any additional modifications after the initial software develop- |
|  | ment are done here, and other tasks are needed to maintain the |
|  | software system. Post-Implementation and In-Process Reviews |
|  | for the software system form part of the documentation for this |
|  | LCP. |
| Disposition | This phase is for any disposition activities to terminate the soft- |
|  | ware system. Important data is also preserved to reactivate the |
|  | software system in the future. Any other termination policies |
|  | and activities must be defined and documented. This ensures |
|  | that the termination of the software system is performed cor- |
|  | rectly and completed, and that the correct data are perma- |
|  | nently removed or preserved. |
|  |  |

There are various adaptations of the LCP listed in Table 1.1 for different SDLC methodolo-gies used in the software development industry [3]. The planning phases of the SDLC should be well-documented, and the software architecture should be well structured and defined to make it easier to implement the LCP related to development and maintenance [4].

Each LCP ensures that the software development is correctly implemented if it is part of the adopted SDLC methodology. The SDLC methodology is implemented for the entire life cycle of the software system. There will be alterations to the SDLC methodology to meet any new design and development requirements.

In the actual implementation of the SDLC methodology, some design patterns may drift away from the initial software designs [5]. This can be due to unforeseen issues during

Using user-based activity logging and analysis to prioritise software maintenance 3

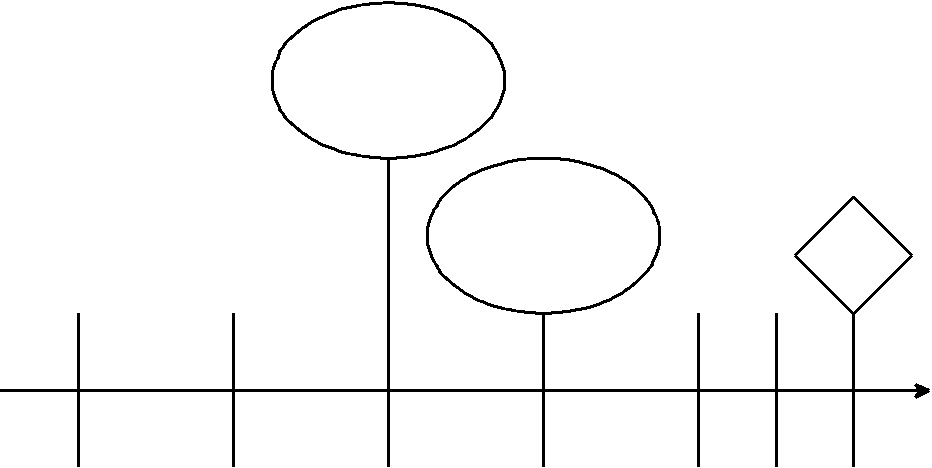
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the development phase due to time or other resource constraints. The initial design of the software system may also not be flexible enough for any newer modifications that can also occur in the operational and maintenance phase.

In both situations, software development could provide workarounds or shortcuts that resolve the identified problems. These short-term benefits will not always translate to good long-term software quality due to prioritising functionality above good software design patterns. The decrease in software code quality is caused by technical debt if the software system was not implemented with suitable SDLC practises [5, 6].

Technical debt can be defined as technical compromises that software engineers and develop-ers will introduce to a software system for short-term goals that can increase the complexity and sustainability of the system in the long term [1, 7]. With the need to consistently de-liver software systems for more innovative, complex, and larger software systems, the risk of introducing technical debt also increases [2, 5].

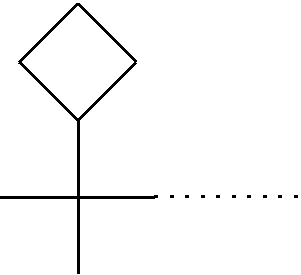
The operations and maintenance phase of the software system is where technical debt is usually resolved or reduced to some extent. More technical debt will increase the maintenance efforts that need to be implemented to offset the negative impact that short-term goals can potentially create. Figure 1.1 represents the repayment of technical debt to the software system during its entire life cycle.



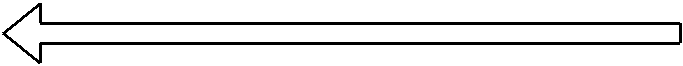
Main deployment

deadline

|  |  |  |
| --- | --- | --- |
| Project start |  | Project end |
|  | TD ticket |  |
|  | priortisation |  |
| pre | meeting | TDT |
| deployment(s) |  | deployments |



|  |  |  |
| --- | --- | --- |
| Main development phase | Initial use phase | TD repayment phase |
|  |  |  |



Feedback loop of team behaviour

Figure 1.1: Project plan with included technical debt repayment phase [8]

Technical debt will always be present to some degree in software systems throughout their life cycle [8]. In Figure 1.1, technical debt repayment refers to software development activities that aim to resolve technical debt issues identified after the initial deployment of the software system.

Tickets are assigned to identified problems caused by technical debt when functional require-ments are reviewed in the initial use phase. The technical debt tickets are then prioritised based on their importance and utilisation. This ensures that the development efforts in the Operations and Maintenance phase are efficiently implemented to ensure user satisfaction and sustainability of the software system.

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According to the United States Department of Commerce, the software maintenance efforts of the SDLC Operations and Maintenance LCP in Table 1.1 will contribute approximately 60% − 80% of the total development cost for the entire life cycle of the software system [4, 9, 10]. Therefore, following good software maintenance practises is necessary to avoid [6]:

* additional software and hardware resources needed that can be costly,
* software quality issues,
* making any new modifications impossible without negatively impacting existing soft-ware features or systems,
* is shortening the usability of the software system, which can lead to earlier termination of the software system.

Maintenance of the LCP operation and maintenance software is essential in software devel-opment. It can directly reduce the cost and effort to create new software systems or modify them in the future and minimise technical debt [6, 11].

1.2 State of the art

1.2.1 Software maintenance

Maintenance of software systems is a continuous process and a reduced form of software development aimed at modifying software systems while preserving their integrity for current and future operations [4,12,13]. Software maintenance aims to improve the software in terms of the following:

* **correctness**: software systems always have some defects or faults that must be cor-rected to improve their traceability, consistency and completeness.
* **enhancements**: existing software components need to be improved to adapt to changes in user requirements and improve system performance and sustainability.

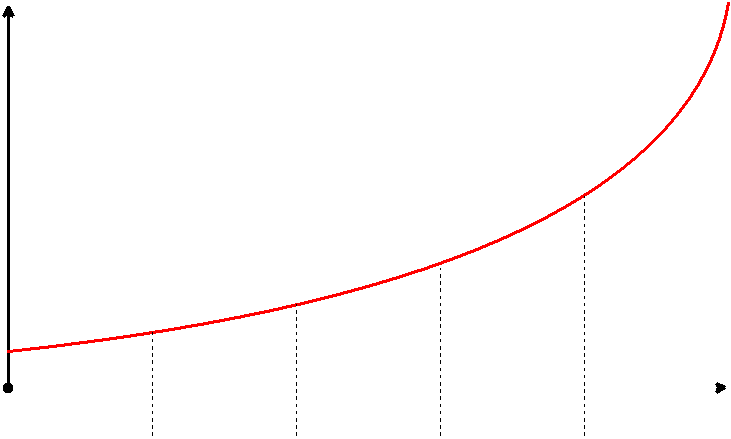
A defined maintenance process must be followed to improve the accuracy and enhancements of the software. According to the IEEE Standard 1219 2, software maintenance includes the following phases [14–16]:

* Identifying the problem or modification and classifying it.
* Analysing the identification of the maintenance issue.
* Designing the solution to implement maintenance.
* Implementing the solution.
* System testing of the modified software system.
* Acceptance testing on the fully integrated system.
* Meeting the delivery requirements of the modified software system.
* IEEE Standards documents are developed within the Technical Committees of the IEEE Societies, and the Standards Coordinating Committees of the IEEE Standards Board [14].

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These maintenance phases of software cannot be omitted when the software system is still active. Software maintenance must be implemented to ensure that the software system can keep up with the new user requirements defined in the future. This will increase the maintenance required on new and old systems [15, 17, 18]. Figure 1.2 represents the total cost of implementing software maintenance.



|  |
| --- |
| Resource Costs |

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| Requirements | Design | Implementation | Testing | Operation and |  |
| Maintenance |  |
|  |  |  |  |  |

Figure 1.2: Resource cost of software maintenance [9]

In Figure 1.2, the total cost of the resources will increase significantly as the need for software maintenance increases. As previously stated, software maintenance can use up to 60%−80% of the unlimited resources, and it can be expected that most of the resource costs will be for the Operations and Maintenance LCP. These software resources that cost both money and time can include the following:

* software developers and other support staff involved in the software maintenance pro-cess,
* software development tools and services such as testing software environments, analysis tools, online surveys, software fault reporting systems, etc.

**Software maintenance types**

Maintenance problems or modifications are regularly identified and addressed based on an initial priority ranking. This priority classification is determined using classification models to determine what type of maintenance is needed, as described in Table 1.2 for the Operations and Maintenance LCP of Table 1.1 [10, 19].

According to Table 1.2, the types of adaptive and perfective maintenance account for ap-proximately 75% of the total maintenance of software development for the Operations and Maintenance LCP. These maintenance types address technical debt issues that may arise after the initial software deployment. They are typically identified through technical debt tickets, as shown in Figure 1.1. Adaptive and perfective maintenance is critical to ensure that the software system continues to evolve and improve, meeting the system requirements to ensure that it is usable and feasible [20].

It is inevitable that there will always be software faults or defects that require repair and deployment. These maintenance software changes are usually minor and aim to increase the accuracy of the software system. Preventive measures may also be taken to avoid technical debt issues in the future through preventive maintenance efforts.

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|  |  |  |
| --- | --- | --- |
|  |  | Chapter 1. Introduction |
|  |  |  |
|  | Table 1.2: Software maintenance types [15, 19] |  |
|  |  |  |
| Maintenance type | Description | % of maintenance activities |
|  |  |  |
|  |  |  |
| Adaptive | Adaptive maintenance in software systems is | ≈ 37.5% |
|  | any modification or enhancements to keep it |  |
|  | usable with a changing or changed software |  |
|  | environment. |  |
|  |  |  |
| Perfective | Perfective maintenance are modifications | ≈ 37.5% |
|  | made based on the change of the end-user |  |
|  | new requirements. It can also improve the |  |
|  | performance or maintainability of the |  |
|  | software system in its life cycle. |  |
|  |  |  |
| Corrective | Corrective maintenance are improvements | ≈ 20% |
|  | made to fix certain defects or errors in a |  |
|  | software system. |  |
| Preventive | Preventive maintenance are improvements | ≈ 5% |
|  | made to software systems that prevent |  |
|  | problems in the future. |  |
|  |  |  |
|  |  |  |

However, prioritising available resources for certain parts of the software system to carry out maintenance and prevent or fix software defects can be a challenging task [14, 15]. The defect density of a software system is determined by the number of possible defects divided by the size of the software system, as shown in Equation (1.1):

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| Def ect Density = | CN DD | | , | (1.1) |  |
|  | KLoC |  |
|  |  |  |  |  |

where:

* CNDD is the cumulative number of defects in the post-release version of the software system
* KLoC (thousands of lines of code) is the size of the observed executable code in a software system

A lower defect density indicates good software quality [21, 22]. However, it does not nec-essarily imply that the software meets all user requirements but that fewer possible faults exist.

In open source software systems (OSS), the defect density tends to increase due to the size of the system and the number of developers working on it [23]. Adding more developers to improve a software system may not always lead to improvements in all maintenance types listed in Table 1.2.

This increase in the size and complexity of the software system may also lead to a higher defect density, increasing the need for corrective maintenance efforts. Therefore, it can further exacerbate developer challenges as they try to resolve maintenance issues [22].

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**Problems with implementing software maintenance**

Under most circumstances, maintenance is implemented if a software system does not meet the required functions specified by the user or performance requirements [9,12]. Maintenance can be difficult to implement due to the following:

* Problem domain being complex: The software may not be well defined or struc-tured during the planning phases of LCP of Table 1.1. This is due to the size of software systems throughout their entire life cycle or the duplicate software components that are made.
* There is a poor understanding of the system architecture or insufficient documenta-tion about the software system when analysing maintenance problems [18]. Software engineers and developers tend not to create or update documentation as it is time-consuming when software needs to be delivered on schedule.
* Difficulties of managing development process: Most companies will strive to increase their digital products and services throughout the life cycle of the software project to maximise possible profits with the invested resources [17]. Increasing the production of the development process will only strain the maintenance efforts of soft-ware systems [12].
* Software engineers and developers already have a busy schedule to deliver software features on time [18, 24]. They will quickly feel overwhelmed and suffer from develop-ment burnout if the development process is not correctly managed to include additional software development by implementing maintenance.
* Flexibility of the software: Trying to predict the future architecture and modify it while preserving the integrity of the software may be difficult in software mainte-nance [25]. Software is flexible if it is adaptable to the problem domain by adding modifications to it [9].
* Most development teams will follow a software development methodology to create a future architecture that is modular and structured to preserve the development in-tegrity of new software [26]. This will also have an impact on the type of maintenance activity (such as in Table 1.2) the development team will need to implement [7, 11].
* Change in user’s requirements: In software development, users will often request additional requirements for the software systems that are delivered to them [9]. Mod-ifying software systems may include new features and other features that change the initial architecture of the system. Maintenance of these systems is crucial to ensure that existing components of the system will work as intended with the new members that are added.
* Environmental changes: Rapid changes in software development are always present, with the need for more innovative solutions to solve new complex problems. These changes are not always compatible with existing software systems, even if the initial software architecture is well defined [9].
* There will always be a need to improve the software system through third-party soft-ware updates and services. The software system needs to be modified to accommodate these new changes, as it is beneficial for its sustainability and operation.

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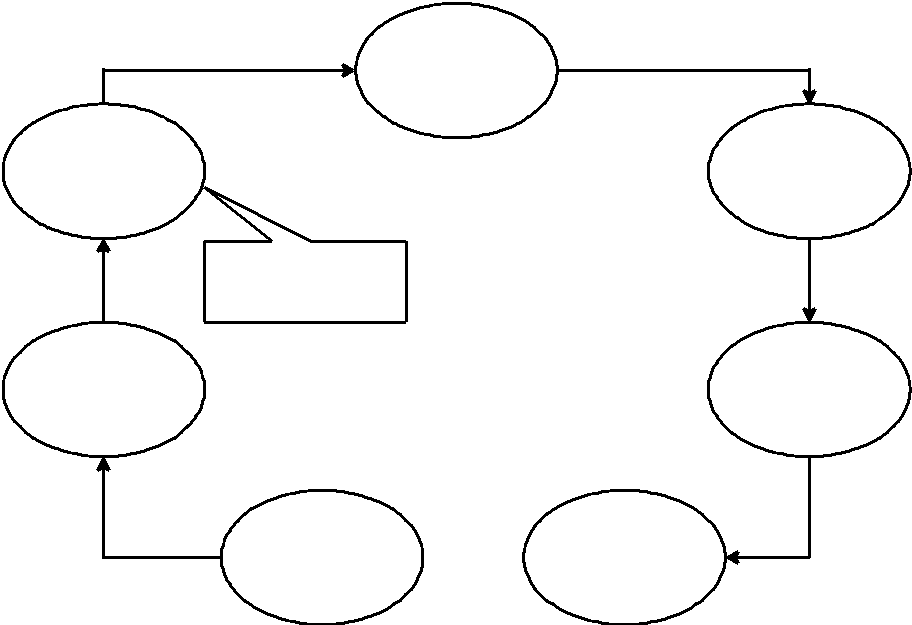
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* Bad design: Maintenance can be difficult if the system is poorly designed when SDLC is implemented. Maintaining the system is impossible or too tricky without making significant changes. The complexity of the software system may be too high for some developers, which will cause the problem domain problem mentioned with complexity in software systems [[24].](#page114)

**Software maintenance prioritisation**

Due to time constraints and available resources, it is challenging to plan maintenance op-erations for most software engineers and developers [6]. The increased cost of software maintenance resources is due to a lack of planning or preventive measures to keep the soft-ware system from degrading [22]. Continuous analysis of identified maintenance problems or modifications enables software engineers and developers to create a preliminary plan to address these problems efficiently [13]. Implementing a suitable maintenance framework to resolve the problems identified reduces technical debt.

Various maintenance models can be used to solve these issues when implementing any of the maintenance types. A software maintenance model is an abstract representation of the evolution of software systems to keep track of all the maintenance activities when implement-ing software maintenance [27]. The IEEE Standard 1219 for software maintenance is the standard that should be followed when planning software maintenance as in Figure 1.3.



|  |  |  |
| --- | --- | --- |
|  | Feasibility |  |
|  | Analysis |  |
| Classification and | Design |  |
| identification |  |
|  |  |
|  | Modification request. |  |
| Delivery | Implementation |  |

Acceptance testing  System testing

Figure 1.3: IEEE Standard 1219 model for software maintenance [27]

The software maintenance model in Figure 1.3 emphasises that software defects or faults must be identified and classified for maintenance. A feasibility analysis of any required changes should be done if the maintenance effort is worth implementing. A certain amount of resources will be allocated to execute maintenance, affecting the design and implementation phase.

For feasibility analysis, the use of a system characterisation report may help identify possible maintenance focus points in a software system [28]. This will increase the effectiveness of designing solutions to implement maintenance as a system assessment focus can be made. The metrics can be defined as:

* positively or negatively impacts the performance of the system,

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* fulfil the defined user’s requirements,
* increase user engagement with the defect and fault fixes or expand existing software components with additional features,
* is worth a large portion of the user base to implement.

User engagement with the software system is what will determine if the software system is sustainable in generating revenue for the organisation. It may be the most crucial focus metric for feasibility analysis to determine whether a maintenance effort is worth imple-menting [28]. Compared to the one in Figure 1.4, a maintenance flow model can resolve this problem.

Figure 1.4 is an example of a practical maintenance flow model that an organisation would likely use to implement software maintenance. Initially, a developer will complete a request form or issue that indicates a new problem or feature request that needs to be implemented [10].

After all maintenance tasks are defined, the development team will prioritise the higher-rated issues that need to be solved. This process will repeat itself until all the work for that specific software system is completed.

To fully follow the IEEE Standard 1219 of implementing maintenance on a software system, the defects or areas of improvement should be identified. The use analysis of event logs can detect hidden flaws or performance problems in a software system to implement software maintenance [29–31].

System and acceptance tests are essential to ensure that the system is fully functional and meets the user’s requirements. After the system is thoroughly tested and approved, it will be available to the user, and the maintenance process will start again when there are new improvements to the software system.

In Section 1.2.1, it was identified that software maintenance is essential to fulfilling the user’s requirements. For any maintenance model, as described in Section 1.2.1, to be effective, the software maintenance model must be able to prioritise maintenance issues efficiently.

Most organisations’ maintenance models will be based on Figure 1.3 to manage their Op-eration and Maintenance LCP maintenance efforts. Up to 50% of a software engineer or developer’s total time invested in implementing maintenance is to understand what the soft-ware system is supposed to do [10]. This is due to the problems with the implementation of maintenance as discussed in Section 1.2.1.

If the issue is a problem in the software system, the severity of the problem must be assessed to decide on the priority level to resolve it. This type of maintenance is mainly corrective and can also be preventive if it is a possible solution to prevent software failures in the future [10]. Other maintenance requests are adaptive or perfective and are usually placed in the development team’s task queue.

Prioritising maintenance for the user’s requirement to extend usability and increase user satisfaction is preferable to maximise profits. When no suitable software maintenance model is used, software maintenance is often reactive [28]. However, this is not a sustainable maintenance policy for larger, more complex software systems.

To prioritise maintenance more efficiently, a systematic characterisation of the software sys-

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tem needs to be made. In Section 1.2.1, user engagement with the software system has been identified as an essential metric when implementing maintenance.

A diagram of a flowchart

Description automatically generatedKnowing what the user uses or interacts with the software system provides valuable data to the development team. But to access those data, some form of tracking is needed to obtain the data automatically.

Figure 1.4: Maintenance flow model [10]

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1.2.2 Event logging

As described in Section 1.2.1, a tracking method is needed to capture data on user engage-ment with the software system for maintenance purposes. It is a common practise in the software industry to record complex system run-time information in event logs. Developers or engineers can analyse these event logs later to solve software-related problems [32].

Event logging is a proven implementation to obtain information on the behaviour of software systems [33]. Event logs are textual files generated by the software system that collect data on reported events of interest during various software system operations. [29, 33].

The technique to collect numeric or textual data that describe the behaviour of a computer system is called the event log [33, 34]. Event logs collect textual data containing records of events that occurred in a software system and are used for system management tasks as in Table 1.3 [30, 33, 35]. Event logging has three main purposes [33, 34]:

* state dump reports the values of certain variables or data structures inside the soft-ware system.
* execution tracing is the reporting of certain states of the software system or what is currently happening in the software system,
* event reporting focuses on any desired events in the software system that has textual information of that event.

Event logs are used mainly for event reporting to support debugging and system integration activities to reduce the amount of code that needs to be inspected [33]. Table 1.3 is the most common use of event logging in the industry is described.

|  |  |
| --- | --- |
|  | Table 1.3: Event logs usage |
|  |  |
| Usage | Description |
|  |  |
|  |  |
| Debugging of | Event logging is used mainly to record events or behaviours of soft- |
| software sys- | ware systems or services during its runtime [30]. |
| tems and ser- |  |
| vices |  |
|  |  |

Anomaly detec- Event logs can detect any abnormal behaviour of the system using

|  |  |
| --- | --- |
| tion | an anomalous detection algorithm using log data [36]. This can also |
|  | be used to find potential vulnerabilities or to predict defects in the |
|  | software environment [37]. |
|  |  |
| Performance di- | Software performance is important to produce quality software for |
| agnosis | the end user [33, 38]. This is also important to make informed de- |
|  | cisions about the improvement of the software system or service to |
|  | improve performance and other financial and resource implications. |
|  | This type of performance event log of software systems or services is |
|  | used to monitor the software system, which is useful for tuning re- |
|  | sources, balancing load and checking system scalability throughout |
|  | the life cycle of the software system or service [39]. |
|  |  |
|  |  |
|  | Continued on next page |

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|  |  |
| --- | --- |
|  | Chapter 1. Introduction |
|  |  |
|  | Table 1.3: (continued from previous page) |
|  |  |
| Usage | Description |
|  |  |
| Auditing | In a software environment, significant changes in database data may |
|  | need to be recorded for audit purposes [30]. All establishments and |
|  | enterprises must ensure that compliance with industry regulations |
|  | is met with their software systems by adding audit logs. They are |
|  | also legally bound to have audit logs to provide legal evidence for any |
|  | legal investigation or administrative tasks to maintain accountability. |
|  |  |
| Error and failure | Event logs are used to analyse the failure behaviours of software sys- |
| analysis | tems that allow software engineers or developers to understand sys- |
|  | tem failure, find the root cause of these failures, prevent them, and |
|  | improve the reliability of future versions of the system [29]. |
|  | |
| Analysis of secu- In any software environment or information technology infrastruc- | |
| rity alerts | ture, security is a major concern for any organisation [37, 40]. It is |
|  | important to know the overall security status of the software system. |
|  |  |

**Logging practise in software development**

Logging practise in software development is not always well documented, and there can be multiple implementations of different logging mechanisms in the same software system [34, 41]. In modern software systems, logging practise is a crucial part of software development and its maintenance throughout its life cycle [35].

In Appendix A, new studies have focused on providing practical logging practise guidelines to software engineers and developers. Logging in the industry uses many third-party log libraries and frameworks, such as Apache’s log4net and Microsoft’s ULS frameworks [35, 42].

Software engineers and developers can use these tools to implement logging in a compatible software system. They will still need to know how to place the logging points to obtain the desired logs strategically. Using the guides provided by the tools and other online guides, the logging practise can be implemented. When using a third-party logging mechanism, the software engineers and developers will, in most cases, need to:

* add the logging points in the software system at locations where it can capture the desired logs,
* enables the log parsing stage to write a log entry into a database.

Logging guides can give examples and suggestions on where to place the log points, but it can still be difficult for software engineers and developers to identify these desired locations. This can be difficult because logging guides are mostly application-specific or the logging mechanism can only capture certain event types to create event logs.

For more custom logging, the software engineers and developers will need to develop new logging mechanisms. This adds new requirements for the logging mechanism to be functional. For a log-keeping practise to be successful, two critical problems need to be resolved [32, 35, 42]:

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* **What needs to be logged?**

In Table 1.3, recording is diverse and will impact how the logging mechanism will be designed.

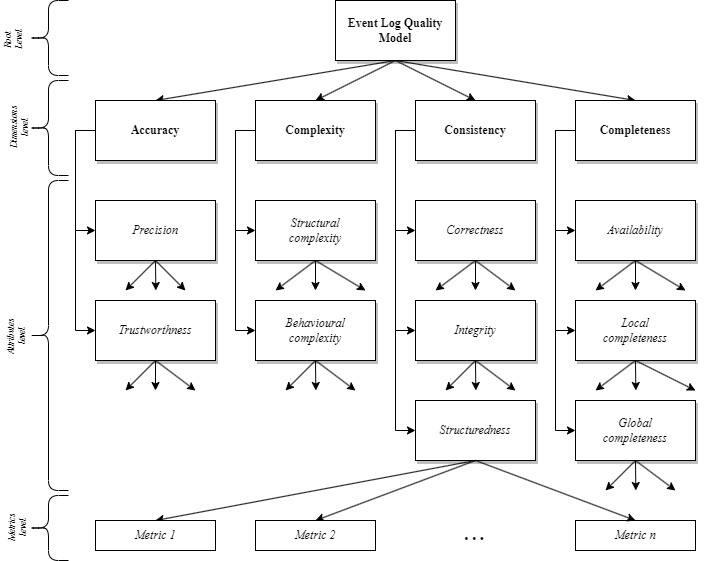
* **Where to log?**

Different types of logs will only be present in the software system at certain locations during runtime. Knowing what to log narrows down which locations can be used to obtain certain events while they are present.

To answer these two questions, the event log has to meet specific log quality require-ments. This ensures that the created logs are correct and consistent when extracted and viewed.

**Logging quality**

Software engineers and developers must make informed logging decisions for event logging. These decisions may negatively affect the software system’s run-time operations and the event logging efficiency [32, 42, 43]. An event log quality model can be defined in Figure 1.5 to ensure that the event logs have consistent integrity when capturing the event log data.



|  |  |  |  |  |
| --- | --- | --- | --- | --- |
|  |  |  |  |  |
|  |  |  |

Figure 1.5: Quality model for event logs [43]

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The event log quality model in Figure 1.5 consists of four different levels to define each property of the event log quality model:

* Root level for the event log quality model. These are the main requirements for the event log quality model,
* Dimension level, which consists of four main dimensions of the event log quality model according to [43] (complexity, accuracy, consistency and completeness of the event log),
* Attributes level where a set of quality attributes for the dimension level,
* Measurement level, which should be defined in the design process of the logging mech-anism to achieve the attributes and dimension levels.

Each of the four dimensions is discussed in detail in the Figure 1.5:

* **Accuracy of event logging**

It can become difficult to record every event in a software system as these systems will become larger and more complex during their development life cycle [16]. Precisely capturing certain events that need to be logged must be consistent to ensure that the data are trustworthy and reliable. The log attributes of the event log also need to be precisely captured for each event log and should be correct.

Capturing more event logs does not guarantee that the accuracy of the event log is acceptable, as the log’s attributes can be incorrect or cause duplicated event logs if the data is the same in a sequence of event logs. In Table 1.4 are the common problems associated with the accuracy.

The accuracy and trustworthiness of the event log are more important than capturing the many available event logs in a software system [42, 45]. The extra unnecessary logs will also take up more storage space, increasing costs, and possibly the software system’s performance.

* **Event log complexities**

Software always has some complexity involved, and it will always increase as the soft-ware system becomes larger. For the event log quality model, the complexity of the event can be split into two different complexities, which are [43]:

– Structural complexity is the application of different algorithms in the software that allows the event log to be evaluated when it occurs, which can alter the behaviour of the event log.

– Behavioural complexity in event logging is the complexity of the behaviour of the event logs that refers to the number of smaller events in each captured trace and the different variations of these traces within an event log.

These two complexity attributes can be costly when the event logging mechanism needs to be constantly maintained in large software systems where it can affect the rest of the system’s performance or integrity of the captured event logs [9]. The constant modification of the event log software can be due to technical debt, as the complexities of the event log system lead to technical issues when attempting to log an event or are not compatible with other systems [6].

* **Consistency of event logging**

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|  |  |
| --- | --- |
|  | Chapter 1. Introduction |
|  |  |
|  | Table 1.4: Problems with too much logging [42] |
|  |  |
| Problem | Description |
|  |  |
|  |  |
| Excess code | Adding multiple logging points may incrAccuracy code added to the |
|  | software system to capture the event logs. The code may take some |
|  | time to write and maintain. This can increase the structural and be- |
|  | havioural complexity of the code throughout its life cycle. |
|  |  |
| System resource | With the additional code needed to capture the logs, the usage of sys- |
| impact | tem resources, such as CPU and I / O channels, will increase. This |
|  | may negatively impact the performance of existing system operations |
|  | or increase the cost to keep the system at the same operation speed by |
|  | increasing the system resources. |
|  |  |
| Unusable logs | Adding numerous logging points or logging too much at points can pro- |
|  | duce numerous trivial or useless logs that will not improve the analysis |
|  | of system utilisation. When implementing the system utilisation anal- |
|  | ysis stage, the logs might need to be filtered more or modified to be |
|  | more meaningful, as much as 70% of the logs may be irrelevant [44]. |
|  | The software engineers and developers write the logs and can some- |
|  | times be irrelevant to other managers or system administrators when |
|  | implementing a log analysis report on the logs. More event logs can |
|  | have missing or incomplete logging attributes due to the excessive log- |
|  | ging points added. The increase in the behavioural complexity of the |
|  | log can impact the decisions made to improve software maintenance. |
|  |  |
|  |  |

The accuracy and consistency of event logs are critical to making reliable decisions based on the identified behaviour of the software system with the historical data that exists in the event logs that are discussed in the previous dimension of event log quality [16,43]. With the accuracy and trustworthiness of the event logs properly applied, their consistency should be acceptable to be correct and verifiable when comparing it to the software system.

An event log quality model is essential to ensure that the logs are of high quality for the log analysis data mining process, and therefore the event log data should be consistent. To ensure the consistency of the event logs, the structure of the event logging points and log parsers should be compatible with capturing all the critical log attributes. The event log data should also be consistently analysed with different methods used in it as part of the consistency of the event logging process.

* **Completeness of event logging**

The event logs will be analysed later; the logs should be fully complete when used, as some of the other logging attributes might not be available at that stage. The event logs’ available attributes should be accurately captured before storing them in a database to ensure that no missing event data or missing events are discarded if the event is discarded due to incomplete information. There are two types of completeness attributes that exclude the availability attribute in Figure 1.5:

– Local completeness refers to all event data that can be captured for an instance

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of the event that takes place that can be added as a log attribute to the event log [43, [46].](#page116)

– Global completeness refers to the occurrence of all possible outcomes or behaviours of the event logs that can be captured, which is required for the system utilisation analysis [43, [46].](#page116)

Ensuring that both completeness levels are achieved and that the event log data is complete can impact performance if specific data is not directly available during the instance when the event has occurred. The logging mechanism must capture this as efficiently as possible without causing performance issues to the rest of the software system’s operations [32, 42].

**Logging parsing and log points**

Knowing what to log can significantly reduce any overhead the logging mechanism may produce in the software system [34, 47]. Preserving quality (as described in Table 1.3) is necessary to ensure that the obtained logs fulfil their purpose when analysing them.

**Logging attributes**

Before the logs can be parsed to a structured data set, the key attributes that will describe the event log [48]. The attributes describing them in Table 1.5 are the essential attributes that a log event should have.

|  |  |
| --- | --- |
|  | Table 1.5: Basic log event attributes [48] |
|  |  |
| Attribute | Description |
|  |  |
|  |  |
| Case number | Unique identifiers for each log event. This is usually the primary iden- |
|  | tifier of the log event. |
|  |  |
| Timestamp | The time and date that the log event occurred. This is part of identi- |
|  | fying the order of events or traces along with the case number of the |
|  | event log [43]. |
|  |  |
| Event type | Each log event can be grouped with other log events with similar actions. |
|  | These event-type attributes should be classified based on a state change, |
|  | failure to execute an instruction, or due to an occurrence of activity, |
|  | such as the availability of service [44]. |
|  | The event type is usually also the log level. The log level in event |
|  | logging reflects the severity of the event log [49]. An event of interest |
|  | may have different log levels, making it easier to capture certain events |
|  | in which software engineers and developers are interested. |
|  |  |
| Originator | The origin of the event in the software system. This can be parts of the |
|  | software that perform the event action or was the cause for the event |
|  | to be initiated by another part of the software. |
|  |  |
| Other metadata | This is any other relevant information that can be used as the event |
|  | log’s attribute that further expands the information of the log event. |
|  | This can be an additional field or many other individual attribute fields. |
|  |  |
|  |  |

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These attributes make it possible to mine and analyse the logs based on their attributes and increase the precision and reliability of the event log [[43].](#page116) The case number and timestamp attributes in Table 1.5 can be defined at any time during the logging process. This is not the case for the rest of the attributes

Every log should have a defined action that will put it in a group of logs that can be defined as the type of event. These event types can be predefined of what is expected from the event action or will need to be observed later in the analysis of the logs in case there is no explicit grouping of the logs [44, 48].

**Log points**

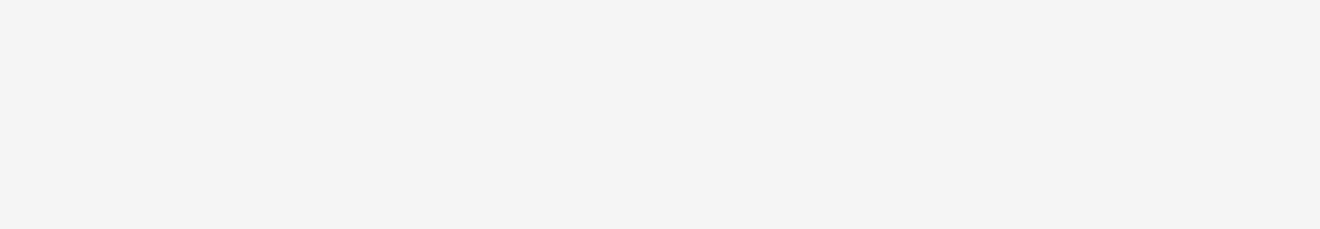
The sources of the log-event assist in determining where the event took place. For event logs, it is essential to try to recreate scenarios or actions based on the relevant parts of the software system that participated in the event action.

Other metadata can increase the quality of the log by providing additional information about the executed software instructions. These attributes add more information that can be used to recreate the scenario or action that may be unique parameters or other events that participated in the event log.

Obtaining the attributes in Table 1.5, an instruction generates the log and parses it onto a data set. These log instructions are called logging points in the software environment [34,42]. They can be any instruction, such as a print function that displays the information for the user to more complex processes or libraries that third-party developers can create. In Figure 1.6 is an example of a logging point parsing a log message in a structured log.

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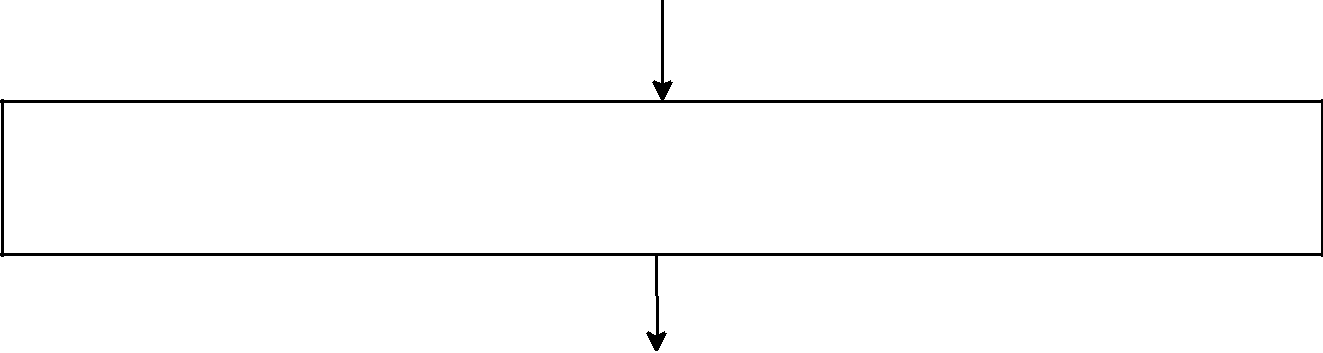
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/\* A logging code snippet extracted from:

hadoop/hfs/server/datanode/BlockReceiver.java \*/

LOG.info("Received block " + block + " of size " + block.getNumBytes() + " from " + inAddr);

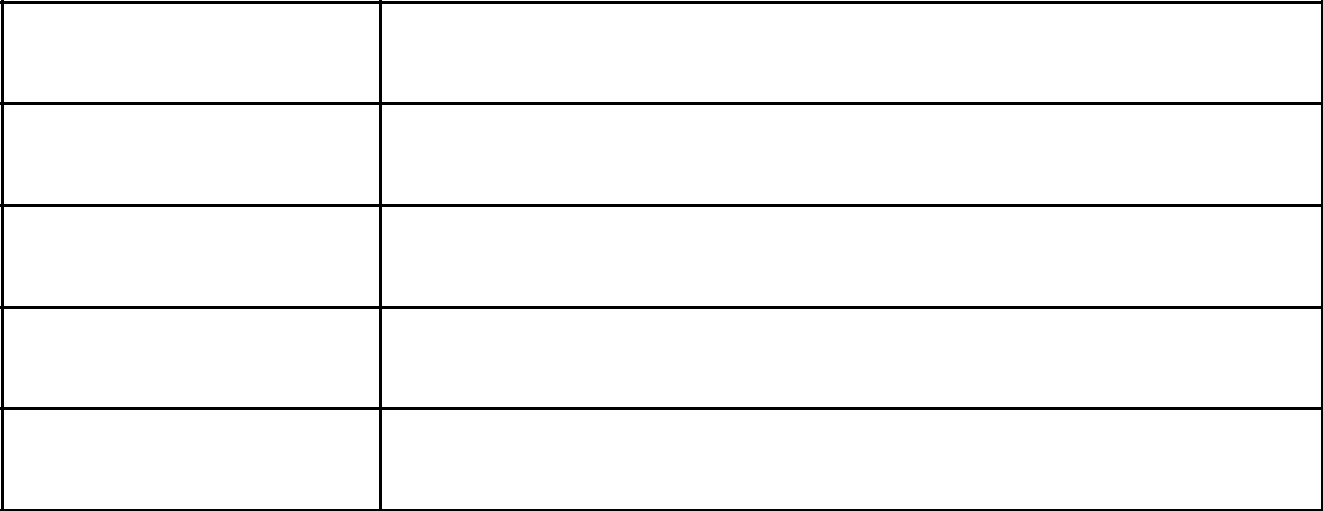


Log Message

2015-10-18 18:05:29,570 INFO dfs.DataNode$PacketResponder: Received

block blk\_-562725280853087685 of size 67108864 from /10.251.91.84

Structured Log



**TIMESTAMP** 2015-10-18 18:05:29,570

**LEVEL** INFO

**COMPONENT** dfs.DataNode$PacketResponder

**EVENT TEMPLATE** Received block <\*> of size <\*> from /<\*>

**PARAMETERS** [“blk\_-562725280853087685”, “67108864”, “10.251.91.84”]

Figure 1.6: An illustrative example of log parsing [32]

The defined attributes are captured by the logging point when the event takes place or occurs. The created log message is then parsed into a structured log to be safe in a database or displayed. The logging point should be strategically placed to capture the attributes required to complete the log event [44].

Determine where to place the logging point in a software that is directly affected by the attributes and if the captured log will be of high quality as described in Table 1.3. The availability of consistent, high-quality logs will directly impact the process of mining the logs in analysing them [43].

To strategically place a logging point, developers need to consider what the activation of the logging point will be during the run time of the software system [29, 34]. The activation can be straightforward if a statement meets specific criteria or instructions that execute after an event or action occurs (e.g. run-time errors).

The log level or event type of Table 1.5 can be used to determine where the log points should be placed. The aim of establishing the logging point should try to capture all the log attributes when the event of interest has happened.

**Log analysis in Web-based applications**

With the log parsing and log points defined in Table 1.3, a log analysis can be made from the stored event logs. The log analysis is the data mining process focused on the software

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system’s generated event logs [50, 51].

The log analysis will use the defined log attributes in Table 1.5 to complete it. Each software system will have some variation of the log attributes in Table 1.5. For a Web-based applica-tion, the log attributes will also contain data about the requests between a Web server and a Web client and its responses [50, 52]. This will also reflect on the log level at which weblogs are obtained for log analysis.

1.2.3 Log analysis

In Web-based applications, the process to get usage statistics and user behaviour data is called a Web analytic [53]. Web analytics can be used for user modelling efforts and is a form of log analysis. User modelling in software engineering is the customisation and adaptation of software systems to the users’ required needs [54, 55].

User modelling can also include the implementation of software maintenance, as maintenance is an adaptation of the software system to the user’s needs, which is the utilisation analysis using event logs. The web analytics focusses on different analytics in Table 1.6 for the study.

|  |  |
| --- | --- |
|  | Table 1.6: Web analytic for user-based data |
|  |  |
| Analytic | Description |
|  |  |
|  |  |
| Identity of the user | This is any information about the user’s identity in the software sys- |
|  | tem. Users can have different roles when using the software system, |
|  | such as a system admin or general user. These roles mostly dictated |
|  | what the user could access and do on a website. |
|  |  |
| Site interaction | The different Web sites the user is accessing during their active Web |
|  | session. This would also contain all the information about the fol- |
|  | lowing: |
|  | * ˆ how often the users visit a website, |
|  | * ˆ how much time they spent on a specific website, |
|  | * ˆ navigation between different web pages of the website. |

These same analytics can be used for none Web-based applications as the:

* identity of the user can be captured if the software system uses a software license,
* different parts of the system can be tracked or services the user uses.

**Analytic tools for event logs**

Numerous third-party analytic tools for event log data monitoring and management to vi-sualise log data graphically. Choosing the correct device to use can depend on what the software engineers and developers want to analyse and the availability of the tools due to external factors like cost and usability.

Event logging monitoring and management tools are sometimes underused and are not often used to their full potential when analysing event logs [44]. This can be due to the fact that

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the log quality of event logs does not meet the standards of Figure [1.5](#page23) not met in Table 1.3 for the correct logs to be available for the system utilisation analysis.

1.2.4 Gap identification

Section 1.1 emphasises that software maintenance is an important stage in the SDLC of software systems. Implementing software maintenance efficiently with the limited available resources that organisations or individuals have is crucial to improve the efficiency of the software maintenance efforts. Assisting developers to make better-informed decisions on which systems to prioritise maintenance can improve software maintenance.

**State of the art topics**

From the literature, there were a few critical focus points identified to create a log-in mecha-nism for user-based activities. These focus points exist for the research done in Sections 1.2.1 to 1.2.3.

The research for this study focused on accredited peer-reviewed published journals or articles for the last two decades (2000-2022). Some exceptions are older than 20 years, since software maintenance has been essential to modern software development for the past few decades. These studies were obtained from the IEEE Digital Library in journals by focussing on three key topics: software maintenance, event logging and log analysis. Each of the three primary states of the art topics is divided into subtopics that explore different studies relevant to the main issue.

**Software maintenance**

Software maintenance implementation in industry and best practises when implementing subtopics of software maintenance are described in Table 1.7.

The three different state-of-the-art subtopics for software maintenance in Table 1.7 evaluate the studies obtained if they discuss software maintenance and software maintenance imple-mentation. These subtopics focus on what is needed to implement software maintenance for any given software environment using industry standards.

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Table 1.7: Software maintenance state of the art sub topics

Topic Description Evaluation criteria

Models Software maintenance models and

implementation in industry.

1. Did the study focus on soft-ware maintenance?
2. Did the study discuss dif-ferent software maintenance implementations?

Problems Challenges with implementing soft-

ware maintenance.

1. Did the study identify fre-quent problems with imple-menting software mainte-nance?

Prioritisation Prioritisation methods.

1. Did the study discuss the

importance of prioritisation

techniques of certain software

maintenance activities, mod-

els or software components?

**Event logging**

Event logging in a software environment and activities implementing state-of-the-art event logging subtopics are described in Table 1.8.

The event logging subtopics aim to create or use a suitable logging mechanism for the log analysis requirements through the captured logging points. In Table 1.8 wants to obtain studies that will adhere to the best industry practises to create the logging mechanism and use or create the design methodology needed for the logging mechanism.

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Table 1.8: Event logging state of the art topics

Topic Description Evaluation criteria

Points Software logging points and log at-

tribute identification

1. Did the study discuss what needs to be logged or how to identify key logging attributes from certain software events?
2. Did the study aim to create or identify key logging points for specific log analysis purposes?

Parsing Challenges with implementing soft-ware maintenance.

1. Did the study aim to create or identify key logging points for specific log analysis purposes in a software environment?
2. Did the study provide a method or standards for log parsing to adhere to a log quality model?

**Log analysis**

Log analysis of software systems using state-of-the-art event logging topics is described in Table 1.9.

Table 1.9: Log analysis state of the art topics

Topic Description Evaluation criteria

Utilisation Utilisation log analysis for user-

based event logging.

1. Is a utilisation analysis done?
2. Prioritisation done based on the utilisation log analogy?

In Table 1.9, the topics focus more on studies that implement a log analysis for utilisation purposes. Tracking certain events is therefore essential for log analysis to ensure that the precision criteria of log quality can be achieved by Table 1.3. To efficiently make use of or create log analysis report for software maintenance.

**State of the art summary**

Using the defined criteria created for the state-of-the-art topics in Tables 1.7 to 1.9 State-of-the-art research for the obtained studies is done in Table 1.10.

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Table 1.10: State of the art

|  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Ref. |  | Software maintenance | |  | Event logging | |  | Log analysis |  |
|  |  |  |  |  |  |  |  |  |  |
|  | Models | Problems | Prioritisation |  | Parsing | Points |  | Utilisation |  |
|  |  |  |  |  |  |  |  |  |  |
|  |  |  |  |  |  |  |  |  |  |
| [9] | Partial | ✓ | ✓ |  | ✘ | ✘ |  | ✘ |  |
|  |  |  |  |  |  |  |  |  |  |
| [10] | Partial | Partial | ✓ |  | ✘ | ✘ |  | ✘ |  |
|  |  |  |  |  |  |  |  |  |  |
| [12] | Partial | ✓ | ✓ |  | ✘ | ✘ |  | ✘ |  |
|  |  |  |  |  |  |  |  |  |  |
| [16] | ✘ | ✓ | ✓ |  | ✘ | ✘ |  | ✘ |  |
|  |  |  |  |  |  |  |  |  |  |
| [18] | ✓ | Partial | ✘ |  | ✘ | ✘ |  | ✘ |  |
|  |  |  |  |  |  |  |  |  |  |
| [24] | Partial | ✓ | ✓ |  | ✘ | ✘ |  | ✘ |  |
|  |  |  |  |  |  |  |  |  |  |
| [28] | Partial | ✘ | ✓ |  | ✘ | ✘ |  | ✘ |  |
|  |  |  |  |  |  |  |  |  |  |
| [32] | ✘ | ✘ | ✘ |  | ✓ | Partial |  | ✘ |  |
|  |  |  |  |  |  |  |  |  |  |
| [35] | ✘ | ✘ | ✘ |  | Partial | Partial |  | ✘ |  |
|  |  |  |  |  |  |  |  |  |  |
| [42] | ✘ | ✘ | ✘ |  | ✓ | ✓ |  | ✘ |  |
|  |  |  |  |  |  |  |  |  |  |
| [43] | ✘ | ✘ | ✘ |  | Partial | Partial |  | ✘ |  |
|  |  |  |  |  |  |  |  |  |  |
| [51] | ✘ | ✘ | ✘ |  | ✓ | ✓ |  | Partial |  |
|  |  |  |  |  |  |  |  |  |  |
| [50] | ✘ | ✘ | ✘ |  | ✓ | ✓ |  | Partial |  |
|  |  |  |  |  |  |  |  |  |  |
| [54] | ✘ | ✘ | ✘ |  | ✘ | ✘ |  | ✓ |  |
|  |  |  |  |  |  |  |  |  |  |
| [56] | ✘ | ✘ | ✘ |  | ✘ | ✘ |  | ✓ |  |
|  |  |  |  |  |  |  |  |  |  |
|  |  |  |  |  |  |  |  |  |  |

In Table 1.10, studies marked with partial status satisfied the subtopic evaluation criteria to some extent. These studies still contained much needed literature for the subtopic, even if it was marked as practically meeting the evaluation criteria.

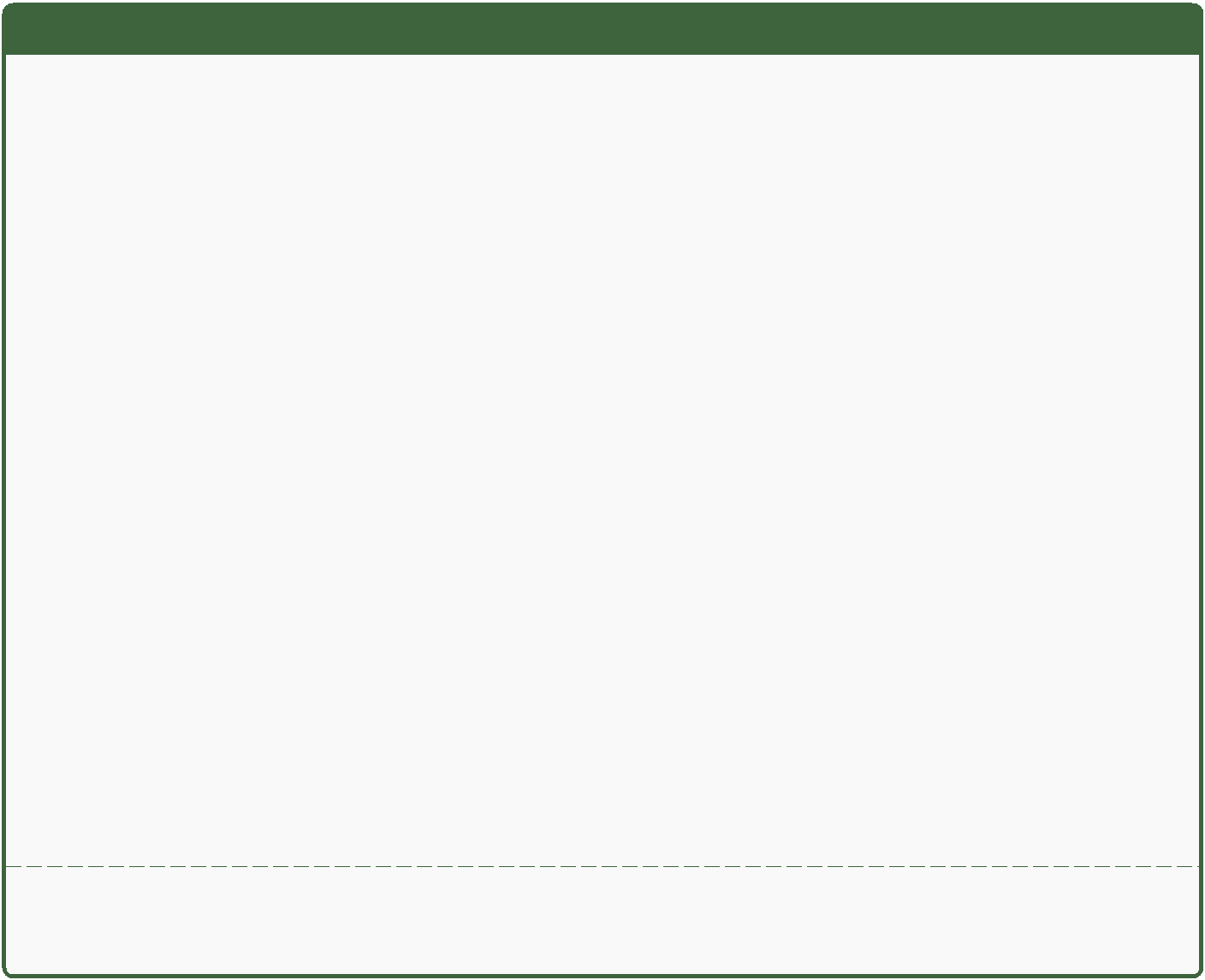
In Table 1.10 the three main topics have split the obtained literature into two main parts. The first part is only about software maintenance and how to implement and prioritise software maintenance using a suitable software maintenance model. The second part is about event logging and log analysis.

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**Review of the State of Art studies**

The State of Art studies in Table 1.10 are described and commentary is provided on the relevance of this study.



On the Relationship between Software Complexity and Maintenance Costs [9]

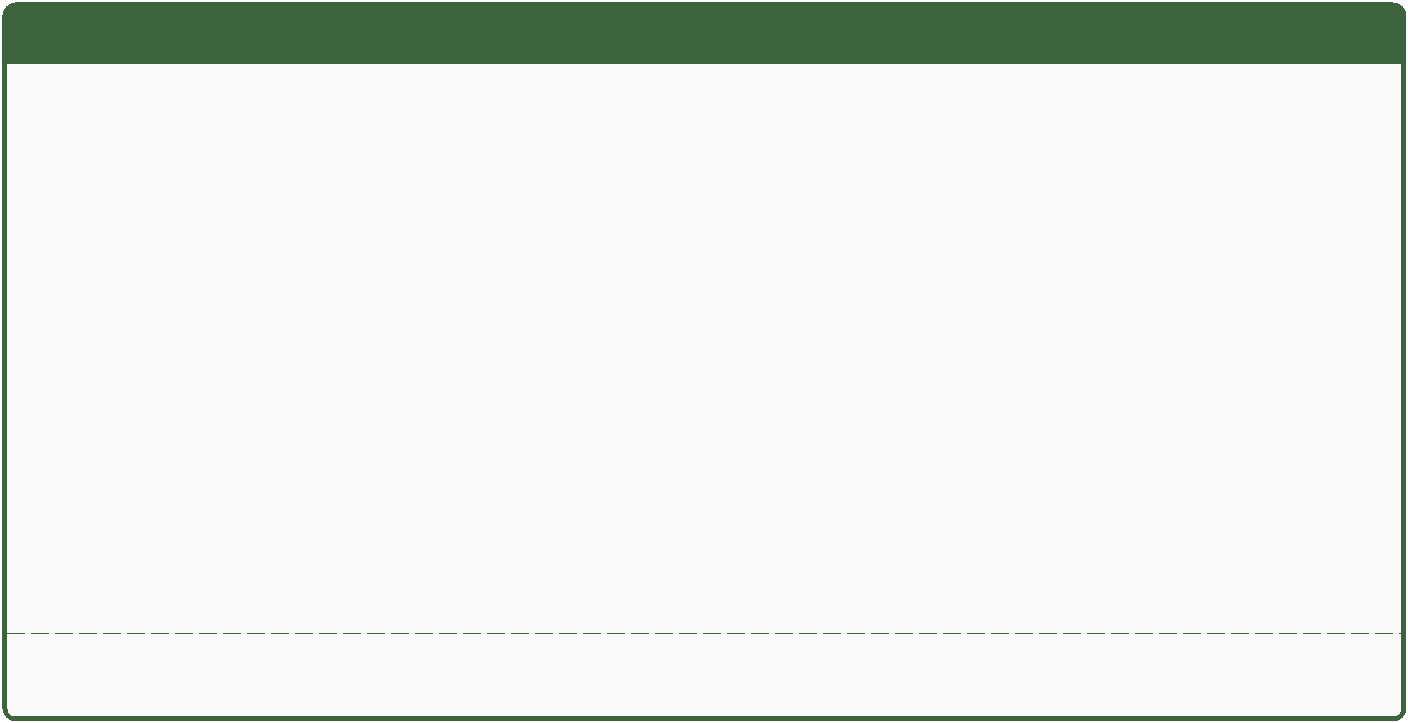
Study summary: Defines the different problems with the implementa-tion of software maintenance and its complexities as de-scribed in Section 1 (Maintenance Problems).

Method: They used three different software operating systems to compare their estimated development costs, main-tenance costs, code lines, and code complexity. This is used in the analysis to determine the relationship be-tween the complexity of the software and the mainte-nance costs.

Results: The results showed that the estimated maintenance costs are high enough that the complexity of the soft-ware needs management to reduce these costs.

Commentary: This study is used in this review of the literature when discussing the importance of software maintenance diffi-culties in the implementation of a software maintenance model. The study does not provide solutions on how to implement software maintenance effectively. It also explores the strategies and best practices in its review of the literature to help with software maintenance re-source costs.

Study keywords: Software; Software Maintenance; Software Evolution; maintenance costs; software; software evolution; software maintenance



Metric-based tracking management in software maintenance [10]

Study summary: Explores the implementation of software maintenance

with roleplayers involved.

Method: Assigned roles of each individual in the software main-

tenance process (user, coordinator, decision maker, and

maintenance operator) and evaluated their impact on

the software maintenance process.

Results: Results indicate explicit management issues when im-

plementing software maintenance.

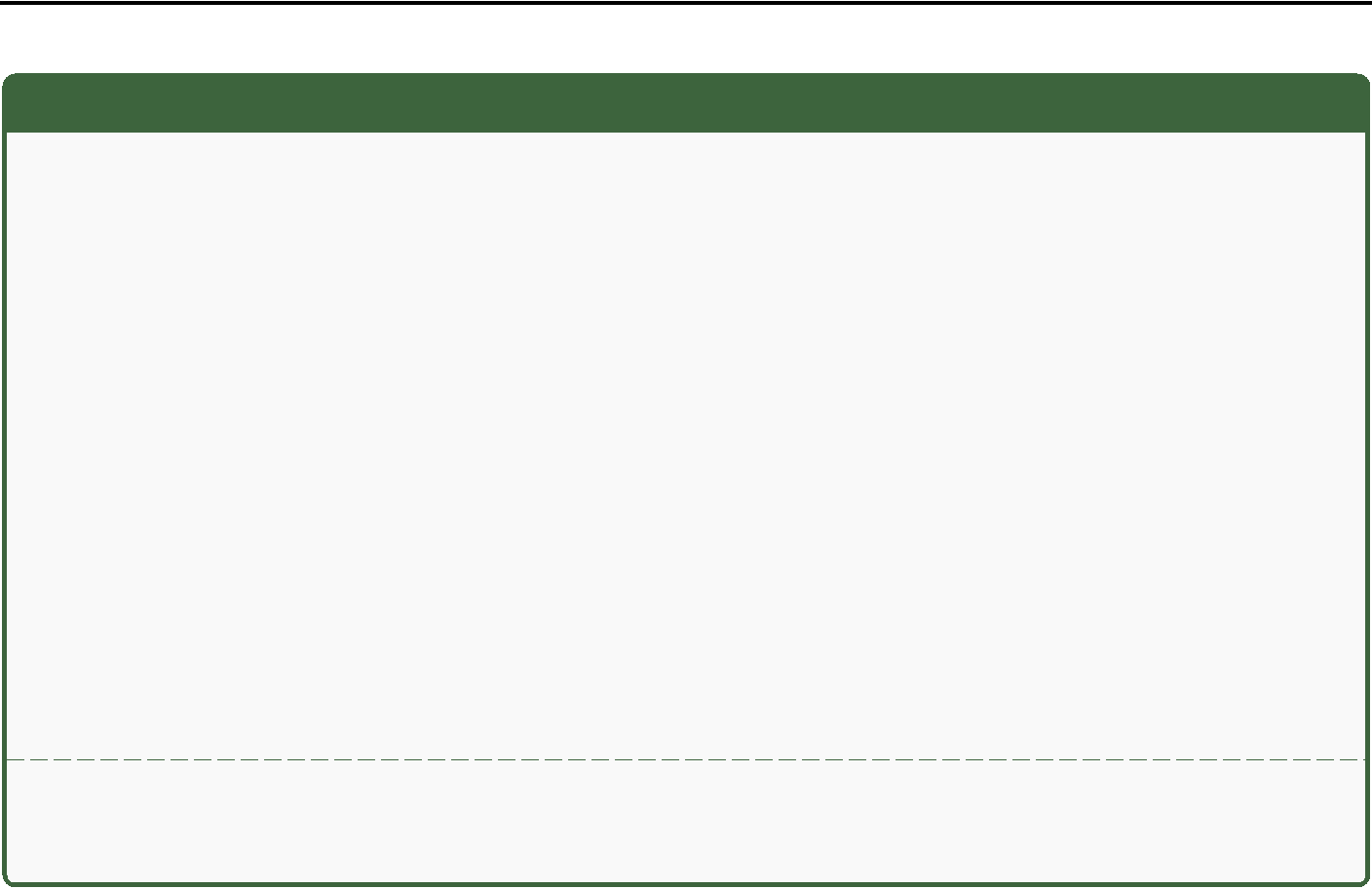
Commentary: The study recommends implementing a practical soft-

ware maintenance model to solve management problems and make maintenance processes more efficient.

Study keywords: Metric; Software maintenance; Tracking management

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A cost model for software maintenance & evolution [12]

Study summary: Examines the cost of software maintenance implemen-

tation and investigates difficulties with software mainte-nance and evolution of maintenance models.

Method: Attempts to assess the cost involved for a software sys-

tem by implementing a prediction cost analysis of mul-tiple types of maintenance activities.

Results: Shows that estimated maintenance costs depend on fac-

tors like the size of the development team, code com-plexity, and code quality.

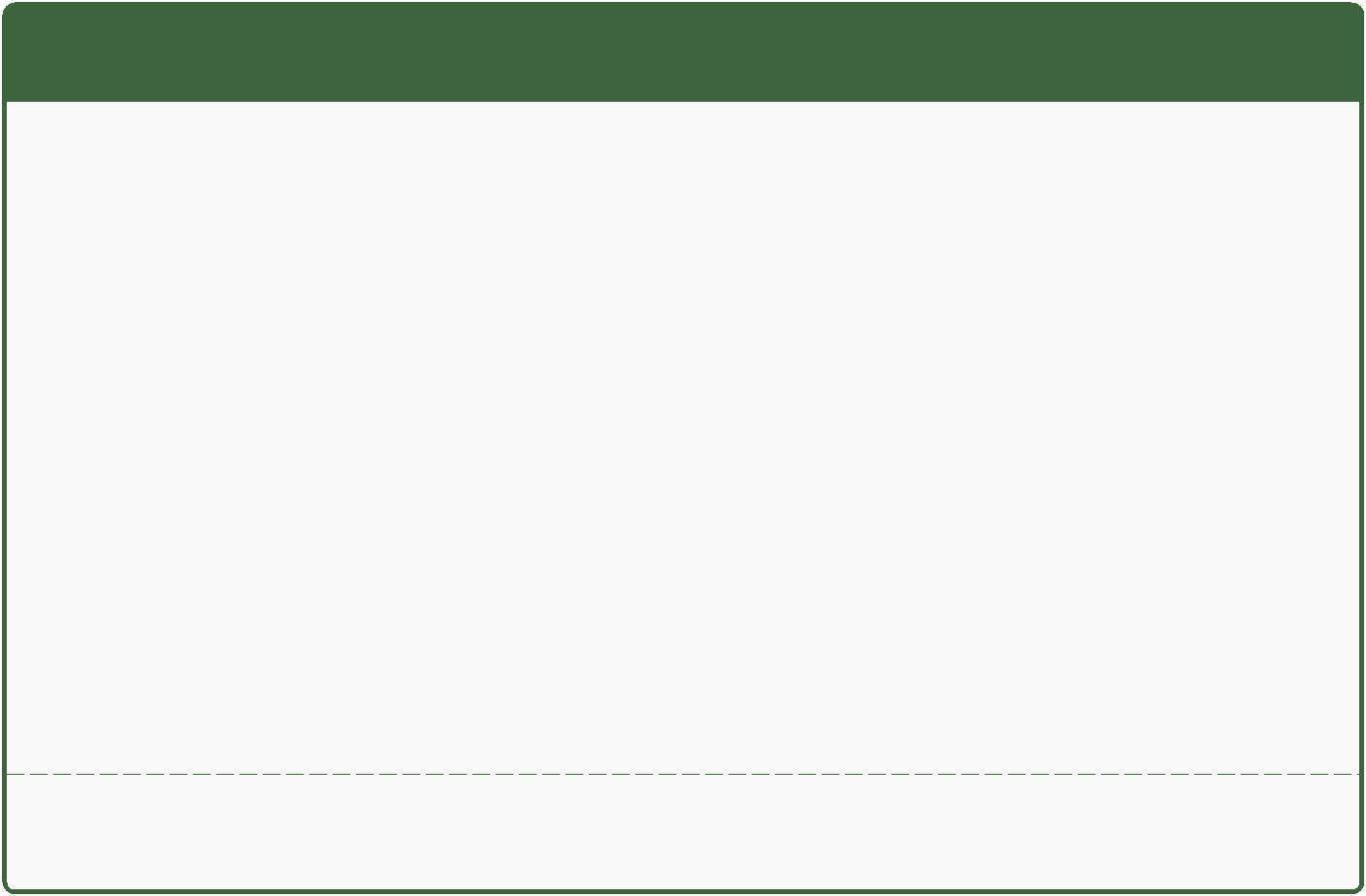
Commentary: Highlights the need for efficient software maintenance

but doesn’t provide solutions. Offers insights into possi-

ble resource costs when implementing a software main-

tenance model.

Study keywords: Maintenance Cost Estimation; Software Life Cycle Costing Mod-els; Software Maintenance and Evolution; Software Product Management



Trends in software maintenance tasks distribution among programmers: A study in a micro software company [16]

Study summary: Examines software maintenance efforts when imple-

menting a software maintenance model. Investigates

how software developers prioritize and distribute main-

tenance tasks.

Method: Classifies maintenance tasks into different types and dis-

tributes them among developers using multiple test dis-tribution techniques.

Results: Effective distribution techniques divide maintenance

tasks between developers and improve study schedul-ing.

Commentary: Focuses on the contribution of maintenance tasks by

developers and how efficiently they distribute the work

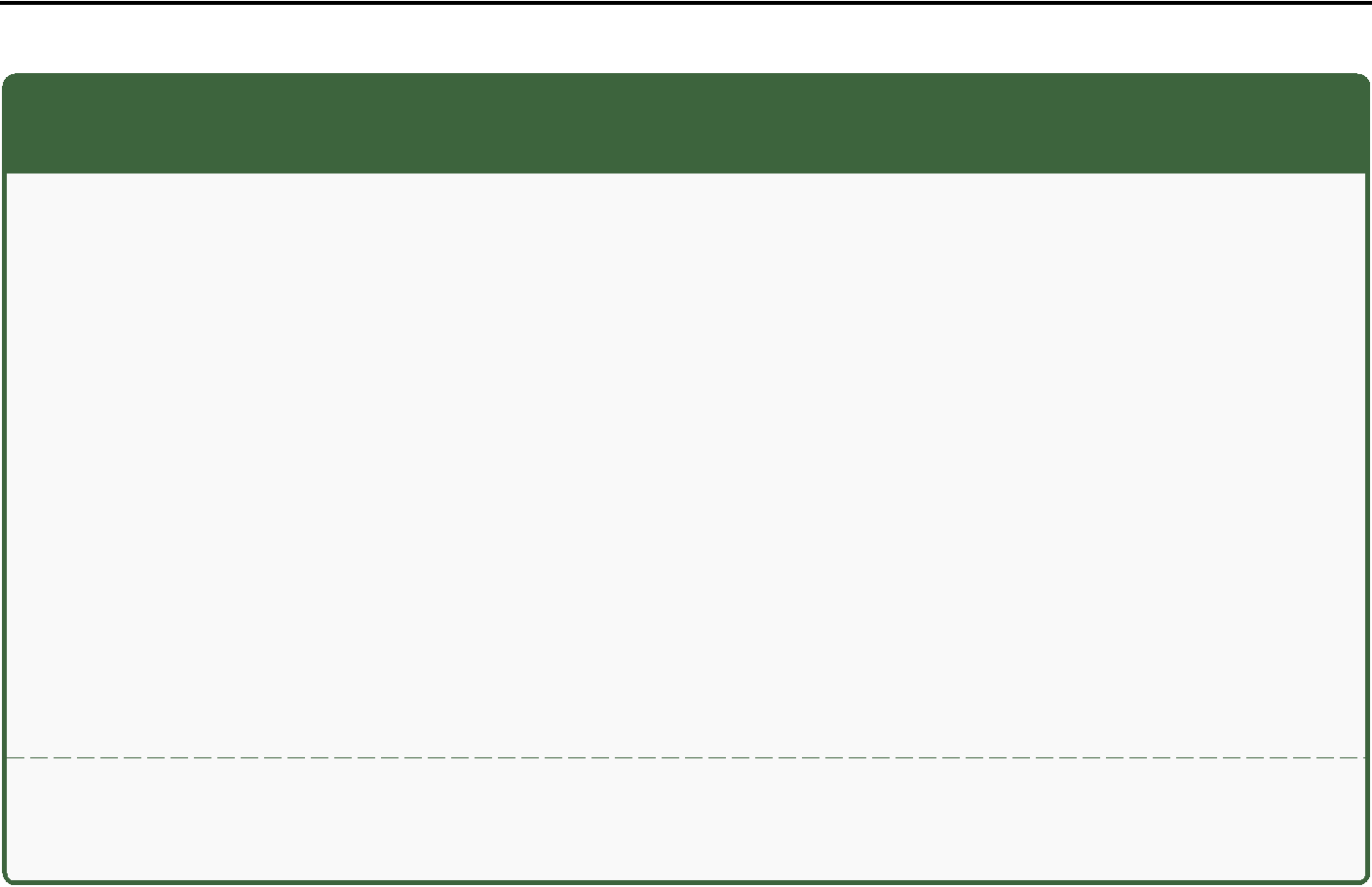
among themselves. Primarily looks at decision-making

based on maintenance tasks obtained by developers.

Study keywords: Maintenance engineering, Market research, Companies, Software maintenance

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Supporting Software Architecture Maintenance by Providing Task-specific Recommen-dations [18]

Study summary: Discusses various types of maintenance in the industry

and the need for software maintenance. Defines mainte-

nance types and associated activities for Operations and

Maintenance.

Method: Aims to address developers’ lack of information when

implementing maintenance.

Results: Lists multiple solutions for software maintenance recom-

mendations.

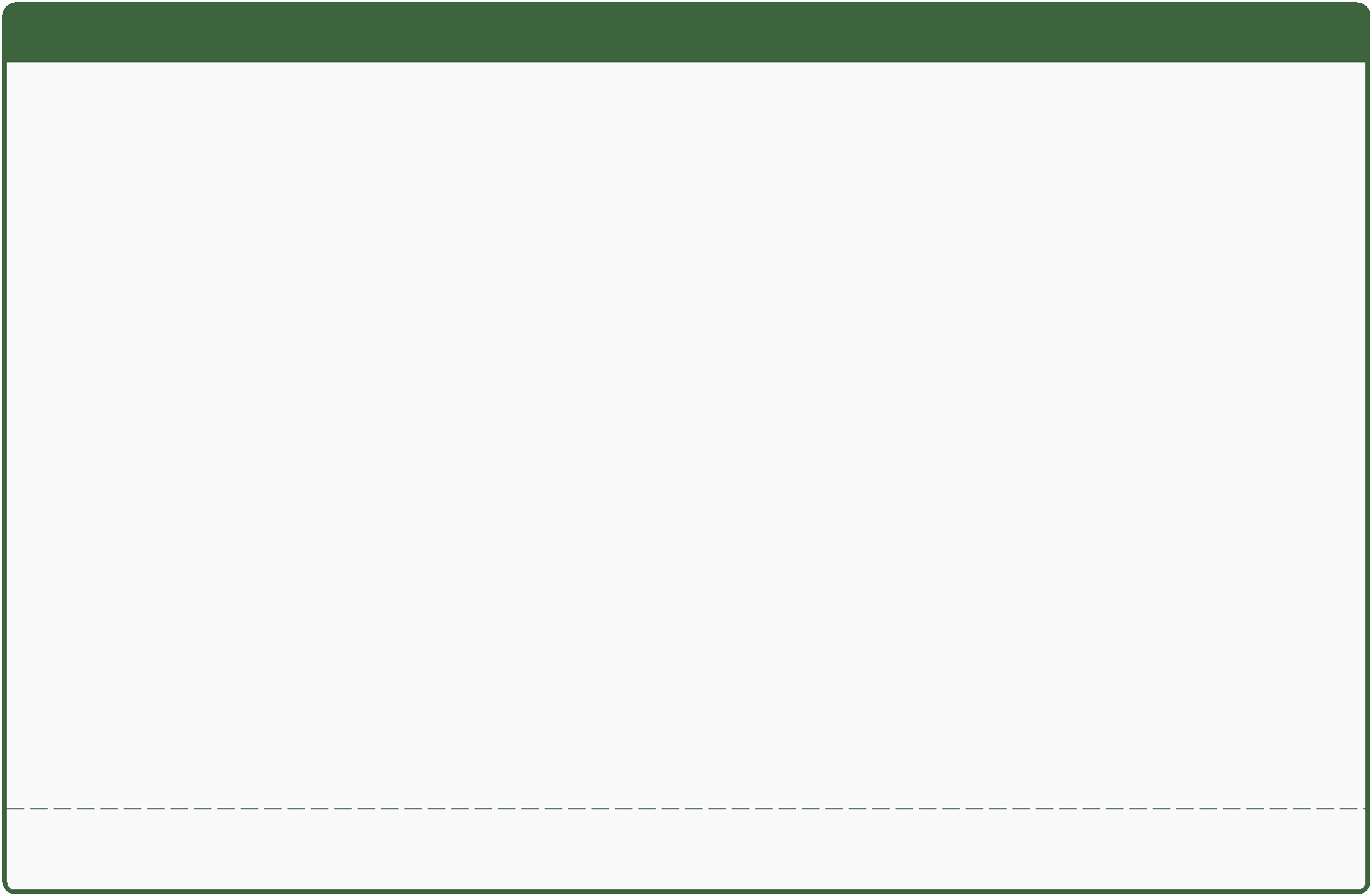
Commentary: Examines the software maintenance process in the in-

dustry, with a focus on maintenance tasks and the cor-

rect approach to efficient implementation, rather than

improvement.

Study keywords: Software maintenance; natural language processing; software architecture; text classification



Analyzing Forty Years of Software Maintenance Models [24]

Study summary: Analyzes software maintenance models and their char-

acteristics over the last four decades.

Method: Obtained studies and conducted a systematic analysis of

1,044 articles from 1970 to 2015 on software maintenance models.

Results: Identifies common aspects and problems in the software

maintenance industry, including limited third-party val-

idation, lack of improvement on existing models, limited

literature comparison, and challenges in replicability due

to private data sets and custom tools.

Commentary: Focuses on highlighting the limitations of software main-

tenance in the industry rather than providing ways to

improve it. Discusses issues such as slow adaptability of

maintenance models, lack of literature comparison due

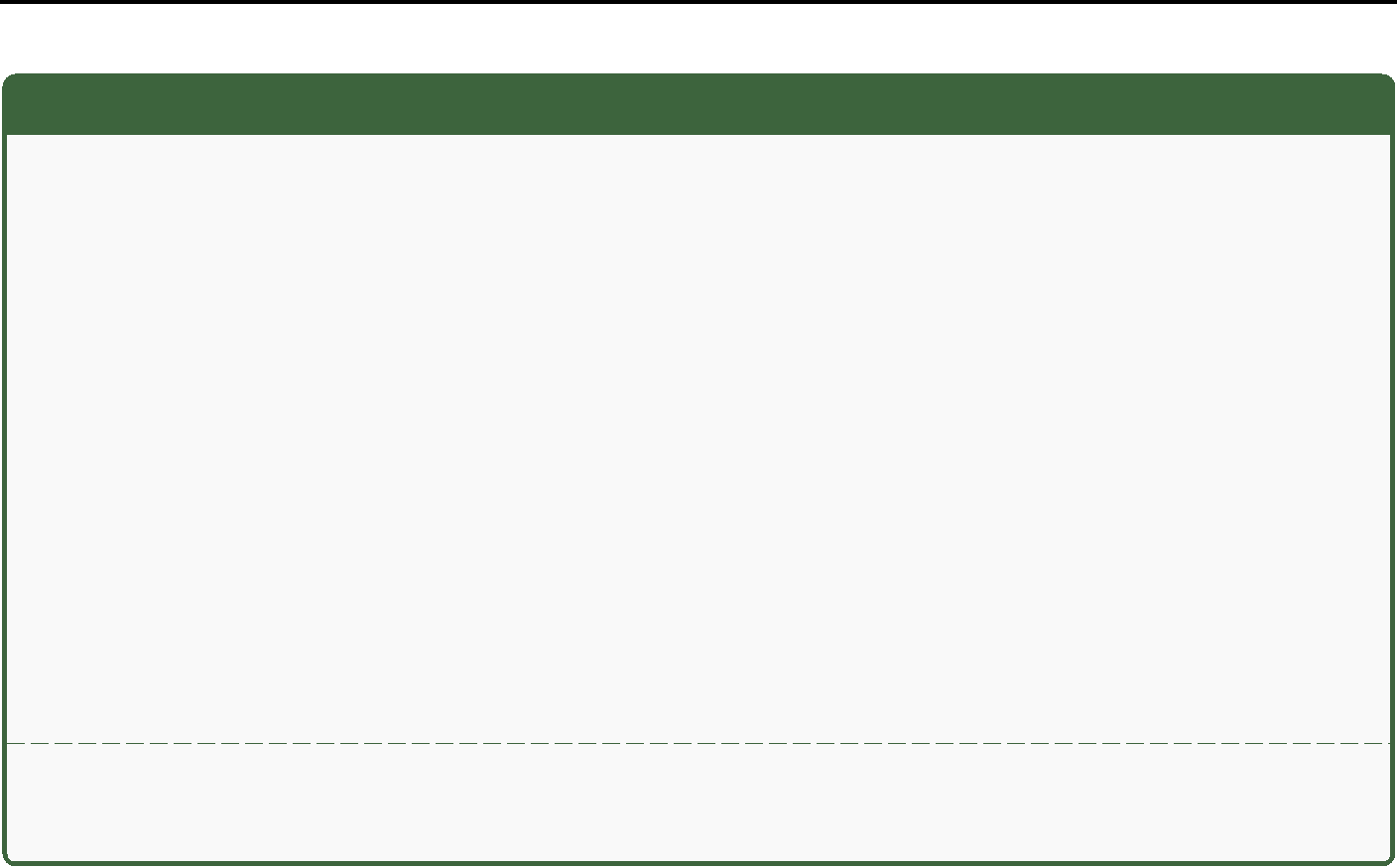
to closed-source models, and challenges in replicating

research studies.

Study keywords: Software Maintenance; Systematic review of the literature.

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A Software Maintenance Methodology: An Approach Applied to Software Aging [[28]](#page115)

Study summary: Discusses the implementation of suitable software main-

tenance models for software maintenance activities by characterizing the software system.

Method: Implements a software rejuvenation method by perform-

ing maintenance on specific systems and evaluates the performance improvement of these older systems.

Results: Shows that applying the software rejuvenation method

to specific systems improves system performance.

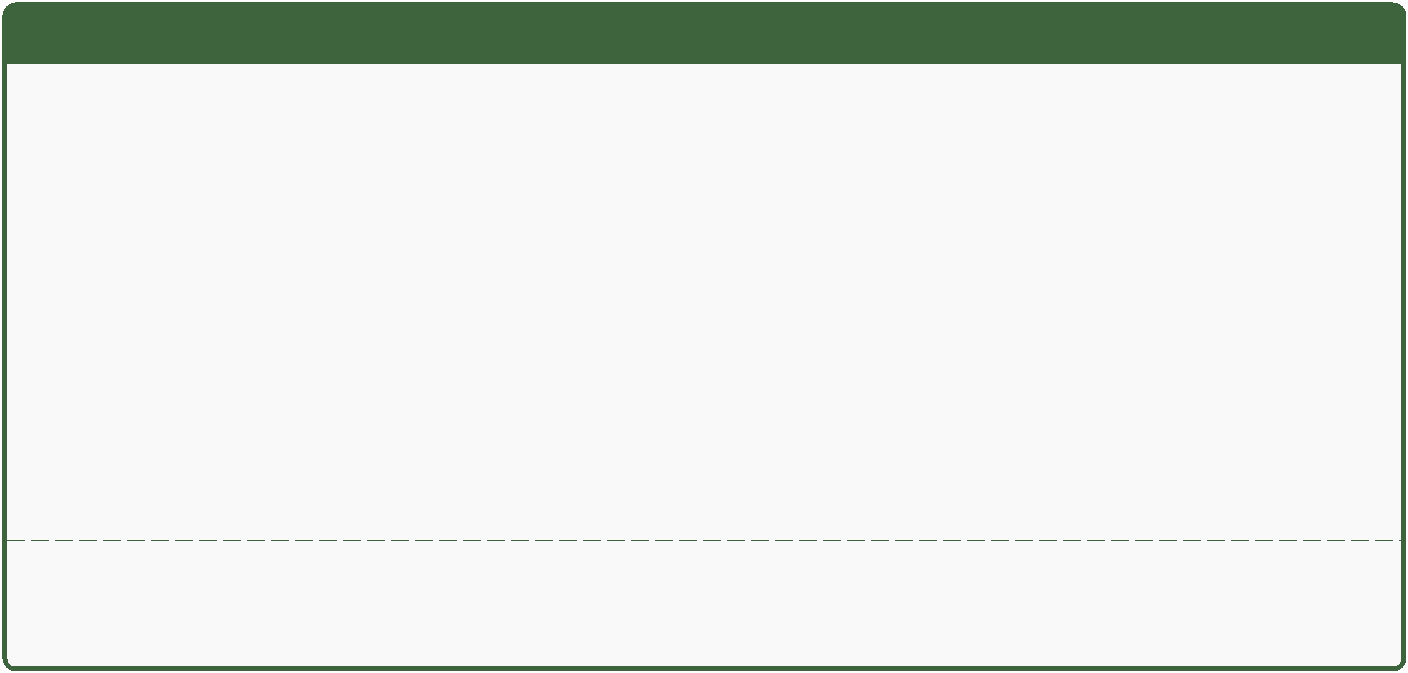
Commentary: Focuses on software maintenance strategies for older sys-

tems without providing a guideline for efficient mainte-

nance implementation. Addresses the use of mainte-

nance methods for such systems.

Study keywords: Software ageing and rejuvenation; methodology; software maintenance



Tools and Benchmarks for Automated Log Parsing [32]

Study summary: Focuses on log parsing and benchmarking different log

parsing methods.

Method: Compares multiple third-party log parsers using various

benchmarks.

Results: Demonstrates the robustness, efficiency, and accuracy of

these log parsers through benchmarking data.

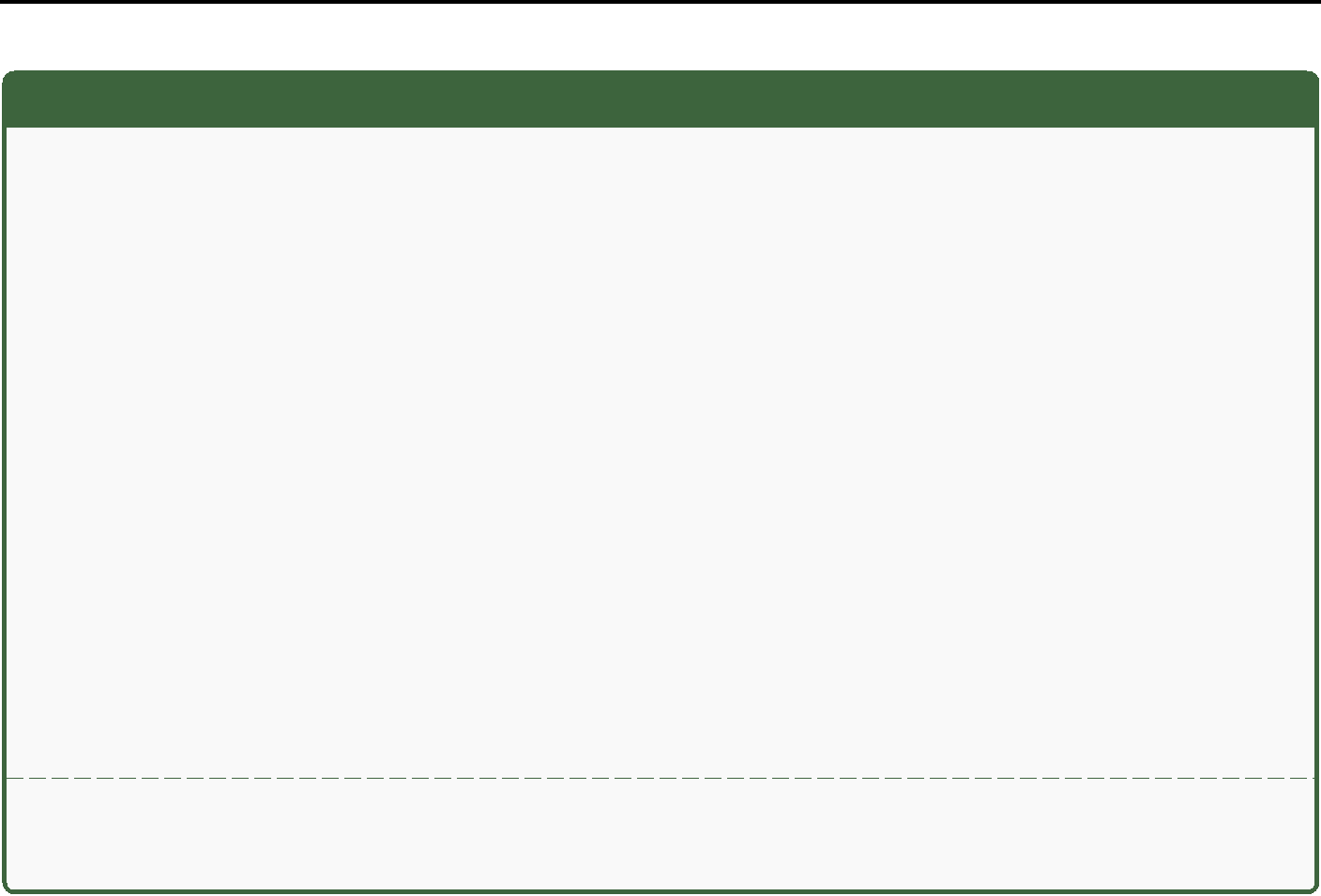
Commentary: Emphasizes the importance of efficiency in event log-

ging. Primarily addresses log parsers for system diag-nostics rather than user-based event logging.

Study keywords: AIOps; anomaly detection; log analysis; log management; log parsing

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A Systematic Review of Logging Practice in Software Engineering [35]

Study summary: Examines how logging practices are implemented in the

industry and highlights the lack of research in this area in software engineering.

Method: Created multiple research equations to obtain and ana-

lyze research on logging practices in software engineer-ing.

Results: Shows that relevant research has been conducted each

year, categorizing the development topics of each arti-cle.

Commentary: Emphasizes the need to establish comprehensive meth-

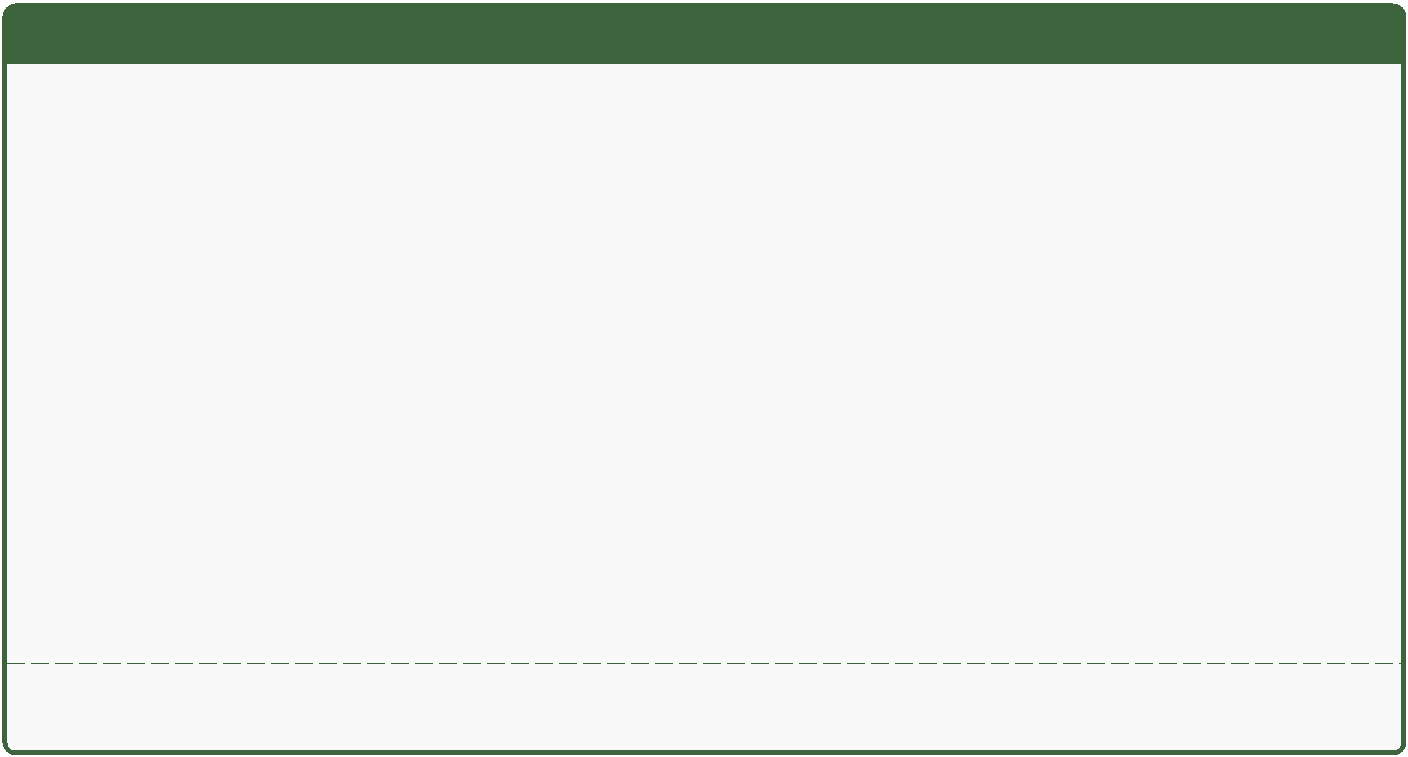
ods for developers to implement logging practices. High-

lights the lack of sufficient research on logging practices

and the importance of specific use cases in the software

industry.

Study keywords: Logging Practice; Software Engineering; Systematic Literature Review



Learning to Log: Helping Developers Make Informed Logging Decisions [42]

Study summary: Summarizes the importance of how and what to log to assist software developers in creating efficient logging mechanisms.

Method: Developed an automated tool called ”LogAdvisor” for developers, trained using different learning models.

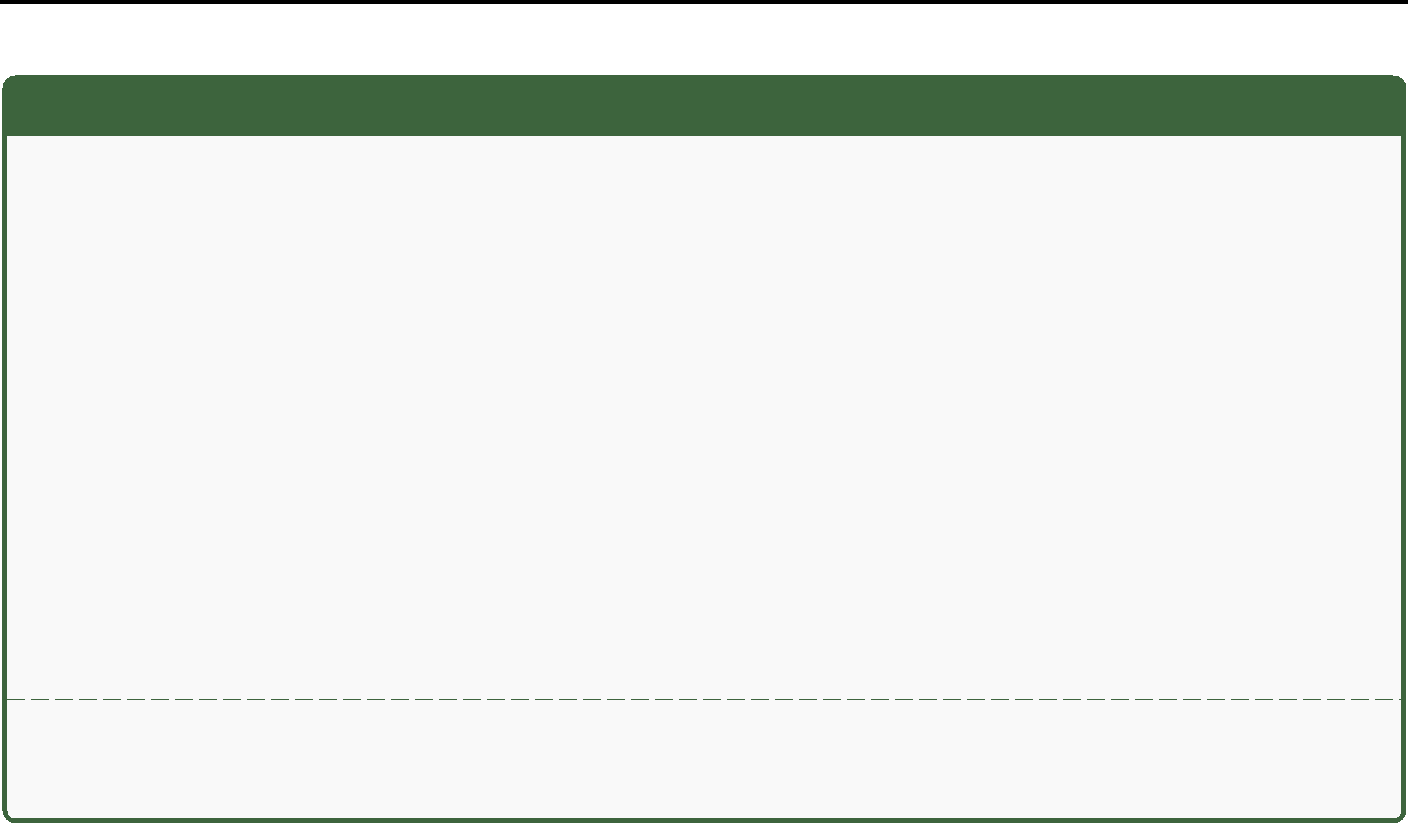
Results: Presents benchmark results of the tool’s performance with various learning models.

Commentary: Provides a generic method for log analysis of events based on intended log analysis. Offers important guide-lines for event logging and log analysis, which should be incorporated into the method of a new logging mecha-nism.

Study keywords: Keywords (not specified in the provided text)

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Towards a Better Assessment of Event Logs Quality [43]

Study summary: Examines development practices that can be imple-

mented to improve or maintain the quality of event logs.

Method: Created metrics for the quality assessment of event logs

in both real-life and artificial case studies.

Results: Validated the quality metrics of event logs using natural

and synthetic data.

Commentary: Highlights the importance of maintaining acceptable log

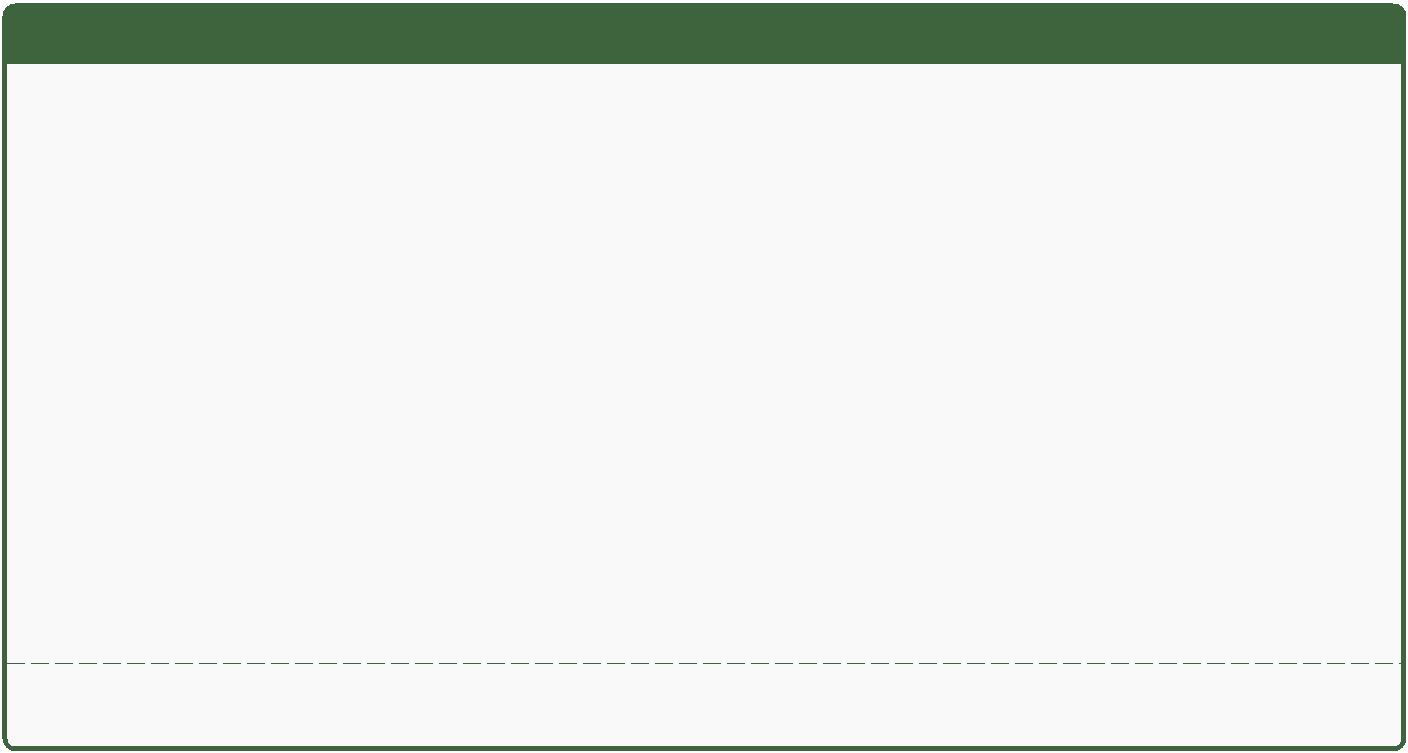
quality to ensure consistency and completeness of logs.

Emphasizes the need for logging mechanisms to accu-

rately capture logs with minimal structural and behav-

ioral complexity.

Study keywords: event logs; process mining; process mining algorithms; qualitative model



Central Audit Logging Mechanism in Personal Data Web Services [51]

Study summary: Aims to create a logging mechanism to obtain audit logs from a web application.

Method: Created a central logging mechanism for audit logs in web services.

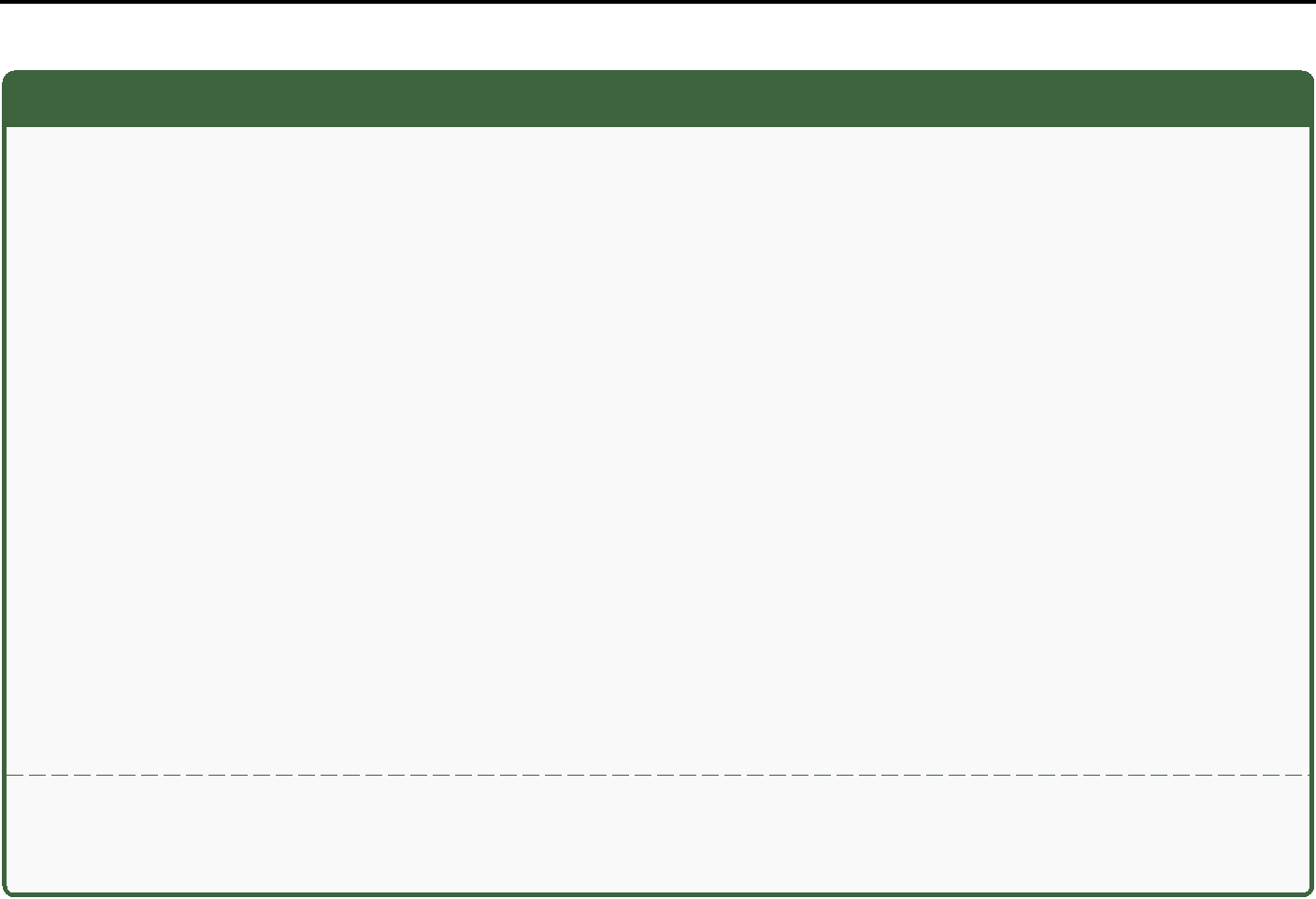
Results: Demonstrated the use of an applied logging model to establish a central audit logging mechanism for a web service.

Commentary: Created a method for audit logs in a web service, but did not perform log analysis on the logs. Explored the ad-vantages and disadvantages of the created logging mech-anism and discussed the differences between client- and server-side logging mechanisms.

Study keywords: API; API Policy; Audit Logging; Personal Data; Web Service

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Chapter 1. Introduction



User Behavioral Patterns and Reduced User Profiles Extracted from Log Files [50]

Study summary: Focuses on extracting behavioral patterns from log files

through log analysis and creating user profiles for com-parison with individual users or user groups.

Method: Analyzes behavioral patterns in a set of log files gen-

erated by users interacting with a system. Aims to

identify similarities between logs based on specific log

attributes.

Results: Demonstrates similarities between users or user groups

when they interact with the system.

Commentary: This study does not provide a specific logging mecha-

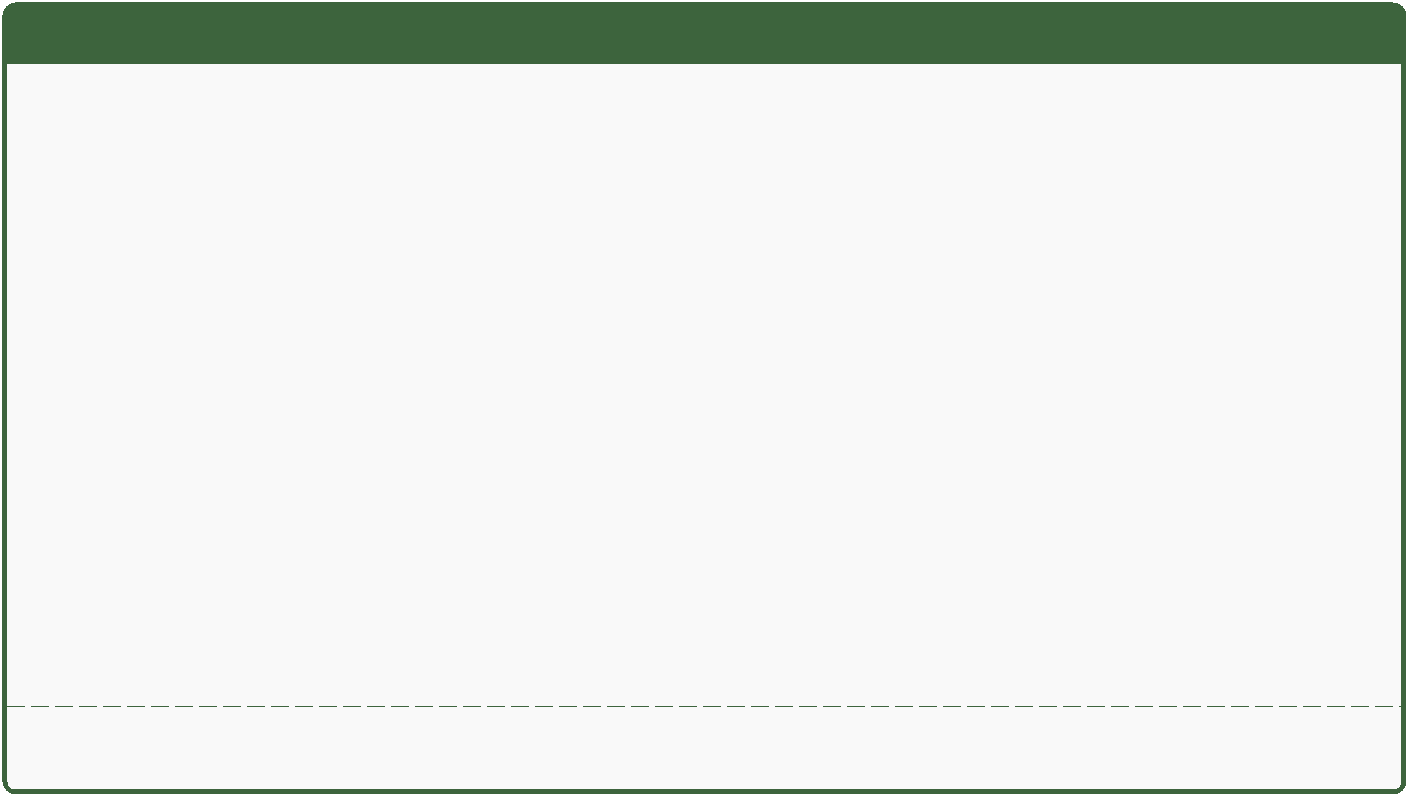
nism method for implementation on any system. In-

stead, it conducts log analysis to create user profiles and

explores what events in a system can be considered user-

based events for log analysis.

Study keywords: Analysis of users’ behavior; Behavioral patterns; Complex net-works; User profiles



Tracking User Activities and Marketplace Dynamics in Classified Ads [54]

Study summary: Focuses on tracking user activities on a web application

when users interact with ads. Implements log analysis to

create a probabilistic model of user behavior data based

on ad interactions.

Method: Creates models to track user activities when interacting

with web page ads.

Results: Demonstrates the performance and evaluation of each

model used.

Commentary: This study specifically records user interactions with ads

for log analysis, highlighting its goal of capturing user-

based data for marketing profiling. This reflects a com-

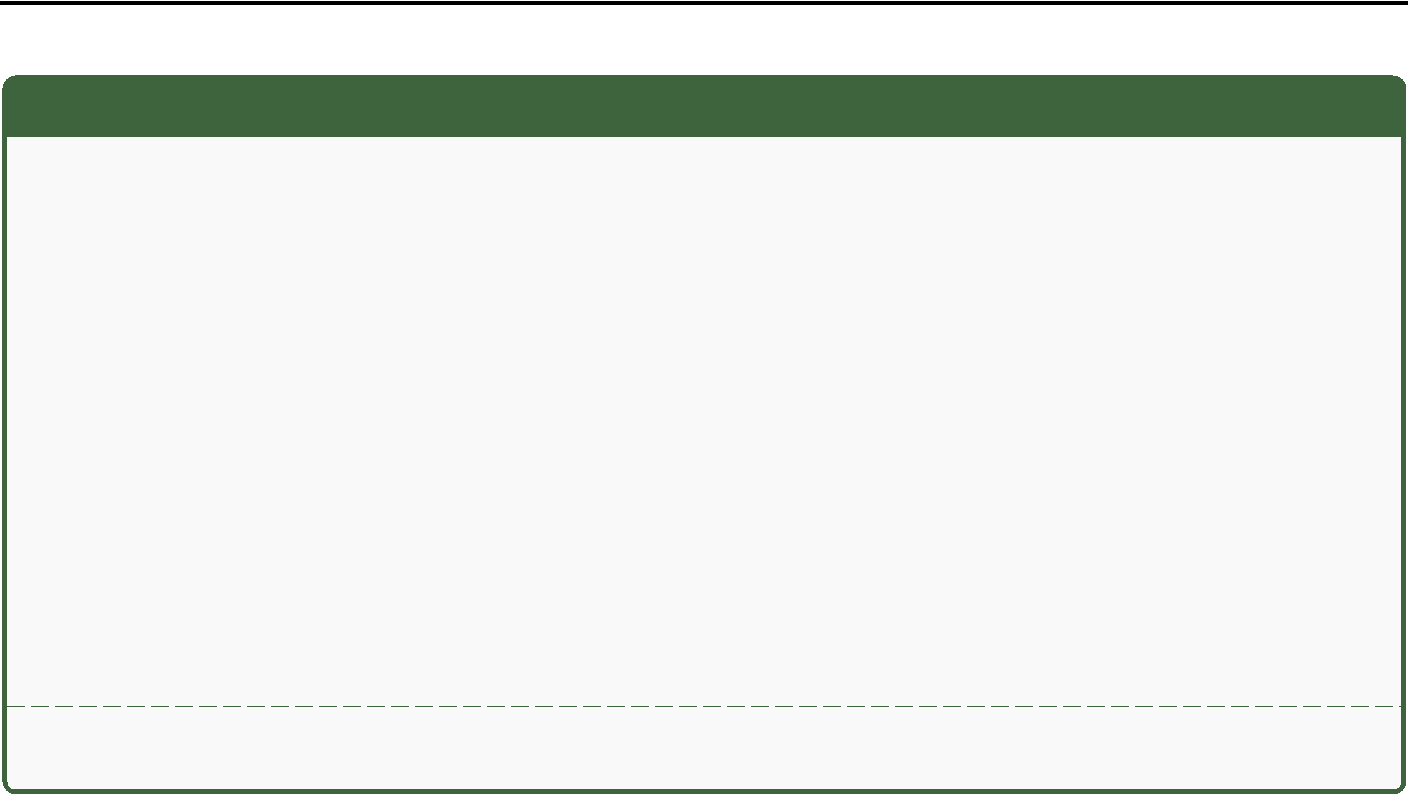
mon objective in the industry where organizations track

user data for commercial purposes.

Study keywords: Classified ads; Temporal analysis; User modeling; User tracking

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Chapter 1. Introduction



Analysis of Visitor’s Behavior from Web Log using WebLog Expert Tool [56]

Study summary: Explains the log analysis for websites using a Web log

tool that performs data processing, pattern discovery,

and research. Aims to obtain user activity data, includ-

ing total time spent per webpage, visited webpages, and

other visitor browser analysis data.

Method: Utilizes a Web Log Tool to capture specific event logs

for Web Log analysis of user behavior.

Results: Indicates that the log data used in the analysis could be

leveraged to enhance the website’s usability.

Commentary: Focuses on log analysis of user data rather than provid-

ing a method for the logging mechanism itself.

Study keywords: web server log; Web usage mining

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Chapter 1. Introduction

1.3 Problem statement

Software maintenance is a vital part of the entire life cycle of any software system. In Section 1.2.1, multiple challenges can make it harder to improve maintenance efforts with limited available resources. It is beneficial to prioritise maintenance to ensure that limited resources are used efficiently.

A possible solution to this problem is using event logs to determine system usage, as it is a proven method industry to track system usage. Software developers can access third-party software logging tools to get the event logs. Most of the tools focus more on system runtime utilisation than user activities. There exist logging tools that can track user-based movements depending on the framework the software system is developed in

Although there are live tools that can track events generated by the user, it is not guaranteed that log quality will be acceptable. Some much-needed logging attributes that will aid log analysis may not be logged.

Designing and implementing a logging mechanism might bridge the gap between software maintenance and log analysis to create a system usage report.

Software developers still need to design the overall logging mechanism and decide where to place the logging points to capture the event logs in a software system. There are proven methods to create a suitable logging mechanism, but not all of them include the analysis of the records for user-based utilisation to improve software maintenance. The problem statement can be summarised as:

Software maintenance is a problem in the industry due to how inefficiently devel-opers prioritise maintenance activities. A proven method to monitor software be-haviours is event logging. The logging mechanism and log analysis to improve soft-ware maintenance need to be explicitly designed for user-based events.

1.4 Objectives of the study

In Section 1.3, the problem of efficiently implementing software maintenance has been iden-tified. There is a need to create a system utilisation analysis report from event logs captured using a logging mechanism.

The study is divided into two components to achieve the primary objective: design and implementation of the logarithmic mechanism.

1.4.1 Literature Objectives:

1. Investigate what will define a user-based event log and how to obtain the needed log attributes for a comprehensive user utilisation log analysis.
2. Investigate where to place logging points in a software system to capture user-based event logs.
3. Investigate how to evaluate the log quality of the stored user-based event logs.
4. Investigate how to implement maintenance prioritisation.

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Chapter 1. Introduction

1.4.2 Empirical objectives:

1. Implement the method to create a user-based logging mechanism on a test system:
   1. Define the user activity types and create the needed log attributes for a user-based event log.
   2. Implement the logging points at strategic locations to capture the log attributes to create events logs.
   3. Implement a software maintenance prioritisation method in the log analysis.
   4. Use or create a log analysis tool to evaluate the log quality of the captured logs.
2. Verify the results for the test system’s software maintenance prioritisation.
3. Validate the software maintenance prioritisation method with a critical analysis of the case studies results.

1.5 Overview of the dissertation

**Chapter 1: Introduction**

This chapter contains the background of software maintenance, event logging, and system utilisation analysis. It defines the complexities and general issues of software maintenance for software developers. Efficient use of limited resources requires software developers to implement better software maintenance decisions. Event logging is a proven method to get system information that can be used to assist with prioritising software maintenance to implement it efficiently.

**Chapter 2: Methodology**

This chapter contains the design of the generic method used to create a logging mechanism from a set of defined logging points and attributes. The software system for which the logging mechanism is made is a Web-based application. The second part of this chapter is the system utilisation analysis, using the captured logs to create an analysis report.

**Chapter 3: Results**

This chapter contains the results of implementing a logging mechanism in a case study web-based application, as designed in Chapter 2. The results of the implemented logging mechanism are analysed as part of a system utilisation analysis, and recommendations are made on improving the maintenance of the case study web-based application. The results are discussed and validated to show how they address the problem statement and fulfil the study objectives.

**Chapter 4: Conclusion**

This chapter concludes by creating a logging mechanism for system utilisation analysis to im-prove software maintenance for a Web-based application. Limitations and recommendations are also made based on methodology and results.

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Chapter 2

Methodology

A white number two

Description automatically generated with medium confidence

Using user-based activity logging and analysis to prioritise software maintenance

Cornelius Scheepers

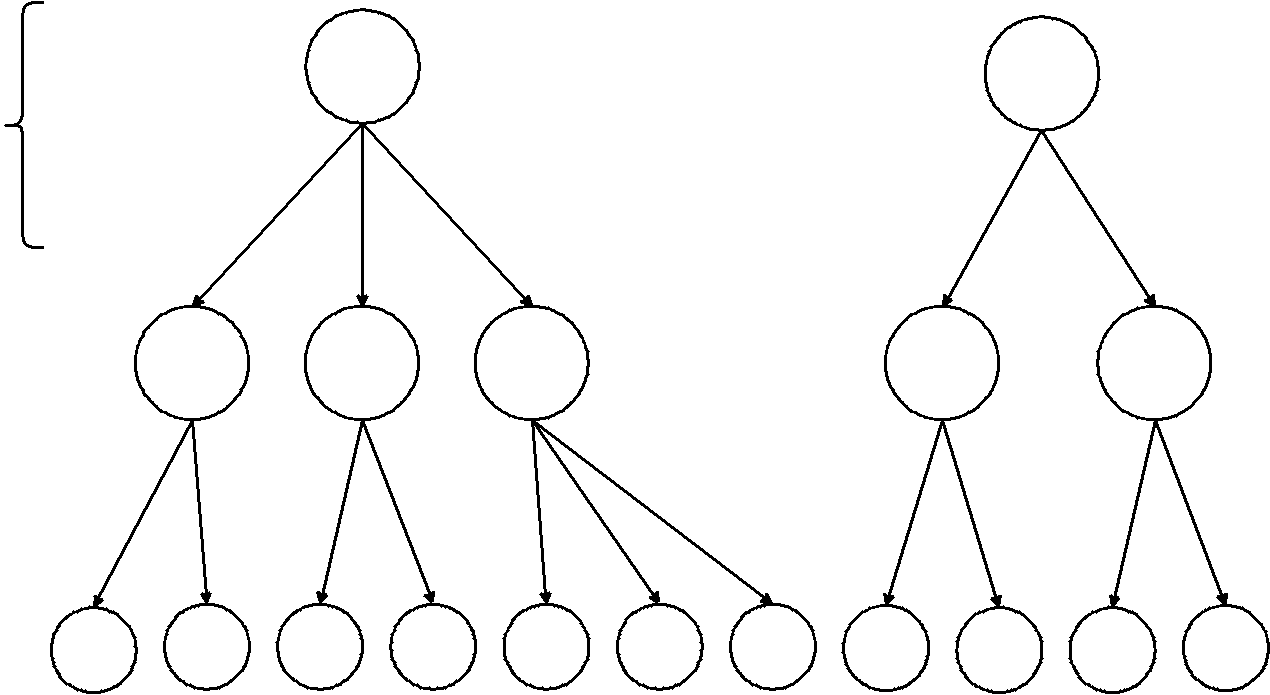
35

Chapter 2. Methodology

2.1 Preamble

The literature in Chapter 1 is used for the method to create a logging mechanism that can capture user-based activity logs to improve software maintenance by analysing the logs obtained. The development of the solution to the identified problem in Section 1.3 will be made specifically for a Web-based application.

Web-based applications are one of the most widely used software implementations that can benefit from an analysis of system usage using user-based event logs. These software systems have many different designs, and for this study Web applications that require the user to be logged in to an active session in the software system will be used as in Figure 2.1.



|  |
| --- |
| *User* |

|  |
| --- |
| *Subsustem System* |

**U1** **U2**



**S1** **S2** **S3** **S1** **S2**



SS1 SS2 SS4 SS5 SS6 SS7 SS7 SS1 SS2 SS7 SS8

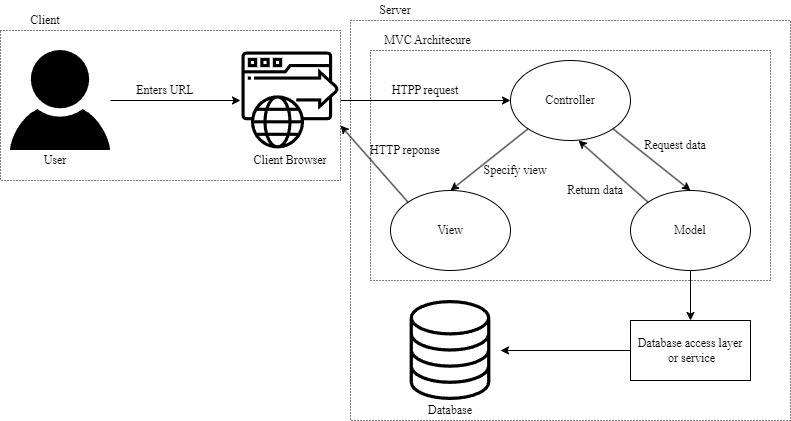
Figure 2.1: Basic design of a software system

In Figure 2.1 is the basic design of the Web application the users interact with different systems. These systems can be different pages or sections of the website and can be further divided into subsystems.

In Section 2.3 the method to create a logging mechanism to capture user-generated events is discussed for web-based applications. The different functional requirements and interfaces are discussed in this section [57].

In Sections 2.3.3 and 2.3.4 the method is discussed to analyse these obtained logs to improve software maintenance by using various tools visualisation tools or creating them based on the available log attributes. In Figure 2.2 is the design for the logging mechanism to capture the user-based event logs.

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Figure 2.2: Logging mechanism basic system design

In Figure 2.2 is the basic system design of the logging mechanism. This design provides a high-level overview of the interaction the user has with the software system to create a user-based event log. The two sides of the design in Figure 2.2:

* Client side which involves the user, the device the user uses to access the website and the user-generated event. The user interacts with the website, this creates a user event that can be captured.
* Server side which has the rest of user activity logging software that consists of multiple or a single logging point. The user activity logger interacts with a structured database to store the captured log created from all the captured log attributes.

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Chapter 2. Methodology

2.2 Development of solution

For this study, the development of the solution consists of four main phases:

* Investigate use methods in the literature or create new methods for a logging mecha-nism and log-maintenance prioritisation analysis.
* Design a logging mechanism to be able to perform software prioritisation log analysis.
* Verify if the solution can meet the design specifications.
* Implement the solution in case studies to evaluate the results obtained.

In Figure 2.3 these four development parts of the solution are used to create the methodology for this study.

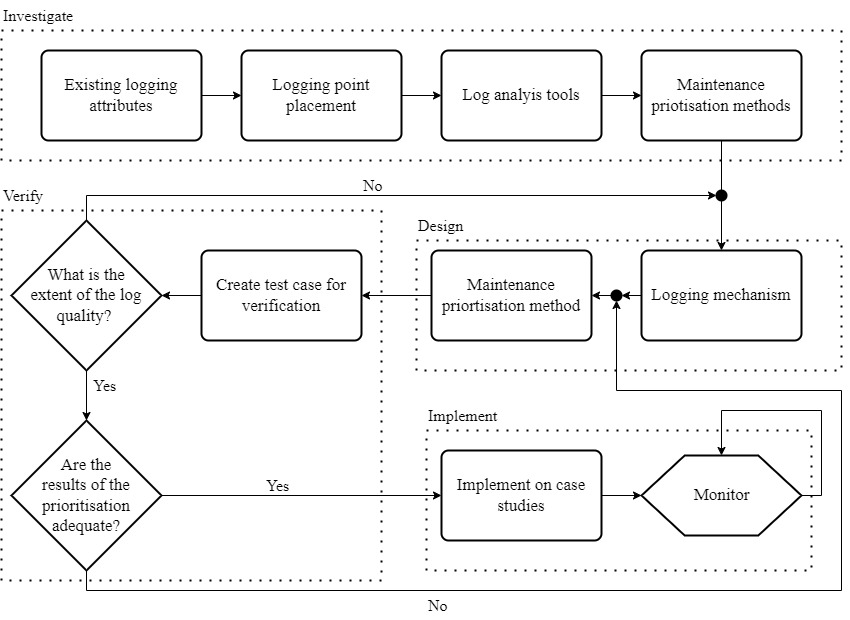


Figure 2.3: Development of solution

The first phase in Figure 2.3 is the investigation in Section 2.3 to define the required re-quirements for the logging mechanism and the prioritisation of software maintenance using the literatrure of Section 1.2. In the second phase, the design of the logging mechanism and the software maintenance priority is made in Section 2.4.

The verification phase focusses on implementing the design specifications of the logarithmic machinery method and the software maintenance method. After the verification phase, the implementation phase, the methods are implemented case studies to obtain results that are further monitored and discussed.

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Chapter 2. Methodology

2.3 Investigate

In this section, functional requirements will be created for the logging mechanism and priori-tisation of software maintenance. In Table 2.1 is the summary of each of the main functional development requirements created from the investigation part of Figure 2.3.

The functional requirements (F/R) in Table 2.1 are used to identify each requirement for the development of a solution that can be verified later. Sub-requirements will use the same labelling.

Table 2.1: Functional requirements of the solution

|  |  |  |
| --- | --- | --- |
| Req. ID Name | | Description |
|  |  |  |
|  |  |  |
| F/R 1 | Identify log attributes | The logarithmic attributes must be identified as |
|  |  | needed to complete the log analysis for prioritisation |
|  |  | of software maintenance. The log attributes form |
|  |  | the characteristics of the obtained event, which for |
|  |  | this study focusses on user-based events. |
|  |  |  |
| F/R 2 | Logging point creation | Logging points capture the desired log attributes |
|  |  | when a user-based event takes place. In Table 1.3 |
|  |  | logging points should be strategically placed in the |
|  |  | software system to capture the event logs. This |
|  |  | stage of development includes identifying where log |
|  |  | points should be placed, creating logs, and interact- |
|  |  | ing with the database. |
|  |  |  |
| F/R 3 | Log analysis tools | Make use of suitable third-party tools or create soft- |
|  |  | ware to do log analysis on the stored event logs. |
|  |  |  |
| F/R 4 | Maintenance prioritising | Create a maintenance prioritising report based on the |
|  |  | log analysis for software maintenance using the log |

analysis tool. The report aims to visualise the use of the system of certain parts of the system and deter-mine maintenance prioritisation.

The design of the logging mechanism system will be defined in this section. This is to create a generic method of how to create a suitable logging mechanism to capture specific user-based event logs. This also defines any other subfunctional requirements to identify log attributes (F/R 1) and the creation of log points (F/R 2).

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Chapter 2. Methodology

2.3.1 Log attributes requirements

The functional requirement of log attributes (F/R 1) focusses on the possible events with which the user has been involved when interacting with the software system. In Table 2.2 are the functional requirements of F/R 1.

Table 2.2: Log attributes functional requirements (F/R 1)

|  |  |  |
| --- | --- | --- |
| Req. ID | Name | Description |
|  |  |  |
|  |  |  |
| F/R 1.1 | User-based | This functional requirement defines the characteristics of |
|  | event log char- | what software system events can be classified as a user- |
|  | acteristics | based event. |
|  |  |  |
| F/R 1.2 | User activity | User activity types further expand on what event types are |
|  | types | valid for F/R 1.1. This is also the first categorisation of |
|  |  | the logs obtained. |
|  |  |  |
| F/R 1.3 | Log attributes | The log attributes are the data obtained that describe a |
|  |  | log of user-based events. These are the primary data that |
|  |  | will be stored in a structured database. |
|  |  |  |
|  |  |  |

Table 2.2 is the first functional requirement for the development of a solution that must be defined. It is important to define and create the characteristics of an event log for a user-based event log. The rest of the logging mechanism depends on what needs to be logged, as discussed in Section 1.2.2 about the importance of what events need to be logged.

**User-based event log characteristics**

The user is the initiator of the logging mechanism. Each action or event that they trigger by interacting with the user interface on their device can be a potential user-generated event. In Table 2.3 are the subrequirements for the user that the event log should fulfil to be classified as a user-based activity log.

Table 2.3: Requirements for an event to be a user-based activity

Req. ID Description

F/R 1.1.1 The event has to be triggered by the user interacting with the user interface using their device and not any other events that the system will self-initiate. The user needs to have interacted directly with the UI. This can also be validated by tracking whether the user did interact with the UI of the HTML element ids.

F/R 1.1.2 The event must consist of different cases (ca ϵ CA the cases consist of events) that are noteworthy to make the event log identifiable [50].

F/R 1.1.3 For certain types of event logs for F/R 1.1.2, the user-generated event should have an origin from which the event took place.

Continued on next page

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Table 2.3: (continued from previous page)

Req. ID Description

F/R 1.1.4 The event log should consist of attributes that expand the identity of the user-based activity.

F/R 1.1.5 The event must have the user as the initiator or input for the user-based activity. This will exclude all events triggered by the system, as the user did not directly start the event.

F/R 1.1.6 Only use the first HTTP requests1 that is sent to the server.

Every interaction the user has with the user interface of the device to the software system can be seen as an event triggered by the user. Most of these events will not have a meaningful impact as they will not fulfil F/R 1.1.2 and F/R 1.1.4 in Table 2.3.

For the user activity event to meet the requirement of F/R 1.1.2 it has to have defined cases that describe the activity type of each event. These activity types form the basic criteria for which events can be parsed, which significantly reduces the number of logs that will be obtained. This will ensure that the event logging process will produce quality user-based logs as discussed in Table 1.3:

* A basic structural complexity to simplify log parsing and development of the logging points in the system,
* Keep the logging consistent by not deviating from the defined cases, and
* Ensure that the event log’s other attributes are complete and available to increase the accuracy and trustworthiness of the event logging when further system utilisation analysis needs to be done.

**User activity types**

The user activity types (F/R 1.2) categorise different user-based event logs when they are obtained before other log attributes are fully defined. In Table 2.4 are the functional re-quirements of the basic user activity types.

The general type of user activity event (F/R 1.2.3) will be the most common user activity event and will be split up into different user activity events. This is determined by the need of what utilisation stage to analyse specific user activity events.

These user activity types can be further expanded with the general activity (F/R 1.2.3) for log analysis purposes. The general activity types will be different for each system based on what the system enables the user to do or what is needed for further system utilisation analysis, such as determining if the action the user triggered was to generate a report that they downloaded.

* A HTTP request is made by a client, to a named host, which is located on a server. The request aims to access a resource on the server.

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|  |  |  |
| --- | --- | --- |
|  |  | Chapter 2. Methodology |
|  |  |  |
|  |  | Table 2.4: User activity types |
|  |  |  |
| Req. ID | Activity Type | Description |
|  | |  |
|  | |  |
| F/R 1.2.1 Web page accessed | | The user may navigate through different web pages in a |
|  |  | session. This is to track when the user first accessed a |
|  |  | certain web page or software system on the page. |
|  |  |  |
| F/R 1.2.2 | Session changes | This is any user activities excluding F/R 1.2.1 that mod-  ifies the user’s session:   * Logging into a Web application. Both successful and failed attempted log-ins. This user-based activity may cause the log attributes that identify   the user will be a NULL value as the user’s session  has not started yet to verify their identity,   * Ending their session by logging out or declining to extend their session when it is about to expire * Modifying any session or other relevant variablesthat can be used in the utilisation analysis |
|  |  |
|  |  |
|  |  |
|  |  |
|  |  |
|  |  |
|  |  |
|  |  |
|  |  |
| F/R 1.2.3 | General activity | Any events excluding the first two types of user-based |
|  |  | activity that the user initiates when they interact with |

the web page. Most user activity logs will have this event type.

Log attributes

The log attributes (F/R 1.3) are the descriptive characteristics of the user-based event logs.

The functional requirements for the log attributes are defined in Table 2.5.

Table 2.5: Logging attributes

|  |  |  |
| --- | --- | --- |
| Req. ID | Logging point | Description |
|  |  |  |
|  |  |  |
| F/R 1.3.1 | Identification number | The activity identification is an incremental number |
|  |  | of the user-based event that is logged. |
|  |  |  |
| F/R 1.3.2 | Timestamp | This is the time the user initiated the user-based ac- |
|  |  | tivity event. This will be the timestamp from which |
|  |  | the log was written in the database, since the log will |
|  |  | be made before the rest of the intended HTTP request |
|  |  | is completed. |
|  |  |  |
| F/R 1.3.3 | Activity type | Each event can be classified into user-based types. |
|  |  | This is the type of activity based on users in Table 2.4. |
|  |  |  |
|  |  |  |

Continued on next page

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Table 2.5: (continued from previous page)

|  |  |  |
| --- | --- | --- |
| Req. ID | Logging point | Description |
|  |  |  |
| F/R 1.3.4 | User identification | Each user has a unique identification number that |
|  |  | links the event to them if their session has been veri- |
|  |  | fied and can be obtained. It will not be available when |
|  |  | the user tries to log in to the system as their session |
|  |  | has not been set yet. |
|  |  |  |
| F/R 1.3.5 | Request origin | In web applications, there are always requests sent |
|  |  | back to the server, which will call the primary function |
|  |  | to handle the request. This can be logged as either |
|  |  | the file from which the request is sent or the Web page |
|  |  | from which the request came. |
|  |  |  |
| F/R 1.3.6 | Metadata | The metadata of the event contain request parame- |
|  |  | ters or other relevant request data of the event. These |
|  |  | metadata add more information about the user’s ac- |
|  |  | tivity. Some of the event types may not have meta- |
|  |  | data added. |
| F/R 1.3.7 | Miscellaneous | These are any non-metadata attributes that can be |
|  |  | consistently captured to be used in the use analysis. |

They expand the characteristics of the log obtained from the user beyond the base attributes.

The logging attributes defined in Table 2.5 are the base attributes that make up the main structure of the user-based event log. For web-based applications on the client side, only some of these attributes can be obtained, as the rest of the attributes can be resolved on the server side. The metadata (F/R 1.3.6) can consist of the request parameters that are available on the server side, but any additional captured data can be added and sent to the server.

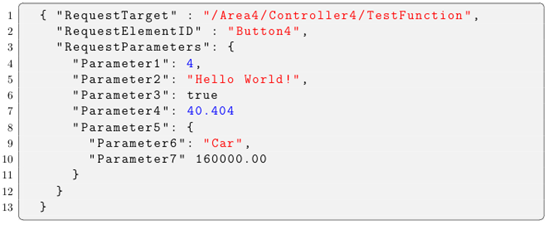
Each of these log attributes combined creates the base log from which key logging points can be created in the software system to capture user-based activity logs in Table 2.5. The activity type (F/R 1.3.3) can be assigned during the user-based activity identification phase with a default value and resolved to a new activity type based on metadata or other parameters by:

* If it alters any of the session variables that are relevant to the system utilisation analysis,
* Access a certain part of the software system that needs all the user-based activities set to a certain type based on the nature of the procedures that need to be executed such as triggering a generation of a report that can be its user-based activity type.
* The activity type is also sorted by HTML element tags, such as a button or text box.

There can be extra parameters captured on the client side such as by the logging point or can either be captured on the server side when the rest of the log’s attributes are being obtained. These extra parameters are shown in Listing 2.1

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|  |  |  |  |
| --- | --- | --- | --- |
|  |  | Chapter 2. Methodology | |
|  |  |  |  |



Listing 2.1: Metadata JSON

The metadata in Listing 2.1 is the possible additional parameter that can be obtained for the user base activity log. The metadata will need to store as a JSON string as it can be a complex object that does not have a set number of parameters. This complex object can have:

* The RequestTarget parameter can be a file path for the website code from which the page is created or a software system. It also contains the function that is called by the HTTP request.
* The RequestElementID is the HTML element ID with which the user interacted that caused the user-based activity. This can be used as another validation that the event was caused by the user. Some of the user-based activities can be set to some of these HTML element types by getting the HTML element tag.
* The RequestParameters is all the parameters in the HTTP request that can be seri-alised into a JSON string. This can be used to determine what the user tried to do using this input for the specific function that is used for F/R 1.1.6 in Table 2.3.

2.3.2 Logging point requirements

The functional requirement of the logarithmic point (F/R 2) focusses on the creation and strategic placement of the logarithmic points. The log points that obtain the log attributes must also store the created event log in a structured database. The logging point’s subfunc-tional requirements are defined in Table 2.6.

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Table 2.6: Server functional requirements (F/R 2)

|  |  |  |
| --- | --- | --- |
| Req. ID | Name | Description |
|  |  |  |
|  |  |  |
| F/R 2.1 | Logging point placement | The logging points are used to capture |
|  |  | and create the user-based event log that |
|  |  | will be stored in a database. |
|  |  |  |
| F/R 2.2 | Storing the user-based activity logs | The event log is stored in a structured |
|  |  | database until it is needed for further log |
|  |  | analysis. |
|  |  |  |

Table 2.2 concludes the design requirements for the logging mechanism. The stored logs will be further processed when the log analysis needs to be implemented.

Logging point placement

In Table 1.3 the logging points should be strategically placed in the software system to capture the log attributes for the user-based activity log. To meet the requirements of Table 2.3 for a user-based activity, the log points should adhere to the functional requirements of the log points of Table 2.7.

Table 2.7: Logging points requirements

Req. ID Description

F/R 2.1.1 The logging point should be placed where the user’s interaction with the software system will send a request back to the server.

F/R 2.1.2 Each logging point should consistently capture the user-based activity as the activity is happening.

F/R 2.1.3 Logging points should be globally complete to capture the user-based activities in the giving software system without too much modification between each point in the same software system.

F/R 2.1.4 The logging points should not interfere with the rest of the system’s opera-tions, this would slow down the system by causing too much overhead in each request that is being sent.

The logging points can be either a single code segment or consist of multiple code segments in a software system that aims to capture user-based actions as they happen. Creating multiple logging points in a software environment will:

* Increase the complexity of the logarithmic mechanism. Each point can be different from the other as it will need certain operations to capture the log,
* The consistency of the logging might differ and increase as the logging points increase in a software system.
* The correctness of the logging will be impacted if the different changes in the logging point are unable to consistently capture the user-based activity or extract all the needed attributes to complete the user-based log.

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Creating a single logging point reduces the complexity and, in most cases, will improve the consistency and correctness of the user-based logs. In Web applications, a globally defined logging point can be used in a modified HTTP request that will form the base template for all or most HTTP request used in the software system as in Section 2.4.1.

The use of a single centralised logging point does not guarantee that the logging mechanism will perform more efficiently and accurately than using multiple logging mechanisms. Using a single logging point may have complexity issues when it needs to capture each user-based activity consistently with different cases.

**Storing the user-based activity logs**

After the logging point has captured the log attributes and created the event log, the log can be saved in a structured database. The storing of the functional requirements of user-based logs (F/R 2.2) should be defined for structured database interactions.

The captured parameters of the log attributes may have some sensitive user data that should not be logged. Functions can be excluded or assigned a new user activity type that will need to filter out certain parameters or not log any parameters at all. This will be any functions that include:

* Session handling functions that contain passwords or other user information that should not be available to anyone but the user. This could lead to unintentional information disclosure of any personal information in the system utilisation analysis if it is available for anyone who can see and use the user-based activity logs,
* Complex parameters such as file upload streams of files that the user tries to upload. This information cannot be broken down to a simple JSON structure as in Listing 2.1, other metadata such as the file size, name, and type can rather be logged. This can also be defined as a separate type of user-based activity event by detecting these complex parameters.

In Table 2.8 is the type of data for the parameters and the functional requirements that it will need to fulfil of Table 2.5.

Table 2.8: Log attributes for database storing of the event logs

|  |  |  |
| --- | --- | --- |
| Req. ID | Column Name | Log attribute requirement |
|  |  |  |
|  |  |  |
| F/R 2.2.1 | ActivityID | F/R 1.3.1 |
|  |  |  |
| F/R 2.2.2 | Timestamp | F/R 1.3.2 |
|  |  |  |
| F/R 2.2.3 | ActivityType | F/R 1.3.3 |
|  |  |  |
| F/R 2.2.4 | UserID | F/R 1.3.4 |
|  |  |  |
| F/R 2.2.5 | Subsystem | F/R 1.3.5 |
|  |  |  |
| F/R 2.2.6 | GroupID | F/R 1.3.7 |
|  |  |  |
| F/R 2.2.7 | MetaData | F/R 1.3.6 |
|  |  |  |
|  |  |  |

In Table 2.8 the functional requirements of log attributes should match the functional re-quirements (F/R 2.2) of the logging attribute (F/R 1.3). Any other needed parameters can

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be added using the miscellaneous [(F/R 1.3.7)](#page52).

New tables or other structured storage entities can be added to save the captured data from the logging point.

2.3.3 Log analysis tool

The log analysis (F/R 3) uses third-party analytical tools or custom-created software log analysis implementations. Developers should use the implementation that will fulfil their log-analysis needs. In Table 2.9 is the log analysis functional requirements (F/R 3).

Table 2.9: Log analysis functional requirements (F/R 3)

|  |  |  |
| --- | --- | --- |
| Req. ID | Name | Description |
|  |  |  |
|  |  |  |
| F/R 3.1 | Log quality | Log quality ensures that the logs obtained are |
|  |  | usable for log analysis. Any incomplete logs |
|  |  | should be either fixed in the log analysis im- |
|  |  | plementation or the logging mechanism should |
|  |  | be adjusted to get the complete logs. |
|  |  |  |
| F/R 3.2 | Log analysis tool requirement | Certain basic requirements are needed for the |
|  |  | log analysis tool to implement a log analysis. |
|  |  |  |

**Log quality**

Log quality has been identified in Table 1.3 should be important when implementing a log-analysis mechanism. Log quality (F/R 3.1) will affect both the performance of the logging mechanism and the accuracy and completeness of the log quality. In Table 2.10 are the functional requirements for log quality (F/R 3.1).

Table 2.10: Log quality functional requirements (F/R 3.1)

|  |  |  |
| --- | --- | --- |
| Req. ID | Requirement name | Description |
|  |  |  |
|  |  |  |
| F/R 3.1.1 | Log availability | The log attributes should be available when the logging |
|  |  | mechanism is actively capturing the user-based events. |
|  |  | It should be locally- and globally complete. |
|  |  |  |
| F/R 3.1.2 | Log completeness | User-based logs should be complete and minimal cor- |
|  |  | rections should be made after logging during the log |
|  |  | extraction process (F/R 3.1.3) and presentation of vi- |
|  |  | sualisation. |
|  |  |  |
| F/R 3.1.3 | log extraction | User-based logs are extracted from the database and |
|  |  | imported into a visualisation presentation for user-based |
|  |  | activity logs. |
|  |  |  |
|  |  |  |

The functional requirements for log availability (F/R 3.1.1) and completeness (F/R 3.1.2) can be achieved, all functional requirements of the user-based activity log in Section 2.3.1 are achieved with minimal processing of the raw logs afterward. There will always be changes

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made to the system that can impact which possible user-based events are considered to be logged.

Log extraction refers to the methods used to obtain the logs from the database with any other relevant data that can be used in the visualisation presentation (F/R 3.2.1). The raw logs will need to make use of foreign references to other tables in the database to provide more details on the user-based event log as in Figure 2.7.

**Log analysis tool requirement**

The log analysis tool (F/R 3.2) is to ensure that a custom or third-party implementation is performed. Will be able to meet some basic log-analysis requirements defined in Ta-ble 2.11.

Table 2.11: Log analysis tool functional requirements (F/R 3.2)

|  |  |  |
| --- | --- | --- |
| Req. ID | Requirement name | Description |
|  | |  |
|  | |  |
| F/R 3.2.1 Log visual presentation | | The visual presentation of the extracted logs should be |
|  |  | shown to the user who will make use of the activity logs in |
|  |  | a custom visual system or make use of other third-party |
|  |  | tools. This will affect how the logs will be extracted |
|  |  | (F/R 3.2.1) from the database as third-party systems |
|  |  | may use an API to get the logs from the database. |
|  |  |  |
| F/R 3.2.2 | Log comparison | Using F/R 3.2, use different log attributes that are |
|  |  | used as defined criteria. This will be to group and com- |
|  |  | pare different types of users, subsystems and activity |
|  |  | types against each other, etc. |
| F/R 3.2.3 | Maintenance suggestions | Maintenance suggestions can be made from system utili- |
|  |  | sation reports by prioritising maintenance or decommis- |

sioning software systems. This can be data or visual rep-resentations of the logarithmic comparison (F/R 3.2.2) using the log visual presentation systems (F/R 3.2.3) or creating a summary report from the visual presentation that contains maintenance suggestions.

Each of these functional requirements ensures that the system utilisation analysis will be achieved for the created logging mechanism in Section 2.3. The main user interface of the system usage analysis will consist of the presentation of user-based activities (F/R 3.2.1). This system will be either a custom-created system to display these logs or third-party software such as Microsoft’s business intelligence platform, PowerBI.

Using the third-party tools has advantages over creating custom software for visual presen-tation (F/R 3.2.1):

* Third-party BI platforms provide all the necessary analytical functionality, making it easy to create visual representations with minimal programming.
* The advanced tools on these platforms offer many ways to visualise user-based activ-ity logs for log comparison (F/R 3.2.2).

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* Maintenance and editing of these representations is usually trouble-free, with ample support and guides available for developers to make updates to custom visual pre-sentations.

These third-party tools do indeed have some other drawbacks, such as:

* Third-party BI platforms are likely to require a subscription, which can be costly for a company licence.
* Additional courses may be necessary to fully utilise the capabilities of these plat-forms.
* Additional functionality, may be required for log extraction (F/R 3.1.3) to import data into the platform.

With the drawbacks listed above, third-party business intelligence platforms are the better visual presentation tools for the system utilisation analysis if it is available for use than creating and managing a custom visualisation platform.

2.3.4 Maintenance prioritisation

Maintenance prioritisation is performed from logarithmic analysis. Maintenance priority functional requirements (F/R 4) are shown in Table 2.12.

Table 2.12: Maintenance prioritising functional requirements (F/R 4)

|  |  |  |
| --- | --- | --- |
| Req. ID | Name | Description |
|  |  |  |
|  |  |  |
| F/R 4.1 | System utilisation | The system utilisation analysis categories are needed |
|  | analysis categories | to complete logging analysis. These categories will |
|  |  | provide the data necessary to make recommendations |
|  |  | on how to prioritise software maintenance using these |
|  |  | log analysis metrics. |
|  |  |  |
| F/R 4.2 | Maintenance prioriti- | The maintenance factor measures the amount of |
|  | sation factor | maintenance required for a given software system. |
|  |  | This will be used to prioritise the software mainte- |
|  |  | nance efforts of the software developers using a scor- |
|  |  | ing system. |
|  |  |  |

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**System utilisation analysis categories**

The system utilisation analysis categories functional requirements (F/R 4.1) is used to cat-egorise the log data for maintenance prioritisation metrics. In Table 2.13 is the functional requirements of the system utilisation analysis categories (F/R 4.1).

Table 2.13: System utilisation analysis categories functional requirements (F/R 4.1)

|  |  |  |
| --- | --- | --- |
| Req. ID | Requirement name | Description |
|  |  |  |
|  |  |  |
| F/R 4.1.1 | Users | Users of software systems can be placed in different cate- |
|  |  | gories according to who uses the software. This can be |
|  |  | both the customer users and the employees using the |
|  |  | software. Using the activities of the customer users will |
|  |  | provide the data on which systems the development team |
|  |  | needs to put their resources. |
|  |  |  |
| F/R 4.1.2 | User activity | User activity types in Table 2.4 can be used as a category to |
|  | types | compare different types of user-based activities with each |
|  |  | other and use a subcategory for categories such as different |
|  |  | users who can use the system (F/R 4.1.1). |
|  | |  |
| F/R 4.1.3 Systems or sub- | | The request origin (F/R 1.3.5) of user-based activities |
|  | systems | can be classified to compare different subsystems and |
|  |  | controllers with each other. |
|  |  |  |
| F/R 4.1.4 | Miscellaneous | This user-based activity category will use the metadata |
|  | categories | attribute (F/R 1.3.7) of Table 2.5. The other fields that |
|  |  | are not set as main categories can also be placed in this |
|  |  | category, as they can take multiple forms. |
|  |  |  |

The categories in Table 2.13 allow the log data to be placed in different categories to compare them with each other. A software maintenance prioritising model can be made with the comparisons of these categories.

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**Maintenance prioritisation factor**

The maintenance priority factor (F/R 4.2) will make use of various parameters created from the logs obtained. This priority factor will need to indicate, for any given subsystem’s software maintenance priorisation, using a consistent method to determine it. In Table 2.14 is the functional requirement for the maintenance priorsation factor (F/R 4.2).

Table 2.14: Maintenance priorisation factor functional requirements (F/R 4.2)

|  |  |  |
| --- | --- | --- |
| Req. ID | Requirement name | Description |
|  |  |  |
|  |  |  |
| F/R 4.2.1 | Users | The total number of users that are active in the subsys- |
|  |  | tems should be a parameter. |
|  |  |  |
| F/R 4.2.2 | Priority | Priority is a precalculated parameter that indicates the |
|  |  | importance of a subsystem. This can be calculated or |
|  |  | defined for each subsystem. |
|  |  |  |
| F/R 4.2.3 | Activities | The total number of user activities for a subsystem must |
|  |  | be used as an input parameter for the software mainte- |
|  |  | nance factor. |
|  |  |  |
| F/R 4.2.4 | Software main- | The software maintenance factor is the measurement of |
|  | tenance factor | the importance of a certain software system. This is cal- |
|  |  | culated using F/R 4.2.1, F/R 4.2.2 and F/R 4.2.3. |
|  |  |  |

Using the functional requirements in Table 2.14 a method can be used to determine the prioritisation of software maintenance of each subsystem in a given system. The defined parameters provide a basic guideline on the input and output parameters the method needs for the calculations.

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2.4 Design

The design of the log mechanism and log analysis will be defined in this section. This section also provides flow diagrams of the logging mechanism and log analysis.

2.4.1 Web application architecture

To determine the types of user activity for a Web application, the architecture of the Web application will be a factor in the logging mechanism. Web applications consist mostly of HTML, JavaScript, and CSS programming languages. The Model-View-Controller (MVC) architecture is mostly used for web-based applications using that programming language [58]. The MVC architecture in Figure 2.4 consists of 3 basic parts which are [58]:

* Model: Is the representation of the records in the database which also interacts with the database through a database access layer or service manipulating the data by using the CRUD operations:

– create operation that adds new data,

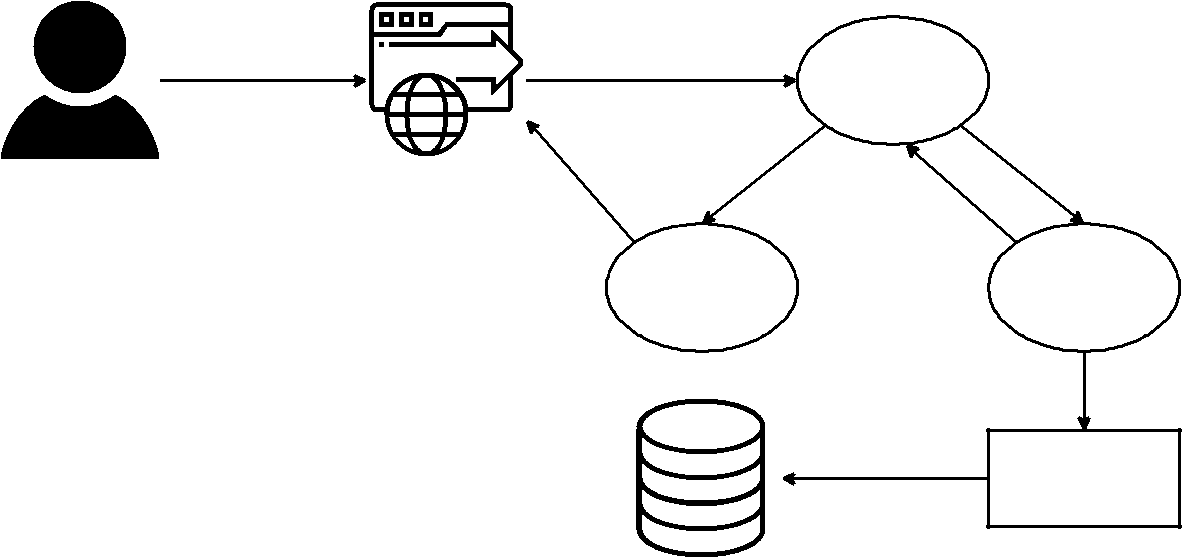
– read operation that gets the data from the database,

– update operation that modifies the existing data,

– delete operation that removes data.

* Controller: Is operates both the View and Model and serves as the connection between the user and the system by controlling the data flow of the Model and View.
* View: This shows the results of the data contained in the Model and enables the user to manipulate the data. The user will only interact with this part of the Web application.

|  |  |  |  |
| --- | --- | --- | --- |
| Client | Server |  |  |
|  |  |  |
|  | MVC Architecure |  |  |
| Enters URL | HTPP request | Controller |  |
|  |  |  |
| User | HTTP reponse | Request data |  |
| Client Browser | Specify view |  |
|  |  |  |
|  |  | Return data |  |
|  | View | Model |  |



Database access layer0

or service

Database

Figure 2.4: MVC architecture for most web-based applications [59]

In Figure 2.4 is the equivalent representation of the MVC architecture of Figure 2.2 where the data flow of the MVC architecture is shown. The user interacts with the Web application through their browser which will send a HTTP requests to the Controller and receive a

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HTTP response[2](#page62) from the View. The Controller will request and return the data to the Model which interacts with the database access layer or service to do the create, update and delete operations.

To classify any interaction between the user [(F/R 1)](#page48) and the server (F/R 2) to meet the functional requirements of Table 2.3 only the HTTP request are used for the logging points in Section 2.3.2 as it:

* Meet F/R 1.1.1 and F/R 1.1.1 as the user interacts with View to modify the data that must be sent back an HTTP request to process the data on the Controller.
* User activity types can be assigned for different scenarios the user triggers when the request is sent.
* Any additional metadata can be sent with the request header3 of the HTTP request. This will reduce the overhead added by the logging mechanism by not sending an additional HTTP request each time back to the server when a user-based activity has been identified.

2.4.2 Server side logging point

In Section 2.3.2 the functional requirements for the logging point must be met to create a suitable logging point for a software system to track user-based activities. The HTTP request will call a function in the system, subsystem, or web page to execute the user’s actions, this request information can be obtained and parsed onto the logging point.

The logging attribute can be created as a centralised code segment that all the software system’s components can execute before executing the targeted software system in Web applications such as:

* In most software frameworks, the HTTP request data can be extracted from the in-build HTTP request models to obtain the custom request headers set on the client side. There should be at least a common global location in the software where a single log point can be called for every HTTP function to execute the log point first before continuing with the rest of the main targeted function. The rest of the log attributes can also be obtained during the execution run time:

– Absolute URI path: The string containing the absolute URI path of the cur-rently active system, subsystem or web page.

– Absolute request URL: The requested URL contains the target system, sub-system, or web page name and function that the request needs to be executed.

* An HTTP response is made by a server to a client. The response aims to provide the client with the resource it requested, inform the client that the action it requested has been carried out, or else inform the client that an error occurred in processing its request. Refer to the source: IBM, ”HTTP responses”, IBM,

Available: <https://www.ibm.com/docs/en/cics-ts/5.2?topic=protocol-http-responses>(visited on 2023-07-24)

* A request header is an HTTP header that can be used in an HTTP request to provide information about the request context so that the server can tailor the response. For example, the Accept- headers indicate the allowed and preferred formats of the response. Refer to the source: MDN Web Docs, ”Request header”, MDN Web Docs, Available: <https://developer.mozilla.org/en-US/docs/Glossary/Request_header> (visited on 2023-07-24)

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– Action parameters: During the execution time some of the parameters which are the request parameters sent with the HTTP request from the client device can be obtained.

* In other older Web applications that is created with programming languages such as PHP a more direct approach needs to be taken when accessing the request data. In this case, multiple logging points are used that call the logging points’ main code segment to capture the attributes and store the log in a database. The parameters may need to be extracted before parsing them into the main logging point code segment.

As long as the logging attributes and the HTTP request headers are obtainable, the logging mechanism can be created on the server side to extract and process the data. The activity type can be resolved by the defined cases e.g. if the request calls the Index function of the system, subsystem or webpage, it can be identified as the Web page accessed user activity type (F/R 1.2.1) of Table 2.4.

If the user-based event is using the system, subsystem or web page or functions that modify the session, it can be classified as session changed event (F/R 1.2.3) and the rest of the user-based activity events need to be tested afterwards if they meet certain criteria defined for the general activity types. If it fails all three types of classification, the event is likely, not user-generated or comes from HTTP request that was executed after the initial first request. In such cases, the last HTML element id that triggered the event should not be listed as a clicked element in JavaScript.

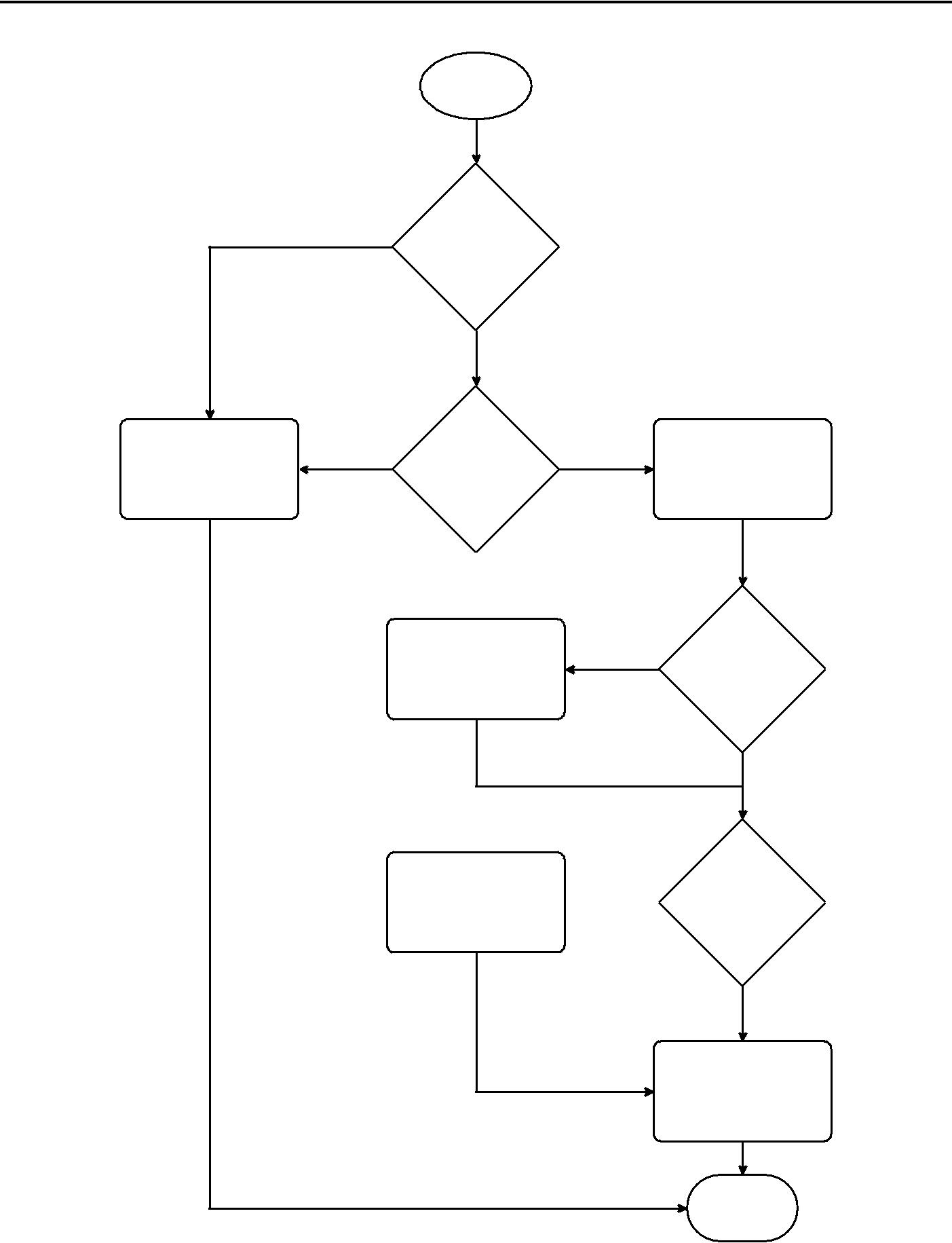
2.4.3 Client functional requirements interaction

In Figure 2.5 is the complete process of the user interacting with the user interface to trigger a user-based activity event to be logged later for the client’s functional requirements. It starts with the user interacting with the user interface. The default activity type is set to general activity (F/R 1.2.3) until it is further processed later in the logging mechanism.

If the activity has additional metadata such as other request parameters, it will also be logged by adding it to the search for it in the completion of the HTTP request operation. The other metadata can also be captured in this stage from the client side like the element that the user clicked to initiate the event. The captured metadata are then placed in a custom request header, and the HTTP request continues its normal operations and sends the data back to the server.

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Start

No

Stop trying to log user No

triggered event.

User inter-0

acted with the

system's UI?

|  |
| --- |
| Yes |

Interaction is0 Yes Update HTTP request

a request action? headers

|  |  |  |  |
| --- | --- | --- | --- |
| Add HTML element's | Yes | Clicked element0 |  |
| ID and tag to the |  | can be found? |  |
| custom request header. |  |  |
|  |  |  |
|  |  | No |  |

Add parameters to the Yes Activity has

custom user activity  additional 0

request header. metadata?

|  |
| --- |
| No |

Continue HTTP

request.

End

Figure 2.5: User-based activity log classification flow diagram

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2.4.4 Server side log parsing

In Figure [2.6](#page66) is the server-side log parsing of the possible user-based activity events obtained for the software system.

The defined globally set logging point will start the user-based activity process before the targeted process is executed in Figure 2.6. At this stage, if something goes wrong with the logging during the execution of this filter, it should be abandoned and let the software system continue to ensure that it does not interfere with the software system’s operations (F/R 1.3.4 of Table 2.7).

In the case of the request method NULL or empty due to errors such as incorrect parameter types for the targeted procedure in the controller, the logging point should stop attempting to log the user-based log. The issue would most likely appear as a runtime error and any user-based activity log procedures will also fail due to incomplete data or cause the logs to be not complete and consistent (F/R 1.3.3 of Table 2.7).

If the captured user-activity log contains any parameters it should be checked for any session-related parameters or any other potential user data that should be removed from the meta-data to prevent any personal information from being accessed by not the owner of the user account. If it does not contain any request parameters, ElementsInfo should be set to NULL.

In Listing 2.2 is the JSON data of ElementInfo.

* { " E l e m e n t T a g N a m e " : " button " ,

2" E le m entI D " : " s u b m i t B u t t o n " ,

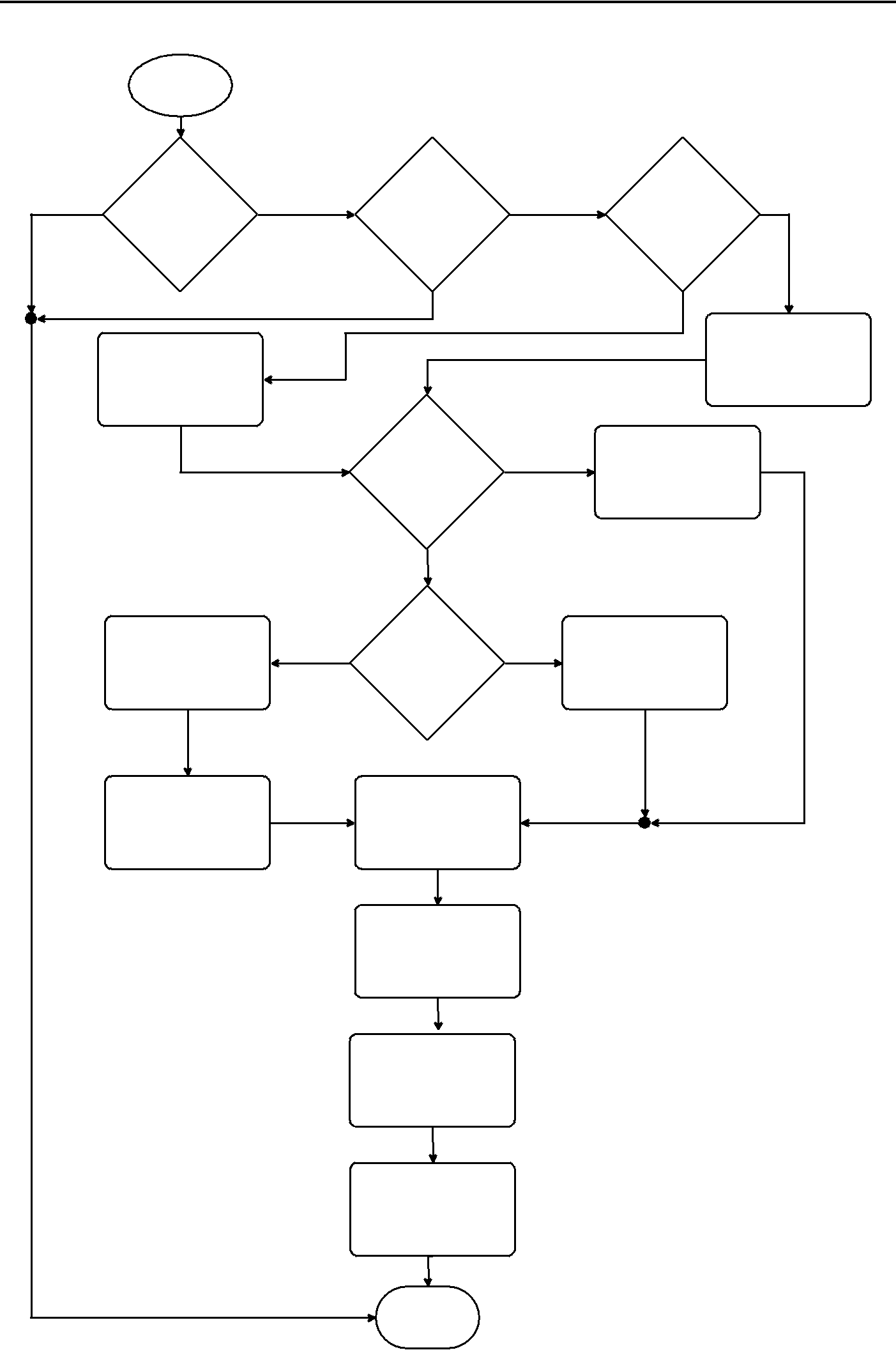


Each of the properties in Listing 2.2 that consist of:

* ElementTagName, is the HTML element’s tag name which is one of the defined accepted tag names such as button, label and td etc.,
* ElementID, identification of the element if it has been assigned to the element and can be obtained on the client side,
* ElementDataKey, additional captured data attributes that expand on the identity of the element if it is a custom-made HTML element control. Some software systems may have other custom-created HTML elements, which also can trigger a user-based activity. There may be other miscellaneous elements, such as a label which are not normal input controls.

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Start

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| No | Track user | Yes | HttpMethod0 | No | Contains user 0 |  |
|  | activities? |  | null or empty? |  | activity 0 |  |
|  |  |  | parameters? |  |
|  |  |  |  |  |  |
|  |  |  |  |  | Yes |  |
|  | Yes |  |  | No |  |  |
|  |  |  |  | Deserialize JSON user |  |
|  |  |  |  |  |  |
|  | Set **ElementInfo** |  |  |  | activity string into an |  |
|  |  |  |  | **ElementInfo** object. |  |
|  | obejct to null. |  |  |  |  |
|  |  |  |  |  |  |
|  |  |  | Request header | Yes | Set **ActitvityType** to |  |
|  |  |  | contains "Index"? |  | MenuAccessed. |  |

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| Set **ActitvityType** to | Yes | **ElementInfo's** | No | Set **ActitvityType** to |  |
| element datakey is | element defined |  |
| CustomControls. |  |  |  |
|  | null or empty? |  | actvity type. |  |
|  |  |  |  |

|  |  |  |
| --- | --- | --- |
| Set **ElementInfo's** | Get the request |  |
| element ID to custom |  |
| absolute path. |  |
| control element. |  |
|  |  |

Get selected group ID

Get other available

meta data.

Parse the data to the

**ActivityLogger**.

End

Figure 2.6: Server side log parsing flow diagram

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If the request header contains the Index keyword, which is the first procedure that needs to be executed for a web page being accessed, the activity can be classified as accessing a system, subsystem, or web page. This activity type is the first user activity type at this point of the log parsing before it is processed again to another user activity type.

If it is not the Index the process will continue to the next operation which checks if the ElementInfo’s ElementDataKey is either a null or empty value. If there are any data avail-able, the activity type can be set to the custom control defined activity type or just custom control to represent all these custom-made elements. The ElementID is set to the custom control element or the defined custom control’s identification.

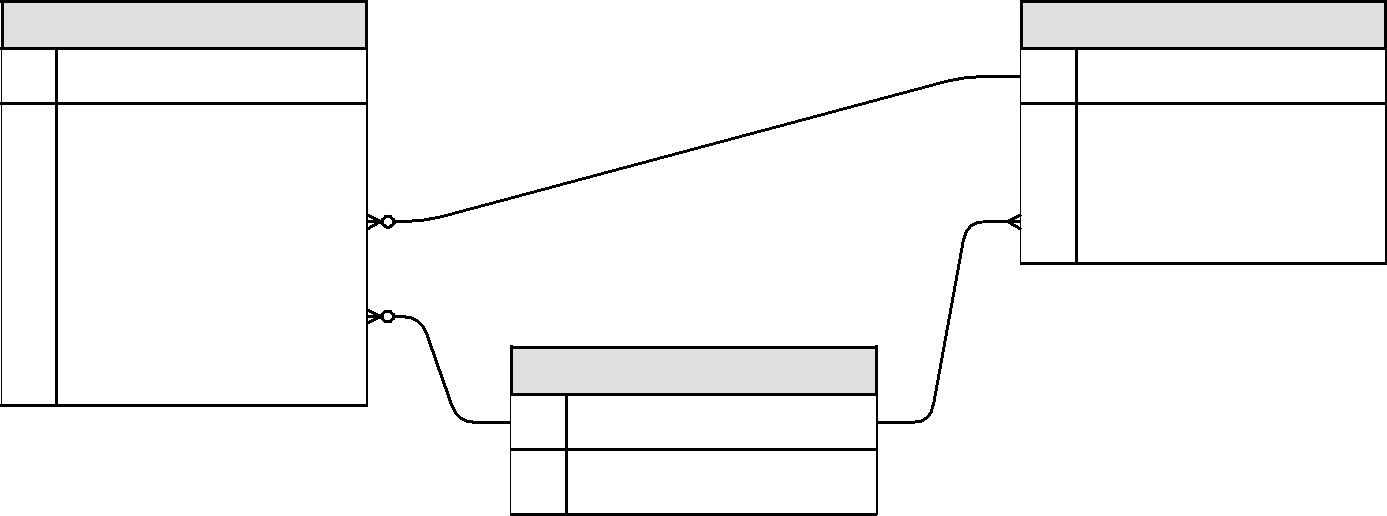
If the ElementInfo’s ElementDataKey is null or an empty value, the user activity type is set to the element’s defined activity type. After the activity type is resolved, the request origin of the user-based activity is obtained by getting the request’s absolute path.

After the request origin has been obtained, other relevant session information such as the group that represents a certain entity data can be obtained as well as the user’s identification and other relevant metadata that is available at this stage to complete the log attributes that need to be captured from Table 2.5 to complete the user-based activity log.

The data is parsed to the activity logger that will write the log into a database if the log was successfully obtained. This will end the logging process until a new user-based event log is ready to be processed and stored in the database.

2.4.5 Storage of event logs

The log attributes in Table 2.8 will have foreign key references to other tables in the database for other tables shown in Figure 2.7.



|  |  |  |  |
| --- | --- | --- | --- |
|  | UserActivities |  | Users |
| PK | **ActivityID** | PK | **UserID** |
|  | **TimeStamp** |  | Firstname |
|  | **ActivityType** |  | Surname |
| FK | UserID | FK | **GroupID** |
|  | Subsystem |  |  |
| FK | GroupID |  |  |
|  | MetaData | Groups |  |

PK **GroupID**

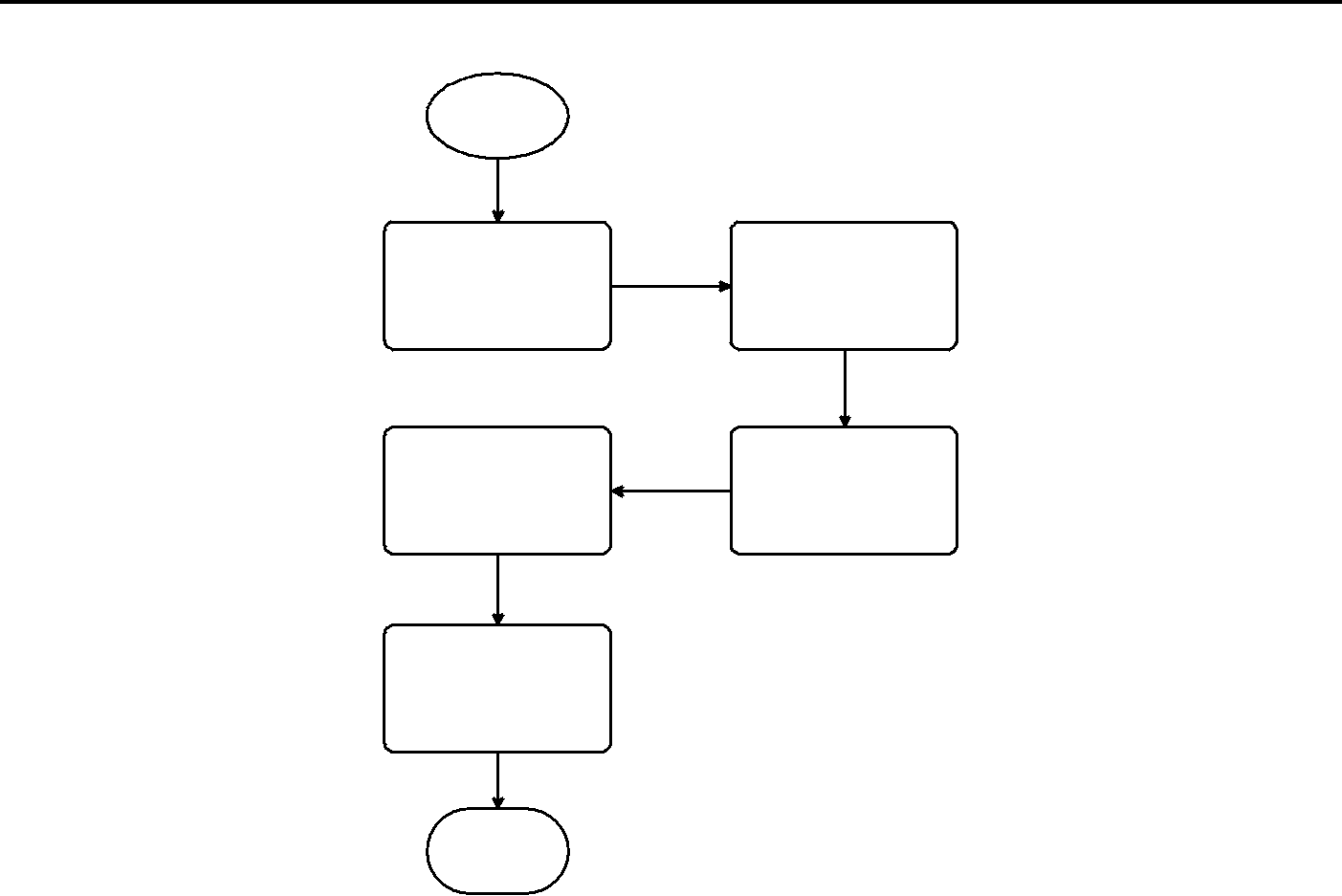
**GroupName**

Figure 2.7: ERD of the user activities

In Figure 2.7 is an ERD diagram that describes the relationship of the table created to store the log attributes with other relevant tables. In the system utilisation analysis, this enables different fields of the other tables to be used to categorise the logs. In Figure 2.8 is the flow diagram of the database interaction to store the event log data.

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Start

|  |  |  |
| --- | --- | --- |
| Initialise database | Get user's ID |  |
| parameter from user's |  |
| connection |  |
| session. |  |
|  |  |

|  |  |
| --- | --- |
| Create query and add | Encode captured |
| all parameters to | parameters as a JSON |
| **Data\_Parameters.** | string. |

Execute the query with

the **Data\_Parameters.**

End

Figure 2.8: Database interaction flow diagram

In Figure 2.8 the connection to the database is established. The user’s identity is obtained from the active session. The obtained meta data is converted into a Json string to be able to store it. The final query is built and executed to store it in the relational database.

2.4.6 Maintenance priortisation

The system utilisation analysis aims to provide maintenance recommendations to developers to improve their maintenance efforts by:

* Prioritising maintenance efforts on systems that are more frequently used.
* Decommission new systems. User-based activities provide a quantitative reason why certain systems can be decommissioned due to inactivity of users.

This can be achieved by implementing maintenance prioritisation using Equation (2.1) cre-ated from the functional requirements for maintenance prioritisation (F/R 4.2):

|  |  |
| --- | --- |
| MP F = AN × PN | (2.1) |

where:

* MP F is the maintenance priority factor,
* AN is the normalised activity for the total logs obtained per subsystem,
* PN is the normalised priority factor for the subsystem.

Normalised user activities per subsystem are described by Equation (2.2):

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|  |  |  |  |
| --- | --- | --- | --- |
| AN = | AX − AMin | , | (2.2) |
|  | AMax − AMin | |  |

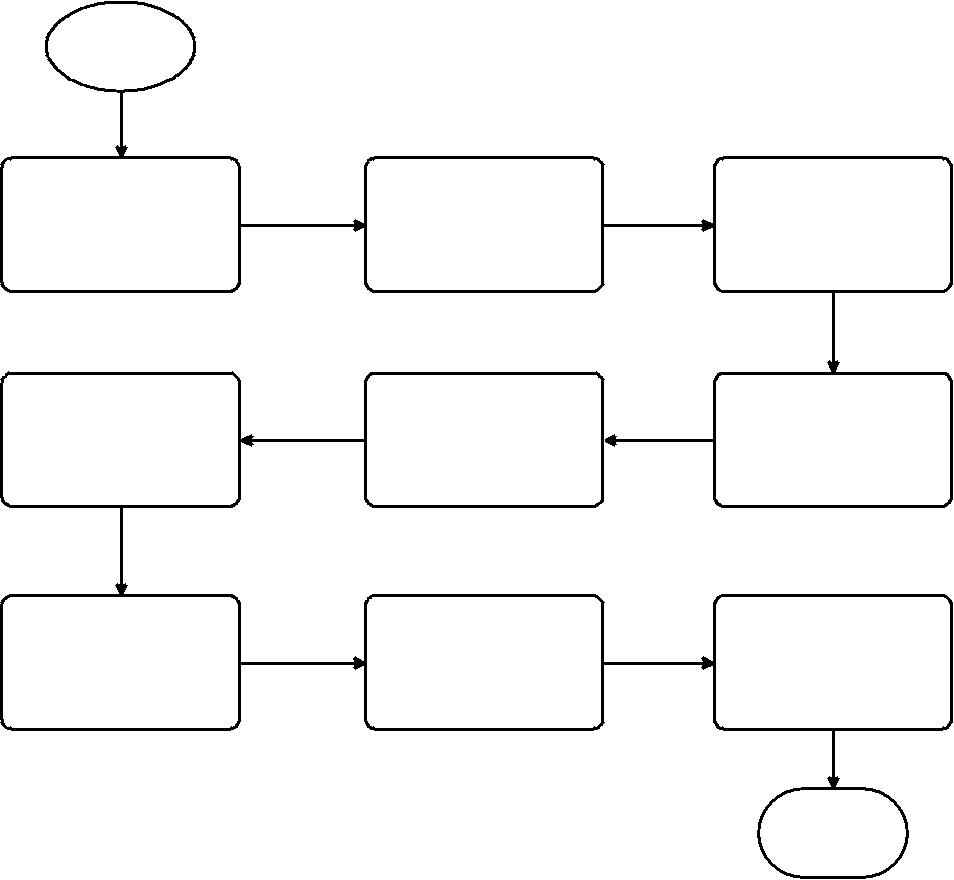
where:

* AX is the total obtained user activities for the specified subsystem
* AMin is the total minimum user activities for a subsystem,
* AMax is a subsystem’s total maximum user activities.

|  |  |  |  |
| --- | --- | --- | --- |
| The normalised priority factor PN is described in Equation (2.3): | | |  |
| PN = | PX − PMin | , | (2.3) |
|  | PMax − PMin | |  |

* PX is the total obtained users that have access to the subsystem,
* PMin is the total minimum number of users that have access to any subsystem,
* PMax is the total maximum number of users that have access to any subsystem.

A normalised value for the priority is used as there is no predefined way to describe the importance of any subsystem. In Figure 2.9 is the log-analysis flow diagram of implementing the maintenance prioritisation for a software system.



Start

|  |  |  |
| --- | --- | --- |
| Import user-based | Aggregate logs per | Get maximum ( *AMax* ) |
| activities. | subsystem. | and minimum ( *AMin* ).0 |

Create the normalised Create the normalised Get maximum ( *PMax* )

priority per subsystem. activity per subsystem. and minimum ( *PMin* ).

|  |  |  |  |
| --- | --- | --- | --- |
| Create maintenance 0 | Evaluate the 0 | Create a summary |  |
| maintenance |  |
| report of the obtained |  |
| priority factor. | priority factors of the |  |
| results. |  |
|  | subsystems. |  |
|  |  |  |
|  |  | End |  |

Figure 2.9: Maintenance prioritisation flow diagram

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In Figure 2.9 the user-based activity logs are imported into the log analysis tool from the relational database. The logs are aggregated into unique subsystems. The total number of user actions are counted as well as the total number unique users associated with the captured logs. Maximum and minimum total user activities (AMax and AMin) and users (PMax and PMin) obtained for the software system.

The normalised activity (AN ) for each subsystem is created from the obtained activities. Normalised priority (PN ) is created from the maximum and minimum priority obtained. The maintenance priority factor is created from the normalised parameters for each system and is then evaluated. A summary report is created for the results obtained from the log analysis using the maintenance prioritisation method.

2.5 Conclusion

In Section 2.3 are the defined functional requirements for a logging mechanism for the system utilisation analysis in Sections 2.3.3 and 2.3.4. The user activity types defined in Table 2.3 are the basis of the log attributes that must be logged to create a user-based log.

The log points capture the logs and send them to the server logging point where they are processed and stored in writing in a database.

The logs are extracted into a visual presentation that enables maintenance improvement suggestions based on the use analysis in Sections 2.3.3 and 2.3.4.

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A number three with a pointy tip

Description automatically generated

Using user-based activity logging and analysis to prioritise software maintenance Cornelius Scheepers

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3.1 Introduction

In Section 2.1, the methodology was created for a web-based software system. As described in this section, users can have multiple systems and subsystems linked to their accounts. The implementation is done for multiple software systems in this section. The system im-plementation will focus more on developing the logging mechanism, and the critical analysis will prioritise software maintenance using a utilisation analysis.

3.2 Implementation

In this section, the implementation of the development of the solution will be discussed using a verification test system. The test system is created in a ASP.NET Core Web SDK software environment.

3.2.1 User activity types

In Figure 2.5 the user-based clarification flow diagram uses Table 2.3 to identify and capture some of the log attributes. Event logs should consist of multiple cases (F/R 1.1.2) that are the primary identifiers for the event log, which are user activity types.

Using the basic operations of the system and what users interact with, user activity types can be made for each software system. For the test system, the basic use will be the following.

* monitor resource usage dynamic dashboards,
* generate PDF reports of the displayed data.

Reporting and monitoring are important for this test system, so the user activity types will need to focus on these activity types. To satisfy the F/R 1.1.2, F/R 1.1.5 and F/R 1.1.6 user activity types, it is defined in Table 3.1.

Table 3.1: Test user activity types

|  |  |  |
| --- | --- | --- |
| Activity | Functional requirement | Description |
|  |  |  |
|  |  |  |
| SystemAccess | F/R 1.2.1 | This activity type detects when a user has navi- |
|  |  | gated to a certain subsystem. |
|  |  |  |
| General | F/R 1.2.3 | This general activity type is for all other activ- |
|  |  | ities that the user initiates that send HTTP re- |
|  |  | quest back to the server. |
|  |  |  |
| ReportExport | F/R 1.2.3 | The other main function of the system is for re- |
|  |  | porting purposes. Separating this type of activity |
|  |  | in its category to capture all report generation |
|  |  | activities that the user has initiated. |
|  |  |  |
|  |  |  |

Table 3.1 doesn’t contain any session changes (F/R 1.2.3) user types. These activities are only triggered when the user logs into their system or terminates their session by pressing the logout button.

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3.2.2 Log attributes

Using the functional requirements discussed in Section [2.3.1,](#page49) data columns are made for the log attributes of the user-based event. These log attributes for a structured database are defined in Table 3.2.

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
|  |  |  |  |  | Table 3.2: Logging attributes |  |
|  |  |  |  |  |  |  |
|  |  |  | Column name | Requirement ID | Description |  |
|  |  |  |  |  |  |  |
|  |  |  |  |  |  |  |
|  |  |  | ID | F/R 1.3.1 | User based activity primary identifier. |  |
|  |  |  |  |  |  |  |
|  |  |  | TimeStamp | F/R 1.3.2 | Date timesstamp when the activity occurred. |  |
|  |  |  |  |  |  |  |
|  |  |  | ActivityType | F/R 1.3.3 | Activity type of the log event. |  |
|  |  |  |  |  |  |  |
|  |  |  | UserId | F/R 1.3.4 | the user identification number associated with the log |  |
|  |  |  |  |  | event. |  |
|  |  |  |  |  |  |  |
|  |  |  | SystemId | F/R 1.3.5 | System where the activity occurred. |  |
|  |  |  |  |  |  |  |
|  |  |  | SubsystemId | F/R 1.3.5 | Subsystem where the activity occurred. |  |
|  |  |  |  |  |  |  |
|  |  |  | MetaData | F/R 1.3.6 | Metadata captured from the HTTP request. |  |
|  |  |  |  |  |  |  |
|  |  |  | ClientId | F/R 1.3.7 | Additional identifiers for the log event. In this case dif- |  |
|  |  |  |  |  | ferent configurations of the same system for a specific |  |
|  |  |  |  |  | client. |  |
|  |  |  |  | | |  |
|  |  |  | The data columns in Table 3.2 are used in a structured database. For this testing environ- | | |  |
|  |  |  | ment, a MySQL database is used for the implementation of the relational database. This | | |  |
|  |  |  | database has preexisting tables that expand on other data such as the UserId, SystemId | | |  |
|  | and SubSystemId. For the MetaData the JSON is similar to Listing 3.1. | | | | |  |
|  |  |  |  |  |  |  |
| 1 |  | { | |  |  |  |
|  |  |  |  |  |  |  |

* " R e q u e s t O r i g i n " : "/ System / S u b s y s t e m 1 / GetData " ,

|  |  |  |
| --- | --- | --- |
| 3 |  | " R e q u e s t E l e m e n t I D " : " B u t t o n S a v e C s v " , |
| 4 |  | " R e q u e s t P a r a m e t e r s " : { |
| 5 |  | " tagIds " : [ |
| 6 |  | " 6284 " , |
|  |  |  |
| 7 | " 20320 " | |
|  |  | |
| 8 |  | ] , |
| 9 |  | " toDate " : "2020 - 04 - 06" , |
| 10 |  | " groupId " : 2 , |
| 11 |  | " fromDate " : "2020 -03 - 30" |
|  |  |  |

1. }

13 } 

Listing 3.1: Metadata JSON

In Listing 3.1 the main JSON parameters capture the following additional data for the user-based event:

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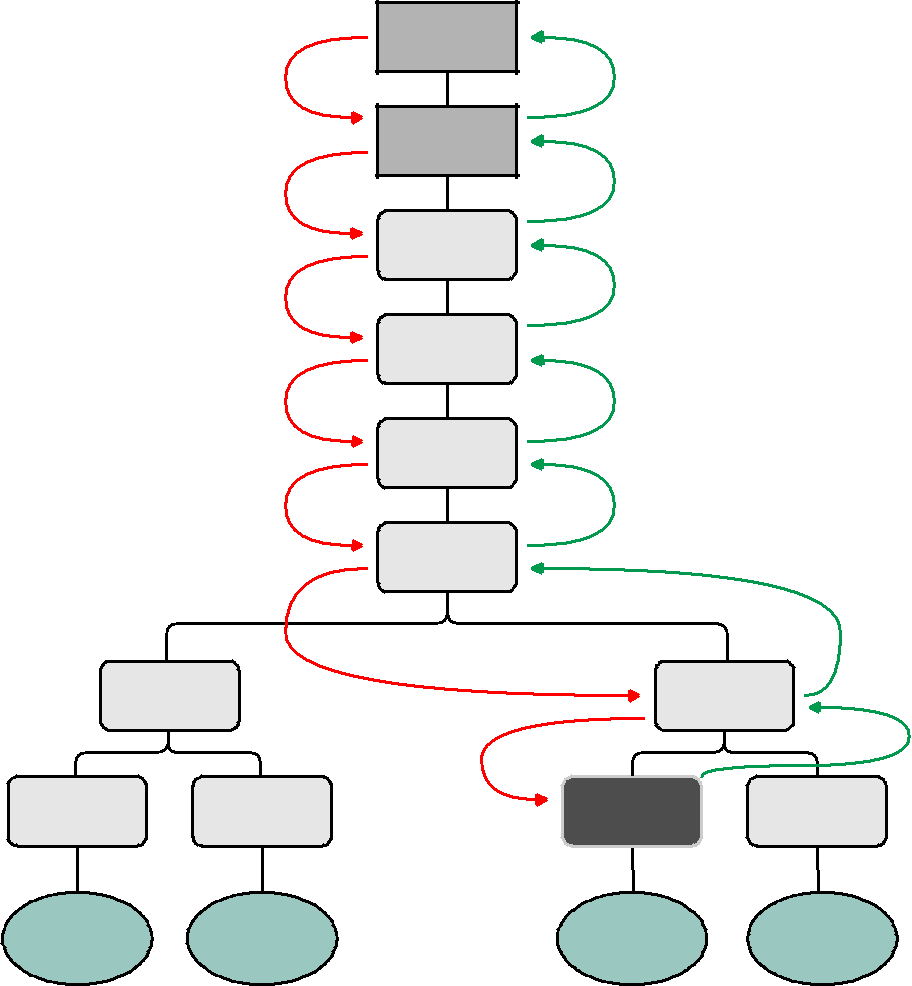
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* RequestOrigin is the complete file path of the subsystem that is used and the functions that are required to fulfil the HTTP request. Some of the subsystems consist of multiple individual files, which trace the origin of the user-based activity accessed from the HTTP request function.
* RequestElementID is the last HTTP element identification that the user interacted with that initiated the user-based activity.
* RequestParameters is the request parameters that are sent with the HTTP request. Any sensitive user data are either ignored by adding flags to certain subsystems or individual functions to obtain the request’s parameters.

Obtaining the element of user-based event

In Section 2.4.1 the user-based activity event will be using a HTTP request to send to the server when the user interacts with an HTML element. For the functional requirements activity type (F/R 1.5.3) and metadata (F/R 1.5.6) in Table 2.5 the HTML element needs to be obtained to get the element’s tag and identification text.

This can be difficult to obtain due to bubbling1 that may occur when searching for the element with which the user specifically interacted. Figure 3.1 is the propagation of the bubbling event.



|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
|  |  | Window |  |  |  |
|  |  | Document |  |  |  |
|  |  | <html> |  |  |  |
|  | Capture |  |  |  |  |
|  | Phase | <body> |  |  |  |
|  | (3) |  |  |  |  |
|  |  | <table> | Bubbling |  |  |
|  |  | Phase |  |  |
|  |  |  |  |  |
|  |  |  | (3) |  |  |
|  |  | <tbody> |  |  |  |
|  | <tr> |  | <tr> |  |  |
| <td> | <td> | Target | <td> | <td> |  |
|  |  |  |  |  |
|  |  | Phase |  |  |  |
|  |  | (3) |  |  |  |
| Shady Grove | Aelian |  | Over the River, | Dorian |  |
|  |  |  |

Charlie

Figure 3.1: JavaScript event propagation

* Bubbling is when an event happens on an element, it first runs the handlers on it, then on its parent, then up on other ancestors. Refer to the source: JavaScript.Info, ”Bubbling and capturing”, JavaScript.Info, Available: <https://javascript.info/bubbling-and-capturing>(visited on 2023-07-24)

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In Figure 3.1 is the example of an event propagation of a child element that has been clicked on that executes a DOM event. Event propagation consists of three phases:

* Capturing phase: The event propagates downward to the target element with which the user interacts.
* Target phase: The event reaches the targeted element to execute the DOM event.
* Bubbling phase: The event bubbles up from the target element.

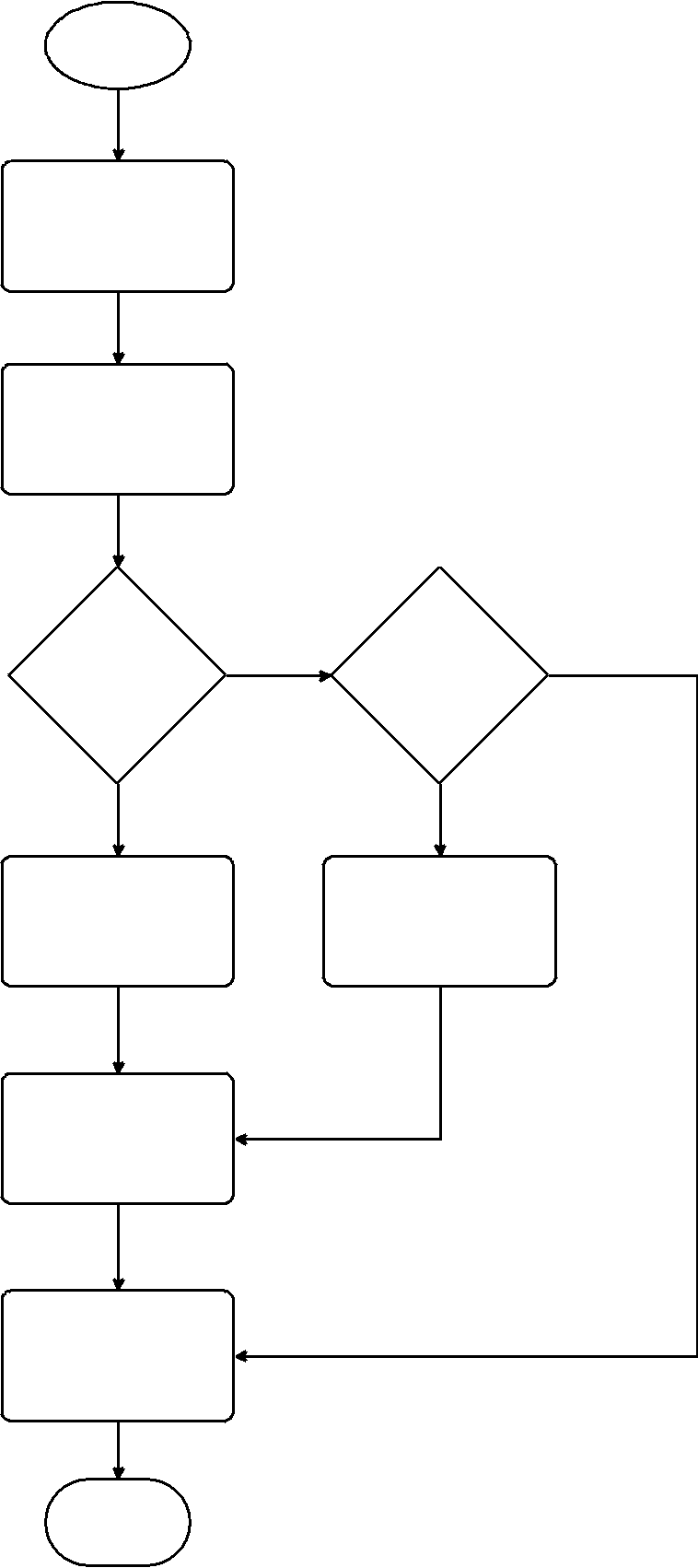
Capturing the targeted element may be difficult as some web pages may have more complex HTML, which can cause event propagation to fail to obtain the correct element information that the user interacted with. In such cases, obtaining the target element by identifying the last known element the user hovered over on the user interface is more accurate, as another DOM event may have started during the initial element’s event.

Figure 3.2 shows the flow diagram to capture the element with which the user interacted for the user-based activity log. This code segment will be initiated during the beforeSend operation of the AJAX request to filter HTML elements by predefined allowed elements. Filtering the element tag names ensures that unwanted, more complex elements or basic elements that are not expected to be the event’s initiator will be excluded.

If the web location has already changed or no element exists, the page’s contents may have already changed during the event propagation. Therefore, the last known element that the user hovered over must be used, as it is most likely the element that the user interacted with. This approach ensures that an element has always been detected and synchronised with the request header in most UI changes.

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Start

Get current element(s)

that the user hovers

over.

Filter out unacceptable

HTML element types.

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Obtained 0 |  | Web page 0 |  |  |
| No | location not 0 | No |  |
| elements0 |  | the same or 0 |  |  |
| array? |  | element 0 |  |  |
|  |  | exists? |  |  |
| Yes |  | Yes |  |  |
| Set **element** to the last |  | Set **element** to |  |  |
| element in the |  |  |  |
| obtained elements |  | **previousElement**. |  |  |
| array. |  |  |  |  |

Set **previousElement 0**

to **element**.

Add element

identification and tag

name to request

headers.

End

Figure 3.2: HTML element capturing flow diagram

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3.2.3 Logging points

Table 2.7 outlines the functional requirements for logging points in the software system. It is crucial to maintain consistency when capturing logs, and placing them in a global location for all HTTP requests will ensure consistency. Filters can be used during the test system, as it is an ASP.NET Core Web SDK. Filters can be initialised during the software system startup phase.

For other web-based systems, the central point where HTTP requests are processed should be used to place single or multiple logging points. In other cases, adding it for smaller groups of subsystems is also viable as long as the logs can be consistently captured when requests come through.

The filter of the test system is the primary component of the logging mechanism. Capture log attributes and metadata on the client side using server-side parsing, as shown in Figure 2.6.

In Section 3.2.2 it has been discussed that some of the logs may contain sensitive data that should not be logged, especially the metadata request parameters. Adding a flag to indicate that certain subsystem requests need to be ignored for event logging should be added.

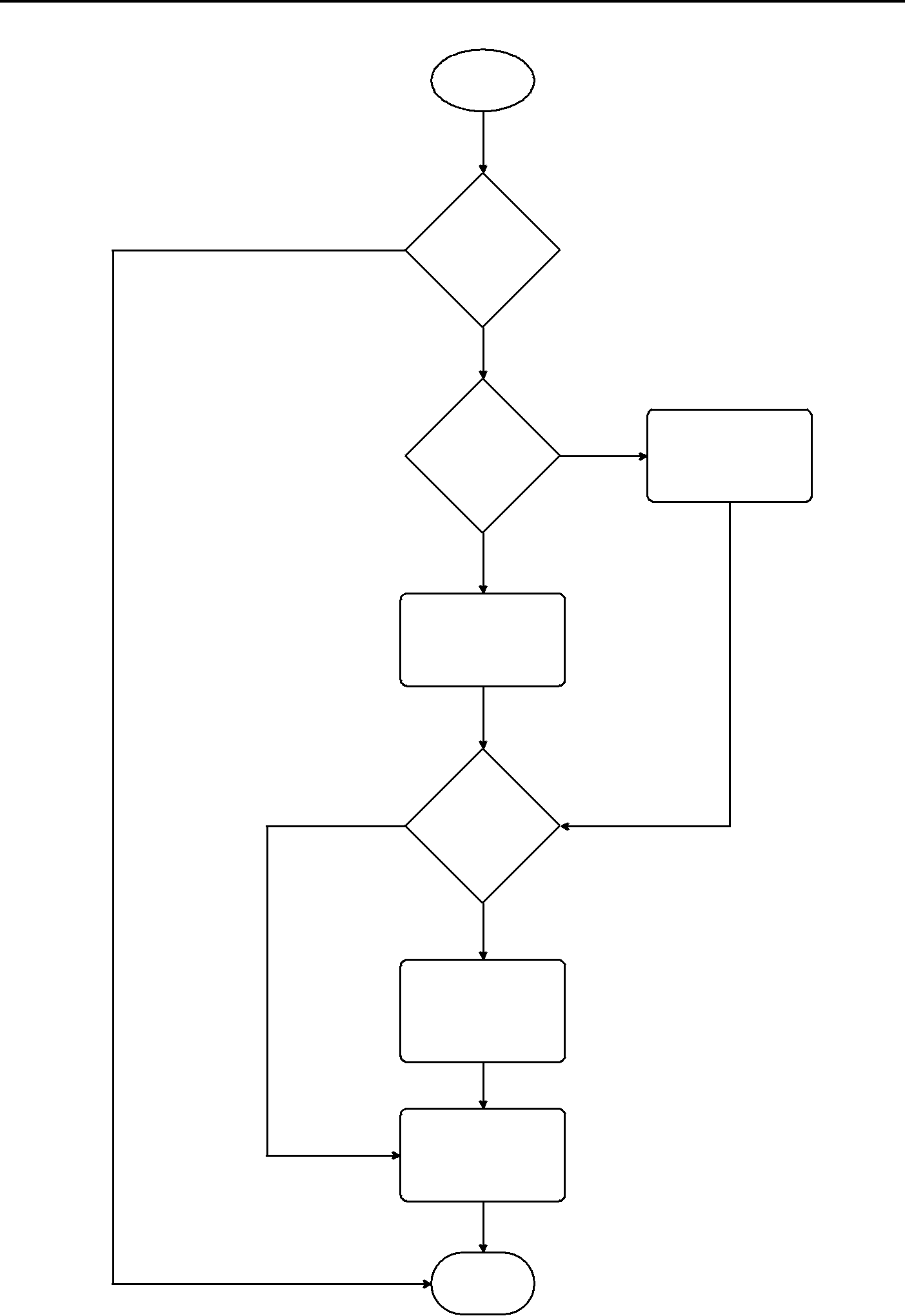
This can also exclude certain parameters from being saved into the database. For the test system, it is an attribute added to certain controllers to ignore the event logs obtained and terminate the logging process.

The logging process in Figure 3.3 is placed on the client-side filter, which runs before the rest of the request is handled. It is important to check whether the request has an action parameter to ensure that the function being executed is called by request and not by the internal system.

If the request has a report action parameter, the user activity should be set to either Activity1 or Activity2. The rest of the request parameters should be obtained and for-matted as a JSON string to be stored in the database.

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|  |
| --- |
| No |

|  |
| --- |
| No |

Start

|  |  |  |  |
| --- | --- | --- | --- |
| Request 0 |  |  |  |
| has action |  |  |  |
| parameter? |  |  |  |
| Yes |  |  |  |
| Request is0 | No | Set user activity type |  |
| a non report 0 |  |
|  | to **ReportExport**. |  |
| action? |  |  |
|  |  |  |
| Yes |  |  |  |
| Set user activity type |  |  |  |
| to **General**. |  |  |  |

Additional 0

user activity 0

parameters?

|  |
| --- |
| Yes |

Add additional

parameters to

ActivityParameters.

Complete event log

data and store in

database.

End

Figure 3.3: Logging point operation for test system

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3.2.4 Log analysis

In Sections 2.3.3 and 2.3.4, the functional requirements for log analysis are defined. For this implementation of log analysis, a custom log analysis tool is created to:

* Visually present user-based event logs through the log analysis tool as required in Table 2.11.
* Filter user-based event logs using different criteria described in Table 2.13.
* Analyse logs for maintenance prioritisation as shown in Table 2.12.

3.3 Verification

The log analysis tool will be used to verify the implementation of the logging mechanism on the test system. The log analysis tool is created in a .NET Framework software environment and uses a MySQL database to store log events.

3.3.1 Log attributes

A sample of the captured log attributes of Table 3.2 that are captured by the logging points is shown in Figure 3.4.

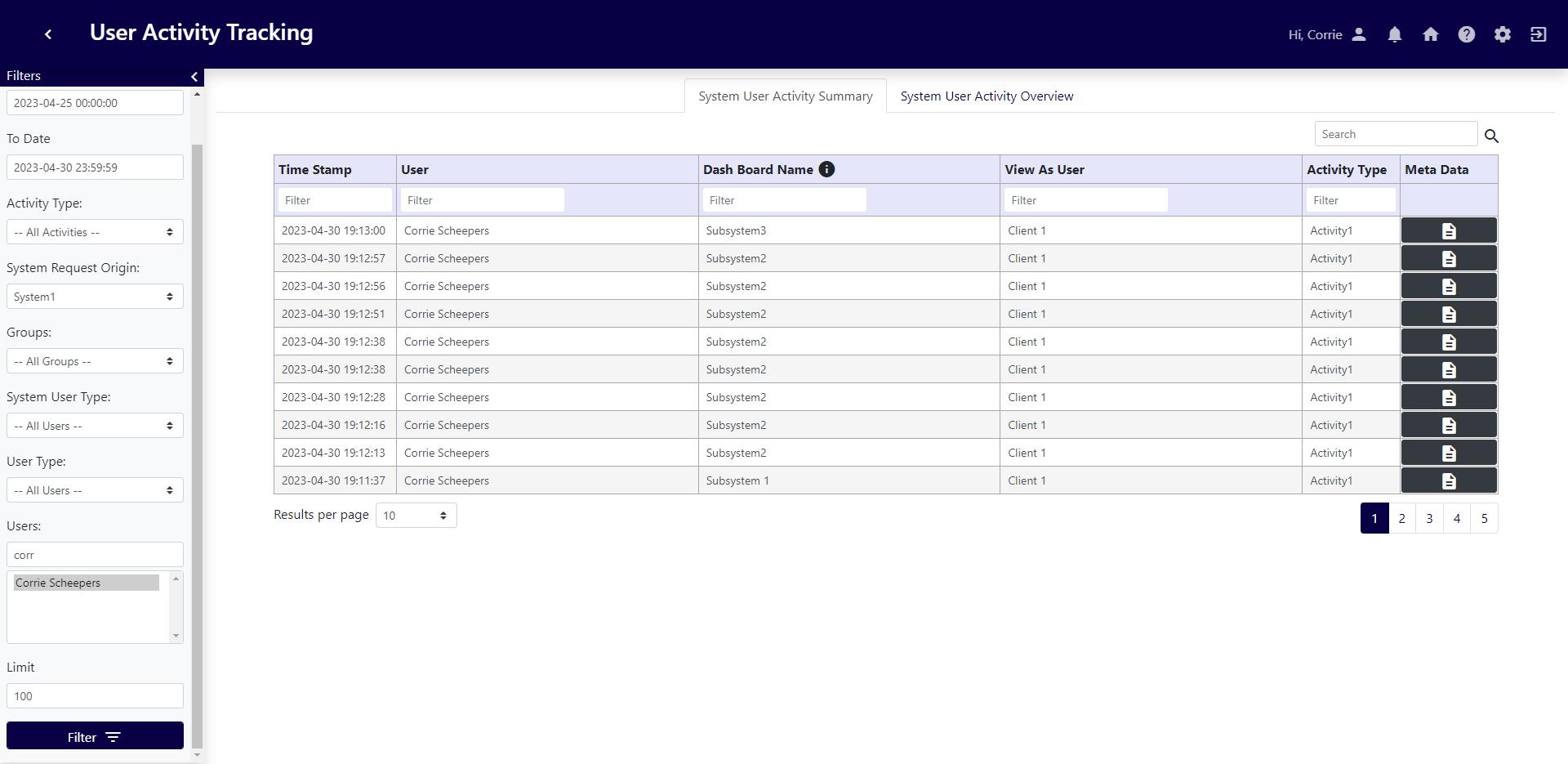


Figure 3.4: Interactive user activity viewer

Figure 3.4 illustrates that the required log attributes defined in Table 3.2 are being tracked for the test systems. The user interface created to display the logs is designed to be more understandable to users who analyse the logs. The meta-data is displayed in a JSON format as in Figure 3.5.

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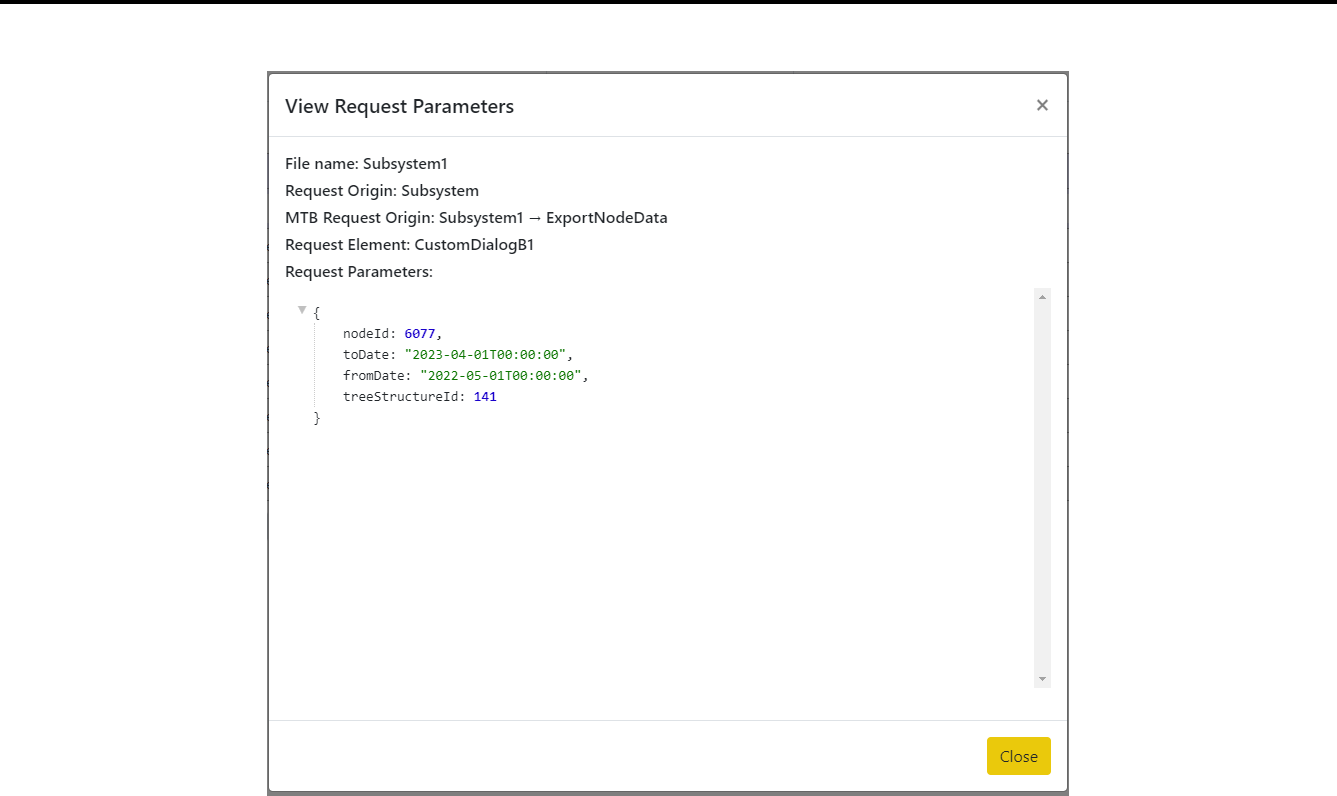


Figure 3.5: JSON test request parameter data

Figure 3.5 includes additional parameters described in Listing 3.1. RequestElementID is obtained using the element capture method described in Figure 3.2, while the other metadata parameters are captured using the built-in methods available in C#.

3.3.2 Log analysis

The log analysis of the logs obtained in Figure 3.4 is done in the same interactive dashboard.

Figure 3.6 compares the logs obtained for the subsystems.

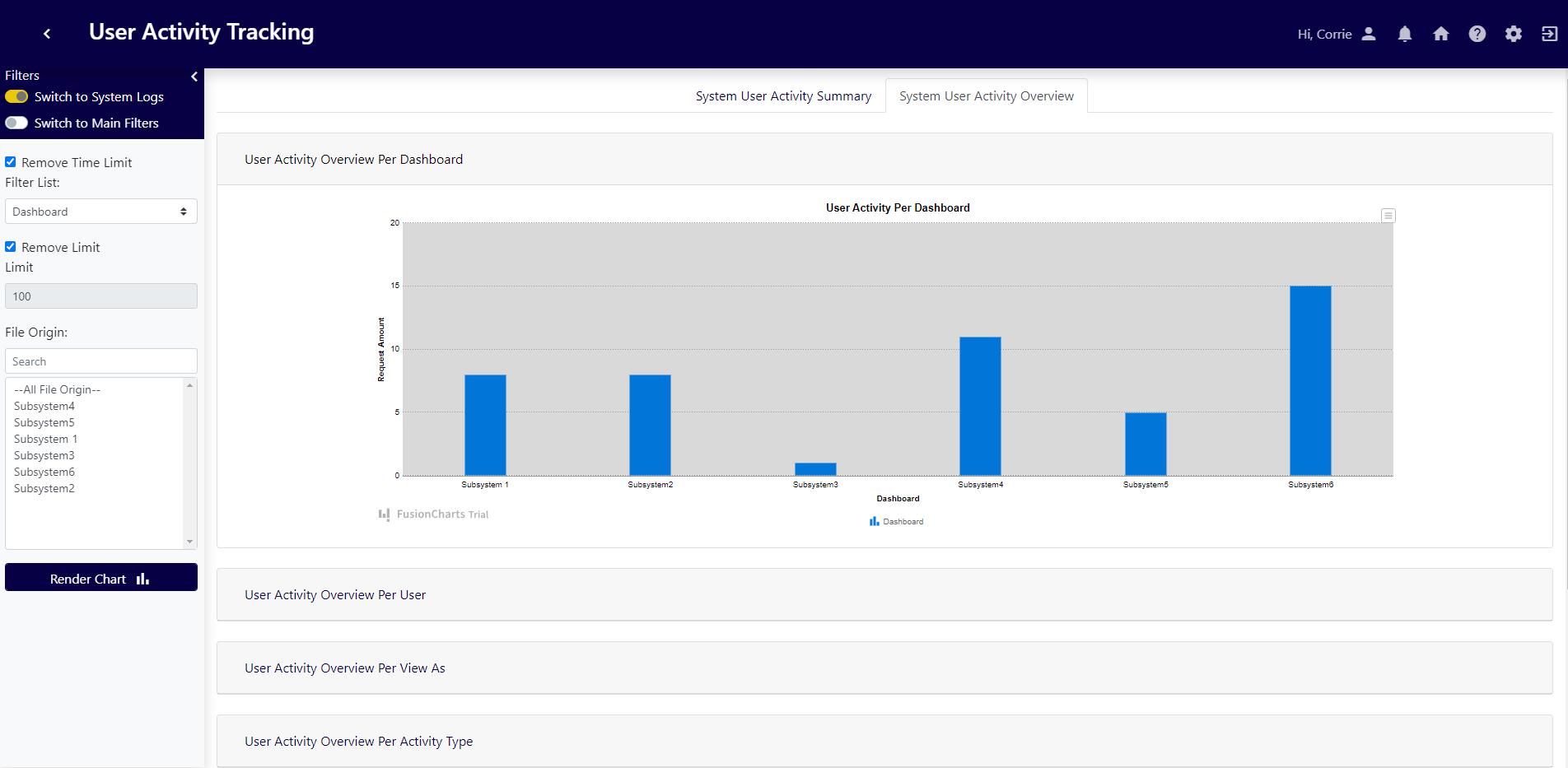


Figure 3.6: Interactive user activity viewer

The log analysis of Figure 3.6 the subsystem’s total recorded user activity logs is compared to each other. Depending on the logging attributes that are required, different categorical comparisons can be made from the obtained user-based event logs.

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By comparing these categories as described in Table 2.13, different categories can be com-pared, as shown in Figure 3.6.



Figure 3.7: Interactive user activity log analysis

Figure 3.7 compares different types of user activity types with each other. For these sub-systems, the Activity3 which is the General user activity type is the most recorded user activity type. This type of activity is expected to be the most prominent for this test system.

**Log quality**

Using the functional requirements for the log quality (F/R 3.1) the log quality of the test system is evaluated in Table 3.3.

Table 3.3: Logging quality assessment of the test system

|  |  |  |  |
| --- | --- | --- | --- |
| Req. ID | Description | Achieved | Comments |
|  |  |  |  |
|  |  |  |  |
| F/R 3.1.1 | Log availability | ✓ | In the implementation of a logging mechanism |
|  |  |  | for the test system the log points were: |
|  |  |  |  Locally complete as all the log attributes |
|  |  |  | were available during the capturing |
|  |  |  | phase of the event log. |
|  |  |  |  Globally complete as defined user activ- |
|  |  |  | ity types were captured for the test sys- |
|  |  |  | tem. The logging points captured the |
|  |  |  | expected logs as defined in Figure 3.3. |
|  |  |  |  |
|  |  |  |  |
|  |  |  | Continued on next page |

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Table 3.3: (continued from previous page)

|  |  |  |  |
| --- | --- | --- | --- |
| Req. ID | Description | Achieved | Comments |
|  |  |  |  |
| F/R 3.1.2 | Log completeness | ✓ | All required log attributes were obtained dur- |
|  |  |  | ing the log capture process of the log point. No |
|  |  |  | post-logging corrections were needed to fix any |
|  |  |  | of the log attributes or to fill in missing log at- |
|  |  |  | tributes. |
| F/R 3.1.3 | Log extraction | ✓ | As previously stated all logs were complete. |
|  |  |  | Any additional information extracted from the |

database is to make the obtained more readable for humans by using the foreign key references to other tables as illustrated in Figure 2.7.

Table 3.3 discussed the log quality of the test system’s user-based event logs that is on an acceptable level. Log analysis should be more accurate with the concurrently obtained logs that are captured by the logging mechanism.

3.3.3 Maintenance prioritisation

For the test system, maintenance prioritisation recommendations can be made as described in Section 2.3.4. A rating system can be used to classify the most critical software systems that need prioritisation, which can help in software maintenance efforts.

Using Equation (2.1) the maintenance priority factor MP F can be determined for a set of systems S1, S2, ..., SN which has captured user activities per system AX . The system will also have several users connected to each system PX . These parameters are set for the test system as in Table 3.4.

Table 3.4: Data for validating test system

|  |  |  |  |
| --- | --- | --- | --- |
| System (SX) | Users per system (PX) | Number of events (AX) | Expected priority |
|  |  |  |  |
|  |  |  |  |
| S1 | 226 | 11 | 1 |
| S2 | 269 | 5 | 2 |
|  |  |  |  |
| S3 | 156 | 8 | 3 |
| S4 | 155 | 1 | 5 |
|  |  |  |  |
| S5 | 146 | 13 | 5 |
| S6 | 154 | 8 | 4 |
|  |  |  |  |

The activities in Table 3.4 were generated by a single user who navigated and interacted with the system, as shown in Figures 3.6 and 3.7. To compare the effect of the total number of user activities per system, we focus on S3 to S6, which have similar numbers of active users who can access the system.

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For the test system S, it is expected that S1 will have the highest maintenance priority factor, given that it has:

* The second highest number of users linked to it. This should increase its normalised active user factor.
* It has the second-highest number of observed user events that were captured.

S2 should have the second highest expected priority. It has the highest active user count and half the amount of total user activities captured of S1. S3 has a much lower user count than the two previous systems. This should place its maintenance priority third, as its normalised user count should be similar to S4 and S6.

S4 has the least number of user events but about the same number of users linked to it. This should have the lowest maintenance factor as it will be zero due to normalised user activity.

S5 will also have the lowest maintenance priority like S4. It has the lowest number of users connected to it. This will set the normalised priority to zero.

S6 should have the fourth highest maintenance priority. It will have a similar normalised user activity count as S3 but lower normalised priority than all the systems except S5.

Using Equation (2.3) to calculate the normalised priority factor of each subsystem using the number of users that have access to the system; also using Equation (2.2) to calculate the normalised activities, the results are shown in Table 3.5.

Table 3.5: Test data

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| SX | PX | PN | AX | AN | MPF | PR |
|  |  |  |  |  |  |  |
| S1 | 226 | 0.6504 | 11 | 0.8333 | 0.5420 | 1 |
| S2 | 269 | 1.0000 | 5 | 0.3333 | 0.3333 | 2 |
|  |  |  |  |  |  |  |
| S3 | 156 | 0.0813 | 8 | 0.5833 | 0.0474 | 3 |
| S6 | 154 | 0.0650 | 8 | 0.5833 | 0.0379 | 4 |
| S4 | 155 | 0.0732 | 1 | 0.0000 | 0.0000 | 5 |
| S5 | 146 | 0.0000 | 13 | 1.0000 | 0.0000 | 5 |
|  |  |  |  |  |  |  |

In Table 3.5, PN for S1 and S2 is the highest, as most users have access to them. Furthermore, S1 and S5 have the highest AN rating, indicating that they were the most used systems. As stated previously, S1 is expected to require the most maintenance activities. Systems with lower maintenance activities and still have similar active users linked to them have a lower maintenance priority factor.

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3.4 Case studies

3.4.1 Case study identification

To fully examine the application of this study, three separate case studies will be used. All the case studies are web-based applications where users need credentials to log in and have restricted access to some parts of the system. These case studies are identified in Table 3.6.

Table 3.6: Case studies

Case study Software framework Description

* ASP.NET Core Web SDK Energy management software system that consists of both internal and external client users.

B PHP An older energy management software system

comprising internal and external client users.

* ASP.NET Core Web SDK Administrative software system used by internal company users. Consist mostly of configuration tools for Case Study A and B and is only accessi-ble to internal users.

These case studies in Table 3.6 are being used because they have different use cases and software framework implementations. Case Study A and B are similar software systems but use older and newer software frameworks. Due to these differences, the logging mechanism needs to be implemented in different ways to capture user-based activities.

For the three case studies, the following results will be obtained:

* Defining commonly occurring user-based activity types.
* Defining how the logging point is implemented for the specific subsystem to obtain the user-based event logs.
* Only user activities of the subsystems that are in the upper quartile are used for each case study that was recorded in October 2022. The results of the rest of the full case studies are in Appendix B.
* The normalised priority for each subsystem of the main system will be calculated using Equation (2.3) based on active users who have access to the system.
* Normalised activities of each subsystem will be calculated using Equation (2.2).
* The maintenance priority factor will be calculated for each subsystem using Equa-tion (2.1).
* The normalisation of the priority factor is only for users who have access to the subsys-tem and interact with the subsystem. All other users who do not meet this requirement will be excluded.

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3.4.2 Case Study A results

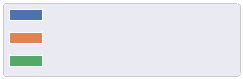
Case Study A is a software system ASP.NET Core Web SDK. The software system has 3 basic user activity types as shown in Table 3.7.

Table 3.7: Case Study A activity types

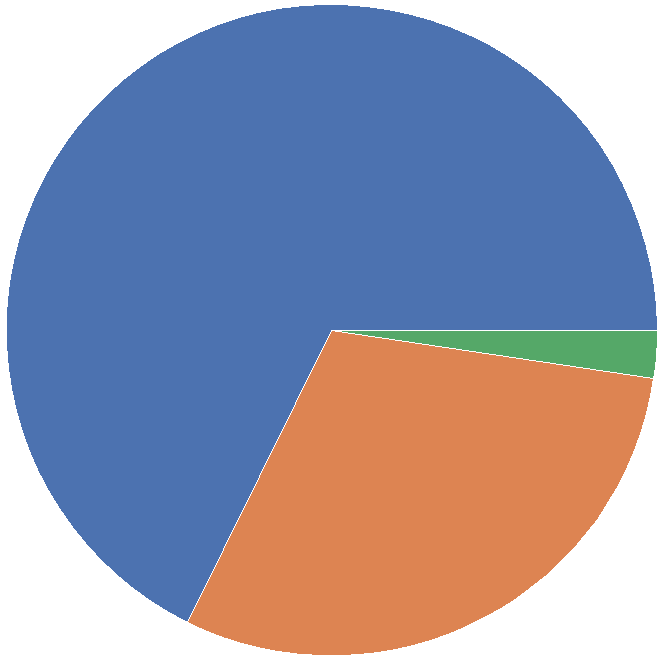
|  |  |  |
| --- | --- | --- |
| Activity | Functional requirement | Description |
|  |  |  |
|  |  |  |
| Dash | F/R 1.2.1 | This activity type detects when a user has navi- |
|  |  | gated to a certain subsystem. |
|  |  |  |
| DetailView | F/R 1.2.3 | This general activity type is for all other activities |
|  |  | that the user initiates that send HTTP request back |
|  |  | to the server. |
|  |  |  |
| Report | F/R 1.2.3 | The other main function of the system is for report- |
|  |  | ing purposes. |
|  |  |  |
|  |  |  |

To capture the types of user activity defined in Table 3.7, the logging point is placed in a central place in the software code. Using the action filters available in ASP.NET Core, the single logging point can be placed in the software system to capture the user-based event logs.

Additional metadata, such as the HTML element associated with the user-based event, is also captured. Using the HTML event capture method shown in Figure 3.2, element information is captured and stored together with the request parameters in the same format as in Listing 3.1. Figure 3.8 is the breakdown of total user activities captured of the user activity types of Table 3.7.



Dash: 26630 (67.7%)



DetailView: 11782 (30.0%)

Report: 926 (2.4%)

Figure 3.8: User activity types breakdown of Case Study A

The Figure 3.8 majority of the user activities for Case Study A’s subsystems is the Dash user activity type. Most of the subsystems do not have many inputs for the user to enter data in

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the system. Provides information back to the user that causes most of the user activities.

A graph of different colored bars

Description automatically generatedFigure 3.9 is the breakdown of the user activity of each subsystem’s utilisation.

Figure 3.9: System utilisation breakdown of Case Study A

In Figure 3.9 each subsystem’s total utilisation is further broken down into user activity types defined in Table 3.7. For systems such as S413, most user activities were from actions the user performed other than accessing the subsystem, which is the DetailView user activity type. This is different from the other top five systems that had the majority of Dash user activity types. Users only viewed the content of the Web page for that subsystem. The log quality assessment for Case Study A is discussed in Table 3.8.

Table 3.8: Logging quality assessment of the test system

|  |  |  |  |
| --- | --- | --- | --- |
| Req. ID | Description | Achieved | Comments |
|  |  |  |  |
|  |  |  |  |
| F/R 3.1.1 | Log availability | ✓ | The log availability for Case Study A is: |
|  |  |  | *  Locally complete as all the log attributes |
|  |  |  | were available during the capturing |
|  |  |  | phase of the event log. |
|  |  |  | *  Globally complete due to the use of a |
|  |  |  | central logging mechanism in the main |
|  |  |  | system that can capture user-based |
|  |  |  | events. |
|  |  |  |  |
|  |  |  |  |
|  |  |  | Continued on next page |

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Table 3.8: (continued from previous page)

|  |  |  |  |
| --- | --- | --- | --- |
| Req. ID | Description | Achieved | Comments |
|  |  |  |  |
| F/R 3.1.2 | Log completeness | ✓ | This system uses the same log attribute struc- |
|  |  |  | ture described in Table 3.2 that is captured with |
|  |  |  | the client- and server-side logging points of this |
|  |  |  | case study. All the log attributes were able |
|  |  |  | to form a complete log without any additional |
|  |  |  | post-logging operations to correct or fill in miss- |
|  |  |  | ing log attributes. |
|  |  |  |  |
| F/R 3.1.3 | Log extraction | ✓ | As previously stated all the logs were locally- |
|  |  |  | and globallly complete. This enables log extrac- |
|  |  |  | tion during log analysis. |
|  |  |  |  |
|  |  |  |  |

Case Study A’s log quality is satisfactory for the log analysis to be able to be done for it. The three basic user activity types enable the logging points to make simple operations to classify the user-based activities.

**Maintenance prioritisation**

The maintenance prioritisation factor for the user activities in the upper quartile of the subsystem for Case Study A is calculated in Table 3.9.

Table 3.9: Case study A’s upper quartile maintenance pefromance

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| SX | PN | AN | MP F | PR |
|  |  |  |  |  |
| S538 | 1.0000 | 0.5281 | 0.5281 | 1 |
| S413 | 0.5469 | 0.8423 | 0.4606 | 2 |
| S570 | 0.4531 | 0.9041 | 0.4097 | 3 |
| S582 | 0.2531 | 1.0000 | 0.2531 | 4 |
| S412 | 0.8344 | 0.2753 | 0.2297 | 5 |
| S546 | 0.6281 | 0.2240 | 0.1407 | 6 |
| S580 | 0.2250 | 0.5923 | 0.1333 | 7 |
| S454 | 0.4781 | 0.2392 | 0.1144 | 8 |
| S577 | 0.2656 | 0.3755 | 0.0997 | 9 |
| S593 | 0.2031 | 0.4496 | 0.0913 | 10 |
| S568 | 0.4719 | 0.1315 | 0.0621 | 11 |
| S445 | 0.4813 | 0.1166 | 0.0561 | 12 |

Continued on next page

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Table 3.9: (continued from previous page)

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| SX | PN | AN | MP F | PR |
|  |  |  |  |  |
| S735 | 0.2625 | 0.1487 | 0.0390 | 13 |
| S476 | 0.2844 | 0.0956 | 0.0272 | 14 |
| S729 | 0.2594 | 0.0976 | 0.0253 | 15 |
| S404 | 0.7000 | 0.0338 | 0.0237 | 16 |
| S441 | 0.5563 | 0.0411 | 0.0229 | 17 |
| S600 | 0.2375 | 0.0808 | 0.0192 | 18 |
| S458 | 0.4500 | 0.0421 | 0.0189 | 19 |
| S469 | 0.4656 | 0.0358 | 0.0167 | 20 |
| S435 | 0.5156 | 0.0192 | 0.0099 | 21 |
| S581 | 0.4750 | 0.0200 | 0.0095 | 22 |
| S755 | 0.2812 | 0.0232 | 0.0065 | 23 |
| S753 | 0.2375 | 0.0258 | 0.0061 | 24 |
| S616 | 0.3219 | 0.0164 | 0.0053 | 25 |
| S503 | 0.4500 | 0.0099 | 0.0045 | 26 |
| S756 | 0.2375 | 0.0099 | 0.0024 | 27 |
| S428 | 0.2594 | 0.0071 | 0.0018 | 28 |

Table 3.9 shows the results of the implementation Equations (2.1–2.3) to calculate the nor-malised priority (PN ), normalised activity (AX ), and maintenance factor (MP F ). The Ta-ble 3.9 only contains the upper quartile subsystems of all the total subsystems of Table B.1. The results are visually presented in Figure 3.9 collected from Table 3.9 with the breakdown of user activity.

In Figure 3.9, subsystem S582 had the most user-generated events, with an average of 72.75 user-generated events per user. The lower PN reduced its maintenance priority factor to the highest 4th for all subsystems. The subsystem S538 had the highest 5th number of recorded user-based activities and the most users who have access to the subsystem. The higher PN had a greater impact on its maintenance performance factor.

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3.4.3 Case Study B results

Case Study B is an older system than A and C that is primarily created in PHP. This system has the same type of user activities as Case Study A’s Table 3.7. To capture the types of users of Table 3.7 this system used multiple logging points.

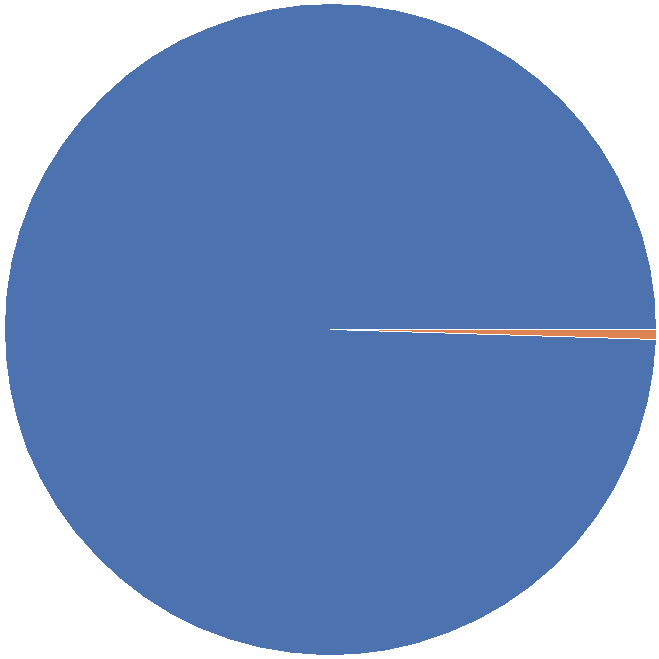
The use of multiple logging points was to:

* Ensure each subsystem’s user activities could be captured as there was no central point in the software architecture to capture the request.
* The system consisted of groups of smaller software systems where the logging points could be added.
* Some adjustments had to be made to the logging points to ensure that the quality of the log was maintained when it was captured.
* Consistency was also important, so each logging has some minor differences added to ensure that it can consistently capture certain user-based events.

The logging points do not track any of the elements that the user interacted with the system. Only some of the request parameters are tracked for any of the user-based activities. The metadata will contain only the RequestParameters used in Listing 3.1. The breakdown of user activity types for this case study is shown in Figure 3.10.



Dash: 7625 (99.5%)



DetailView: 36 (0.5%)

Figure 3.10: User activity types breakdown of Case Study B

In Figure 3.10 the Dash user activity type is about 99.5% of all user activities recorded. Case Study B has fewer subsystems that require the user to interact with the web page to add data. The system mostly has web pages that display data only for the user. There were no Report user activity types as the users did not create reports to export from these subsystems. Figure 3.11 is the breakdown of the user activity of each subsystem’s utilisation.

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A graph of a bar graph

Description automatically generated with medium confidence

|  |
| --- |
|  |

Figure 3.11: System utilisation breakdown of Case Study B

In Figure 3.11 all the subsystems have the majority Dash user activity type. About 99.5% of the user activities is Dash user activity. This is because this older system made in PHP is only used for monitoring energy systems. The subsystems have simple inputs, such as date pickers and category pickers. These types of input only refresh the page, which causes more Dash activities to load new data for the user.

S417 has the most user activities, almost 2.5 times higher than the second system S409 and has the most users that are active in this system. The log quality assessment for Case Study B is discussed in Table 3.10.

Table 3.10: Logging quality assessment of Case Study B

|  |  |  |  |
| --- | --- | --- | --- |
| Req. ID | Description | Achieved | Comments |
|  |  |  |  |
|  |  |  |  |
| F/R 3.1.1 | Log availability | Mostly | The log availability for Case Study B is:: |
|  |  |  | ˆ Mostly locally complete as all the log |
|  |  |  | attributes were available during the cap- |
|  |  |  | turing phase of the event log. Each of |
|  |  |  | the log points had its method of obtain- |
|  |  |  | ing the same log attributes. |
|  |  |  | ˆ Mostly globally complete due to the use |
|  |  |  | of multiple logging mechanisms may |
|  |  |  | have differences in their ability to iden- |
|  |  |  | tify a user-based event and capture the |
|  |  |  | necessary log attributes to complete the |
|  |  |  | log. |
|  |  |  |  |
|  |  |  |  |
|  |  |  | Continued on next page |

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Table 3.10: (continued from previous page)

|  |  |  |  |
| --- | --- | --- | --- |
| Req. ID | Description | Achieved | Comments |
|  |  |  |  |
| F/R 3.1.2 | Log completeness | Mostly | The use of multiple logging points will yield dif- |
|  |  |  | ferent results in the same main software system. |
|  |  |  | Some post-logging operations may be needed to |
|  |  |  | fix and exclude some event logs. |
|  |  |  |  |
| F/R 3.1.3 | Log extraction | ✓ | Although the availability and completeness of |
|  |  |  | the event logs are generally achieved, the log |
|  |  |  | extraction process is still possible. |
|  |  |  |  |
|  |  |  |  |

Table 3.10 emphasises the issues of using multiple different logging points that have different operations to obtain user-based events. Case Study B will need to use post-logging operations in the log analysis tool were done to exclude some of the unfixable logs, make corrections were applicable, and fill in missing log attributes based on other log attributes.

**Maintenance prioritisation**

The maintenance prioritisation factor for the user activities in the upper quartile of the subsystem for Case Study B is calculated in Table 3.11.

Table 3.11: Case study B’s upper quartile maintenance pefromance

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| SX | PN | AN | MP F | PR |
|  |  |  |  |  |
| S417 | 1.0000 | 1.0000 | 1.0000 | 1 |
| S288 | 0.6756 | 0.3347 | 0.2261 | 2 |
| S258 | 0.9733 | 0.1663 | 0.1619 | 3 |
| S259 | 0.9733 | 0.1487 | 0.1448 | 4 |
| S170 | 0.7600 | 0.1487 | 0.1130 | 5 |
| S225 | 0.6089 | 0.1403 | 0.0855 | 6 |
| S72 | 0.6711 | 0.0780 | 0.0523 | 7 |
| S83 | 0.6711 | 0.0664 | 0.0445 | 8 |
| S268 | 0.5067 | 0.0720 | 0.0365 | 9 |
| S718 | 0.0089 | 0.0988 | 0.0009 | 10 |
| S409 | 0.0000 | 0.3774 | 0.0000 | 11 |
|  |  |  |  |  |

The upper quartile of the maintenance performance of the subsystems of Table B.2 is used to create the results of Table B.2 using Equations (2.1–2.3). There is a greater disparity between the top AN and the rest of the other subsystems AN . This significantly impacts the maintenance performance ranking, as S417 is ranked as the most important system.

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3.4.4 Case Study C results

Case Study C is also a APS.NET Core Web SDK software system. The software system has 7 primary user activity types that are described in Table 3.12.

Table 3.12: Case Study A activity types

|  |  |  |
| --- | --- | --- |
| Activity | Functional requirement | Description |
|  |  |  |
|  |  |  |
| MenuAccessed | F/R 1.2.1 | Tracks user’s navigation to a certain subsys- |
|  |  | tem. |
|  |  |  |
| LogoutAttempt | F/R 1.2.2 | Log-out attempt by the user to end their ses- |
|  |  | sion using logout controls. |
|  |  |  |
| LogoutAttempt | F/R 1.2.2 | This is a user activity when the user uses any |
|  |  | of the log-in page controls. |
|  |  |  |
| ResetPassword | F/R 1.2.2 | This is a user activity when the user uses any |
|  |  | of the reset password page controls. |
|  |  |  |
| SessionTracking | F/R 1.2.2 | Case Study C has some data stored in its ses- |
|  |  | sion. Any changes to these data are tracked |
|  |  | when the user interacts with any controls on |
|  |  | the web page to change certain session data. |
|  |  |  |
| CustomControls | F/R 1.2.3 | Case Study C has some custom HTML ele- |
|  |  | ments that have the same functionality as the |
|  |  | HTMLElement user activity type. |
| HTMLElement | F/R 1.2.3 | This general activity type is for all other |
|  |  | activities that the user initiates that send |

HTTP request back to the server. This type of user is primarily associated with HTML el-ements that the user used to interact with the subsystem that are:

ˆ SpanClicked,

ˆ ButtonClicked,

ˆ DivClicked,

ˆ HyperLinkClicked,

ˆ ListClicked,

ˆ LabelClicked,

ˆ ImageClicked,

ˆ FormInput,

ˆ SelectClicked

For Case Study C, the user activities listed in Table 3.12 have been expanded to include the captured HTML elements with which the users interact. As stated in Table 3.6, Case Study C is an administrative software system used to configure and manage Systems A and B. Compared to the monitoring software subsystems of Case Study A and B, the user

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interaction in Case Study C involves more complex user interactions

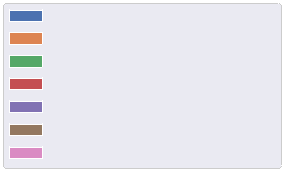
To facilitate analysis for maintenance prioritisation, the increased types of user activity in Table 3.12 can be grouped. The HTMLElement type is a grouped user activity type of smaller individual user activity types. Despite their differences, these activity types share a common base functionality where they primarily show the users’ engagement with the system.

Case Study C uses a single logging point on the server side to capture the user event logs. The logging point for this implementation of the logging mechanism makes use of an action filter to:

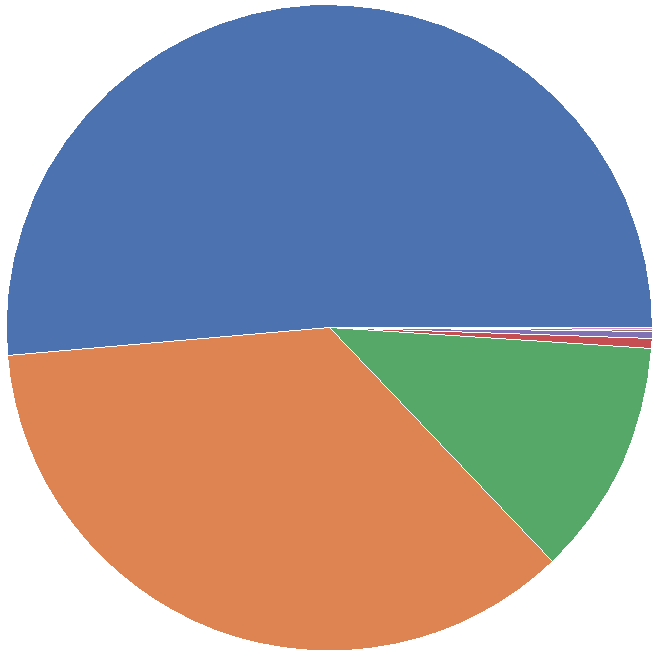
* ensures that the logging point is executed before the rest of the request is serviced by the function that is called by the subsystem,
* globally defined for all the controllers for the system,
* capture any additional user activity attributes,
* save the completed log into the database before the logging process is finally termi-nated.

This logging point is similar to the one used for Case Study A, but differs only in the key logging attributes that it needs to capture. Due to the tag name of the HTML element used to define some of the user activities of Table 3.12, the client side uses a similar logging point to capture the HTML element that the user interacted with.

The client-side logging point adds the last or clicked HTML element that the user used for the user-based event and saves it in a custom request header. Figure 3.12 is the breakdown of user activity of Case Study C’s activity types in Table 3.12.



CustomControls: 135083 (51.4%)



HTMLElement: 94134 (35.8%)

MenuAccessed: 31069 (11.8%)

LoginAttempt: 1318 (0.5%)

SessionTracking: 928 (0.4%)

ResetPassword: 246 (0.1%)

LogoutAttempt: 215 (0.1%)

Figure 3.12: User activity types breakdown of Case Study C

The breakdown of user activities in Figure 3.12 the majority of user activities for Case Study C is CustomControl user activity type. The more interaction with the system increases the total amount of the general user activity types (CustomControl and HTMLElement). Figure 3.13 is the breakdown of the user activity of each subsystem’s utilisation.

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|  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| *S* |  | *S* |  |  |  |  |  | 1 | 1 |  | 3 | 4 | 5 |  |  | 6 | 7 |  |  | 9 | *S* | 9 |  |  |  |  |
|  |  |  |  |  | *S* | *S* | *S* | *S* | *S* | *S* | *S* | *S* | *S* | *S* | *S* | *S* | *S* | *S* | *S* | *S* |  | *S* |  | *S* | *S* |  |

A graph of different colored bars

Description automatically generated

Figure 3.13: System utilisation breakdown of Case Study C

In Figure [3.13](#page94) the total captured user-based event logs are dominated by S97, S93 and S12. Most user-based events are general activity types for all the subsystems, as this case study is used for configuration purposes. Editing these configurations will create more general user activity types than other types of user activity. The log quality assessment for Case Study B is discussed in Table 3.13.

Table 3.13 indicated that were logging attributes missing for some types of user activity. This is not as severe as the incomplete logging attributes of Case Study B. It is expected that the main purpose of these activity types is to track log-in and log-out attempts.

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|  |  |  |  |
| --- | --- | --- | --- |
|  |  |  | Chapter 3. Results |
|  |  | | |
|  | Table 3.13: Logging quality assessment of Case Study C | | |
|  |  |  |  |
| Req. ID | Description | Achieved | Comments |
|  |  |  |  |
|  |  |  |  |
| F/R 3.1.1 | Log availability | ✓ | The log availability for Case Study C is: |
|  |  |  | *  Locally complete due to most of the log |
|  |  |  | attributes being available during the |
|  |  |  | capturing phase of the event log. There |
|  |  |  | are incomplete logs observed where log |
|  |  |  | attributes were not obtained for user ac- |
|  |  |  | tivity types such as the LoginAttempt. |
|  |  |  | The user’s identity is not yet known on |
|  |  |  | some of the captured. Just like Case |
|  |  |  | Study A, this case study uses a central |
|  |  |  | logging point for the client- and server- |
|  |  |  | side. |
|  |  |  | * ˆ Globally complete due to the use of a |
|  |  |  | single log point on the client and server |
|  |  |  | side of the main software system that |
|  |  |  | captures events in most of the subsys- |
|  |  |  | tems. |
|  |  |  |  |
| F/R 3.1.2 | Log completeness | ✓ | The logging attributes is complete for all the |
|  |  |  | subsystems, as no other post-logging operations |
|  |  |  | are needed to fix some of the logs. |
|  |  |  |  |
| F/R 3.1.3 | Log extraction | ✓ | Although the availability and completeness of |
|  |  |  | the event logs is mostly achieved, the log ex- |
|  |  |  | traction process is still possible. |
|  |  |  |  |
|  |  |  |  |

**Maintenance prioritisation**

The maintenance prioritisation factor for the user activities in the upper quartile of the subsystem for Case Study C is calculated in Table 3.14.

Table 3.14: Case study C’s upper quartile maintenance pefromance

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| SX | PN | AN | MP F | PR |
|  |  |  |  |  |
| S97 | 1.0000 | 1.0000 | 1.0000 | 1 |
| S93 | 0.9931 | 0.8464 | 0.8405 | 2 |
| S12 | 0.5903 | 0.1694 | 0.1000 | 3 |
| S8 | 0.5625 | 0.1763 | 0.0992 | 4 |
|  |  |  |  |  |
| S5 | 0.2917 | 0.3312 | 0.0966 | 5 |
|  |  |  |  |  |

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Table 3.14: (continued from previous page)

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| SX | PN | AN | MP F | PR |
| S6 | 0.7083 | 0.0859 | 0.0608 | 6 |
| S1 | 0.8681 | 0.0660 | 0.0573 | 7 |
| S82 | 0.8681 | 0.0291 | 0.0253 | 8 |
| S14 | 0.5208 | 0.0391 | 0.0204 | 9 |
| S90 | 0.7778 | 0.0231 | 0.0180 | 10 |
| S13 | 0.3264 | 0.0529 | 0.0173 | 11 |
| S92 | 0.1736 | 0.0359 | 0.0062 | 12 |
| S11 | 0.2500 | 0.0223 | 0.0056 | 13 |
| S10 | 0.2778 | 0.0188 | 0.0052 | 14 |
| S46 | 0.4167 | 0.0095 | 0.0039 | 15 |
| S67 | 0.1181 | 0.0194 | 0.0023 | 16 |
| S7 | 0.2778 | 0.0070 | 0.0019 | 17 |
| S70 | 0.0833 | 0.0197 | 0.0016 | 18 |
| S95 | 0.1597 | 0.0076 | 0.0012 | 19 |
| S39 | 0.0417 | 0.0238 | 0.0010 | 20 |
| S79 | 0.0347 | 0.0182 | 0.0006 | 21 |
| S64 | 0.0625 | 0.0100 | 0.0006 | 22 |
| S51 | 0.0208 | 0.0245 | 0.0005 | 23 |
| S54 | 0.0486 | 0.0056 | 0.0003 | 24 |
| S30 | 0.0278 | 0.0077 | 0.0002 | 25 |
|  |  |  |  |  |

The upper quartile of the maintenance performance of the subsystems of Table B.3 is used to create the results of Table B.3 using Equations (2.1–2.3). The results of Table 3.14 are visually presented in Figure 3.13.

The high usage of S97, S93, and S12 with a high number of users linked to each one increased their maintenance priority factor. Other systems such as S6, S1 and S82 have a higher priority normalisation than S12, but they have a significantly lower normalisation of user activity.

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3.4.5 Critical analysis results

Summary of comparison between case studies

The three case studies that result in Sections 3.4.2 to 3.4.4 have some similarities and dif-ferences between them. The logging mechanism used for Case Study A and Case Study C is similar to each other. Both case studies make use of the MVC architecture discussed in Section 2.4.1:

* Both systems have a modified application of the Section 3.2.2 client-side event log to obtain the HTML element with which the user interacts.
* Using action filters in C# to create a single log point on the server side to capture any user-based events.
* The log quality of these two case studies is similar, as both systems would identify user-based events through the action filter used as a logging point.

The older subsystems of Case Study C use multiple logging points in the logging mechanism to capture logs. The same user-based event types were identified that Case Study A has defined in Table 3.7. Case Study C has, therefore:

* Multiple logging points than Case Study A and B.
* Higher chance in the variance of the log quality than Case Study A and B’s logging points. Different subsystems require modification of the logging points to ensure that the user-based event logs are captured for Case Study C.
* Decreased adaptability and maintainability due to the increased logging points.

Each case study had different breakdowns of their types of user activity. For Case Study A and B, which have the same type of user activity, the analysis of Figures 3.8 and 3.10 had different results. Most of Case Study B were of type Dash. This is due to how the system works by only refreshing the entire page to obtain new data.

There weren’t many DetailView activity types for these older subsystems with a more simple design as Case Study B’s subsystem. Case Study B had about 30% of its activities of the type DetailView. The more complex subsystems with more input needed from users increased this user type’s share of the total captured logs.

These logs could have also been broken up into other more descriptive user activity types, such as Case Study C. For Case Study A it was not needed because the purpose of its maintenance priority is more comparable to the software system in Case Study B, which has a similar operational goal.

All three case studies’ user-based event logs are stored in a structured database with Case Study A and B using the same data structures. For the log analysis, Case Study A and Case Study B use the same analysis procedures.

Case Study C’s logs did not have a corresponding subsystem data table for log analysis. Additional post-logging operations are used to group all the different request URLs into subsystems. For a more complex and larger software system used in Case Study C, it was preferable to use this method to categorise logs into subsystems using the request URLs target controller file.

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Priority normalisation for Case Study A was better and had a higher impact on maintenance priority factor than Case Study A and C. Even if there were systems with a higher total amount of user activity, the total number of active users had a greater impact than the number of activities for most subsystems.

Case Study B’s highest subsystem ranked for maintenance priority had all the highest nor-malised priority and user activities. This subsystem is a home page that all users can access and use to navigate the rest of the system.

Case Study C had two subsystems where the maintenance priority factor was greater than 0.1. Even if many users have been active in a subsystem, the number of captured user activities had a greater impact on the maintenance priority factor than in Case Study A and B.

**Value add per case study**

In each case study, some obstacles must be overcome to create a suitable logging mechanism for log analysis. Some of the unique obstacles and the value added for each case study:

* Case Study A

– Provides insightful data for management on which systems are used that can be used for more strategic business decisions and the services provided to the end user.

* Case Study B

– This case study made use of multiple logging points. Each logging point had unique obstacles to overcome to ensure that log quality is consistent and at a level for log analysis.

– There are multiple old subsystems for this case study. The lack of activity on some of these systems provides evidence that these systems are no longer used.

* Case Study C

– The additional logging types for the user’s session changes provided logs to mon-itor the user’s access to the system.

– The capture of the request parameters that are stored in the metadata log at-tribute provides additional information for developers to troubleshoot errors or bugs that occurred in the software system. Developers don’t need direct aid from the user to understand what sequence of actions they did to get a certain response from the system.

– Multiple subsystems provided the same functionality. The subsystems that are used more than the others are updated with any missing functionality from the less used similar subsystems. This reduced the number of subsystems and possibly integrated similar functionality into one subsystem to improve the user experience.

**Summary of positive points**

From the observations made about each case study, some positive points can be sum-marised:

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* Similiar architecture software systems can use the same logging points that do not require too many modifications.
* Log quality for similar logging mechanisms is about the same to compare software systems to each other in log analysis.
* Log analysis tools can be used on all captured logs with the correct log extraction process used.
* Log analysis can be used for maintenance priority factor calculations.
* The lowest ranked maintenance priorities can be reviewed if they are still valuable to keep in the software system.

Summary of negative points

* Some systems needed additional logging points that were each modified to obtain the desired user-based event logs.
* Log quality may differ for different implementations of logging points. This can also happen in the same software system with multiple logging points.
* Log quality may impact the maintenance priority factor as some of the variables can have extreme cases where values are extremely high. Certain subsystems, such as a navigation page, do not have a meaningful impact on the user but are needed to use the rest of the system.

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**Functional requirement addressed**

The functional requirements that were defined in Chapter 2 for case studies A, B, and C are addressed in Table 3.15.

Table 3.15: Functional requirements addressed

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Req. ID |  | Case study |  |  |
|  |  |  |  |  |
|  | A | B | C |  |
|  |  |  |  |  |
|  |  | Log attributes (F/R 1) |  |  |
|  |  |  |  |  |
|  |  |  |  |  |
| F/R 1.1.1 | ✓ | ✓ | ✓ |  |
|  |  |  |  |  |
| F/R 1.1.2 | ✓ | ✓ | ✓ |  |
|  |  |  |  |  |
| F/R 1.1.3 | ✓ | ✓ | ✓ |  |
|  |  |  |  |  |
| F/R 1.1.4 | ✓ | ✓ | ✓ |  |
|  |  |  |  |  |
| F/R 1.1.5 | ✓ | ✓ | ✓ |  |
|  |  |  |  |  |
| F/R 1.1.6 | ✓ | ✓ | ✓ |  |
|  |  |  |  |  |
| F/R 1.2.1 | ✓ | ✓ | ✓ |  |
|  |  |  |  |  |
| F/R 1.2.2 | ✘ | ✘ | ✓ |  |
|  |  |  |  |  |
| F/R 1.2.3 | ✓ | ✓ | ✓ |  |
|  |  |  |  |  |
| F/R 1.3 | ✓ | ✓ | ✓ |  |
|  |  | |  |  |
|  | Logging point creation (F/R 2) | |  |  |
|  |  |  |  |  |
|  |  |  |  |  |
| F/R 2.1.1 | ✓ | ✓ | ✓ |  |
|  |  |  |  |  |
| F/R 2.1.2 | ✓ | Mostly | ✓ |  |
|  |  |  |  |  |
| F/R 2.1.3 | ✓ | Mostly | ✓ |  |
|  |  |  |  |  |
| F/R 2.1.4 | ✓ | ✓ | ✓ |  |
|  |  |  |  |  |
| F/R 2.2 | ✓ | ✓ | ✓ |  |
|  |  | |  |  |
|  |  | |  |  |
|  | Log analysis tools (F/R 3) | |  |  |
|  |  |  |  |  |
|  |  |  |  |  |
| F/R 3.1.1 | ✓ | Mostly | ✓ |  |
|  |  |  |  |  |
| F/R 3.1.2 | ✓ | Mostly | ✓ |  |
|  |  |  |  |  |
| F/R 3.1.3 | ✓ | ✓ | Mostly |  |
|  |  |  |  |  |
| F/R 3.2.1 | ✓ | ✓ | ✓ |  |
|  |  |  |  |  |
| F/R 3.2.2 | ✓ | ✓ | ✓ |  |
|  |  |  |  |  |
|  |  |  |  |  |

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Table 3.15: (continued from previous page)

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Req. ID |  | Case study |  |  |
|  |  |  |  |  |
|  | A | B | C |  |
|  |  |  |  |  |
| F/R 3.2.3 | ✓ | ✓ | ✓ |  |
|  |  | |  |  |
|  | Maintenance prioritising (F/R 4) | |  |  |
|  |  |  |  |  |
|  |  |  |  |  |
| F/R 4.1.1 | ✓ | ✓ | ✓ |  |
|  |  |  |  |  |
| F/R 4.1.2 | ✓ | ✓ | ✓ |  |
|  |  |  |  |  |
| F/R 4.1.3 | ✓ | ✓ | ✓ |  |
|  |  |  |  |  |
| F/R 4.2.1 | ✓ | ✓ | ✓ |  |
|  |  |  |  |  |
| F/R 4.2.2 | ✓ | ✓ | ✓ |  |
|  |  |  |  |  |
| F/R 4.2.3 | ✓ | ✓ | ✓ |  |
|  |  |  |  |  |
| F/R 4.2.4 | ✓ | ✓ | ✓ |  |
|  |  |  |  |  |
|  |  |  |  |  |

In Table 3.15 the functional requirements for the logging attributes (F/R 1) defined in Table 2.2 all three case studies met the requirements that were defined. In each case study, only user-based events were captured for the user activity types defined for each case study. For each case study, the log attributes that are captured from the user-based event are obtained.

Case Study A and B did not meet the F/R 1.2.2 requirement. Session changes in user activity type were not needed for these case studies. For these case studies, internal and external users’ actual interaction with the systems was more important and there were no other session-related activities that could contribute to the log analysis.

The functional requirement of the logging point (F/R 2) Case Study A and C addressed all sub-functional requirements. Case Study B did not meet all requirements as F/R 2.1.2 and F/R 2.1.3 are not fully met. In this older system, using multiple logging points requires modifications to work for groups or individual subsystems. This can cause inconsistencies in log quality, as some potential user-based event logs may not be consistently identified.

Log analysis functional requirements (F/R 3) by using or creating a log analysis tool. Since user-based events could be efficiently obtained from the software system, the quality of the log (F/R 3.1) for Case Study A and B was complete.

Case Study B had lower log quality, as the availability and completeness of the logs were lower due to the use of multiple log points. The log extraction (F/R 3.1.3) for Case Study C was achieved mainly because additional post-logging activities with the log analysis tool had to be used to create subsystems using the logs.

Through the log analysis, maintenance priority (F/R 4) could be performed for each case study. The results of each case study were evaluated by comparing the software maintenance prioritisation and with the other case studies.

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**Gaps identified**

The gaps identified for this study by analysing the results of case studies and the results of the test:

1. Log quality is important for further analysis of user-based events. Improvement in the implementation of the logging mechanism can increase the:

* accuracy of the logging mechanism to capture logs,
* trustworthiness of more complete consistent logs,
* decreased performance impact on the rest of the software system.

Applying more fundamentals of Figure 1.5 could have improved the logging mechanism. This should also improve the log quality, especially for implementing Case Study B’s logging mechanism.

1. The log analysis used Equations (2.1–2.3) to rank the maintenance priority of each subsystem. In each case study, there were some outliers for one of the two main parameters used for Equation (2.1). Some gaps for this study with these parameters:

* The normalised priority (PN ) uses the total active users. Some users were internal and external clients, and others were software developers. Adding weight to some of these user types can improve the impact that PN has on MP F . As some users such developers are necessarily important users to determine if a subsystem is important when there are external client users who pay for the software system to use it.
* Normalised user activities (AN ) have a similar problem to PN . There are less important user activity types, and adding weight on how important each user activity type is can improve log analysis. For Case Study C some of the similar user activity types were grouped to form one user activity type. This can be used more, or user activity types should be better defined to have more distinct user activity types.

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3.5 Conclusion

This chapter explored the implementation of the methodology defined in Chapter 2 to create a logging mechanism for different case studies. A test system was used to initially verify the development of the solution before it was implemented in three different case studies.

Log analysis was performed for all logs obtained for October 2022. The following was done for each case study:

* Identification of the type of activity of the user.
* Implementations of log-points.
* Log analysis

– User activity type breakdown.

– Priority normalisation.

– Normalisation of user activity.

– Maintenance priority factor calculation.

* Maintenance priority ranking and recommendations.

All results were compared with each other for the case study. The overall result of the log analysis is that the implementation of a user-based event-logging mechanism can aid in prioritising software maintenance. There are a few gaps identified that can improve maintenance prioritising.

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Chapter 4

Conclusion

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Cornelius Scheepers

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4.1 Discussion

4.1.1 Contributions made to literature

Chapter 1 highlighted the importance of software maintenance throughout the life cycle of most software systems. A gap in the literature was identified in Section 1.2.4 from the studies obtained on software maintenance.

Using event logging to create a log analysis for utilising the software systems is a possible solution to make software maintenance prioritisations. A State Of The Art analysis in Table 1.10 was made for the literature on software maintenance, event logging, and log analysis. This study will be referred to as Study U, filling in the gaps in the literature obtained with the method in Chapter 2 that is included in the updated State of The Art in Table 4.1.

Table 4.1: State Of The Art

|  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Ref. |  | Software maintenance | |  | Event logging | |  | Log analysis |  |
|  |  |  |  |  |  |  |  |  |  |
|  | Models | Problems | Prioritisation |  | Parsing | Points |  | Utilisation |  |
|  |  |  |  |  |  |  |  |  |  |
|  |  |  |  |  |  |  |  |  |  |
| [9] | Partial | ✓ | ✓ |  | ✘ | ✘ |  | ✘ |  |
|  |  |  |  |  |  |  |  |  |  |
| [10] | Partial | Partial | ✓ |  | ✘ | ✘ |  | ✘ |  |
|  |  |  |  |  |  |  |  |  |  |
| [12] | Partial | ✓ | ✓ |  | ✘ | ✘ |  | ✘ |  |
|  |  |  |  |  |  |  |  |  |  |
| [16] | ✘ | ✓ | ✓ |  | ✘ | ✘ |  | ✘ |  |
|  |  |  |  |  |  |  |  |  |  |
| [18] | ✓ | Partial | ✘ |  | ✘ | ✘ |  | ✘ |  |
|  |  |  |  |  |  |  |  |  |  |
| [24] | Partial | ✓ | ✓ |  | ✘ | ✘ |  | ✘ |  |
|  |  |  |  |  |  |  |  |  |  |
| [28] | Partial | ✘ | ✓ |  | ✘ | ✘ |  | ✘ |  |
|  |  |  |  |  |  |  |  |  |  |
| [32] | ✘ | ✘ | ✘ |  | ✓ | Partial |  | ✘ |  |
|  |  |  |  |  |  |  |  |  |  |
| [35] | ✘ | ✘ | ✘ |  | Partial | Partial |  | ✘ |  |
|  |  |  |  |  |  |  |  |  |  |
| [42] | ✘ | ✘ | ✘ |  | ✓ | ✓ |  | ✘ |  |
|  |  |  |  |  |  |  |  |  |  |
| [43] | ✘ | ✘ | ✘ |  | Partial | Partial |  | ✘ |  |
|  |  |  |  |  |  |  |  |  |  |
| [51] | ✘ | ✘ | ✘ |  | ✓ | ✓ |  | Partial |  |
|  |  |  |  |  |  |  |  |  |  |
| [50] | ✘ | ✘ | ✘ |  | ✓ | ✓ |  | Partial |  |
|  |  |  |  |  |  |  |  |  |  |
| [54] | ✘ | ✘ | ✘ |  | ✘ | ✘ |  | ✓ |  |
|  |  |  |  |  |  |  |  |  |  |
| [56] | ✘ | ✘ | ✘ |  | ✘ | ✘ |  | ✓ |  |
|  |  |  |  |  |  |  |  |  |  |
| U | Partial | ✓ | ✓ |  | ✓ | ✓ |  | ✓ |  |
|  |  |  |  |  |  |  |  |  |  |

Study U: Using user-based activity logging and analysis to prioritise software maintenance

Table 4.1 there is a divide between software maintenance, event logging, and log analysis in the State Of The Art. Study U can contribute to the literature by providing a comprehensive method that includes all three of these main research topics.

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Event logging and log analysis overlap more in the literature than software maintenance as a primary topic. It was identified that research on software maintenance could be limited by a lack of third-party validation, not always trying to improve or build existing software maintenance models, little comparison with other literature, and difficulty replicating due to private data sets or custom tools.

The obtained studies that discussed software maintenance commonly identified that the efficiency of implementing software maintenance is essential. Some studies attempted to use specific software maintenance models on certain software maintenance types for better efficiency.

Other studies tried to create a task distribution for developers to improve software mainte-nance efficiency. Other studies attempted to isolate certain software maintenance resource costs in the entire Software Development Life-Cycle (SDLC).

Additionally, these studies did not attempt to provide the method needed to prioritise these software systems. The method needs to use a logging mechanism to do the log analysis, which is not present in software maintenance-related studies.

Study U does not explicitly use any software maintenance models as it is irrelevant to pri-oritising software systems. For this reason, the model’s State Of The Art topic is marked as partially achieved. From the software maintenance problems identified in the literature, the requirements for the log analysis are created for the software maintenance prioritisa-tion.

The methods for the event logging mechanisms are not fully described or use third-party tools. Software maintenance does not overlap with this topic, as most event logs are for system diagnostics.

There were logging mechanisms that captured user-based logs. The purpose of those logs obtained is mainly used for user-behavioural analysis instead of system utilisation analysis. Study U contributes to the literature on system utilisation analysis for software maintenance when prioritised.

4.1.2 Value added to industry

The method in Chapter 2 is used in different case studies in Section 3.4. Each of these case studies explored the various applications of the generic logging mechanism to obtain user-based events. The results proved that the logging mechanism could get the desired user-based activities. However, additional adaptations were needed for each case study to ensure that log quality was acceptable for consistent and reliable log analysis.

These adaptations were due to the software environment (software languages and design methodologies used) and the purpose of the software system. Older systems had to use different logging points to produce the same result as newer software systems that can use less or one logging point.

These systems used the same user-based event type with similar operational software use cases. Systems with the same software architecture but different functional use cases also had various adaptations to their logging mechanism. These adaptations ensured that the desired log attributes were correctly obtained for the log analysis.

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The maintenance prioritisation recommendations for each study case used the defined generic methodology. The log analysis for each case study was similar as the log requirements for the user-based utilisation for all the case studies were only different for each of their user-based event types. These user-based event types represent the operational use cases for the case study to further observe the kind of utilisation of the subsystems.

The results proved that the generic methodology defined in Chapter 2 could be implemented on different software systems with other operational use cases for each case study. In the web development industry, similar software systems as the case study or other software systems will benefit from implementing this methodology to improve software maintenance decisions using these recommendations for prioritisation.

4.1.3 Validation strategy

The following five-step validation strategy is used for the outcomes of this study:

1. Revisit the literature gap defined in Section 1.2.4.
2. Revisit the original problem statement defined in Section 1.3.
3. Revisit the study objectives defined in Section 1.4.

IV. Reflect on the results and results of the study methodology in Chapter 3.

1. Determine whether a solution has been presented to the original problem statement. This study is validated by:
2. Gap in literature

The literature gap defined in Section 1.2.4 for implementing software maintenance efficiently is summarised as:

Implementing software maintenance efficiently with the limited available re-sources that organisations or individuals have is crucial to improve the ef-ficiency of the software maintenance efforts. Assisting developers to make better-informed decisions on which systems to prioritise maintenance can im-prove software maintenance.

1. Original problem statement

The original problem statement defined in Section 1.3 to able to make software main-tenance priorisations:

Software maintenance is a problem in the industry due to how inefficiently de-velopers prioritise maintenance activities. A proven method to monitor soft-ware behaviours is event logging. The logging mechanism and log analysis to improve software maintenance need to be explicitly designed for user-based events.

Study objectives

Study objectives defined in Section 1.4 that have been met in Table 4.2 for this study.

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Table 4.2: Study validation

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Objective ID |  | Objective | Section | Objective met |
|  |  |  |  |  |
|  |  | Literature Objectives |  |  |
|  |  | |  |  |
|  |  | |  |  |
| L1 | Investigate what will define a user-based | | Sections 2.3.1 | ✓ |
|  | event log and how to obtain the needed | | and 2.4.1 |  |
|  | log attributes for a comprehensive user | |  |  |
|  | utilisation log analysis. | |  |  |
|  |  | |  |  |
| L2 | Investigate where to place logging points | | Sections 2.3.2 | ✓ |
|  | in a software system to capture user- | | and 2.4.1 |  |
|  | based event logs. | |  |  |
|  |  | |  |  |
| L3 | Investigate how to evaluate the log qual- | | Section 2.3.3 | ✓ |
|  | ity of the stored user-based event logs. | |  |  |
|  |  | |  |  |
| L4 | Investigate how to implement mainte- | | Section 2.3.4 | ✓ |
|  | nance prioritisation. | |  |  |
|  |  |  |  |  |
|  |  | Empirical Objectives |  |  |
|  |  | |  |  |
|  |  | |  |  |
| E1 | Implement the method to create a user- | | Section 3.2 | ✓ |
|  | based logging mechanism on a test sys- | |  |  |
|  | tem: |  |  |  |
|  | (a) | Define the user activity types and |  |  |
|  |  | create the needed log attributes for a |  |  |
|  |  | user-based event log. |  |  |
|  | (b) | Implement the logging points at |  |  |
|  |  | strategic locations to capture the |  |  |
|  |  | log attributes to create events logs. |  |  |
|  | (c) | Use or create a log analysis tool to |  |  |
|  |  | evaluate the log quality of the cap- |  |  |
|  |  | tured logs. |  |  |
|  | (d) | Implement a software maintenance |  |  |
|  |  | prioritisation method in the log anal- |  |  |
|  |  | ysis. |  |  |
|  |  | |  |  |
| E2 | Verify the results for the test system’s | | Section 3.3 | ✓ |
|  | software maintenance prioritisation. | |  |  |
|  |  | |  |  |
| E3 | Validate the software maintenance priori- | | Section 3.4 | ✓ |
|  | tisation method with a critical analysis of | |  |  |
|  | the case studies results. | |  |  |
|  |  |  |  |  |
|  |  |  |  |  |

In Table 4.2 the objective L1 The characteristics of the event log are defined with the expected log attributes needed for the log analysis. The characteristics of the event log focus only on obtaining user-based event logs with the necessary qualities that the

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logging point can capture and store.

For objective L2, the log attributes of each user-based event must be obtained from the software system using a logging point. The logging points are placed strategically in the software system where they have little impact on the performance of the software system. The requirements for the event logs are created to guide developers in making the logging points to capture the event logs.

For objective L3, the quality of the logs is essential for log analysis. This objective ensures that the captured event logs are complete, accurate, and available when the logs are extracted by the log analysis tool. The method requirements were defined to adhere to the log quality specification

For objective L4, maintenance prioritisation is determined. The calculations needed for this log analysis are explained for this objective that needs to be executed in the log analysis. Prioritisation of each subsystem will be calculated in the specified time frame. For this objective, the requirements for which logs to use are also defined, as some types of user activity can be excluded based on the software system used.

Empirical objectives use the method in a test system to verify the results and imple-ment it in case studies. It also reflects on the study methodology using the results to determine whether this solution has resolved the problem statement.

For objective E1, the following sub-objectives are met for the implementation of the method on the test system:

1. The user activity types and log attributes for the test system were defined. A logging point(s) was placed on the client or server side for the test system.
2. This strategic placement of the logging point(s) was determined by what log attributes need to be obtained in certain stages of the software system’s logging mechanism, structure, and complexity. The logging points store the event logs in a structured database.
3. A log analysis tool is created or a suitable third-party tool is used to analyse the extracted logs. Log quality is also checked in this objective to determine if logs are in an acceptable standard set by the requirements in L3.
4. Maintenance prioritisation is calculated for each subsystem for this sub-objective using L4.

For objective E2, the results of the implementation of the method in the test system are verified in this objective. Objectives L1, L2, L3 and L4 verified if the method can create software maintenance prioritisations for the test system by comparing it to the expected results.

For objective E3, the verified method of E1 is applied to multiple case studies and the results are evaluated. A critical analysis of the case studies is performed to validate the software maintenance prioritisation for this study with the results of the case studies. With this validation strategy, this study is validated that it meets the study objectives with the created solution for the original problem statement.

IV. Reflection on methodology

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In Chapter 2 the development of the functional requirements of the solution is made in Section 2.2. This provides a generic method to create a logging mechanism and analyse the obtained user-based logs. A test logging mechanism is designed with a log analysis of usage to validate the development of functional requirements for the solution of Table 2.1.

This logging mechanism aims to implement each sub-functional requirement in a test system by testing certain inputs to verify expected outputs. The following validation method was used for this test implementation in Section 3.2:

* Identifying and creating the log attributes needed for the log analysis (F/R 1). The software system’s key log attributes are precisely defined for maintenance prioritisation. The user-activity type forms the base requirement for a user-based log.
* Logging points are made to capture these logging attributes at specific locations in the software system (F/R 2). The placement of the logging points to capture user-based logs is verified if it can be done consistently, accurately, and discretely without impacting the software system’s performance.
* Log analysis is verified using a third-party log analysis tool or the implementation of a log analysis (F/R 3). For the log analysis to be successful, the quality must be acceptable. This is verified by the logging points’ performance and the usability of the logs without too many post-logging corrections made.
* Creating software maintenance prioritising (F/R 4) from the results of log anal-ysis. In the log analysis, the different subsystems’ maintenance priority (MP F ) are calculated from the normalised total active users (PN ) multiplied by the nor-malised total user activity (AN ) for a specified subsystem in Equations (2.1–2.3).
* These results are verified with the test case study and Case Studies A, B, and C in Section 3.4 on different software systems with different operational use cases. The results obtained for the maintenance priority validate the implementation of the previous one using the defined user-based logs to perform the log analysis for the maintenance priority.

1. Conclusion

For this study the following outcomes are presented on how the solution has been presented to solve the original problem statement:

* The solution in this study aims to prioritise software maintenance by using event logging and log analysis.
* The results of this study showed that the solution could create a logging mecha-nism for prioritisation of software maintenance, as stipulated in the study objec-tives of Table 4.2.
* Therefore, the need to develop a method to be able to do log analysis for software maintenance by creating a suitable logging mechanism to capture user-based event logs has been addressed by the study objectives.
* The original problem statement defined in Section 1.3 has been successfully ad-dressed by the study objectives.

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* Finally, the identified gap has been addressed and fulfilled by providing a solution to the original problem statement.

4.2 Recommendations

In Section 3.4, the case studies highlighted the limitations of the method.

4.2.1 Logging quality

Table 1.3 describes the quality of the event log as an essential part of the logging mechanism. Event logs must be accurate, manage complex structures, and be consistent and complete. For the methodology used, not all dimensions of Figure 1.5 are used to design the logging mechanism.

This presents the functional requirement of Case Study B’s logging points (F/R 2). The multiple logging points introduced inconsistencies in the event logs for the groups of sub-systems used. There are studies on improving event log quality, but creating an event log quality model specifically for user-based event logging can increase log quality.

Some of the defined event log quality model requirements specified in Figure 1.5 still need to be fully integrated into the method. Some of these requirements can add value to log quality.

4.2.2 Maintenance prioritisation

The maintenance prioritisation (F/R 4) can have improvements made in multiple ways. Equations (2.1–2.3) uses the full user-based event logs per subsystem and the total users linked per system as its base variables

From the results observed in the case studies in Section 3.4, the base variables had an overwhelming impact on the prioritisation factor. Introducing other variables that represent other factors from the log attributes can improve the accuracy of maintenance prioritisation. An important variable that could have been used is the type of user activity of each case study.

**User activity types**

Throughout the study, the type of user activity was essential to describe what can be clas-sified as a user event. This primary log attribute can add another dimension to the results, as some user activities may be more important than others.

For software systems, as in Case Study C, where most types of user activity were grouped, the final results can be beneficial. There are some differences between some activity types.

**User and activity parameters**

Normalisation is used in Equations (2.1–2.3) to make a comparable scale for both main variables for software maintenance prioritisation. While normalisation yielded similar results, there were numerous outliers on each variable’s low and high ends. The data do not follow a specific distribution or pattern as S582 of Case Study A with a normalised activity of 1. This

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subsystem had the highest normalised activity but had the 4th highest maintenance priority due to its lower unique active user base.

Using different techniques to formulate a software maintenance priority factor may have placed S582 higher. If the effect of total unique users was not used as the primary prioritisa-tion factor for this situation.

**Use of other classification strategies**

Normalisation was used for maintenance priority calculations. Using other statistical meth-ods can yield improved prioritisation. Only one prioritisation method was used. There is a need to enhance prioritisation by comparing different prioritisation methods.

4.3 Conclusion

4.3.1 In summary

* There is a need to improve software maintenance activities in the industry, but software maintenance prioritisation is still a problem for most software developers.
* Event-based logging is a proven method to get valuable information about a software system.
* A log analysis of the utilisation of the software system can provide the needed evidence to prioritise software systems based on the extracted log data.
* Creating a user-based event logging mechanism to implement a system utilisation log analysis solves the identified problem.
* Three different case studies with two other operational use cases verified the method-ology designed for this study.

4.3.2 In conclusion

Analysing user-based event logs can improve software maintenance resource management by prioritising maintenance tasks through a comprehensive log analysis.

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Appendix A

Logging practise in software engineer-ing

Providing a guide for software engineers and developers to implement a suitable logging mechanism in their software systems has proven to be a vital tool for both industrial use and academic progress [30]. Guoping Rong et al. conducted a study to review published articles on logging practises and improve the performance and efficiency of logging implementation. From their study, they established selection criteria to include (as in Table A.1) and exclude (as in Table A.2) academic papers on logging practises [30, 35].

Rong’s selection criteria yielded numerous research articles on logging practises applied in the industry, either through creating a new logging mechanism or optimising existing log-ging mechanisms. Reviewing 41 identified articles, they found that many practitioners and researchers recognise the importance of logging practises in software engineering. However, there is a lack of guidance available to provide software engineers or developers with the tools necessary to create or improve efficient logging mechanisms [30, 42].

Table A.1: G. Rong’s inclusion selection criteria [30]

Identification Criteria

I1. Publications that investigate the methodology for logging practice.

I2. Publications that investigate the tools, frameworks, systems which support logging practice.

I3. Publications that propose a standard for logging practice.

I4. Publications that are peer-reviewed (conference paper, journal article).

I5. Publications that are primary studies on logging practice.

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References

Table A.2: G. Rong’s exclusion selection criteria [30]

Identification Criteria

E1. Publications that investigate log analysis.

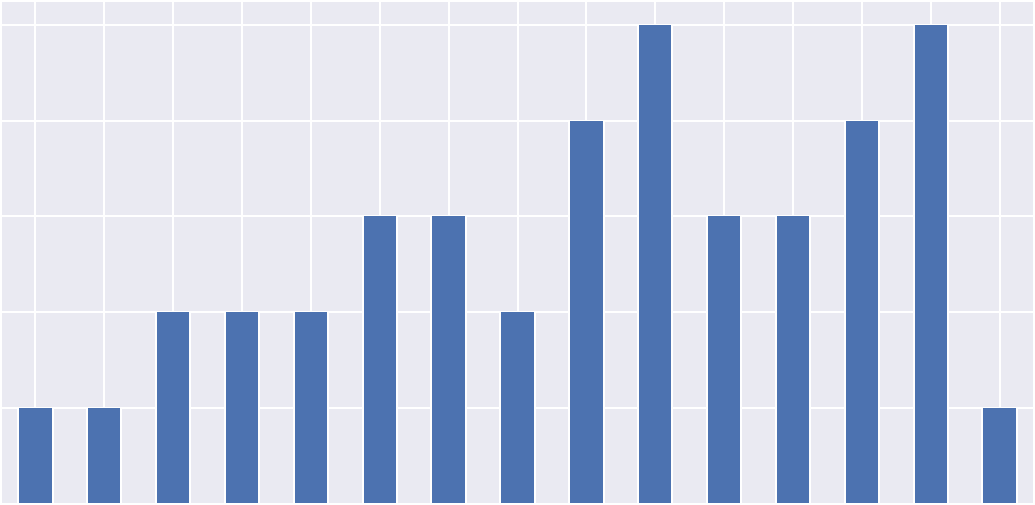
E2. Publications that investigate the usage of logs.

E3. Publications that investigate the technologies on logging user behaviours.

E4. Publications that are not written in English.

E5. Additionally, short papers, demo or industry publications are excluded.

Figure A.1 shows the distribution of the 41 published papers obtained for Rong’s research on logging practises. Event logging plays an increasingly important role in modern software systems; therefore, research on logging practises in software engineering has been on the rise between 1990 and 2017.



|  |
| --- |
| Number of published papers |

5

4

3

2

1

|  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| 0 | 1990 | 1996 | 2001 | 2003 | 2005 | 2006 | 2009 | 2010 | 2011 | 2012 | 2013 | 2014 | 2015 | 2016 | 2017 |  |
|  |  |
|  |  |  |  |  |  |  |  | Year |  |  |  |  |  |  |  |  |

Figure A.1: The distribution of the papers’ published years [30]

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Appendix B

Case study results

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| B.1 | Case study A | |  |  |  |  |
|  |  | Table B.1: Case study A results | | |  |  |
|  |  |  |  |  |  |  |
| SX | PX | PN | AX | AN | MPF | PR |
|  |  |  |  |  |  |  |
| S538 | 322 | 1.0000 | 3189 | 0.5281 | 0.5281 | 1 |
| S413 | 177 | 0.5469 | 5086 | 0.8423 | 0.4606 | 2 |
| S570 | 147 | 0.4531 | 5459 | 0.9041 | 0.4097 | 3 |
| S582 | 83 | 0.2531 | 6038 | 1.0000 | 0.2531 | 4 |
| S412 | 269 | 0.8344 | 1663 | 0.2753 | 0.2297 | 5 |
| S546 | 203 | 0.6281 | 1353 | 0.2240 | 0.1407 | 6 |
| S580 | 74 | 0.2250 | 3577 | 0.5923 | 0.1333 | 7 |
| S454 | 155 | 0.4781 | 1445 | 0.2392 | 0.1144 | 8 |
| S577 | 87 | 0.2656 | 2268 | 0.3755 | 0.0997 | 9 |
| S593 | 67 | 0.2031 | 2715 | 0.4496 | 0.0913 | 10 |
| S568 | 153 | 0.4719 | 795 | 0.1315 | 0.0621 | 11 |
| S445 | 156 | 0.4813 | 705 | 0.1166 | 0.0561 | 12 |
| S735 | 86 | 0.2625 | 899 | 0.1487 | 0.0390 | 13 |
| S476 | 93 | 0.2844 | 578 | 0.0956 | 0.0272 | 14 |
| S729 | 85 | 0.2594 | 590 | 0.0976 | 0.0253 | 15 |
| S404 | 226 | 0.7000 | 205 | 0.0338 | 0.0237 | 16 |
| S441 | 180 | 0.5563 | 249 | 0.0411 | 0.0229 | 17 |
| S600 | 78 | 0.2375 | 489 | 0.0808 | 0.0192 | 18 |
| S458 | 146 | 0.4500 | 255 | 0.0421 | 0.0189 | 19 |
|  |  |  |  |  |  |  |

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References

Table B.1: (continued from previous page)

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| SX | PX | PN | AX | AN | MPF | PR |
| S469 | 151 | 0.4656 | 217 | 0.0358 | 0.0167 | 20 |
| S435 | 167 | 0.5156 | 117 | 0.0192 | 0.0099 | 21 |
| S581 | 154 | 0.4750 | 122 | 0.0200 | 0.0095 | 22 |
| S755 | 92 | 0.2812 | 141 | 0.0232 | 0.0065 | 23 |
| S753 | 78 | 0.2375 | 157 | 0.0258 | 0.0061 | 24 |
| S616 | 105 | 0.3219 | 100 | 0.0164 | 0.0053 | 25 |
| S503 | 146 | 0.4500 | 61 | 0.0099 | 0.0045 | 26 |
| S754 | 146 | 0.4500 | 37 | 0.0060 | 0.0027 | 27 |
| S756 | 78 | 0.2375 | 61 | 0.0099 | 0.0024 | 28 |
| S736 | 146 | 0.4500 | 29 | 0.0046 | 0.0021 | 29 |
| S716 | 146 | 0.4500 | 26 | 0.0041 | 0.0019 | 30 |
| S428 | 85 | 0.2594 | 44 | 0.0071 | 0.0018 | 31 |
| S737 | 146 | 0.4500 | 23 | 0.0036 | 0.0016 | 32 |
| S668 | 86 | 0.2625 | 34 | 0.0055 | 0.0014 | 33 |
| S675 | 147 | 0.4531 | 20 | 0.0031 | 0.0014 | 34 |
| S663 | 86 | 0.2625 | 30 | 0.0048 | 0.0013 | 35 |
| S537 | 73 | 0.2219 | 35 | 0.0056 | 0.0012 | 36 |
| S667 | 146 | 0.4500 | 15 | 0.0023 | 0.0010 | 37 |
| S432 | 167 | 0.5156 | 13 | 0.0020 | 0.0010 | 38 |
| S618 | 75 | 0.2281 | 28 | 0.0045 | 0.0010 | 39 |
| S639 | 86 | 0.2625 | 24 | 0.0038 | 0.0010 | 40 |
| S544 | 149 | 0.4594 | 14 | 0.0022 | 0.0010 | 41 |
| S748 | 92 | 0.2812 | 22 | 0.0035 | 0.0010 | 42 |
| S536 | 94 | 0.2875 | 21 | 0.0033 | 0.0010 | 43 |
| S563 | 152 | 0.4688 | 13 | 0.0020 | 0.0009 | 44 |
| S679 | 147 | 0.4531 | 13 | 0.0020 | 0.0009 | 45 |
| S623 | 86 | 0.2625 | 21 | 0.0033 | 0.0009 | 46 |
| S578 | 149 | 0.4594 | 12 | 0.0018 | 0.0008 | 47 |
| S701 | 147 | 0.4531 | 12 | 0.0018 | 0.0008 | 48 |

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Table B.1: (continued from previous page)

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| SX | PX | PN | AX | AN | MPF | PR |
|  |  |  |  |  |  |  |
| S680 | 147 | 0.4531 | 12 | 0.0018 | 0.0008 | 48 |
| S496 | 156 | 0.4813 | 11 | 0.0017 | 0.0008 | 50 |
| S757 | 86 | 0.2625 | 18 | 0.0028 | 0.0007 | 51 |
| S510 | 157 | 0.4844 | 10 | 0.0015 | 0.0007 | 52 |
| S738 | 74 | 0.2250 | 19 | 0.0030 | 0.0007 | 53 |
| S614 | 85 | 0.2594 | 16 | 0.0025 | 0.0006 | 54 |
| S468 | 157 | 0.4844 | 9 | 0.0013 | 0.0006 | 55 |
| S311 | 150 | 0.4625 | 9 | 0.0013 | 0.0006 | 56 |
| S459 | 159 | 0.4906 | 8 | 0.0012 | 0.0006 | 57 |
| S571 | 72 | 0.2188 | 14 | 0.0022 | 0.0005 | 58 |
| S629 | 149 | 0.4594 | 7 | 0.0010 | 0.0005 | 59 |
| S547 | 148 | 0.4562 | 7 | 0.0010 | 0.0005 | 60 |
| S464 | 165 | 0.5094 | 6 | 0.0008 | 0.0004 | 61 |
| S559 | 154 | 0.4750 | 6 | 0.0008 | 0.0004 | 62 |
| S500 | 86 | 0.2625 | 10 | 0.0015 | 0.0004 | 63 |
| S742 | 31 | 0.0906 | 27 | 0.0043 | 0.0004 | 64 |
| S504 | 172 | 0.5312 | 5 | 0.0007 | 0.0004 | 65 |
| S508 | 162 | 0.5000 | 5 | 0.0007 | 0.0003 | 66 |
| S567 | 152 | 0.4688 | 5 | 0.0007 | 0.0003 | 67 |
| S566 | 147 | 0.4531 | 5 | 0.0007 | 0.0003 | 68 |
| S681 | 147 | 0.4531 | 5 | 0.0007 | 0.0003 | 68 |
| S727 | 146 | 0.4500 | 5 | 0.0007 | 0.0003 | 70 |
| S658 | 74 | 0.2250 | 8 | 0.0012 | 0.0003 | 71 |
| S659 | 86 | 0.2625 | 7 | 0.0010 | 0.0003 | 71 |
| S507 | 158 | 0.4875 | 4 | 0.0005 | 0.0002 | 73 |
| S620 | 147 | 0.4531 | 4 | 0.0005 | 0.0002 | 74 |
| S677 | 146 | 0.4500 | 4 | 0.0005 | 0.0002 | 75 |
| S740 | 33 | 0.0969 | 13 | 0.0020 | 0.0002 | 76 |
| S517 | 146 | 0.4500 | 3 | 0.0003 | 0.0001 | 77 |
|  |  |  |  |  |  |  |

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References

Table B.1: (continued from previous page)

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| SX | PX | PN | AX | AN | MPF | PR |
| S709 | 146 | 0.4500 | 3 | 0.0003 | 0.0001 | 77 |
| S493 | 163 | 0.5031 | 2 | 0.0002 | 0.0001 | 79 |
| S506 | 159 | 0.4906 | 2 | 0.0002 | 0.0001 | 80 |
| S467 | 155 | 0.4781 | 2 | 0.0002 | 0.0001 | 81 |
| S541 | 147 | 0.4531 | 2 | 0.0002 | 0.0001 | 82 |
| S657 | 146 | 0.4500 | 2 | 0.0002 | 0.0001 | 83 |
| S688 | 146 | 0.4500 | 2 | 0.0002 | 0.0001 | 83 |
| S694 | 146 | 0.4500 | 2 | 0.0002 | 0.0001 | 83 |
| S739 | 146 | 0.4500 | 2 | 0.0002 | 0.0001 | 83 |
| S470 | 17 | 0.0469 | 7 | 0.0010 | 0.0000 | 87 |
| S477 | 82 | 0.2500 | 2 | 0.0002 | 0.0000 | 88 |
| S583 | 82 | 0.2500 | 2 | 0.0002 | 0.0000 | 88 |
| S481 | 81 | 0.2469 | 2 | 0.0002 | 0.0000 | 90 |
| S466 | 156 | 0.4813 | 1 | 0.0000 | 0.0000 | 91 |
| S485 | 2 | 0.0000 | 4 | 0.0005 | 0.0000 | 91 |
| S732 | 146 | 0.4500 | 1 | 0.0000 | 0.0000 | 91 |
| S465 | 155 | 0.4781 | 1 | 0.0000 | 0.0000 | 91 |
| S576 | 146 | 0.4500 | 1 | 0.0000 | 0.0000 | 91 |
| S725 | 146 | 0.4500 | 1 | 0.0000 | 0.0000 | 91 |
| S711 | 80 | 0.2437 | 1 | 0.0000 | 0.0000 | 91 |
| S699 | 146 | 0.4500 | 1 | 0.0000 | 0.0000 | 91 |
| S693 | 146 | 0.4500 | 1 | 0.0000 | 0.0000 | 91 |
| S505 | 159 | 0.4906 | 1 | 0.0000 | 0.0000 | 91 |
| S676 | 149 | 0.4594 | 1 | 0.0000 | 0.0000 | 91 |
| S513 | 157 | 0.4844 | 1 | 0.0000 | 0.0000 | 91 |
| S514 | 157 | 0.4844 | 1 | 0.0000 | 0.0000 | 91 |
| S661 | 80 | 0.2437 | 1 | 0.0000 | 0.0000 | 91 |
| S515 | 166 | 0.5125 | 1 | 0.0000 | 0.0000 | 91 |
| S520 | 154 | 0.4750 | 1 | 0.0000 | 0.0000 | 91 |

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Using user-based activity logging and analysis to prioritise software maintenance 114

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
|  |  |  |  |  |  | References |
|  |  |  | | |  |  |
|  |  | Table B.1: (continued from previous page) | | |  |  |
|  |  |  |  |  |  |  |
| SX | PX | PN | AX | AN | MPF | PR |
|  |  |  |  |  |  |  |
| S528 | 167 | 0.5156 | 1 | 0.0000 | 0.0000 | 91 |
| S530 | 81 | 0.2469 | 1 | 0.0000 | 0.0000 | 91 |
| S607 | 148 | 0.4562 | 1 | 0.0000 | 0.0000 | 91 |
| S543 | 146 | 0.4500 | 1 | 0.0000 | 0.0000 | 91 |
| S573 | 81 | 0.2469 | 1 | 0.0000 | 0.0000 | 91 |
|  |  |  |  |  |  |  |

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| B.2 | Case study B | |  |  |  |  |
|  |  | Table B.2: Case study B results | | |  |  |
|  |  |  |  |  |  |  |
| SX | PX | PN | AX | AN | MPF | PR |
|  |  |  |  |  |  |  |
| S417 | 297 | 1.0000 | 2502 | 1.0000 | 1.0000 | 1 |
| S288 | 224 | 0.6756 | 838 | 0.3347 | 0.2261 | 2 |
| S258 | 291 | 0.9733 | 417 | 0.1663 | 0.1619 | 3 |
| S259 | 291 | 0.9733 | 373 | 0.1487 | 0.1448 | 4 |
| S170 | 243 | 0.7600 | 373 | 0.1487 | 0.1130 | 5 |
| S225 | 209 | 0.6089 | 352 | 0.1403 | 0.0855 | 6 |
| S72 | 223 | 0.6711 | 196 | 0.0780 | 0.0523 | 7 |
| S83 | 223 | 0.6711 | 167 | 0.0664 | 0.0445 | 8 |
| S73 | 223 | 0.6711 | 164 | 0.0652 | 0.0437 | 9 |
| S257 | 231 | 0.7067 | 151 | 0.0600 | 0.0424 | 10 |
| S268 | 186 | 0.5067 | 181 | 0.0720 | 0.0365 | 11 |
| S172 | 242 | 0.7556 | 80 | 0.0316 | 0.0239 | 12 |
| S271 | 212 | 0.6222 | 89 | 0.0352 | 0.0219 | 13 |
| S275 | 282 | 0.9333 | 57 | 0.0224 | 0.0209 | 14 |
| S305 | 225 | 0.6800 | 74 | 0.0292 | 0.0198 | 15 |
| S173 | 241 | 0.7511 | 62 | 0.0244 | 0.0183 | 16 |
| S171 | 242 | 0.7556 | 60 | 0.0236 | 0.0178 | 17 |
| S208 | 240 | 0.7467 | 42 | 0.0164 | 0.0122 | 18 |

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References

Table B.2: (continued from previous page)

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| SX | PX | PN | AX | AN | MPF | PR |
|  |  |  |  |  |  |  |
| S190 | 211 | 0.6178 | 30 | 0.0116 | 0.0072 | 19 |
| S336 | 204 | 0.5867 | 28 | 0.0108 | 0.0063 | 20 |
| S487 | 118 | 0.2044 | 78 | 0.0308 | 0.0063 | 21 |
| S223 | 209 | 0.6089 | 17 | 0.0064 | 0.0039 | 22 |
| S418 | 118 | 0.2044 | 24 | 0.0092 | 0.0019 | 23 |
| S224 | 206 | 0.5956 | 8 | 0.0028 | 0.0017 | 24 |
| S426 | 106 | 0.1511 | 20 | 0.0076 | 0.0011 | 25 |
| S419 | 168 | 0.4267 | 7 | 0.0024 | 0.0010 | 26 |
| S718 | 74 | 0.0089 | 248 | 0.0988 | 0.0009 | 27 |
| S421 | 118 | 0.2044 | 9 | 0.0032 | 0.0007 | 28 |
| S209 | 208 | 0.6044 | 2 | 0.0004 | 0.0002 | 29 |
| S212 | 208 | 0.6044 | 2 | 0.0004 | 0.0002 | 29 |
| S213 | 206 | 0.5956 | 2 | 0.0004 | 0.0002 | 31 |
| S343 | 168 | 0.4267 | 2 | 0.0004 | 0.0002 | 32 |
| S719 | 74 | 0.0089 | 20 | 0.0076 | 0.0001 | 33 |
| S425 | 101 | 0.1289 | 2 | 0.0004 | 0.0001 | 34 |
| S720 | 74 | 0.0089 | 11 | 0.0040 | 0.0000 | 35 |
| S423 | 99 | 0.1200 | 1 | 0.0000 | 0.0000 | 36 |
| S420 | 118 | 0.2044 | 1 | 0.0000 | 0.0000 | 36 |
| S409 | 72 | 0.0000 | 945 | 0.3774 | 0.0000 | 36 |
| S446 | 118 | 0.2044 | 1 | 0.0000 | 0.0000 | 36 |
| S344 | 168 | 0.4267 | 1 | 0.0000 | 0.0000 | 36 |
| S488 | 119 | 0.2089 | 1 | 0.0000 | 0.0000 | 36 |
| S210 | 209 | 0.6089 | 1 | 0.0000 | 0.0000 | 36 |
| S211 | 209 | 0.6089 | 1 | 0.0000 | 0.0000 | 36 |
| S410 | 72 | 0.0000 | 21 | 0.0080 | 0.0000 | 36 |

B.3 Case study C

Using user-based activity logging and analysis to prioritise software maintenance 116

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
|  |  |  |  |  |  | References |
|  |  |  | | |  |  |
|  |  | Table B.3: Case study C results | | |  |  |
|  |  |  |  |  |  |  |
| SX | PX | PN | AX | AN | MPF | PR |
|  |  |  |  |  |  |  |
| S97 | 145 | 1.0000 | 84494 | 1.0000 | 1.0000 | 1 |
| S93 | 144 | 0.9931 | 71516 | 0.8464 | 0.8405 | 2 |
| S12 | 86 | 0.5903 | 14312 | 0.1694 | 0.1000 | 3 |
| S8 | 82 | 0.5625 | 14899 | 0.1763 | 0.0992 | 4 |
|  |  |  |  |  |  |  |
| S5 | 43 | 0.2917 | 27985 | 0.3312 | 0.0966 | 5 |
| S6 | 103 | 0.7083 | 7257 | 0.0859 | 0.0608 | 6 |
| S1 | 126 | 0.8681 | 5580 | 0.0660 | 0.0573 | 7 |
| S82 | 126 | 0.8681 | 2461 | 0.0291 | 0.0253 | 8 |
| S14 | 76 | 0.5208 | 3307 | 0.0391 | 0.0204 | 9 |
| S90 | 113 | 0.7778 | 1951 | 0.0231 | 0.0180 | 10 |
| S13 | 48 | 0.3264 | 4473 | 0.0529 | 0.0173 | 11 |
| S92 | 26 | 0.1736 | 3034 | 0.0359 | 0.0062 | 12 |
| S11 | 37 | 0.2500 | 1886 | 0.0223 | 0.0056 | 13 |
| S10 | 41 | 0.2778 | 1593 | 0.0188 | 0.0052 | 14 |
| S46 | 61 | 0.4167 | 800 | 0.0095 | 0.0039 | 15 |
| S67 | 18 | 0.1181 | 1644 | 0.0194 | 0.0023 | 16 |
| S7 | 41 | 0.2778 | 594 | 0.0070 | 0.0019 | 17 |
| S91 | 95 | 0.6528 | 246 | 0.0029 | 0.0019 | 18 |
| S70 | 13 | 0.0833 | 1662 | 0.0197 | 0.0016 | 19 |
| S95 | 24 | 0.1597 | 647 | 0.0076 | 0.0012 | 20 |
| S39 | 7 | 0.0417 | 2015 | 0.0238 | 0.0010 | 21 |
| S96 | 33 | 0.2222 | 258 | 0.0030 | 0.0007 | 22 |
| S79 | 6 | 0.0347 | 1535 | 0.0182 | 0.0006 | 23 |
| S64 | 10 | 0.0625 | 850 | 0.0100 | 0.0006 | 24 |
| S51 | 4 | 0.0208 | 2070 | 0.0245 | 0.0005 | 25 |
| S3 | 40 | 0.2708 | 155 | 0.0018 | 0.0005 | 26 |
|  |  |  |  |  |  |  |
| S2 | 14 | 0.0903 | 400 | 0.0047 | 0.0004 | 27 |
| S15 | 18 | 0.1181 | 303 | 0.0036 | 0.0004 | 28 |

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References

Table B.3: (continued from previous page)

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| SX | PX | PN | AX | AN | MPF | PR |
|  |  |  |  |  |  |  |
| S65 | 14 | 0.0903 | 391 | 0.0046 | 0.0004 | 29 |
| S54 | 8 | 0.0486 | 477 | 0.0056 | 0.0003 | 30 |
| S30 | 5 | 0.0278 | 655 | 0.0077 | 0.0002 | 31 |
| S58 | 9 | 0.0556 | 304 | 0.0036 | 0.0002 | 32 |
| S45 | 36 | 0.2431 | 57 | 0.0007 | 0.0002 | 33 |
| S76 | 9 | 0.0556 | 214 | 0.0025 | 0.0001 | 34 |
| S77 | 10 | 0.0625 | 122 | 0.0014 | 0.0001 | 35 |
| S80 | 7 | 0.0417 | 179 | 0.0021 | 0.0001 | 36 |
| S24 | 5 | 0.0278 | 208 | 0.0024 | 0.0001 | 37 |
| S60 | 6 | 0.0347 | 142 | 0.0017 | 0.0001 | 38 |
| S87 | 4 | 0.0208 | 193 | 0.0023 | 0.0000 | 39 |
| S63 | 4 | 0.0208 | 174 | 0.0020 | 0.0000 | 40 |
| S59 | 6 | 0.0347 | 103 | 0.0012 | 0.0000 | 41 |
| S9 | 12 | 0.0764 | 45 | 0.0005 | 0.0000 | 42 |
| S53 | 5 | 0.0278 | 115 | 0.0013 | 0.0000 | 43 |
| S33 | 4 | 0.0208 | 125 | 0.0015 | 0.0000 | 44 |
| S72 | 4 | 0.0208 | 117 | 0.0014 | 0.0000 | 45 |
| S68 | 4 | 0.0208 | 88 | 0.0010 | 0.0000 | 46 |
| S17 | 3 | 0.0139 | 130 | 0.0015 | 0.0000 | 47 |
| S83 | 13 | 0.0833 | 22 | 0.0002 | 0.0000 | 48 |
| S44 | 4 | 0.0208 | 82 | 0.0010 | 0.0000 | 49 |
| S71 | 4 | 0.0208 | 73 | 0.0009 | 0.0000 | 50 |
| S85 | 5 | 0.0278 | 49 | 0.0006 | 0.0000 | 51 |
| S69 | 4 | 0.0208 | 65 | 0.0008 | 0.0000 | 51 |
| S31 | 4 | 0.0208 | 53 | 0.0006 | 0.0000 | 53 |
| S62 | 3 | 0.0139 | 79 | 0.0009 | 0.0000 | 53 |
| S78 | 3 | 0.0139 | 70 | 0.0008 | 0.0000 | 55 |
| S66 | 7 | 0.0417 | 23 | 0.0003 | 0.0000 | 56 |
| S16 | 3 | 0.0139 | 57 | 0.0007 | 0.0000 | 57 |
|  |  |  |  |  |  |  |

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References

Table B.3: (continued from previous page)

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| SX | PX | PN | AX | AN | MPF | PR |
| S75 | 6 | 0.0347 | 23 | 0.0003 | 0.0000 | 58 |
| S29 | 3 | 0.0139 | 43 | 0.0005 | 0.0000 | 59 |
| S89 | 9 | 0.0556 | 11 | 0.0001 | 0.0000 | 60 |
| S42 | 2 | 0.0069 | 51 | 0.0006 | 0.0000 | 61 |
| S74 | 2 | 0.0069 | 48 | 0.0006 | 0.0000 | 62 |
| S84 | 2 | 0.0069 | 37 | 0.0004 | 0.0000 | 63 |
| S38 | 2 | 0.0069 | 33 | 0.0004 | 0.0000 | 64 |
| S19 | 3 | 0.0139 | 15 | 0.0002 | 0.0000 | 65 |
| S22 | 2 | 0.0069 | 24 | 0.0003 | 0.0000 | 66 |
| S23 | 3 | 0.0139 | 10 | 0.0001 | 0.0000 | 67 |
| S47 | 3 | 0.0139 | 9 | 0.0001 | 0.0000 | 68 |
| S28 | 2 | 0.0069 | 14 | 0.0002 | 0.0000 | 69 |
| S50 | 3 | 0.0139 | 6 | 0.0001 | 0.0000 | 70 |
| S32 | 2 | 0.0069 | 9 | 0.0001 | 0.0000 | 71 |
| S36 | 2 | 0.0069 | 8 | 0.0001 | 0.0000 | 72 |
| S26 | 2 | 0.0069 | 7 | 0.0001 | 0.0000 | 73 |
| S25 | 2 | 0.0069 | 3 | 0.0000 | 0.0000 | 74 |
| S43 | 2 | 0.0069 | 3 | 0.0000 | 0.0000 | 74 |
| S61 | 1 | 0.0000 | 1 | 0.0000 | 0.0000 | 76 |
| S86 | 1 | 0.0000 | 1 | 0.0000 | 0.0000 | 76 |
| S4 | 1 | 0.0000 | 14 | 0.0002 | 0.0000 | 76 |
|  |  |  |  |  |  |  |
| S18 | 1 | 0.0000 | 8 | 0.0001 | 0.0000 | 76 |
| S20 | 1 | 0.0000 | 10 | 0.0001 | 0.0000 | 76 |
| S94 | 1 | 0.0000 | 2 | 0.0000 | 0.0000 | 76 |
| S21 | 1 | 0.0000 | 4 | 0.0000 | 0.0000 | 76 |
| S27 | 1 | 0.0000 | 1 | 0.0000 | 0.0000 | 76 |
| S88 | 1 | 0.0000 | 8 | 0.0001 | 0.0000 | 76 |
| S34 | 1 | 0.0000 | 1 | 0.0000 | 0.0000 | 76 |
| S35 | 1 | 0.0000 | 61 | 0.0007 | 0.0000 | 76 |

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References

Table B.3: (continued from previous page)

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| SX | PX | PN | AX | AN | MPF | PR |
|  |  |  |  |  |  |  |
| S57 | 1 | 0.0000 | 2 | 0.0000 | 0.0000 | 76 |
| S37 | 1 | 0.0000 | 3 | 0.0000 | 0.0000 | 76 |
| S40 | 1 | 0.0000 | 1 | 0.0000 | 0.0000 | 76 |
| S81 | 1 | 0.0000 | 48 | 0.0006 | 0.0000 | 76 |
| S41 | 1 | 0.0000 | 2 | 0.0000 | 0.0000 | 76 |
| S48 | 1 | 0.0000 | 36 | 0.0004 | 0.0000 | 76 |
| S49 | 1 | 0.0000 | 26 | 0.0003 | 0.0000 | 76 |
| S52 | 1 | 0.0000 | 61 | 0.0007 | 0.0000 | 76 |
| S55 | 1 | 0.0000 | 1 | 0.0000 | 0.0000 | 76 |
| S56 | 1 | 0.0000 | 5 | 0.0000 | 0.0000 | 76 |
| S73 | 1 | 0.0000 | 3 | 0.0000 | 0.0000 | 76 |
| S99 | 1 | 0.0000 | 1 | 0.0000 | 0.0000 | 76 |

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