Identifying Metrics For Measuring Maintainability Of Models Defined in SystemWeaver

An Industrial Case Study

Master's thesis in Software Engineering

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CHALMERS UNIVERSITY OF TECHNOLOGY
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Abstract

Software maintenance forms a crucial activity of any viable software system. Sometimes it becomes the most expensive and time-consuming phase in the life cycle of the software product. Software maintainability on the other hand, measures how easy it is for a software product to be modified. Since software products are growing fast and are becoming more sophisticated over time, measuring the maintainability during early stages of the development process, such as the phase of designing models, will be vital for reducing costs and improving quality of later stages. Our Study focused on studying software models presented in SystemWeaver, one of the systems that utilises models extensively for a wide range of industrial purposes. We analysed the structures of the models collected and used their revision history to obtain more knowledge and define situations reflecting some of the maintenance issues that the developers faced during their development activities. Many of the defined situations were confirmed later by interviewing experts in the collected data. The confirmed situations, named patterns, were used to validate a set of maintainability metrics which were extracted from literature and other research. The correlation tests for validating the mentioned metrics showed promising results and proved that metrics can be good candidates for measuring the maintainability of models. The results of this study included (1) a prove that struggles during the development processes can be recognised by inspecting some occurring patterns. (2) metrics can be used to measure the maintainability of models such as the set of metrics we provided at the final chapter of this report.

Keywords: Computer science, Software engineering, Case study, Models, Maintainability, Patterns, Metrics.

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Abdullah Awad & Sinan Saleh
Gothenburg, September 2020

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Introduction

Software maintenance forms a crucial activity of any viable software system. Sometimes it can become the most expensive and time-consuming phase within the software life cycle [4]. Costs of maintenance increase over time as software products develop and gain more complexity [4], therefore, it is essential for maintainers to predict the "degree of effectiveness and efficiency with which a system can be modified" [1] during its continuous evolving to conform to new requirements, fixes, hardware changes as well as technology updates.

Software maintainability on the other hand, is a quality identified as "the capability of a software product to be modified" [2]. In other words, maintainability measures "the ease with which a software system or component can be modified to correct faults, improve performance and characteristics, or adapt to a changed environment" [3]. Development activities can complicate the source code and drift it from its original design, making the measuring of the maintainability harder through time [4]. As a result, keeping an eye on the maintainability during the early stages of the software creation process is vital in reducing final costs and improving the quality of later stages [5].

1.1 Software Models

Software development processes, such as the unified process (UP), are usually architectural centric and relies extensively on models. Models, on the other hand, are important as they shape both problems and solutions. "A model is a simplification of reality that helps us master a large, complex system that cannot be comprehended easily in its entirety" [25]. Moreover, as industrial software systems are growing and becoming more sophisticated, an essential need to segregate the industrial problems from implementation is required. Software models aid in this area through expressing such systems at multiple levels of abstraction and a variety of perspectives [19]. As a result, having a system developed and built based on models means that the maintainability of such models might be related to the maintainability of the derived final product.

1.2 Measuring Maintainability

Measuring maintainability has been a challenge for both practitioners and researchers at the same time. Practitioners find it hard as it requires a deep understanding of the systems, which is an obstacle when people measuring the maintainability are not the same ones who were involved in development phases [6]. On the other hand, researchers have lots of areas to cover regarding maintainability, some of them include various software artefacts (e.g. requirements, designs, models and code), while others cover different aspects like enterprise architectures and their relation to the maintainability of software products [5]. Measuring maintainability in such areas require finding metrics that “first understand the characteristics of maintainable software and then attempt to measure them” [7].

In traditional software development processes like OOP, developers use code metrics to indicate which parts of the system are too hard to maintain. Based on that, they take corrective actions like refactoring [4] or applying code reviews to keep the code in a maintainable state. However, this is not applicable in the early stages of software development processes where the focus is on models (e.g. model-driven software development). Therefore, it seem to be useful to identify a set of metrics that can evaluate the maintainability of models and provide a mean of measuring it in such early phases of development.

1.3 Maintainability of Models

Model Driven Software Development (MDSD) helps in separating the business design from software system design as it generates an abstraction of code to be used within a defined domain, mostly an industrial one. It also enables developing complex systems through presenting concepts that are much less bound to the underlying implementation technology and much closer to the problem domain itself [8].

Accordingly, MDSD promises to improve maintainability during the evolution of the system over conventional development approaches [9]. However, in MDSD users may not be aware of the software quality as their roles will mostly be restricted to designing the domain specifications and characteristics. Designers may lack the experience and/or the understanding of the domain and they may not consider the quality attributes within the design. Consequently, this will create aggregated problems within the final design leading to unmaintainable products in the future.

1.4 Aim of Study

The study aims at identifying metrics that support assessing the maintainability of models to help the designers evaluate their quality. The focus will be on the models created and used in SystemWeaver, which is a model-driven software development environment representing its models as items connected to each other. Despite the used environment, we hope that the final results will be applicable to general software models as the ones studied share many characteristics with them but are tied to a specific industrial domain. However, this is not a promise and it might require further studies to impose that.

The research will define some situations or patterns representing maintainability issues in the models of SystemWeaver and then identify a list of metrics derived from literature. At the end, a comparison between the measures of the identified metrics and the results of the defined patterns will be applied to indicate how good can the metrics be in expressing the maintainability of models.

1.5 Report Sections

Following this chapter, a generic background will be presented in chapter 2 to cover the tools, the techniques and the scope which this study will focus on. A brief history of research and related work will come next in chapter 3 introducing terminologies and metrics used for measuring different maintainability aspects. The chapter 4, will go through the methodologies adapted and followed by our study to answer our research questions. However, this chapter will also define a set characteristics and metrics to be used in generating tangible results later. The actual results will be introduced and described in chapter 5, while the generated values will be listed in appendixes (B, C, D, E, F,G and H). The last two chapters in our report, chapter 6 and chapter 7, will be saved for presenting our discussion and drawing conclusions based on the mentioned results.

2

Background

This chapter presents information regarding the environment, the tools, the techniques and the scope which our study is going to focus on.

2.1 Systemite and SystemWeaver

The company, Systemite, has been in the industry for more than 20 years now, supporting the activities of many development teams and helping them manage their increasingly complex environments in the digital transformation of system engineering. Their main software product, SystemWeaver, which is the tool used by our study, delivers integrated information management and effective communication for fast-paced agile workflows [17].

SystemWeaver is one of the systems that utilises models extensively. Customers can build their own models using different artefacts (e.g. requirements and configurations) which are represented as items in the system. These items support designing the models by playing the role of a carrier of relevant information. It is worth noting that the models contain design components (e.g. parts, attributes and relations) and can include connectors or be connected to other models as well (model branches).

The benefits promised by SystemWeaver are provided through a set of three integrated applications. The server application, which hosts a database containing all the data and enables real-time updates between all connected clients. The architect application, used for generating meta-models which form the backbone of the models in the system and define their relations and attributes. And finally, the client application which counts on the meta models to generate all needed models according to the required specifications.

Accessing the data stored in the database is restricted to the architect and client applications. However, an API exists in case the two mentioned applications cannot support the operations needed on the data.

2.2 Meta Models in SystemWeaver

A meta model is a group of formalised statements that are used to build or describe models based on predefined structure and concepts [24].

In SystemWeaver a meta model contains the defined building blocks used to build models as well as the rules for specifying such blocks. The basic building blocks of a meta model in SystemWeaver are: Items, Parts and Attributes.

An item (or node) is the smallest reusable object in SystemWeaver. It can be used as a standalone entity or as a piece of another item. Each item has a type which determines, for example, what parts the item is allowed to have. You will often recognise item types by their icon, but an item type is also identified with unique identifiers. Tracking changes on items is possible through a revision history that is available for each one.

A part is a link or a relationship among defined items. Parts are owned by items themselves and also have types. We will call parts as links or connections for simplicity and their direction is important as it defines the dependency. For instance, a part going from item A to item B, makes the item A a parent to item B and item B a child for item A.

Figure 2.1[1] shows an example of a meta-model designed in SystemWeaver. The boxes represent items, and their types can be seen in the top right corner of each box. Arrows between boxes represent parts, the name of the part is printed on the arrow and the type of the part can be found in the parentheses.

Attributes on the other hand, are used to describe items as well as parts in a structured manner compared to just using free texts. There are two categories of attributes, default ones for each created item or part, and additional custom ones which can be specified when designing the meta-model. The values of these attributes can be edited in the system depending on the type that the attribute has. Figure 2.2[1] shows how to edit the values of the attributes of one item.

2.3 Report Terminology

In the following we define a few terms that will be used throughout this report.

Root Item: A root item or a top item is the first item in the hierarchy of a meta model or a model. Other items in the model come beneath such item in the hierarchy. Figure 2.1 shows the root item named as “Specification architecture”

Inner Item: An inner item is an item available in the hierarchy of a meta model or a model that is not a root item and owns at least one part. The item “Feature” is an example of an inner item in the meta model shown in Figure 2.1.

Leaf Item: A leaf item is an item available in the hierarchy that is not a root item nor an inner item like the “Feature requirement” in Figure 2.1.

[1] Retrieved from https://support.systemweaver.se/support/solutions/

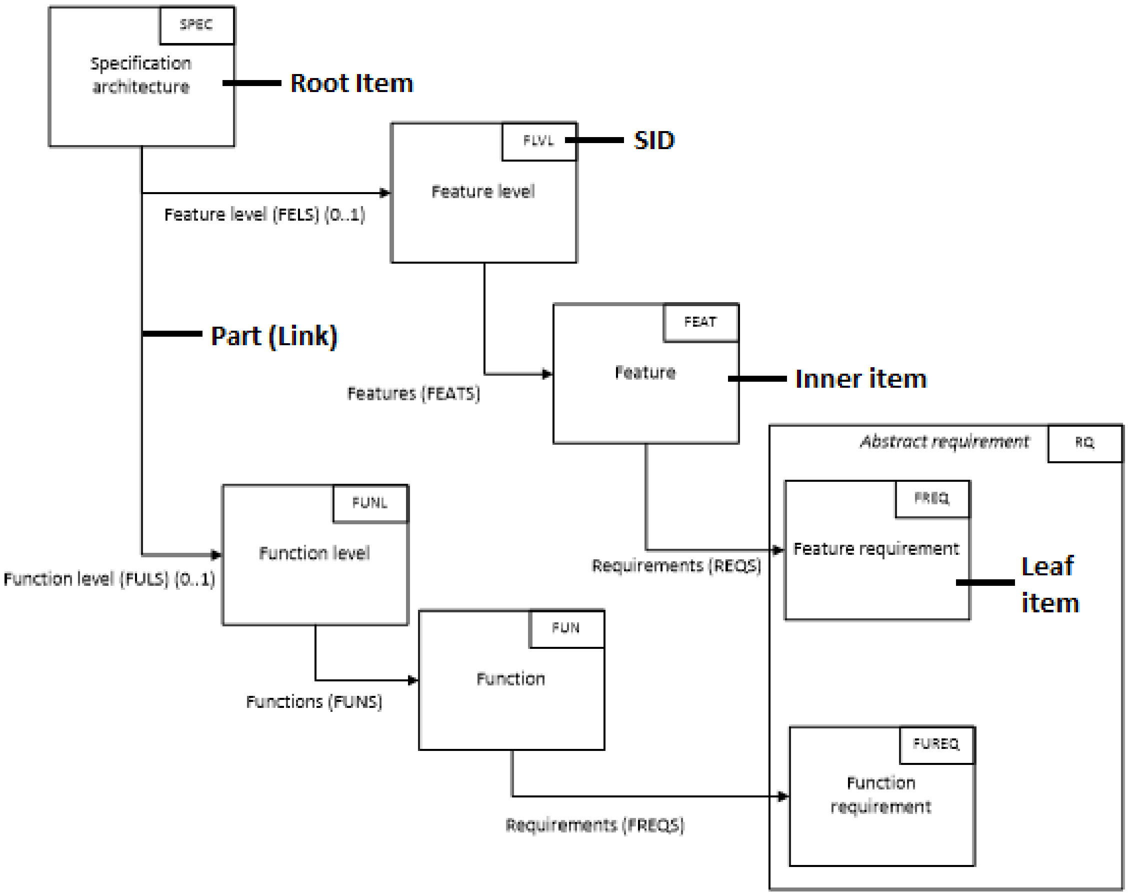


Figure 2.1: Example of a requirement meta model in SystemWeaver

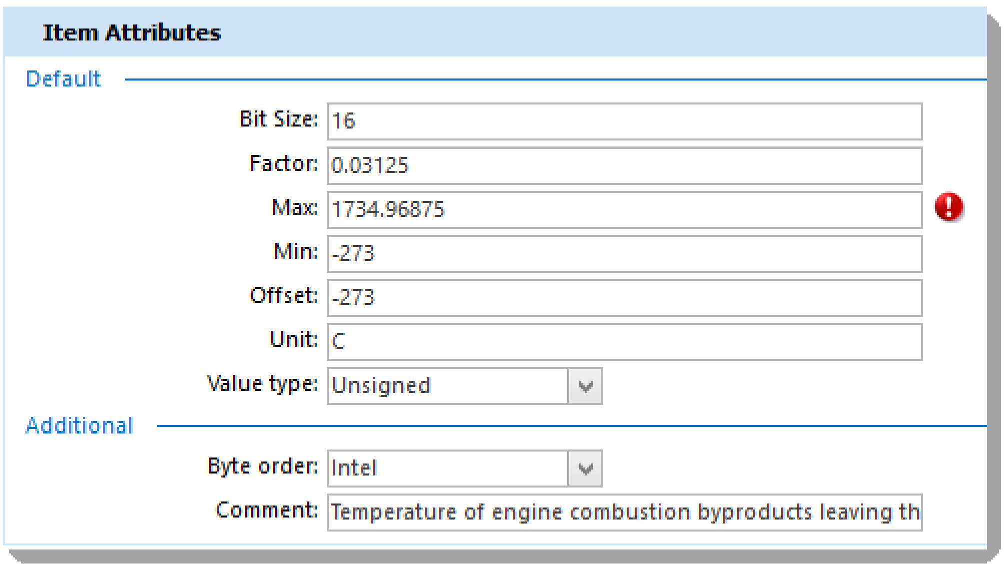


Figure 2.2: Example of item attributes in SystemWeaver

Item Level: The term item level or item depth indicates the number of connections (parts) that an item needs to follow in order to reach the root item. Root Items have the Level 0. The box representing Function requirement in Figure 2.1 would have a level of 3.

Item Handle: A handle is a unique numeric identifier that distinguishes any item, it can be considered as a key which is used to fetch a specific item in the database. When an item is changed, it acquires a new handle. However, each item keeps a record of its original handle (called top handle) throughout its life cycle. The first version of any item will have a top handle identical to its handle.

SystemWeaver Identifier (SID): An SID is a unique textual identifier that reflects a type. SIDs distinguishes an item or a part from others, in Figure 2.1, a function is identified by the SID: FUN.

Model Version (Model): The term model version will be used to refer to any model of the models available in SystemWeaver database at a specific period of time. The version number of a model is related to the versions of its items. Therefore, when items are changed (upgraded to newer versions) the related model will get a increase in version number.

Model Group: A model group is a set of model versions which are related together (their root items have identical top handles) and were developed over time to support a life cycle of a product. It can be seen as a software that went through a set of iterations during development. Therefore, a model group in this case will be all the produced model versions combined in a group and distinguished by version numbers.

The model shown earlier in Figure 2.1 has some of the previously explained terminologies in bold texts.

2.4 Software Models

Figure 2.3 shows an example of a software model in the form of a UML diagram[2]. In this diagram we can see some base classes (inner-items) such as the “Car” class, as well as child classes (leaf-items) like “Engine” and “Body”. The main class for this diagram, or the root class, is the “Car Model” which represents a very abstract concept that a “Car” can inherit from.

The links between the classes define the relationships and dependency between their objects, for example, each “Car” can have one “Engine”, one “Body”, but one or more “Suspension” systems. Thus, the abstract concept “Car Model” can be an umbrella of many different “Cars”. The objects instantiated from the mentioned classes can differ according to the values of their own attributes and/or related children’s attributes. For instance, changing the “Body” and the “Engine” (or any leaf-item in general) can produce a new “Car” object.

[2]Retrieved from https://online.visual-paradigm.com/diagrams/features/uml-tool/

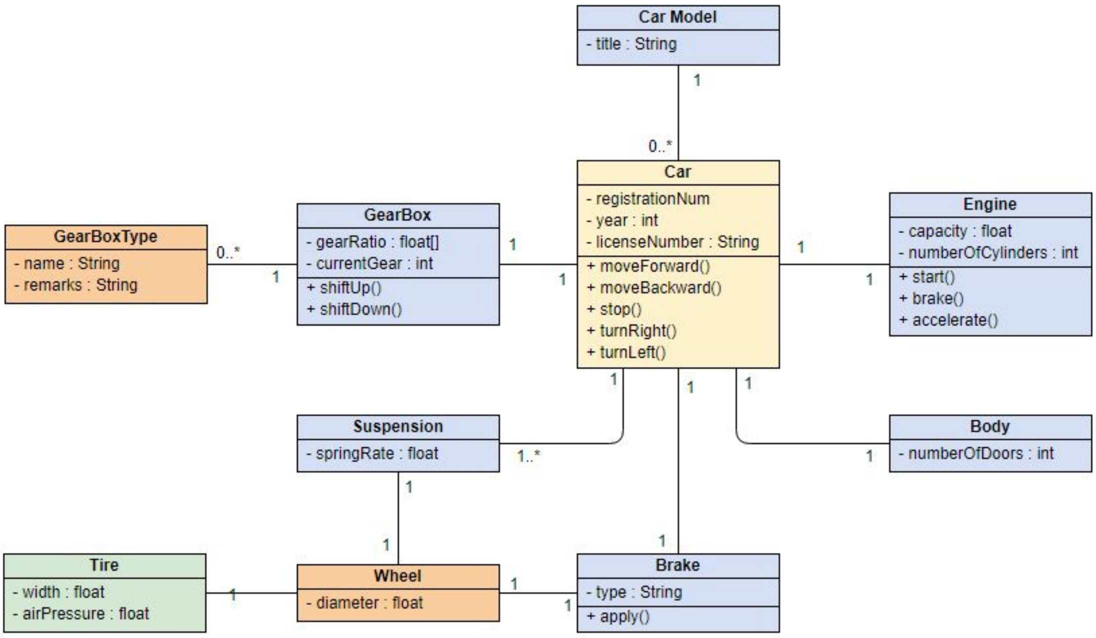


Figure 2.3: Example of a software model - UML diagram

2.5 SystemWeaver Models

Models in SystemWeaver supports managing a wide variety of domains. For instance, a feature model would describe the features of a product and a design model will contain all aesthetics components. Similarly, a requirement model, e.g. the one partly shown in Figure 2.1, would manage all the requirement-related activities of a product like managing versions, configuration, attributes and others. Moreover, a hardware model would contain a set of components representing the hardware circuits, while a network model would be expected to describe the communications between those hardware components as signals.

By identifying such models and many others, and specifying the way that components relate together, SystemWeaver can provide a capability of generating specifications of products easily and automatically.

Looking back at Figure 2.1, we can see that the meta-model, similarly to the models described in section 2.4, has items and links. The complexity of the structure depends on the number of available inner-items and leaf-items, as more items will require more management (attributes, links and relations ... etc). Figure 2.4 shows the corresponding tree structure of the aforementioned meta-model.

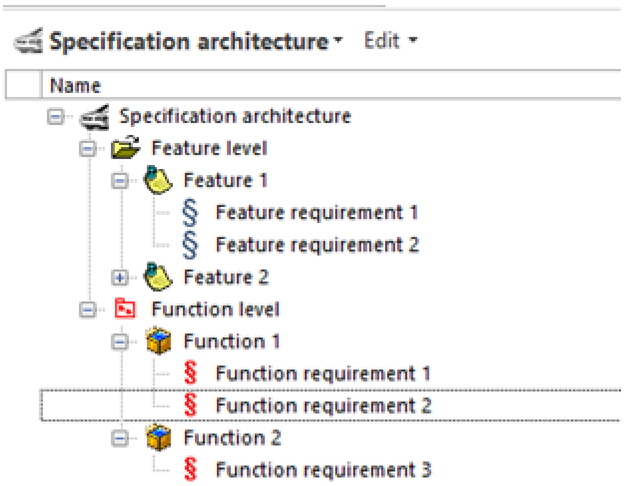


Figure 2.4: Example of a requirement model in SystemWeaver

3

Related Work

In this chapter, we will describe the related studies conducted to evaluate maintainability within the model-driven software development processes. We will also dig into the literature to explore the state-of-the-art metrics used nowadays for assessing maintainability as well as detailing some of them within the last section.

Research topics regarding software maintainability usually cover the phases related to writing code. More specifically, the ones using object oriented programming languages (OOP). As a result, maintainability in that area has been investigated deeply and thoroughly in several aspects compared to very little research around the area of models. The following sections will provide a literature review for all studies we found in both areas, the OOP languages and the models.

3.1 Maintainability Metrics

Maintainability metrics have been already studied to measure the maintainability of object-oriented software [10][11] and software architecture [5][15]. However, the metrics used to estimate the maintainability were mostly based on measuring the size and complexity of the code.

Saraiva et al. [10] aimed at categorising a large number of metrics proposed by research for the purpose of facilitating the decision-making process about which metrics should be selected for experiments in the object-oriented software maintainability aspects. The study managed to identify 7 categories and 17 subcategories of metrics, then generated catalogues based on the selection of categorisations. Finally, a quasi-experiment was conducted to check the coverage index of the catalogues generated with the suggested approach against catalogues suggested by experts.

In a similar way, Sonal et al. [11] described the different types of metrics and focused on the ones related to static code and object-oriented languages as well. The results were a summarization of the studied metrics based on their relevance of assessing complexity to better help measuring the maintainability of code, thus retaining quality and reducing costs. Moreover, Subhas Misra [12] in another study, covered twenty "design and code measures to obtain indications of their effect on maintainability".

3.2 Measuring Maintainability of Models

By using analytical research methodology, Lagerström et al. [5] provided a framework for assessing maintainability through proposing extended influence diagrams and defining enterprise architecture models and prediction models for maintainability analysis. A set of measurable attributes were defined and applied to the proposed framework. One example was the level of maturity of the studied system and maintenance personnel, which was measured by three attributes: "(1) the staff's level of experience with development and maintenance work, (2) the staff's level of language expertise on the programming languages used within the system, and finally (3) the staff's level of knowledge on the system they are maintaining".

A case study conducted by Koziolek et al. [15], tried to asses architecture-level metrics selected to measure sustainability concerns. The study was implemented by tracking the metrics over two years. Even though the defined metrics were able to draw some insights of how to be used, the architecture-level metrics had to obtain different sources of architecture information ranging from humans to highly automated code reports. Moreover, it was found that focusing on scenario analysis would not help in handling architecture erosion, and similarly, focusing on architecture-level code metrics would neglect changing requirements and technologies.

Goldschmidt et al. [9] present the ideas on how to approach the problem of evaluating maintainability within a model-driven development environment. They tried to assess maintainability within UML models by partly adopting metrics from object-oriented development and employing new UML specific metrics such as the counts of "total rules" and "total helper functions" as well as "documentation quota". The study compares the metrics in the models against those of non-model-driven approaches to decide in which scenarios such an approach is beneficial to maintainability costs and eventually concludes that the efforts of maintaining a system is influence by "not only the maintainability of the developed domain models but also the meta-models, profiles and transformations that are used".

Interesting research carried by Schroeder et al. [13] focused on assessing the complexity of Simulink models using two size metrics before validating the results against experts' reviews and gathering some insights on the maintainability aspects in the industry. The paper mentions the correlation between the complexity of models and the maintainability, then emphasises the high complexity of Simulink models nowadays representing complete vehicles. Metrics of size such as lines of code (LOC) and block count (BC) were used for measuring the degree of complexity in many models. Then interviews with experts were held to validate the used metrics and prove how well they were in addressing the new usage. Eventually, the study proved the applicability of the mentioned metrics on Simulink software models for the purpose of measuring their complexity.

On the other hand, Bagheri et al. [14] conducted research on the maintainability of feature models in a product line software. The study implemented controlled experimentation by devising a set of feature model structural metrics that serve as internal quality attributes used in object-oriented systems and tried to find the relation to the properties required within the framework of measurement theory. Later, they investigated and analysed whether these structural metrics were good early indicators of maintainability or not. Although the research methodology was a controlled experiment, it managed to give a considerable indicator to the model maintainability. Moreover, the metrics defined in the study can be used as a reference to our identified sub-group of metrics for our research.

The research of Szőke [4] tried to measure the maintainability resulted from some refactoring operation using a probabilistic quality model. In general, the study aimed at recognising the change in maintainability caused by a single refactoring. While this research was not related directly to our topic, it seemed interesting to use prediction models and the refactoring applied on a single product that can be presented as a model.

Our study will be similar to the one presented by Schroeder et al. [13] in terms of the process of identifying metrics used to measure the maintainability of software artefacts other than models and then validate their ability to measure the maintainability of software models as well. However, our study will differ from theirs in the context, as we will focus on maintainability aspects instead of complexity. Moreover, the type of used models in our case will be the software models defined in SystemWeaver instead of Simulink models. The process of identifying metrics in our study will depend on supportive studies similarly to theirs. However, the process of validating such metrics will rely on checking with patterns extracted from the historical data of models and validated by experts.

3.3 Predefined Maintainability Metrics

This section will list the maintainability metrics we covered during our literature review. A subset of these metrics will be used later for the purposes of answering our research questions. The selected metrics can be found in section 4.5 along with more details regarding the selection. Moreover, as metrics in literature were categorised into different groups, our list will maintain the same categorisation. For example Ludwig et al. [20] categorised their metrics depending on the aspects of architecture, complexity and comments, while Bagheri et al. [14] sorted the metrics based on size, structural complexity and length.

3.3.1 Architectural Metrics

Propagation Cost [20]: This describes "the proportion of software components that are directly or indirectly linked to each other". If component A calls B, then A and B are directly linked. If B calls C, then B and C are directly linked while A and C are indirectly linked. Given this, if C is changed, B might need to be changed, and if B is changed, then A might need to be changed. So, a change in a component might require both direct links and indirect links to be changed. “The propagation cost provides a single, system-wide measure of how linked the code is”.

Core Size [20]: This metric calculates the size of “the largest set of components that are interdependently linked to each other”.

3.3.2 Complexity Metrics

Lines of Code (LOC) [20]: “The number of lines containing source code, including inactive regions, in a component. LOC is a measure of size and/or volume”.

Weighted Method Count - Unweighted (WMC Unweighted) [20]: Which is a “simple count of the number of methods implemented in a component”, withought assigning a weight to the methods.

Weighted Method Count – McCabe (WMC-McCabe) [20]: Similar to the WMC-Unweighted, but here each method implemented in the component is weighted according to its McCabe Cyclomatic complexity value. “Cyclomatic complexity is the number of independent paths through a method”.

Response for Class (RFC) [20]: “The sum of the number of methods in a component plus the sum of all the methods it directly references in other components”.

Coupling Between Objects (CBO) [20]: Defined as “a measure of how many other components are relied on by a given component”.

3.3.3 Comment Metrics

Code-To-Comment Ratio [20]: Used mostly used by developers as an initial measure of code commenting.

3.3.4 Size Metrics

Number of features (NF) [14]: “The total number of features that are present in a feature model. This includes both leaf and parent features [inner items]. NF counts all of the items in the feature model tree”.

Number of top features (NTop) [14]: “The number of features that are first direct descendants of the feature model root. In other words, the number of items in depth one of the tree”.

Number of leaf features (NLeaf) [14]: “The number of features with no children [leaf items] or further specialisations. These correspond with the leafs of the feature model tree”.

3.3.5 Structural Complexity Metrics

Cyclomatic complexity (CC) [14]: "The number of distinct cycles that can be found in the feature model". Although some models are represented in the form of trees where no cycles can exist, the constraints between the available features can cause such cycles.

Cross-tree constraints (CTC) [14]: "The ratio of the number of unique features involved in the feature model integrity constraint over all of the number of features in the feature model. This measure represents the degree of involvement of features in the definition of the integrity constraints".

Ratio of variability (RoV) [14]: "The average branching factor of the parent features [inner items] in the feature model. In other words, the average number of children of the items [leaf items] in the feature model tree".

Coefficient of connectivity—density (CoC) [14]: "The ratio of the number of edges over the number of features in a feature model. In graph theory, the coefficient of connectivity represents how well the graph components are connected".

Flexibility of configuration (FoC) [14]: "This is the ratio of the number of optional features over all of the available features in the feature model. The rationale behind this is that the more optional features exist in the feature model, the more choices are available for the designers to choose from while configuring the feature model".

Number of valid configurations (NVC) [14]: "The number of all possible and valid configurations that can be derived from the feature model in the face of its integrity constraints and tree structure".

3.3.6 Length Metrics

Depth of Tree (DT) [14]: "The length of the longest path from the feature model root to leaf features in the feature model".

3.3.7 Other Metrics

Reuse Ratio (U) [21]: Which is the "ratio of number of super classes to the total number of classes", this indicates that the higher the value is the deeper the hierarchy will be and the more the items will be reused, while a "lower reuse ratio [will] indicate a better design from the maintenance point of view".

Number Of Ancestors (NOA) [22]: Which is a "metric [that] measures the number of classes that a given class directly or indirectly inherits from".

Coupling Factors (CBO) and (COF) [23]: "CBO and COF measures count method invocations and references to both methods and attributes". Several types of interactions between classes can be observed like class-attribute, class-method along with method-method interactions. Not to mention import and export coupling as well as other types of relationships like friends, ancestors, descendants and others.

Number of Incoming Invocation (NII) [4]: Which counts the invocations to a method defined in code base.

Number Of Outgoing Invocations (NOI) [4]: Finds the number the calls made within a method in the code base.

New Methods (NM) [4]: Counts the number of new methods added to the class after inheritance from another class.

New Attributes (NA) [4]: Finds the number of new attributes added to the class after inheritance from another class.

Nesting Level (NLE) [4]: Checks how nested the classes are within the code base.

Number Of Statements (NOS) [4]: Similar to LOC, but it counts the number whole statements as some statements might be spreaded over multiple lines.

4
Methodology

In this chapter, we present the study design and describe the methods that will be used to conduct the research. We also detail the plan of execution and how the analysis of the data will be performed.

4.1 Methodology Overview

Our study itself is a case study which was conducted in cooperation with Systemite as an industrial partner. The raw data provided by the industrial partner was related to a well-known Swedish company which uses the platform developed by Systemite, known as SystemWeaver, to store and manage the data.

The thesis started with a goal in mind of identifying metrics for measuring the maintainability of SystemWeaver's models. The proposed plan suggested collecting data using the aforementioned platform, then analysing it to grasp its different aspects and allocate possible problematic situations which can be confirmed by experts through interviews. A subset of metrics provided by the literature will be applied on the collected data. The final step will be to compare the results of the metrics with the confirmed situations to discuss and answer the research questions besides orchestrating a conclusion.

4.2 Research Questions

Within this section, we will present the research questions we are ought to answer using the results of this study as well as the steps we will follow to find the answers.

RQ1: How can a revision history of a model be used to judge its maintainability?

Answering such question begins with identifying situations in a revision history of a model where maintainers faced issues which caused them to stumble and exert more efforts in order to complete their intended work. Therefore, this research question can be rephrased as the following:

How can we identify situations in a revision history of a model where developers faced maintainability issues related to that model?

To answer this question we will need to collect an adequate amount of data representing models along with their history and versions, the data will then go through a series of analysing steps, digging into the history, to generate statistics and understand what the data reflects over a variety of aspects. Analysing the data and generating the mentioned statistics will allow us to allocate anomalies and situations in the history of models that might cast back moments where maintainers struggled to finish their tasks. To name a few, such situations could include a massive amount of changes happening at once, changes affecting a specific type of items or perhaps an increase in the amount of maintainers participating in a model at some point in history. The mentioned situations can then be considered as patterns, which once detected in a history of a model, they indicate a possible issue or struggle. However, to approve such patterns, some interviews with experts need to be held to confirm which patterns succeeded and which should not be considered.

RQ2: What metrics can be used to predict the maintainability of models?

Moving to the second question in our study, where we want to check if it is possible to reuse some of state of the art metrics in the area of software maintainability to indicate the maintainability of models. This will require investigating maintainability metrics in the literature first, then evaluating them and selecting a subset which can potentially predict the maintainability of our studied models. The selected metrics will then be applied on the models and their values will be statistically analysed against the identified patterns we mentioned earlier in order to find correlations that can help us cast some conclusions and decide which ones can be used to measure models' maintainability.

4.3 Data Collection

SystemWeaver is the core product used in managing massive data for multiple third party customers. This software product is based on Server-Client concept and techniques, where it hosts the data inside a database under the umbrella of a server, while clients connect to the server and access the data. This unique technique enables SystemWeaver to manage changes in real-time between clients as changes are managed centrally across clients through the server. In order to collect data for our study we had to explore the mentioned software product and get familiar with its features.

4.3.1 SystemWeaver Desktop Applications

Besides setting up and maintaining the required infrastructure, Systemite develops two tightly connected software products under the roof of SystemWeaver. The first is called SystemWeaver Architect and the second being SystemWeaver Client. The Architect product enables end users to create and manage meta-models, known as the set of rules or the skeleton that future created models will be based on. Meta-models define the type of items that can be created, their locations and allowed connections among each other. The Client product, is the main interface for managing models that are built upon the previously mentioned meta-models. This software product enables end-users to manage whole models as a tree of connected items (structure) where it is possible to create, edit, relocate and delete items beside plenty of other features which includes generating charts, track history, search, generate reports and export data.

The focus in our study was the client product, as we were focused on studying whole models and exploring their versions. In order to get the data, we tried exporting it to excel files. This was a tedious task due to the massive amount of items we wanted to extract and the limitations found in the client product regarding memory management.

Although we managed to export the data in batches, we have realised that the exported data did not contain all information we needed. For example, it was hard at a given item in the exported data to report its model and parent or child items (connected through parts), not to mention that each item was fetched once, removing the possibility of tracking reusability of each item across different models. The solution was to create our own structure for managing and accessing the data, thus we had an urge to switch to using SystemWeaver API instead of the Client product.

4.3.2 SystemWeaver Desktop API

SystemWeaver Desktop API, is another solution provided by Systemite to manage their data. It promises more flexibility compared to the default solutions represented with the desktop applications (architect and client). The API is explained through their website and provides integration for multiple programming languages. The API we used was the .NET one, which can be used by including a library in any .NET programming project.

Data hosted by Systemite servers can be accessed through the API using specific credentials for security and authentication purposes. The API enables developers to fetch a list of the available libraries, which are logical containers for items in the server's database. Each library can then provide a list of items besides the ability to filter them by type or other criteria.

Since we are focused on studying whole models, the type of models we collected was related to models representing an entire structure. This includes all kind of items that are allowed to be created and linked within such a model (e.g. signals, hardware, software, requirements, tests and so on). In later sections, the algorithms we used to fetch data will be detailed.

4.3.3 Custom Software Tool

Due to the restrictions mentioned earlier in SystemWeaver desktop applications, such as the lack of the ability to export an entire structure of a model along with the details of its items, as well as the limitations of memory usage when traversing large models, an obvious need aroused for building a custom software tool for collecting the data.

Using SystemWeaver API framework, the custom tool can help us fetch fully detailed structures of models according to our needs as the flexibility of using an API will enable us to select specific details to fetch for each item. On the top of that, adding more features to the tool itself will make it powerful enough for analysing, understanding and visualising the collected data.

4.3.4 Accessed Data

Systemite provided us with access to the biggest database they have ever worked with. The data stored in that database expands over 15 years of development and includes more than 11 million items distributed across 259 models in total. More details about the data will be provided later within section 5.2

4.4 Data Analysing

This section will focus on the techniques and methodologies we are going to follow in order to analyse our collected data.

4.4.1 Data Characteristics

In order to analyse the collected data and better understand how it reflects and relates to the studied models, a set of characteristics were defined to be explored thoroughly. These characteristics can be seen as ways of measuring different aspects of the studied models. Table 4.1 lists the mentioned characteristics and describe each of them besides assigning a unique code that will be used later for reference.

ID	Name	Code	Description
01	Version Number	V	The number representing the model version sequence in a given model group.
02	Max Depth	MD	The deepest level of an item in a model version (degree of cascading).
03	References Weight	RW	The sum of how many times each leaf node of a model version is referenced across all models. For instance, a model version having 3 leaves where each of them is referenced 4 times, and 2 other leaves where each of them is referenced 10 times will lead to a reference weight of: $(3 \times 4) + (2 \times 10) = 32$
04	Employees Count	Emp	The count of employees that worked on a given model version.
05	Leaves Count	L	The count of items that are leaf items (see section 2.3).

06	Inner-Nodes Count	IN	The count of items that are inner items (see section 2.3).
07	Total Items Count	T	The total count of items in a model version[1].
08	Leaf Changes - Updates	LCu	Represents the count of update changes between two model versions that are applied on all Leaf Nodes.
09	Leaf Changes - Additions	LCa	Represents the count of addition changes between two model versions that are applied on all Leaf Nodes.
10	Leaf Changes - Deletions	LCd	Represents the count of deletion changes between two model versions that are applied on all Leaf Nodes.
11	Leaf Changes - Relocations	LCr	Represents the count of relocation changes between two model versions that are applied on all Leaf Nodes.
12	Leaf Changes - Total	LCt	Represents the sum of the four different types of changes mentioned earlier (updates, additions, deletions, relocations).
13	Inner Node Changes - Updates	INCu	Represents the count of update changes between two model versions that are applied on all Inner Nodes.
14	Inner Node Changes - Additions	INCa	Represents the count of addition changes between two model versions that are applied on all Inner Nodes.
15	Inner Node Changes - Deletions	INCd	Represents the count of deletion changes between two model versions that are applied on all Inner Nodes.
16	Inner Node Changes - Relocations	INCr	Represents the count of relocation changes between two model versions that are applied on all Inner Nodes.
17	Inner Node Changes - Total	INCt	Represents the sum of four different types of changes mentioned previously (updates, additions, deletions, relocations).
18	Total Changes - Updates	TCu	Represents the count of update changes between two model versions that are applied on all Nodes.

[1]This might not be equal to L + IN because some inner items play the role of leaf items in other branches of the same model version and subsequently get calculated twice.

19	Total Changes - Additions	TCa	Represents the count of addition changes between two model versions that are applied on all Nodes.
20	Total Changes - Deletions	TCd	Represents the count of deletion changes between two model versions that are applied on all Nodes.
21	Total Changes - Relocations	TCr	Represents the count of relocation changes between two model versions that are applied on all Nodes.
22	Total Changes - Total	TCt	Represents the sum of the four aforementioned different types of changes (updates, Additions, deletions, relocations).
23	Leaf Changes Percentage	LCP	The percentage of leaves changes out of all nodes changes ($LCt \div TCt$).
24	Inner Node Changes Percentage	INCP	The percentage of inner node changes out of all nodes changes ($INCt \div TCt$).
25	Leaf Changes Coverage	LCoP	The percentage of leaves that were affected by leave changes ($LCt \div L$).
26	Inner Node Changes Coverage	INCoP	The percentage of inner-nodes that were affected by inner-node changes ($INCt \div IN$).
27	Clustered Changes AVG	Clust	The average number of the items changing together at a given model group (by examining all of its versions)[2].
28	Employees Changes	EC	The greatest number of changes applied by a single employee in a given model group (by examining all of its versions)[2].
29	Age In Weeks	AW	The age of the model group in weeks[2].
30	Max Changes Count Over Weeks	MCW	Maximum number of changes applied over a week on the versions of a given group model[2].
31	Changes Week	CW	The week that had the most number of changes in a given model group (by examining all of its versions)[2].
32	Age In Months	AM	The age of the model group in months[2].

[2]This is applicable only on Model Groups as whole and not on each Model Version.

33	Max Changes Count Over Months	MCM	Maximum number of changes applied over a month on the versions of a given group model[2].
34	Changes Month	CM	The month that had the most number of changes in a given model group (by examining all of its versions)[2].
35	Age In Years	AY	The age of the model group in years[2].
36	Max Changes Count Over Years	MCY	Maximum number of changes applied over a year on the versions of a given group model[2].
37	Changes Year	CY	The year that had the most number of changes in a given model group (by examining all of its versions)[2].

Table 4.1: Studied characteristics of the collected data

4.4.2 Pattern Exploration

Through analysing the collected data of models, and diving into their reversion history, this step will try to allocate abnormal events and situations which might reflect potential maintenance issues. Such historical events will be sought manually by analysing the data and checking its characteristics which we are ought to calculate in order to find indications (e.g. massive amount of changes happening at once). Some charts and visual aids are expected to be used along the way to make it easier for us to spot the aforementioned situations, also called patterns.
Eventually, we managed to discover eight patterns in total and we will provide more details regarding them later in section 5.5.

4.4.3 Interviews

Interviews with experts are used as a supportive methodology to help mitigate the bias of our case study. Our research follows guidelines regarding the creation of in-depth interviews [18], which is conducted because of the research nature mainly (as part of case studies context) and the time limitation imposing intensive interviews with a small number of interviewees. Interviews are designed and evaluated regarding research questions, but more importantly, they serve the goal of confirming the identified patterns resulted after analysing the collected data and this is the corner stone that the following results is built upon.

The interviews include direct questions about the patterns after introducing and describing them, for instance: "would it be possible to confirm that the first pattern is able to detect maintenance issues in general?". While other questions target specific models where patterns showed issues to confirm that they succeeded in doing so, for example: "at the model version n our pattern p showed an indication of issues during development, was that true?".

Although the intensive in-depth interviews are conducted with a limited number of respondents individually, the added value is gained by the detailed information and our understating of the studied data context. Moreover, the detailed questions and the experience of the interviewees regarding the historical data mitigate the threat of reflecting our own perspective into the answers. Furthermore, the interviews are directed towards complementing each other to fill information-gaps that might be introduced; hence, each of the studied patterns is guaranteed to be covered with at least one expert review.

4.5 Metric Exploration

Maintainability metrics are usually applied on software code blocks to measure the efforts needed for maintaining and changing them. Since the purpose of this study is to explore the ability of applying such metrics on models, we had to dig into multiple studies and literature to come up with a selected set of them. Ultimately, the study should cover as much as possible of metrics to serve the purpose of identifying the ones able to measure the maintainability of the studied models. However, due to time restrictions, we ended up choosing a set of them only. The selection was based on the consideration of which of the metrics we covered in section 3.3 could be applied directly on models or with the least amount of tweaks. As a result, the following tables will summarise the metrics we chose and what each of them will measure when used against our collected models.

Name:	Metric 1 (M1) - Depth of Tree [14]
Code:	DT
Description:	Usually it indicates "the length of the longest path from the feature model root to leaf features in the feature model" [14]. On the other hand, such metric can be used to "calculate how far down a class is declared in the inheritance hierarchy." [22]
Usage:	Will indicate the length of the longest path starting from a model's root to one of its leaf-nodes.

Table 4.2: Metric 1 (M1) - Depth of Tree

Name:	Metric 2 (M2) - Size or Lines Of Code [20]
Code:	S (LOC)
Description:	"The number of lines containing source code, including inactive regions, in a component" which is a measure of size or volume [20].
Usage:	In case of models this will represent the count of all items.

Table 4.3: Metric 2 (M2) - Size and/or Lines Of Code

Name:	Metric 3 (M3) - Ratio of Variability [14]
Code:	RoV
Description:	"The average branching factor of the parent features [inner items] in the feature model. In other words, the average number of children of the nodes [leaf items] in the feature model tree" [14].
Usage:	Will indicate the average number of leaf-nodes in a given model.

Table 4.4: Metric 3 (M3) - Ratio of Variability

Name:	Metric 4 (M4) - Reuse Ratio [4]
Code:	U
Description:	It is the "ratio of number of super classes to the total number of classes". Moreover, "higher reuse ratio reflects that the system is having deep hierarchy and high reuse value." [21].
Usage:	Measures the inner-nodes percentage out of all nodes in a model.

Table 4.5: Metric 4 (M4) - Reuse Ratio

Name:	Metric 5 (M5) - Number of Ancestors [4]
Code:	NoA
Description:	Measures "the number of classes that a given class directly or indirectly inherits from" [22].
Usage:	In a given model this will indicate the average level of leaf-nodes.

Table 4.6: Metric 5 (M5) - Number of Ancestors

Name:	Metric 6 (M6) - Coupling Between Objects [20]
Code:	CBO
Description:	"This is a measure of how many other components are relied on by a given component" [20].
Usage:	For a given model how many other models are relied on by it by calculating the sum of the items that the given model is referencing in other models.

Table 4.7: Metric 6 (M6) - Coupling Between Objects

Name:	Metric 7 (M7) - Number of Features (Use Cases) [14]
Code:	NF-UC
Description:	Which is "the total number of features that are present in a feature model. This includes both leaf and [inner] features as NF counts all of the nodes in the feature model tree" [14].
Usage:	Will indicate the total number of specific type of items available in a given model for both leaf and inner nodes. This item will count items representing the type "Use Case" in a model.

Table 4.8: Metric 7 (M7) - Number of Features (Use Cases)

Name:	Metric 8 (M8) - Number of Features (Requirements) [14]
Code:	NF-R
Description:	See Table 4.8
Usage:	Will indicate the count of items representing "Requirements" in a given model.

Table 4.9: Metric 8 (M8) - Number of Features (Requirements)

Name:	Metric 9 (M9) - Number of Features (Functional Requirements) [14]
Code:	NF-FR
Description:	See Table 4.8
Usage:	Will indicate the count of items representing "Functional Requirements" in a given model.

Table 4.10: Metric 9 (M9) - Number of Features (Functional Requirements)

4.6 Statistical Analysis

Having the confirmed identified patterns and a set of metrics applicable on models, the case study will land on a final step, which is running statistical analysis. The goal of this step will be to confirm whether metrics are capable of predicting issues of maintainability in models, but further more, spotting which ones are best to serve that purpose. Since some patterns might be confirmed by experts, a strong enough correlation to those ones will provide an answer to our second research question.

Pearson correlation tests will be applied on the measurements of patterns and metrics via a simple Python script. The tests will run on all models at once to get the main correlation results (r-values) and their p-values representing the statistical significance. Furthermore, the r-values will be categorised into five distinct groups using predefined levels to point out the strong correlations, not to mention that the input data will be graphically represented to facilitate understanding the final results. More info about this will come later in section 5.8.

5
Results

All the results which this study generated will be described in this chapter. First, a few detailed sections will cover how we started exploring the data and the custom software tool we created for the purpose of collecting and analysing it. Afterwards, a list of the collected models will be presented along with the statistics we calculated around their various aspects. Another list for the patterns reflecting difficult situations in the history of the models will be described, followed by reviews of experts to verify such patterns. Finally, a set of selected metrics will be applied on the history of same models, which will shape the input for the final step of holding correlation tests comparing metric results to the results of the previously mentioned patterns.

5.1 First Trials

We spent some time trying to understand the data on our own by exploring the meta-models and their related models in SystemWeaver. We focused on exploring certain models more than others based on the suggestions of our advisor as these models had a complete set of items making them more suitable for our study. We tried generating some initial statistics and comparing different models together but the client application of SystemWeaver was limited in those areas. As a result, we decided to export the data to excel files to enable generating more detailed statistics. Exporting the data to excel took some days for the following reasons: (1) We agreed on visiting Systemite twice a week only. (2) The data access was provided through a network having technical issues (a wireless network interfering with plenty of others around the building which made it very slow).

A large number of items were needed to be exported which filled the memory easily and made the client application unresponsive as it was not meant to be used for exporting all data at the first place. To deal with the issues, we had to export the data in stages, filtered by the date of changes, and grouped on a quarterly, half-yearly or a full-yearly basis. Eventually, the data was exported which enabled us to apply the initial statistics. However, the fact that the size of the data was too big (32 excel files), made it not practical for us to apply further statistics on that many number of files, not to mention that combining the files was a bad idea as it generated one file with more than 2 million rows to handle. The solution to that obstacle was to use access files instead of excel as a simple DBMS.

Although an access file managed to combine the data in one database, the queries applied on the data took long time and the database was not efficient for future needs of more complex queries. This new dilemma and the other problems mentioned earlier in subsection 4.3.1 left no other choice for us but to create a custom tool that can employ the available SystemWeaver API to access the data.

5.2 ASTS Tool and the Statistical Charts

ASTS (Abdullah's and Sinan's Tool for Systemite) is a .NET tool built with C-sharp and Microsoft SQL Server Compact technologies to use the SystemWeaver API and fetch the data needed for our study. The tool has around 2,500 lines of code, hosted in a private repository on Github, and uses Live-Charts library to enable generating manual visually descriptive statistics based on our own data queries.

The tool managed to get all the 2,600,157 items and store them in an SQL table within a day after dealing with some issues related to memory handling (32 bit vs. 64 bit structures). Later, we built another special structure to enable us track the collected items and group them by models. We used the API to fetch the items again and fill the new SQL table built according to the new structure. This time, the tool took more than 15 visits to Systemite to finish fetching 259 models with more than 11,655,216 items in total.

As the total number of items in the collected models exceeded 11,6 millions, and the total number of distinct items was just about 2.6 millions, we figured out that many of these items were reused extensively across the collected models. The subsection 5.2.1 will describe the actual algorithms we used to collect the mentioned data, while section 5.3 will later provide more information regarding the collected models.

5.2.1 Implemented Data Collection Algorithms

SystemWeaver takes its own approach for storing its data. Items of models are represented as objects which have relationships among each other and are distributed across logical containers called libraries. The API provides methods for fetching the mentioned libraries, and then for each library there is the possibility to get all of its items despite their types or just the items of a specific type.

To deal with this approach, our tool relied on a couple of algorithms to collect the data needed for the study. The core algorithm was the one used for fetching child items based on a given item. This algorithm will use an item as input, then call the API to fetch all connections initiated from this item to collect the items on the opposite end. The pseudo code of algorithm 1 explains this with more details.

On the other hand, for the ASTS tool to collect all models stored by SystemWeaver, we had to select a type of these models, which is basically the type of the root item. Since Systemite provided access to data related to a company producing physical products, our choice was to get all models illustrating an entire product structure.

The algorithm 2 explains how we fetch all models by a specific item type and then how we reuse the algorithm 1 to traverse and store all the items of these models.

Besides collecting all models representing whole structures, we wanted to collect all unique items available in the database to help us generate some specific statistics, such as the amount of reusability and references applied across the models. This was achieved through using the algorithm 3.

Algorithm 1: Fetch child items of a given item

Data: Current Item, Level, Previous Item, Root Item
Result: All items listed below *CurrentItem* as *List*

$CurrentItem \leftarrow SetParent(PreviousItem)$
$CurrentItem \rightarrow List$
$Connections \leftarrow GetAllConnections(CurrentItem)$
for *each Connection in Connections* **do**
  if *Connection is a valid connection type* **then**
    $NextItem \leftarrow GetNextItem(Connection)$
    if *Next Item is valid and not in the List* **then**
      $FetchChildItems(NextItem, Level + 1, CurrentItem, RootItem)$
    end
  end
end

Algorithm 2: Fetch all models of specific type along with their items

Data: Item Type
Result: All models and their items as *List*

$Libraries \leftarrow FetchAllAvailableLibraries()$
for *each Library in Libraries* **do**
  $Items \leftarrow FetchAllItems(Library, ItemType)$
  for *each Item in Items* **do**
    $Childs \leftarrow FetchChildItems(Item, 0, NULL, Item)$
    $List \leftarrow Childs$
  end
end

5.2.2 Tool Features

While collecting the data of models, we started designing SQL queries to generate different types of statistics. The queries were integrated in the tool and were used to generate useful charts, meaning that the tool was built to cover three main purposes:

Algorithm 3: Fetch all items ever

Result: All available items as *List*

```
Libraries ← FetchAllAvailableLibraries()
for each Library in Libraries do
    Items ← FetchAllItems(Library)
    for each Item in Items do
        Childs ← FetchChildItems(Item, 0, NULL, Item)
        List ← Childs
    end
end
```

(1) collecting, (2) analysing and (3) visualising the data.

The first interface showed after launching the tool will be a login interface asking users for server address info as well as credentials (Figure A.1). Such info is needed to secure the connection and authorise the access to SystemWeaver data stored on the specified server. The credentials must be created and provided by Systemite in the form of a username and a password. For our study, Systemite provided us with a test server containing a copy of the data we can access along with a set of a username and a password for each of us. However, users are not obligated to login. They can skip the process in order to use the data that is already available in the local database and was collected earlier using an authorised access.

After logging in successfully, or skipping the process, the user will end up in the main interface showed in Figure A.2, which is the interface that provides the door to all available functionalities in the tool. The main interface holds a menu bar on top containing four menus that will be explained in details within the following sections.

5.2.2.1 File Menu

The File menu, is a simple menu that provides three options: (1) Login, (2) Logout and (3) Exit.

Login option will launch the login interface again shown in Figure A.1 to enable users to establish a new connection with a different server and/or credentials. The logout option will drop the connection to end the authorised access while the Exit option will stop running the tool and ends the application processes in the host operating system.

5.2.2.2 Load Menu

This is responsible for presenting ways of collecting data. Currently the tool supports three main ways: (1) collecting all items, (2) collecting all models of a certain type, and (3) collecting a specific model with a defined ID.

Each option opens a related interface to complete the task. Figure A.3 shows the interface for the first option, where users can collect data about all items from scratch, or continue a previous process of collecting items. Figure A.4 on the other hand, is an interface of the second option, which enables the users to specify the type of the models to load and whether old data of same typed models should be dropped or added up. For our study we selected models having the type of a whole product structure to load as much data as possible. Finally, Figure A.5 provides a way to load a specific model into the database by providing its identifier as input (Handle Item).

5.2.2.3 Analyze Menu

Here, the access to the interfaces responsible for analysing and visualising the collected data can be found. In the analyze menu we can find three different options, (1) items statistics, (2) models statistics and (3) pattern analysis.

Item Statistics: This option provides interfaces for generating statistics related to all items available in the database. Such statistics include the count of all items collected ever, shown in Figure A.6. The count of items according to their types, like items representing requirements, signals, hardware parts, test-cases and so on. One way to distinguish the item type is by its SID which is shown in Figure A.7, while another way would be to use its name like in Figure A.8. Moreover, counts can be generated according to item status (e.g. frozen, under-development or released items), which is what Figure A.9 shows. As well as counts according to versions number (e.g. the count of all items having 4 versions in database) which is seen in Figure A.10. Each of these interfaces provide the ability to filter data and zoom in and out through the charts.

Model Statistics: With this option users can get statistics regarding the collected models, like the count of all available models shown in Figure A.11. The count of all items across the models including reusable items like in Figure A.12. The count of items per model as in Figure A.13. The count of versions per model, which can be according to a model group top handle like in Figure A.14 or according to model group top handle and name as in Figure A.15. Statistics related to maximum depth of each model can also be generated, which is what Figure A.16 shows. Other statistics cover the number of employees working per model as in Figure A.17. These interfaces also provide users with the ability of filtering the data and zooming in and out in the rendered charts.

Pattern Analysis: This option presents the most complicated interface in the tool which gives the user the ability to select a specific model group and all or just one of the model versions available under that group. According to this selection, the interface will generate statistics such as the total number of leaves, like Figure A.18, the total number of inner nodes, in Figure A.19, the total changes (e.g. updates, additions, deletions, and relocations), shown in Figure A.20, the changes of leaf nodes only as in Figure A.21 or the changes of inner nodes only like Figure A.22. There is also the possibility of showing clustered changes together (e.g. set of items that change together throughout the different versions of the selected model group) illustrated by Figure A.23, as well as changes applied per dates (e.g. changes per years/months/weeks of the model's lifespan) in Figure A.24. Finally, statistics about references can be calculated which is presented in Figure A.25 and Figure A.26. Filtering data as well as zooming in and out is also available in these interfaces, and its worth noting that the horizontal axis in most of the figures represents the model versions.

5.2.2.4 Export Menu

The final menu, provides two options for exporting data: (1) Statistics Exporter and (2) Metrics Exporter.

The first exporter, shown in Figure A.27, launches an interface to export the data characteristics we mentioned in subsection 4.4.1 into an excel file, while the second exporter, represented by Figure A.28, can calculate and export the set of metrics we chose in section 4.5.

5.3 Studied Models

In our study we decided to include model groups having at least 3 model versions to enable comparison between the versions and measure aspects such as changes applied between versions. Table 5.1 shows a list of model groups and the IDs of the versions available for each, the last column in the table indicates whether the model group was included in the study or not. Altogether, we included (9) model groups (10, 19, 52, 70, 163, 203, 214, 233 and 236) containing a total of (164) models.

Model Group ID	**Versions Count**	**Versions ID Range**	**Studied**
1	1	1	No
2	1	2	No
3	1	3	No
4	1	4	No
5	1	5	No
6	1	6	No
7	1	7	No
8	2	8 - 9	No
10	9	10 - 18	Yes
19	33	19 - 51	Yes
52	18	52 - 69	Yes
70	73	70 - 142	Yes
143	2	143 - 144	No
145	1	145	No
146	1	146	No

Model Group ID	Versions Count	Versions ID Range	Studied
147	1	147	No
148	1	148	No
149	1	149	No
150	1	150	No
151	1	151	No
152	1	152	No
153	1	153	No
154	2	154 - 155	No
156	1	156	No
157	1	157	No
158	2	158 - 159	No
160	2	160 - 161	No
162	1	162	No
163	4	163 - 166	Yes
167	1	167	No
168	1	168	No
169	1	169	No
170	1	170	No
171	1	171	No
172	1	172	No
173	1	173	No
174	1	174	No
175	1	175	No
176	1	176	No
177	2	177 - 178	No
179	1	179	No
180	1	180	No
181	1	181	No
182	1	182	No
183	1	183	No
184	1	184	No
185	1	185	No
186	1	186	No
187	1	187	No
189	1	189	No
190	1	190	No
191	1	191	No
192	1	192	No
193	1	193	No
194	1	194	No
195	1	195	No
196	1	196	No
197	1	197	No
198	1	198	No

Model Group ID	Versions Count	Versions ID Range	Studied
199	1	199	No
200	1	200	No
201	1	201	No
202	1	202	No
203	3	203 - 205	Yes
206	1	206	No
207	1	207	No
208	1	208	No
209	1	209	No
210	1	210	No
211	1	211	No
212	2	212 - 213	No
214	6	214 - 219	Yes
220	1	220	No
221	1	221	No
222	1	222	No
223	1	223	No
224	1	224	No
225	1	225	No
226	1	226	No
227	1	227	No
228	1	228	No
229	2	229 - 230	No
231	2	231 - 232	No
233	3	233 - 235	Yes
236	15	236 - 250	Yes
251	1	251	No
252	2	252 - 253	No
254	2	254 - 255	No
256	1	256	No
257	1	257	No
258	1	258	No
259	1	259	No

Table 5.1: IDs of model groups and their related model versions

5.4 Data Characteristics Results

This section presents the results of applying the data characteristics defined in subsection 4.4.1 on the collected models. The actual values can be found in Appendix B which lists them in three separated tables for each model group. However, a summary about those values will be provided in the following paragraphs.

Model Group 10: Model group 10 evolved dramatically over 176 weeks. A peak in some values shown in Table B.2 and Table B.3 can be noticed for the row of model version 14, which was due to starting some refactoring according to the expert interview (Appendix I). After this refactoring the model group continued to evolve and got more complicated as the reference weight values show.

Model Group 19: The measured values for model group 19 show some steady increases over the 351 weeks of development. This can noticed when checking the newer versions as the references weight becomes bigger through time in Table B.5 and Table B.6. We notice that most of the changes of this model group were applied on leaf nodes.

Model Group 52: This model group is a bit more stable and more mature in developing. This can be indicated by the slight vibrations in fewer values in Table B.8 and Table B.9 compared to previous model group. The model group becomes more complicated through the span of 384 weeks of development.

Model Group 70: This is the largest model group containing more than 70 model versions developed over 528 weeks. Despite the up and downs in the values, we see that the model group, like others, evolved consistently and got more complicated aligning with newer versions. It is also noticeable that the amount of changes applied by employees was the largest compared to other model groups as Table B.11 and Table B.12 reveal.

Model Group 163: In this model group the values of Table B.14 and Table B.15 decreased efficiently in the last version as a serious amount of deletion changes were conducted on it. Overall the model group was not as complicated as the previously mentioned ones and it lasted for only 159 weeks of development.

Model Group 203: Despite lasting for 433 weeks in development, this model group had only three model versions in total. It can be noticed that the last version had the highest share of values regarding to defined characteristics according to Table B.17 and Table B.18.

Model Group 214: With 6 model versions developed over 515 weeks, this model group shows high stability in the values of characteristics both in Table B.20 and Table B.21. One major change which pumped the total items count with addition specifically on leaf nodes can be observed in version 216. The following versions had smaller changes.

Model Group 233: This model group evolved quickly over only 3 versions and 429 weeks. The biggest increment of values shown in Table B.23 and Table B.24 can be noticed in the last version (235). It is also clear that the total count of items in this model group is relatively small and it seems that the items are not much related to each other as the number of clustered changes is very low.

Model Group 236: According to the interview with the experts, available in Appendix I, this model group picked up from model version 124 and 125 in model group 70. This explains the high values in early versions of this model group which then started to increase gradually with some ups and downs for the span of 525 weeks of development time as seen in Table B.26 and Table B.27.

5.5 Patterns

Using the extracted characteristics mentioned in subsection 4.4.1, we explored eight situations that we thought would describe the degree of easiness of introducing changes to the studied models. These situations can be described using base formulas relying on two or more of the data characteristics. The list of the patterns we found will be described further with the next subsection.

5.5.1 Pattern Design

Data characteristics by themselves did not provide more than numbers measuring different aspects for each model version. These numbers enabled us to get an idea of how each model group developed over time, which is what led to the next step of allocating situations in these model groups, based on their version history, to represent activities of maintenance or events which imposed changes on such models.

The following tables, present the eight situations we defined after studying the generated data characteristics. Each situation will be called a pattern and will shed light on activities of maintenance by providing a base formula combining one or more of the previously mentioned data characteristics (Table 4.1) and a main formula that applies the base formula on each two consecutive models (n and $n+1$).

To confirm the presence of maintenance issues, the main formula will expect an increase greater or equal to a percentage (x) in the value of the second model ($n+1$). The percentages will be calculated later in subsection 5.5.2.

Name:	Pattern 1 (P1) - Increasing references of items.
Description:	A sudden increase in the references of items in a model version (n) compared to its predecessor; indicates difficulties with maintenance in that version.
Justification:	We expect to see more changes when having more References Weight (RW) per Total Items Count (T) in a model. This comes from the fact that changing an item that is referenced by many other models will require more attention and efforts to keep things correct and reliable.
Base formula:	$RW \div T$
Formula:	$(RW_{n+1} \div T_{n+1}) > x \times (RW_n \div T_n)$ Where $x \geq 3.96$ (as calculated in subsection 5.5.2)

Table 5.2: Pattern 1 (P1) - Increasing references of items

Name:	Pattern 2 (P2) - Increasing leaf nodes and their changes.
Description:	A big increase in the count of leaf nodes and the changes applied on them in a model version (n) compared to its predecessor; indicates difficulties with maintenance in that version.
Justification:	We expect models to grow over time, thus more leaf nodes to be added and more changes to be applied on them. The ratio between Leaf-Nodes Percentage (Leaves Count out of Total Items Count, L/T) and their Change Percentage (LCP) might indicate the difficulties faced during maintaining a model version.
Base formula:	$L \div T \times LCP$
Formula:	$(L_{n+1} \div T_{n+1} \times LCP_{n+1}) > x \times (L_n \div T_n \times LCP_n)$ Where $x \geq 6.6$ (as calculated in subsection 5.5.2)

Table 5.3: Pattern 2 (P2) - Increasing leaf nodes and their changes

Name:	Pattern 3 (P3) - Increasing inner nodes and their changes.
Description:	A big increase in the count of inner nodes and the changes applied on them in a model version (n) compared to its predecessor; indicates difficulties with maintenance in that version.
Justification:	We expect models to grow over time, thus more inner nodes to be added and more changes to be applied on them. The ratio between Inner-Nodes Percentage (Inner-Nodes Count out of Total Items Count, IN/T) and their Change Percentage (INCP) might indicate the difficulties faced during maintaining a model version.
Base formula:	$IN \div T \times INCP$
Formula:	$(IN_{n+1} \div T_{n+1} \times INCP_{n+1}) > x \times (IN_n \div T_n \times INCP_n)$ Where $x \geq 7.88$ (as calculated in subsection 5.5.2)

Table 5.4: Pattern 3 (P3) - Increasing inner nodes and their changes

Name:	Pattern 4 (P4) - Increasing changes of items.
Description:	A situation with a sudden increase in the changes of items in a model version (n) compared to its predecessor; indicates difficulties with maintenance in that version.
Justification:	A stable model is expected to have a steady ratio between its Total Changes (TCt) and its Total Items Count (T), thus an increase in that ratio is expected to indicated difficulties in maintaining a model version.
Base formula:	$TCt \div T$
Formula:	$(TCt_{n+1} \div T_{n+1}) > x \times (TCt_n \div T_n)$ Where $x \geq 31.64$ (as calculated in subsection 5.5.2)

Table 5.5: Pattern 4 (P4) - Increasing changes of items

Name:	Pattern 5 (P5) - Increasing leaf changes and their coverage.
Description:	A sudden increase in the number of changes applied on leaf nodes which affect a large number of them in a model version (n) compared to its predecessor; indicates difficulties with maintenance in that version.
Justification:	Giving that models become complicated over time, we expect that the difficulties in maintaining them will increase when having more Leave Changes (LCt) and more Leave-Changes Coverage (LCoP).
Base formula:	$LCt \times LCoP$
Formula:	$(LCt_{n+1} \times LCoP_{n+1}) > x \times (LCt_n \times LCoP_n)$ Where $x \geq 84.62$ (as calculated in subsection 5.5.2)

Table 5.6: Pattern 5 (P5) - Increasing leaf changes and their coverage

Name:	Pattern 6 (P6) - Increasing inner changes and their coverage.
Description:	A sudden increase in the number of changes applied on inner nodes which affect a large number of them in a model version (n) compared to its predecessor; indicates difficulties with maintenance in that version.
Justification:	Giving that models become complicated over time, we expect that the difficulties in maintaining them will increase when having more Inner Node Changes (INCt) and more Inner-Changes Coverage (INCoP).
Base formula:	$INCt \times INCoP$
Formula:	$(INCt_{n+1} \times INCoP_{n+1}) > x \times (INCt_n \times INCoP_n)$ Where $x \geq 72.77$ (as calculated in subsection 5.5.2)

Table 5.7: Pattern 6 (P6) - Increasing inner changes and their coverage

Name:	Pattern 7 (P7) - Increasing versions, depths and items.
Description:	A big increase in the values of version, depth and items count of a model version (n) compared to its predecessor; indicates difficulties with maintenance in that version.
Justification:	Giving that models become complicated over time, their Version Number (V), Maximum Depth (MT) and Total Items Count (T) will increase, which we expect will indicate the difficulties in maintaining these models.
Base formula:	$V \times MD \times T$
Formula:	$(V_{n+1} \times MD_{n+1} \times T_{n+1}) > x \times (V_n \times MD_n \times T_n)$ Where $x \geq 63.38$ (as calculated in subsection 5.5.2)

Table 5.8: Pattern 7 (P7) - Increasing versions, depths and items

Name:	Pattern 8 (P8) - Increasing employees and their changes on items.
Description:	A big increase in the number of employees as well as the amount of changes applied on items in a model version (n) compared to its predecessor; indicates difficulties with maintenance in that version.
Justification:	When models get complicated, We expect more employees to be allocated, thus the Employees Count (Emp) and their Total Changes (TCt) over the Total Items Count (T) are expected to increase. This increase should indicate the difficulties in maintaining a given model.
Base formula:	$Emp \times TCt \div T$
Formula:	$(Emp_{n+1} \times TCt_{n+1} \div T_{n+1}) > x \times (Emp_n \times TCt_n \div T_n)$ Where $x \geq 32.03$ (as calculated in subsection 5.5.2)

Table 5.9: Pattern 8 (P8) - Increasing employees and their changes on items

5.5.2 Pattern Thresholds

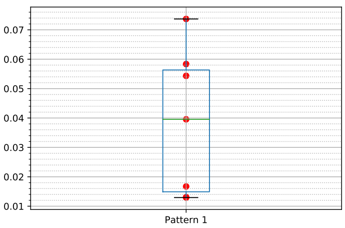
In order to figure out the thresholds of our identified patterns, we applied their base formulas against our models. After getting all the values for each model group, we calculated the percentage of change between each two sequential model versions in that model group (value of version n - value of version $n+1$). The resulted percentages (called steps) were combined into one average value. The reason we chose to calculate the average of all the steps in each model group was that the average will be affected with large steps, and such large steps are more likely to detect bigger maintenance issues.

Table 5.10 lists those average values for each model group then provides the median for each pattern. The median helps in separating the averages, as half of them will be above the median value while the other half will be below. Therefore, the median value will be a good candidate for the pattern threshold (x) as it will take the upper part of averages (more likely to detect bigger maintenance issues). Those median values along with the aforementioned averages are visually represented as box plots in Figure 5.1.

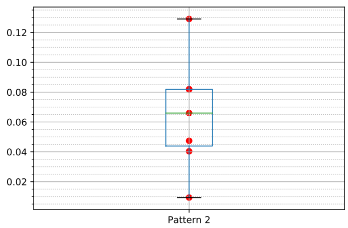
Note that the model groups 163 and 233 were excluded as they provided unreliable results (outliers) due to the drastic changes applied on their latest model versions (pointed out earlier in subsection 4.4.1).

Model Group	P1	P2	P3	P4	P5	P6	P7	P8
10	7.37%	4.74%	17.30%	38.45%	75.30%	62.74%	49.49%	35.81%
19	5.84%	12.90%	13.57%	44.21%	113.53%	140.68%	48.06%	52.24%
52	1.67%	8.20%	6.85%	36.81%	107.61%	84.81%	85.37%	41.39%
70	5.43%	8.19%	7.88%	31.64%	84.62%	59.73%	77.89%	32.03%
203	1.31%	0.94%	9.45%	19.47%	52.24%	72.77%	74.35%	21.94%
214	1.29%	6.60%	1.65%	26.41%	74.76%	60.83%	10.46%	28.26%
236	3.96%	4.03%	4.12%	28.04%	92.26%	113.22%	63.38%	28.68%
MEDIAN	**3.96%**	**6.60%**	**7.88%**	**31.64%**	**84.62%**	**72.77%**	**63.38%**	**32.03%**
163	32.42%	14.73%	15.75%	279267.60%	3095877.25%	2115088.48%	115.40%	9365.20%
233	205.59%	9.52%	3.75%	22.60%	5692.63%	5205.67%	5483.27%	1055.06%

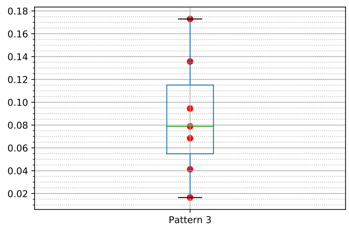
Table 5.10: Average steps of the pattern values for each model group



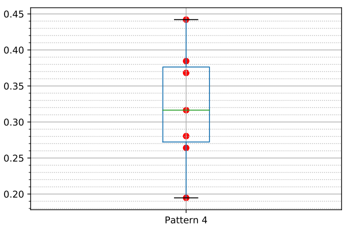
(a) P1 - Increasing references of items



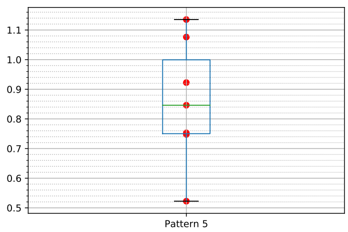
(b) P2 - Increasing leaf nodes and their changes



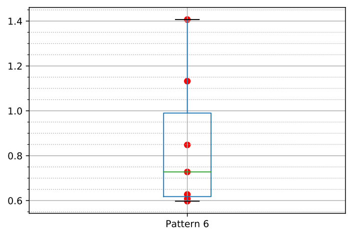
(c) P3 - Increasing inner nodes and their changes



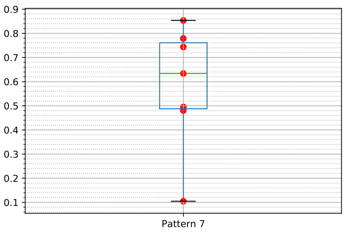
(d) P4 - Increasing changes of items



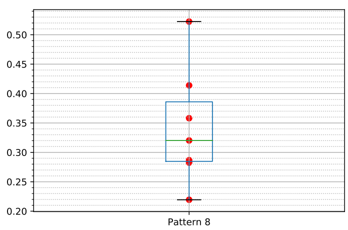
(e) P5 - Increasing leaf changes and their coverage



(f) P6 - Increasing inner changes and their coverage



(g) P7 - Increasing versions, depths and items



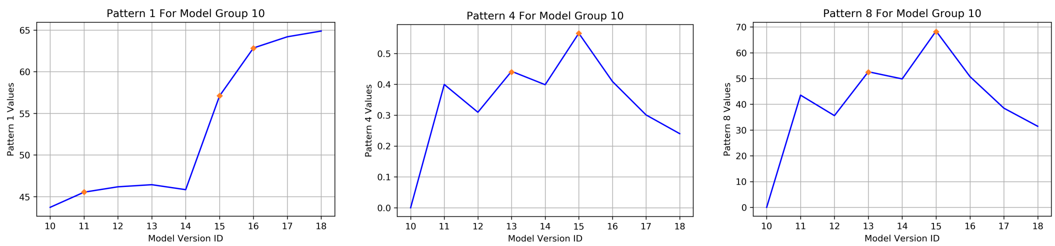
(h) P8 - Increasing employees and their changes on items

Figure 5.1: Box plots for the average steps of patterns

5.5.3 Pattern Results

This section introduces the results of the patterns when we applied their base formulas on the collected data with the help of the already generated data characteristics. The detailed numbers can be found in Appendix C along with the respective line charts in Appendix D since the following paragraphs will just summarise the results for each model group and shed light on some examples.

Model Group 10: This Model group, as detailed in Table C.1, shows a semi-consistent behaviour across applied patterns. Measurements related to the base formulas of patterns increase in a sustainable pace until reaching versions in the middle (14 and 15) where sudden increases (based on patterns threshold percentages) are noticed before the old behaviour hits back. Graphical charts in Figure D.1 support this situation which was explained by the experts interviews in Appendix I as the model during the peak numbers was going through a set of serious changes and refactoring events which helped in making it more maintainable. The Patterns P1, P4 and P8 for example indicated difficulties in maintenance efforts in model 15 compared to its predecessor, when their value-changes (steps) surpassed the defined percentages. This can be noticed with the yellow marks in the small graph Figure 5.2 taken out of the full graph of Figure D.1.



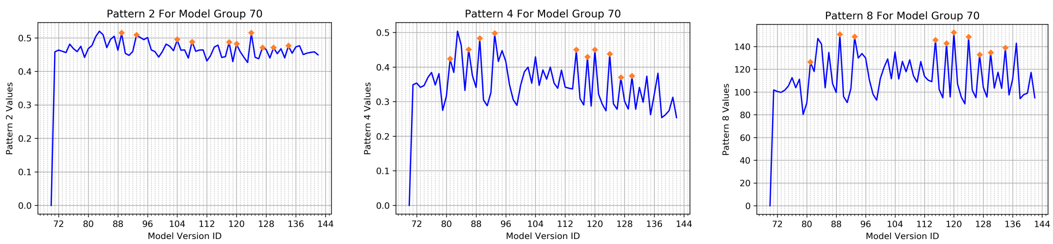
(a) P1 - Increasing references of items **(b)** P4 - Increasing changes of items **(c)** P8 - Increasing employees and their changes on items

Figure 5.2: P1, P4 and P8 base formula values for Model Group 10

Model Group 19: Unlike the previous model group, here we see some inconsistency in the numbers. While the model group 19 was derived into more than 30 versions, its behaviour regarding the applied patterns shows autonomous distinct increases in different versions as the detailed measurements in Table C.2 and their related charts in Figure D.2 reveal. Most of the patterns indicated maintenance difficulties at the beginning between model 20 and 21 when their steps surpassed the defined percentages. Same goes for model version 28 covered by patterns P1, P3, P4, P5, P6 and P8.

Model Group 52: This model group shows peaks of sudden increases in early and middle versions followed by slight changes afterwords. This is true for roughly all patterns except P1, which is a bit exceptional with a behaviour showing difficulties in middle versions mainly. For instance, looking at Table C.3 and Figure D.3, we see patterns P4, P6 and P8 indicating difficulties in model version 54.

Model Group 70: In this model group, which is the largest we studied with over than 70 versions, the distinct changes between consequent versions is objective to different styles. The re-versioning that happened at model versions 124 and 125 according to experts views in Appendix I, explains the sudden changes of the measurements for most of the patterns, which can be tracked in both Table C.4. Clearly, patterns P2, P4, P5, P6 and P8 indicated the difficulties in model 124 when their steps exceeded the thresholds. This can also be checked in Figure D.4 which we show part of it here in Figure 5.3 with yellow marks representing the mentioned steps.



(a) P2 - Increasing leaf nodes and their changes

(b) P4 - Increasing changes of items

(c) P8 - Increasing employees and their changes on items

Figure 5.3: P2, P4 and P8 base formula values for model group 70

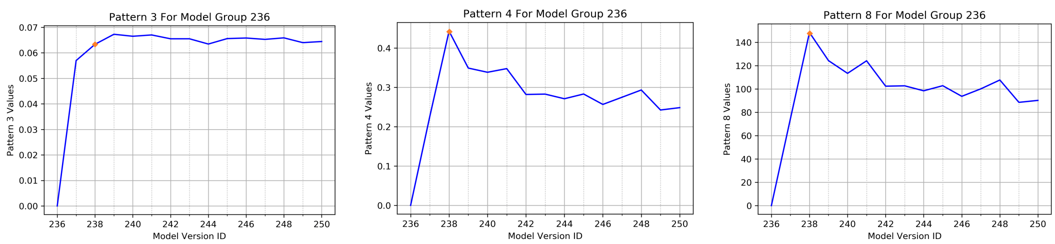
Model Group 163: This model group with only four versions shows in Table C.5 an exceptional increase in the last version for most of the patterns but the first two and the seventh as Figure D.5 shows. Since the values in this model group increased massively at the end, it seems that the model is not reliable enough which is why we ignored it when specifying the percentages for our identified patterns.

Model Group 203: With this small model group which has only three versions, the changes in measurements were noticeable in the last versions mainly (Table C.6), where we can spot increases in values indicating difficulties according to P3 and P7 with Figure D.6.

Model Group 214: Model group 214 shows that high values early versions which suddenly decrease in the middle before it rise a little again at the end. Values in Table C.7 and charts of Figure D.7 show this, and despite that they were not explained by experts in their interviews, the patterns P2, P4, P5, P6 and P8 indicates difficulties in model 216.

Model Group 233: Similarly to the behaviour of model group 203, the measurements for this one rise in the last version for all the patterns as seen in Table C.8 and Figure D.8. However, like model group 163, the values increased massively at the last version which made this model group unreliable enough for the study.

Model Group 236: Model group 236 was derived from Model group 70 at the point of developing its versions of 124 and 125, this was confirmed by the first expert in their interview (Appendix I). The model group itself shows some consistent changes regarding the applied formulas of most of the patterns. It seems that, based on the values in Table C.9, the model group was going through changes followed by refactoring events which explains the ups and downs between each pair of sequential versions. An indication of difficulties in maintenance was detected by P3, P4, P5, P6 and P8 in version 238 which is one of the early versions after the split from model group 70. This can be spotted with yellow marks in Figure 5.4 which is taken from the full chart of Figure D.9.



(a) P3 - Increasing inner nodes and their changes

(b) P4 - Increasing changes of items

(c) P8 - Increasing employees and their changes on items

Figure 5.4: P3, P4 and P8 base formula values for model group 236

5.6 Interview Results

The two interviews were conducted separately in different time spans with two experts having great experience in the collected data coming from direct engagement and guidance through the years of development. The first interview took about three hours while the second took roughly one hour. Although the first one covered a detailed investigation, the time ran out and two patterns were excluded from the interview. The second interview, however, tried to build upon the first one by asking direct questions in order to get more general answers. The transcripts of the interviews can be found in Appendix I.

Both interviewees needed an extra explanation of most of the patterns, the first interviewee tried to get the pattern understanding from the historical data which explained some of the numbers we got in specific model versions, whereas the second one tried to grasp it based on experience. The expert in the first interview mentioned that the numbers we presented were indicating events in the models. Note that we did not have the time to explain and cover all the peaks we explored, but rather focus on some model groups like Model Group 10, Model Group 70, Model Group 236 and a glimpse of Model Group 19.

Both interviewees agreed that the first and the fourth patterns (increasing references/changes of items) represented acceptable indications of issues related to maintenance in the version histories of the discussed model groups. However, the second and the third patterns (increasing leaf-nodes/inner-nodes and their changes) were confirmed only by the second interviewee as the time ran out with the first one while discussing them. Overall, we will consider the first four patterns as confirmed and semi-confirmed.

As for patterns 5 and 6 (increasing leaf-changes/inner-changes and their coverage), we see that they were not discussed in the first interview, and in the second one the interviewee tried to avoid confirming their applicability, therefore, those two patterns will be considered unconfirmed by experts.

On the other hand, pattern 7 (increasing versions, depths and items), was a tricky one for the first interviewee but interesting as “depth means more changes” according to their experience. The second interviewee believed this pattern to be a perfect representations of maintenance issues. As a result, we will consider this pattern as semi-confirmed.

As regarding pattern 8 (increasing employees and their changes on items), both declared that it is an interesting pattern in the light of the presented results and that it should be studied further. However, since the first interviewee only “somehow” confirmed it when discussing the Model Group 236, this pattern seemed not strong enough to be considered as fully confirmed and will only be considered semi-confirmed.

Finally, the in-depth interviews that are used to validate the mentioned patterns, are supported by the experience of the interviewees in both: SystemWeaver and the studied historical data. This helps in projecting the experts’ practical background on the data itself rather than just the output of the statistical analysis. Furthermore, having the patterns representing situations that might reflect potential maintenance issues in the actual system, will allow the experts in that system to give trustworthy answers, which besides the mentioned experience, helps to increase the overall reliability of the interview results that we summarise in Table 5.11.

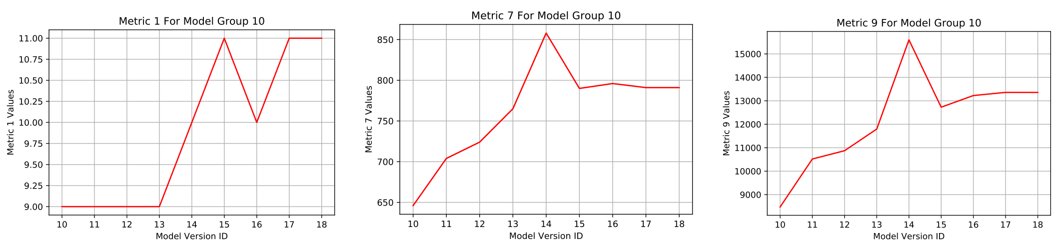
5.7 Metric Results

The metrics we selected and discussed in section 4.5 were applied on the studied model groups and their histories of versions. The actual values of applying these metrics can be found in Appendix E while their graphical representation can be seen with the charts provided in Appendix F. The following paragraphs cast the big idea of what the mentioned values represent for each of the model groups.

Pattern	First Interview	Second Interview	Result
P1	Correct.	Makes Sense.	Confirmed.
P2	Logical, "it is easy to change leaves", but could not track changes clearly to confirm it.	True, Needed more clarification.	Semi-Confirmed.
P3	Could not track changes clearly to confirm it.	True, but also depends on the position of the inner-node (depth).	Semi-Confirmed.
P4	Logical.	Logical, but after more clarification and examples.	Confirmed.
P5	Not discussed.	OK, could be.	Unconfirmed.
P6	Not discussed.	OK, could be.	Unconfirmed.
P7	Tricky, it took time to understand. Agrees that "more depth means more changes".	It is perfect.	Semi-Confirmed.
P8	Interesting results regarding the statistics. Somehow confirmed.	Interesting results regarding the statistics, thought of doing research about it.	Semi-Confirmed.

Table 5.11: Comparison between the results of interviews

Model Group 10: For this model group, the measurements of the metrics show a gradual increase along the version numbers. In the model versions 14 and 15, where a refactoring process was held according to our expert in the first interview (Appendix I), we see, according to Table E.1, that many measures show a distinct increase. This is also supported with the charts of Figure 5.5 taken of the full graph in Figure F.1.



(a) M1 - Depth of Tree

(b) M7 - Number of Features (Use Cases)

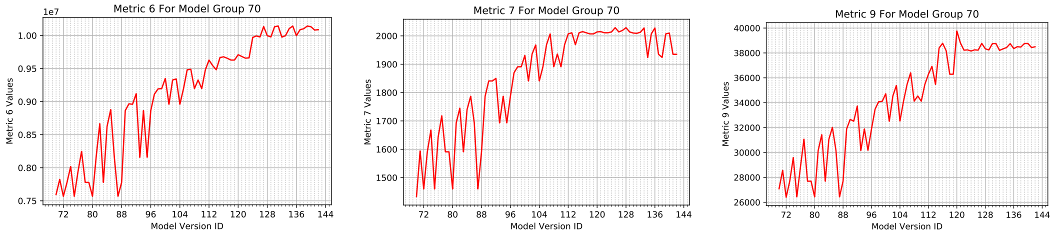
(c) M9 - Number of Features (Functional Requirements)

Figure 5.5: M1, M7 and M9 charts for Model Group 10

Model Group 19: In general, as Table E.2 shows, there is a consistent behaviour regarding the applied metrics, where a noticeable increment in six of the used metrics seem obvious within Figure F.2 and aligns with the evolution of the model.

Model Group 52: Similarly to the previous model group, this one also shows a gradual increment along the model evolution. Values of Table E.3 and Figure F.3 agree with this.

Model Group 70: Model group 70 shows a rising behaviour in the values up to the model versions 124 and 125 where they seem to reach a high level and settle down with small changes afterwards. Table E.4 and Figure 5.6 (taken form Figure F.4) present better view for this. The mentioned two model versions were the same that our expert pointed out as a development shift where the model group continued in another parallel stream that turned out to be the model group 236 (Appendix I).



(a) M6 - Coupling Between Objects

(b) M7 - Number of Features (Use Cases)

(c) M9 - Number of Features (Functional Requirements)

Figure 5.6: M6, M7 and M9 charts for model group 70

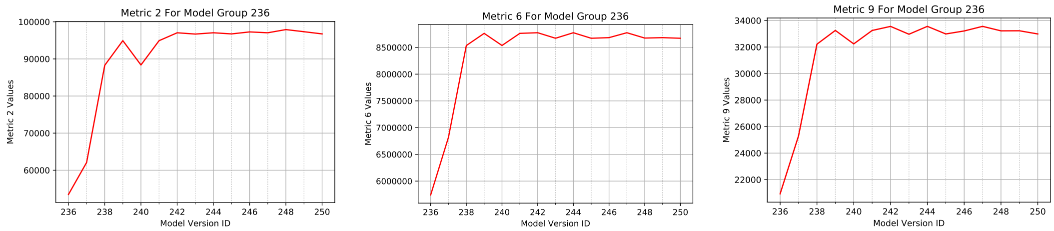
Model Group 163: There is a weird behaviour to be noticed when applying metrics on this model group as the values shown in Table E.5 as well as Figure F.5 seem to declined sharply in the last version named model 166. Looking at the data characteristics of this model group in Table B.14 and Table B.15, we see what it looks like to be a possible extensive refactoring that was held over the last version by deleting many items from the model. This clearly describes the drastic change in the values of our metrics.

Model Group 203: This model group includes three versions, and unlike the previous model group, the changes pace regarding the values of the metrics are increasing towards the newer version in almost all metrics as Table E.6 and Figure F.6 reveal.

Model Group 214: Values of metrics in Table E.7 for model group 214 seem to max out in the last four versions (model versions 216 to 219) which is spotted with Figure F.7.

Model Group 233: The values of the measurements increased sharply in the last version of this model group according to Table E.8 and the respective charts of Figure F.8, which can be explained by the development applied on that model group to add many items as the data characteristics disclose in Table B.23 and Table B.24,.

Model Group 236: Here the values seem to not follow a certain style in all metrics. The metrics M2, M6 and M9 shown in Figure 5.7 seem too similar in increasing along the development of the model group, While metrics M1, M4, M7 and M8 go in ups and downs. The rest of metrics follow their own peaces which is obvious in Table E.9 and Figure F.9.



(a) M2 - Size or Lines Of Code

(b) M6 - Coupling Between Objects

(c) M9 - Number of Features (Functional Requirements)

Figure 5.7: M2, M6 and M9 charts for model group 236

5.8 Comparison and Statistical Analysis

The next step in analysing data was conducting statistical analysis to draw conclusions and infer answers to our research questions presented in section 4.2. The values of the base formulas of our identified patterns along with the measurements of the chosen metrics formed the input to the Pearson correlations tests we applied.

The values of base formulas are listed in Appendix C, while the measurements of the metrics can be seen in Appendix E. To better track these values and measurements we showed them in multiple tables, one for each model group. However, for the correlation tests, we used the values of all studied models at once (e.g. All 164 values of pattern 1 and all 164 measurements of metric 1).

The diverse libraries available in Python language enabled us to generate simple plots, like the ones in Appendix G and Appendix H, which will help us understand the results alongside the numeric values.

5.9 Correlation Tests - Patterns and Metrics

We ran (72) Pearson Correlation tests, covering all possible combinations of pattern and metric pairs. The results of these tests, which will be discussed and shown in the following sections, involved r-values, p-values and intense levels. Line charts for each correlation test was also generated and can be tracked in Appendix G.

5.9.1 R-Values

The main result of Pearson Correlation tests are the r-values, which indicates the strength of the correlation as a decimal number in the range of [-1, +1]. Negative values refers to an inverse relationship (e.g. Values of a pattern rises while the corresponding values of the metric decreases). The higher the r-value the stronger the correlation is. Table 5.12 shows all the results we got which we will describe later in subsection 5.9.4

		Patterns							
		P1	**P2**	**P3**	**P4**	**P5**	**P6**	**P7**	**P8**
Metrics	**M1**	+4.28995e-01	-4.87541e-02	+3.81120e-01	-3.62870e-01	-3.61414e-01	-3.56776e-01	+1.14764e-01	-2.36474e-01
	M2	-1.92891e-01	+1.83040e-02	+4.78184e-01	-1.63778e-01	-1.60610e-01	-1.45497e-01	+8.16659e-01	+2.63671e-02
	M3	-2.02742e-01	+4.74352e-03	-6.00864e-01	-3.54541e-02	-3.73335e-02	-4.94410e-02	-3.48392e-01	-2.19482e-01
	M4	+3.83244e-01	+2.61196e-01	+2.86975e-01	+9.23561e-03	+9.82725e-03	+1.38843e-02	+8.52150e-02	+6.90410e-02
	M5	+2.26356e-01	-1.22976e-01	-1.05280e-01	-2.12943e-01	-2.13820e-01	-2.21604e-01	-1.63489e-01	-2.66098e-01
	M6	+5.34097e-02	-1.06575e-02	+5.37755e-01	-1.84558e-01	-1.81460e-01	-1.65983e-01	+6.85477e-01	+2.17721e-02
	M7	-5.71208e-02	-1.66804e-02	+4.60559e-01	-1.95412e-01	-1.92203e-01	-1.77702e-01	+6.86237e-01	-2.29204e-03
	M8	-2.92141e-01	+5.04240e-04	+1.34309e-01	-2.95189e-02	-2.88858e-02	-2.73833e-02	+3.72689e-01	+1.88375e-02
	M9	-7.49395e-02	+1.09370e-02	+5.26486e-01	-1.83158e-01	-1.79939e-01	-1.64117e-01	+7.30584e-01	+2.12572e-02

Table 5.12: Pearson correlation r-values between patterns and metrics

5.9.2 P-Values

In order to provide an indication of the statistical significance of the presented r-values, we generated the p-values of the correlation tests. Those values shown in Table 5.13 will be used when judging the validity of the correlations in subsection 5.9.4.

		Patterns							
		P1	**P2**	**P3**	**P4**	**P5**	**P6**	**P7**	**P8**
Metrics	**M1**	9.96136e-09	5.35290e-01	4.78536e-07	1.79488e-06	1.98766e-06	2.74180e-06	1.43388e-01	2.29954e-03
	M2	1.33387e-02	8.16048e-01	9.44756e-11	3.61256e-02	3.99329e-02	6.30388e-02	1.61543e-40	7.37520e-01
	M3	9.22508e-03	9.51931e-01	1.80585e-17	6.52204e-01	6.35064e-01	5.29548e-01	4.84198e-06	4.74637e-03
	M4	4.08130e-07	7.29648e-04	1.94819e-04	9.06566e-01	9.00610e-01	8.59937e-01	2.77961e-01	3.79704e-01
	M5	3.56223e-03	1.16701e-01	1.79706e-01	6.18869e-03	5.97501e-03	4.34787e-03	3.64603e-02	5.73268e-04
	M6	4.96991e-01	8.92262e-01	1.12766e-13	1.79920e-02	2.00513e-02	3.36604e-02	4.28486e-24	7.81996e-01
	M7	4.67531e-01	8.32111e-01	5.46253e-10	1.21563e-02	1.36784e-02	2.28196e-02	3.65010e-24	9.76763e-01
	M8	1.47194e-04	9.94887e-01	8.64157e-02	7.07499e-01	7.13496e-01	7.27795e-01	8.90224e-07	8.10785e-01
	M9	3.40238e-01	8.89454e-01	4.46245e-13	1.88990e-02	2.11348e-02	3.57370e-02	1.22602e-28	7.87027e-01

Table 5.13: Pearson correlation p-values between patterns and metrics

5.9.3 Intense Levels

Table 5.14 shows the corresponding intense levels of the r-values according to five levels (Weakest, Weak, Medium, Strong, Strongest) that matches the ranges of ([0, 0.19], [0.2, 0.39], [0.4, 0.59], [0.6, 0.79], [0.8, 1]) respectively.

		Patterns							
		P1	**P2**	**P3**	**P4**	**P5**	**P6**	**P7**	**P8**
Metrics	**M1**	Medium	Weakest	Weak	Weak	Weak	Weak	Weakest	Weak
	M2	Weakest	Weakest	Medium	Weakest	Weakest	Weakest	Strongest	Weakest
	M3	Weak	Weakest	Strong	Weakest	Weakest	Weakest	Weak	Weak
	M4	Weak	Weak	Weak	Weakest	Weakest	Weakest	Weakest	Weakest
	M5	Weak	Weakest	Weakest	Weak	Weak	Weak	Weakest	Weak
	M6	Weakest	Weakest	Medium	Weakest	Weakest	Weakest	Strong	Weakest
	M7	Weakest	Weakest	Medium	Weak	Weakest	Weakest	Strong	Weakest
	M8	Weak	Weakest	Weakest	Weakest	Weakest	Weakest	Weak	Weakest
	M9	Weakest	Weakest	Medium	Weakest	Weakest	Weakest	Strong	Weakest

Table 5.14: Pearson correlation intensity between patterns and metrics

5.9.4 Significant Results

Looking at intense levels in Table 5.14 along with the r-values shown in Table 5.12 and the p-values in Table 5.13, we see five values that are considered medium in intense due to having r-values in the range [0.4, 0.59], four values that are strong with r-values between [0.6, 0.79] and one very strong value in the range of [0.8, 1]. The rest of the results show weak correlations with values ranging between [0, 0.39].

In Table 5.15 we list the significant results ordered based on r-values. Since the p-values are way less than 0.05, we reject the null hypothesis that there is no correlation between the specified patterns and metrics and conclude that a significant relationship does actually exist. Based on these significant results we will consider to discuss the patterns (P1, P3, P7) and the metrics (M1, M2, M3, M6, M7, M9) in the next chapter.

Pattern	Metric	Intense	Relationship	r-value	p-value	Chart
P7	M2 (S)	Strongest	Direct	+8.16659e-01	1.61543e-40	G.7b
P7	M9 (NF-FR)	Strong	Direct	+7.30584e-01	1.22602e-28	G.7i
P7	M6 (CBO)	Strong	Direct	+6.85477e-01	4.28486e-24	G.7f
P7	M7 (NF-UC)	Strong	Direct	+6.75372e-01	3.46040e-23	G.7g
P3	M3 (RoV)	Strong	Inverse	-6.00864e-01	1.80585e-17	G.3c
P3	M6 (CBO)	Medium	Direct	+5.37755e-01	1.12766e-13	G.3f
P3	M9 (NF-FR)	Medium	Direct	+5.26486e-01	4.46245e-13	G.3i
P3	M2 (S)	Medium	Direct	+4.78184e-01	9.44756e-11	G.3b
P3	M7 (NF-UC)	Medium	Direct	+4.60559e-01	5.46253e-10	G.3g
P1	M1 (DT)	Medium	Direct	+4.28995e-01	9.96136e-09	G.1a

Table 5.15: Pearson correlation significant results of patterns and metrics

5.10 Correlation Tests - Patterns Together

Another way to analyse the results we obtained was to compare the results of patterns together. This might give other insights about their validity and enable us to compare them to the interviews we conducted with experts. Similarly to the tests applied on patterns and metrics, these tests will present r-values, p-values and intense levels with the following subsections which we will describe in subsection 5.10.4. Charts for these correlations can also be checked in Appendix H.

5.10.1 R-Values

Table 5.16 lists the r-values or the correlation tests applied on all unique combinations of the available patterns, therefore we will obviously ignore tests of patterns with themselves and tests covering a duplicate form of a reciprocal relationship (testing P1 and P2 is the same as testing P2 and P1).

	P1	**P2**	**P3**	**P4**	**P5**	**P6**	**P7**
P2	-2.02841e-02						
P3	+1.17722e-01	+6.34721e-01					
P4	-3.53191e-01	+5.02882e-02	-1.10597e-01				
P5	-3.53866e-01	+5.04884e-02	-1.09641e-01	+9.99988e-01			
P6	-3.55968e-01	+5.60578e-02	-9.63390e-02	+9.99618e-01	+9.99722e-01		
P7	-3.12302e-01	+2.05192e-02	+3.12169e-01	-6.45564e-02	-6.20942e-02	-4.89006e-02	
P8	-3.42306e-01	+1.39949e-01	+8.15352e-02	+9.63073e-01	+9.64067e-01	+9.69312e-01	+6.50571e-02

Table 5.16: Pearson correlation r-values between patterns together

5.10.2 P-Values

The p-values of the correlation tests on patterns together can be seen in Table 5.17

	P1	**P2**	**P3**	**P4**	**P5**	**P6**	**P7**
P2	7.96559e-01						
P3	1.33284e-01	7.10589e-20					
P4	3.50360e-06	5.22509e-01	1.58590e-01				
P5	3.34635e-06	5.20853e-01	1.62244e-01	0.00000e+00			
P6	2.89841e-06	4.75871e-01	2.19762e-01	1.95262e-254	1.49397e-265		
P7	4.67850e-05	7.94253e-01	4.71543e-05	4.11499e-01	4.29602e-01	5.34063e-01	
P8	7.24310e-06	7.38854e-02	2.99316e-01	3.12742e-94	3.57358e-95	1.24236e-100	4.07873e-01

Table 5.17: Pearson correlation p-values between patterns together

5.10.3 Intense Levels

The intense levels of the r-values are listed in Table 5.18. Unlike the previous correlation tests, here we have no medium levels for the results. Most of them are representing weak correlations, despite the fact that we have some very strong ones.

5.10.4 Significant Results

Considering the r-values of Table 5.16, p-values of Table 5.17 and the intense levels in Table 5.18, we get one strong correlation (P2 and P3), as well as six very superb correlations (for P4, P5, P6 and P8). These significant results are presented in Table 5.19 where we see very negligible p-values that enable us to reject the null hypothesis of not having correlations and infer that a significant relationship does exist. These mentioned patterns will be discussed further in the next chapter.

	P1	**P2**	**P3**	**P4**	**P5**	**P6**	**P7**
P2	Weakest						
P3	Weakest	Strong					
P4	Weak	Weakest	Weakest				
P5	Weak	Weakest	Weakest	Strongest			
P6	Weak	Weakest	Weakest	Strongest	Strongest		
P7	Weak	Weakest	Weak	Weakest	Weakest	Weakest	
P8	Weak	Weakest	Weakest	Strongest	Strongest	Strongest	Weakest

Table 5.18: Pearson correlation intensity between patterns together

Pattern	**Pattern**	**Intense**	**Relationship**	**r-value**	**p-value**	**Chart**
P4	P5	Strongest	Direct	+9.99988e-01	0.00000e+00	H.4a
P5	P6	Strongest	Direct	+9.99722e-01	1.49397e-265	H.5a
P4	P6	Strongest	Direct	+9.99618e-01	1.95262e-254	H.4b
P6	P8	Strongest	Direct	+9.69312e-01	1.24236e-100	H.6b
P5	P8	Strongest	Direct	+9.64067e-01	3.57358e-95	H.5c
P4	P8	Strongest	Direct	+9.63073e-01	3.12742e-94	H.4d
P2	P3	Strong	Direct	+6.34721e-01	7.10589e-20	H.2a

Table 5.19: Pearson correlation significant results of patterns together

6

Discussion

Within this chapter, a comparison to the related work mentioned in chapter 3 will be introduced, followed by a discussion to answer our research questions. Later, a list of the possible validity threats will be presented before we conclude with the lessons we learned and the possible future work for this study.

6.1 Comparison With Related Work

As the chapter 3 showed, previous research mainly focused on assessing maintainability aspects from a code-base perspective [10][11]. Many studies concentrated on size and complexity of OOP languages and focused on categorising the available metrics to support the decision-making processes regarding which ones to use [10].

Although some research looked at how models should be built and designed to achieve better levels of maintainability [5], not many explored the road of defining metrics to measure these levels. Here, our study decided to shine by taking the process of assessing maintainability to an earlier stage in the software development process that is more abstract when compared to the implementation one focusing on code base.

Few studies like Schroeder et al.[13] applied metrics measuring size on specific types of software models, despite the results were successful and showed correlation with maintainability, they did not apply more appropriate types and amounts of metrics such as the ones our study explored and looked at. Moreover, the metrics and the type of models used in our case were different, not to mention that the process of validating these metrics was distinct as it relied on a comparison with patterns extracted from historical data and validated by experts. However, it should be noted that one of the size metrics used in the study of Shroeder et al.[13] was the same as our second metric (M2). According to Table 5.14, this metric showed both a very strong correlation and a medium one with the patterns P7 and P3, and we will discuss these results in detail with the following section.

6.2 Research Questions Answers

Now that we have collected, explored and analysed the data in the previous chapters, and with the help of the results we presented, it is possible to provide answers to our listed research questions.

RQ1: How can a revision history of a model be used to judge its maintainability?

As seen in the studied data, each chosen model group had multiple model versions ranging in count between 3 and more than 70. Each version represented changes compared to its predecessor through describing data characteristics covering different aspects like: addition of new items, updating old ones, deleting or relocating some within the structure as well as many others. These changes in characteristics, were driven by the process of enhancing a given model version and pushing its capabilities to the next level by the actual maintainers.

The first interview with the expert, available in Appendix I, assured at the end, that our results, including both data characteristics and pattern values, managed to point out important events in the life cycle of the studied models (e.g. Refactoring events and splitting the development of a model version in the favour of starting a new one). Although the limited time of the first interview prohibited us from reviewing all the nine selected model groups, we managed to discuss three of them to a level we consider good enough, which are: Model Group 10, Model Group 70 and Model Group 236. This interview proved that identifying situations reflecting difficulties in the development process of a model using its historical events, can be used to indicate how easy it was to introduce changes and thus the level of maintainability a model had or could have.

How can we identify situations in a revision history of a model where developers faced maintainability issues related to that model?

The manual data analysis we applied on the revision history of each model group, was the starting point of identifying patterns reflecting difficulties in the development process of the models. The analysation relied on running lots of queries to calculate the values of the data characteristics we decided to explore. Looking at these values with an eye of a critic, our personal point of view and intuition, along with the guidance of our supervisor, we managed to form a few patterns that can possibly indicate development issues. Some of these patterns, mentioned in the previous chapter in subsection 5.5.3, were confirmed by the experts in the interviews and thus used as a point of judgement of models maintainability.

The first interview confirmed the patterns P1 and P4, but semi-confirmed P7 and P8. The second interview focused on covering all patterns which managed to confirm P1, P2, P4, P7 but semi-confirm P3 and P8. As a result, we see that P1 and P4 were the main confirmed patterns while P2, P3, P7 and P8 were the semi-confirmed ones. These results, listed in Table 5.11, along with the reviews of the experts regarding them, prove that identifying situations reflecting difficulties in the development process of a model can be achieved by monitoring changes in the collected data, such as the values of the data characteristics we used.

RQ2: What metrics can be used to predict the maintainability of models?

Using the metrics we selected and comparing their results to the confirmed patterns through our correlation tests, we infer that some metrics can be used as a way of indicating the maintainability of models. The strong correlation results, listed earlier in Table 5.15, between the pattern P7 and the metrics M2, M9, M6 and M7 indicate that the mentioned metrics can be used to a certain extent to judge the maintainability of models since the aforementioned pattern was only a semi-confirmed one. Although we can explain the very strong correlation between that pattern and the metric M2 as both relies on measuring the size of a model, we cannot completely explain the strong correlations in the rest of the metrics (M9, M6 and M7) which makes them better candidates than M2. Similarly, the strong correlation of the semi-confirmed pattern P3 and the metric M3 which cannot be explained easily (as both do not rely on the same measurements), suggest the metric M3 as a fourth candidate. However, due to the inverse relationship of this correlation we need to interpret the results of metric M3 on an inverses scale, therefore the higher the value of this metric, the higher the maintainability would be (the value of a metric indicates how hard it is to maintain a model).

Looking at the medium correlations of the semi-confirmed pattern P3 and the metrics (M6, M9, M2 and M7) we gain more assurance regarding the three metrics (M9, M6 and M7). Again in here we can explain the correlation with M2 as this metric shares interest in size with the pattern P3, meaning that M2 is still less considered than the rest.

Finally, the confirmed pattern P1 suggests the metric M1 as another promising metric, but due to the fact that the correlation is medium in intense (around 42.9% match in results) and the metric was pointed out only with this correlation, we will count it as good as the rest of proven metrics because of its correlation to a confirmed pattern (versus a semi-confirmed one for the previous metrics).

Surprisingly, the confirmed pattern P4 correlated very weakly with the chosen metrics, and the p-values of the tests covering that pattern could not indicate any statistical significance (high p-values). Therefore we could not count on pattern P4 to validate any of our chosen metrics.

To conclude and provide an answer to this research question based on the discussion we provided, we can consider the metrics in the following order (defined by the average of r-values for each one): M9, M6, M7, M3 and M1 as good candidates for measuring the maintainability of models, keeping in mind the inverse relationship that M3 had and that the discussed correlation results had very low p-values which made them significant enough to reject the null hypothesis and prove the relationships.

6.3 The Extra Correlation Tests

Although our focus was on running correlation tests between patterns and metrics, we had curiosity to check the correlations between patterns together. For one reason, this might be another possible way of gaining confirmations regarding patterns, especially the unconfirmed ones such as P5 and P6, as well as the patterns confirmed by one expert only or by both but without a high degree of certainty (semi-confirmed). A second reason would be to rely on statistics with the help of the experience of experts to better assure our results.

Checking the list of strongest correlations available in Table 5.19, we see the confirmed pattern P4 correlates strongly with the unconfirmed P5, with almost 100% match in r-value and a p-value close to 0. This means that the pattern P5 can also be considered confirmed although not discussed in first interview and was marked as "could be" for the second expert. Another highly correlated patterns are the newly confirmed P5 and the pattern P6. Similarly we can confirm the previously unconfirmed P6.

As P5 and P6 turned out to correlate strongly, and since P4 correlated earlier with P5, we see the next correlation test confirming the relationship between P4 and P6, which was obviously expected. On the other hand, the pattern P6 correlates again with the semi-confirmed P8, making the later a possibly fully confirmed pattern. And because of the close relation ship between P4, P5 and P6 we see the pattern P8 correlating with P5 and P4 as well.

The final correlation, which had a strong intensity instead of a very strong one like the previously mentioned tests had, suggest a correlation between the two semi-confirmed pattern P2 and P3, with almost 63.5% match in values of both. This correlation can actually be explained as the both patterns complement each others where P2 considers the leaf- nodes while P3 checks the inner-nodes of a model. Yet it's interesting to see these correlations.

The negligible p-values of these tests make the result significant enough, but since we do not have metrics that strongly correlates to these discussed patterns, the results can be kept as discussed and the new findings can be used for future work covering a wider range of metrics.

6.4 Other Results

Many of the correlation results had weak to very weak intensity levels. The very weak ones had relatively high p-values making them not significant enough to reject the null hypothesis of not having a relationship (for both cases of pattern-metric tests and pattern-pattern tests). On the other hand, the weak results had some acceptable p-values that can be used to reject the null hypothesis and prove the existence of a relationship, but the fact that the intensity level was weak, such relationships could not form a steady base for any conclusions, which is why we ignored them at the first place.

Moreover, to better grasp the concepts of our patterns, we could consider an example of a traffic jam as an issue that can be detected via different situations. Such situations could include having slow vehicles, a large number of them trying to cross the road, some construction work along the way or even a combination of these. The different situations, similarly to our patterns, may indicate a traffic jam in many streets but not all ones (e.g. the same number of vehicles may not cause the traffic jam in all streets). Thus, a pattern that indicates the presence of an issue may not detect it in all models. This means that the patterns that are weakly correlated with metrics (or with other patterns) might be because of indicating different issues from each other and/or not being able to indicate any in the selected models.

Based on our example, we see that tests with higher intensity levels are better for detecting a relationship where both parties are indicating similar or matching issues, while lower ones are incapable of doing so, which stress again why we decided to ignore them.

6.5 Validity Threats

This research might be limited because of the number of threats affecting its validity. Therefore, based on the scheme of Runeson et al. [16], we will cover four aspects of validity threats including: construct validity, internal validity, external validity, and reliability. The most significant ones will be described with an initial degree of prioritisation as the validity was examined and analysed throughout the phases of this study.

6.5.1 Construct Validity

The study is conducted based on two sorts of data: the data of models collected by the custom tool and the feedback of experts collected by interviews.

The first type of data relied on our custom tool which was developed based on our gained understanding of the original structure via the training provided by Systemite. This means that the validity of the data partly depends on the validity of the developed structure. However, we mitigated the threats related to this area by the comparisons we did between the early exported data from SystemWeaver through excel files and the data which our tool collected using the API, as well as the feedback we received from experts during interviews telling that our analyzation of the data revealed some events without being aware of its context. In addition, the database is structured to present the generic concept of the model which helps in handling the models as entities separated from the context of system. Although the size of the collected data was big, it is still considered limited as it was collected from one source only.

On the other hand, the second type of data was limited because of the time needed to help interviewees understand the used structure. It might have also been limited by the interviewers' perspective and the units used in the case study. Furthermore, driving the interviews by the study conductors themselves might have affected the opinions of the interviewees and provided more motivation towards personal conclusions. However as mentioned previously, the great experience of the interviewees regarding the system and the collected data mitigates the deficiencies in this area.

6.5.2 Internal Validity

The design of the study and the collected data might have affected the ability of including all the factors that should have been considered for such research. Thus some factors might have been ignored for some reason. For example, the selection of the specified metrics and the criteria used to make this selection, besides the identification of the used patterns. This means that our internal validity is defined with the capacity of these metrics and patterns.

However, the study concludes the efficiency of the selected metrics and patterns rather than finding the right ones, meaning that the internal validity is supported by this. Not to mention that it also depends on the maturity and stability of the original system with its provided data worth of more than 15 years of history.

6.5.3 External Validity

This study was conducted on data related to one company in a specific industry following the model defined by SystemWeaver, which makes it vulnerable to threats of external validity. However, it should be noted that the developed tool extracted the data and stored it in a general structure that follows the definition of general models. Thus, in future, the tool can be applied on other models and meta-models without changing the same structure that helped us draw our conclusions.

6.5.4 Reliability

The reliability of this study is inspired by the identified patterns and the selected metrics. The analysis conducted on the collected data could have led to other patterns than the ones we identified, and the metrics we chose were selected based on research and our understanding of data pieces like models and meta-models. As long as the patterns are considered valid, and the used metrics are supported by research and experiments, the study should be reliable enough.

6.6 Generalisability of Results

Being able to generalise our results means that we can use the identified metrics to assess the maintainability of models in general. Despite the fact that the findings are gained from studying models related to a specific industrial domain, they can be generalised to models in other domains for the following reasons:

6.6.1 Generic Database Structure

The custom tool (ASTS) was built for the purpose of collecting and analysing the models of SystemWeaver in particular. However, we kept in mind through the entire period of development, the applicability of its database structure to future models and other domains. Therefore, a generic structure was produced to be able to host all kinds of models as long as they are re-presentable in a tree view structure.

6.6.2 Reliable Collected Data

As mentioned in section 6.5, we ensured that our custom tool managed to collect the data correctly when we compared its output to the data we exported directly from SystemWeaver (discussed further in section 5.1). We also gained more trust in our collected data and the applied analysation when experts pointed out that our results revealed some important development events in the histories of the models without being ourselves part of the actual development processes or being aware of the context of such models.

6.6.3 Generic Data Characteristics

The data characteristics mentioned in subsection 4.4.1 were used to describe the studied models by covering their generic attributes (such as items count, references count and changes count) as well as their generic meta-data aspects (like version numbers, life span and employees count). Although our findings were based on the data of a specific industrial domain, we think that they are generalisable due to the fact that they emerged from validating patterns identified by analysing changes in the mentioned generic characteristics. However, future studies will need to show whether the results can be reproduced with other model types or not.

6.6.4 Validated Metrics

Besides the fact that the used metrics were supported and validated by research, they also were selected according to the consideration of their direct applicability to the collected models (with the least possible amount of modifications). This makes them generic and reusable and also makes their results easily reproducible across other types of models.

6.7 Lessons Learned

One of the most important lessons we learned would be that measuring the maintainability of a whole model might depends on many factors, and one metric may not be enough in describing that aspect entirely by itself. This comes from the fact that we could not identify a single metric that correlates strongly with confirmed patterns, but rather a few ones that seem to have an acceptable relationship. However, as we could not cover many metrics in our study, the possibility of finding one in the future that can describe the maintainability of various models precisely, remains viable.

6.8 Future Work

Taking this study to a next level might include covering more patterns and/or metrics and probably trying to categorise them into groups specifying the areas that the group is trying to assess (e.g. changeability, complexity, understandability ... etc). Furthermore, combining metrics might be beneficial to provide a precise and more-detailed measurement of maintainability. We would also encourage measuring the maintainability of software models in real projects then compare it with the maintainability levels of the respective code-base to find correlations and distinguish the problems that can models disclose in earlier stages.

7
Conclusion

In the light of the discussed results of chapter 6, we conclude the possibility of using the revision history of SystemWeaver's models to identify situations symbolising the difficulties that the developers faced during their development processes

The mentioned situations represented patterns that if detected in a model history will be able to indicate issues related to maintenance. Furthermore, a relationship between a few patterns and metrics proved the potentiality of using such metrics for measuring the maintainability levels of models. Thus, our study demonstrated how it is possible to measure the maintainability of models as the highly abstracted artefacts of software products.

The Metric M9 (NF-FR), measuring the number of functional requirements presented within a model seems to provide a good indication of maintainability. The metric M6 (CBO), concerned about coupling between objects comes next, followed by M7 (NF-UC) measuring the number of use-cases in a model. The ratio of variability, measured by metric M3 (RoV) reserved a penultimate place which makes the last metric M1 (DT), that focuses on depth of models, come at the end of the list.

Covering more metrics might lead to better results and a wider selection of applicable ones, but due to the time limitations of our study we had to cover only a subset of them which yielded five good candidates.

Bibliography

[1] International Organization for Standardization. (2011). Systems and Software Engineering: Systems and Software Quality Requirements and Evaluation (SQuaRE): System and Software Quality Models. ISO/IEC 25010:2011.

[2] ISO/IEC, "Software engineering — Product quality — Part 1: Quality model," 2001.

[3] IEEE Std. 610.12-1990. Standard Glossary of Software Engineering Terminology, IEEE Computer Society Press, Los Alamitos, CA, 1993.

[4] Szőke, G., Antal, G., Nagy, C., Ferenc, R., Gyimóthy, T. (2017). Empirical study on refactoring large-scale industrial systems and its effects on maintainability. Journal of Systems and Software, 129, 107-126.

[5] Lagerström, R. (2007). Analyzing System Maintainability using Enterprise Architecture Models. Proceedings Of The Second Workshop On Trends In Enterprise Architecture Research (Tear 2007), 31-39.

[6] Berns, G. (1984). Assessing software maintainability. Communications of the ACM, 27(1), 14-23.

[7] Elmidaoui, S., Cheikhi, L., Idri, A. (2017). Software product maintainability prediction: A survey of secondary studies. Control, Decision and Information Technologies (CoDIT), 2017 4th International Conference on, 2017, 0702-0707.

[8] Di Rocco, J., Di Ruscio, D., Iovino, L., Pierantonio, A. (2015). Collaborative repositories in model-driven engineering [software technology]. IEEE Software, 32(3), 28-34.

[9] Goldschmidt, T., Kübler, J. (2008). Towards Evaluating Maintainability Within Model-Driven Environments. In Software Engineering (Workshops) (Vol. 122, pp. 205-211).

[10] Saraiva, De França, Soares, Filho, De Souza. (2015). Classifying metrics for assessing Object-Oriented Software Maintainability: A family of metrics' catalogs. The Journal of Systems Software, 103(C), 85-101.

[11] Sonal, D., Kaur, G. (2013). Comparative Study of the Software Metrics for the complexity and Maintainability of Software Development. International Journal of Advanced Computer Science and Applications, 4(9), International Journal of Advanced Computer Science and Applications, 2013, Vol.4(9).

[12] Misra, S. (2005). Modeling Design/Coding Factors That Drive Maintainability of Software Systems. Software Quality Journal,13(3), 297-320.

[13] Schroeder, J., Berger, C., Herpel, T., Staron, M. (2015). Comparing the Applicability of Complexity Measurements for Simulink Models during Integration Testing - An Industrial Case Study. Software Architecture and Metrics (SAM), 2015 IEEE/ACM 2nd International Workshop on, 35-40.

[14] Bagheri, E., Gasevic, D. (2011). Assessing the maintainability of software product line feature models using structural metrics. Software Quality Journal, 19(3), 579-612.

[15] Koziolek, H., Domis, D., Goldschmidt, T., Vorst, P. (2013). Measuring architecture sustainability. IEEE software, 30(6), 54-62.

[16] Runeson, P. and Höst, M., 2009. Guidelines for conducting and reporting case study research in software engineering. Empirical software engineering, 14(2), Pp.131-164.

[17] “SystemWeaver”, Systemite, https://www.systemweaver.se

[18] Boyce, C., Neale, P. (2006). Conducting in-depth interviews: A guide for designing and conducting in-depth interviews for evaluation input.

[19] France, R. and Rumpe, B., 2007, May. Model-driven development of complex software: A research roadmap. In 2007 Future of Software Engineering (pp. 37-54). IEEE Computer Society.

[20] Ludwig, J., Xu, S., Paperbber, F. (2017, October). Compiling static software metrics for reliability and maintainability from GitHub repositories. In 2017 IEEE International Conference on Systems, Man, and Cybernetics (SMC) (pp. 5-9). IEEE.

[21] Felix. B. Tan, Karl. A. Stroetmann. (2014). New Perspectives in Information Systems and Technologies, Volume 1. Á. Rocha, A. M. Correia (Eds.). Springer International Publishing.

[22] Rocha, A., Correia, A. M., Costanzo, S., Reis, L. P. (Eds.). (2015). New contributions in information systems and technologies (Vol. 1). Springer.

[23] Poshyvanyk, D., Marcus, A. (2006, September). The conceptual coupling metrics for object-oriented systems. In 2006 22nd IEEE International Conference on Software Maintenance (pp. 469-478). IEEE.

[24] Jeusfeld M.A. (2009) Metamodel. In: LIU L., ÖZSU M.T. (eds) Encyclopedia of Database Systems. Springer, Boston, MA

[25] Kruchten, P. (2004). The rational unified process: an introduction. Addison-Wesley Professional.

A
ASTS Tool

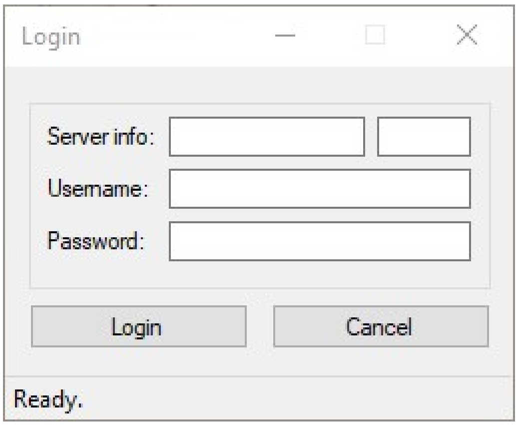


Figure A.1: ASTS interface - login

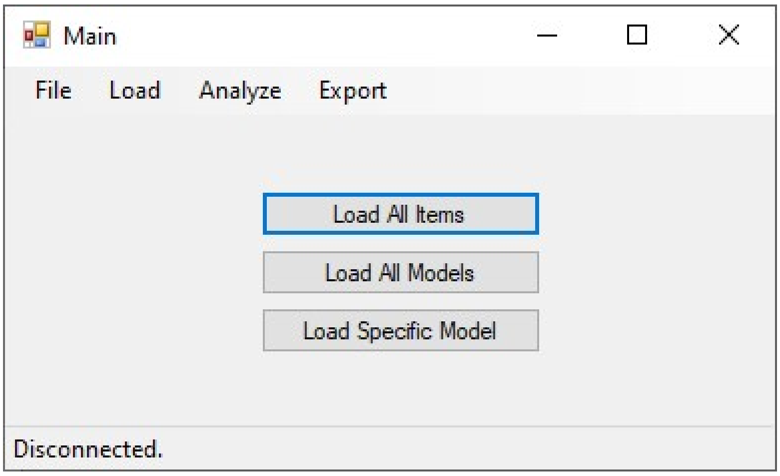


Figure A.2: ASTS interface - main

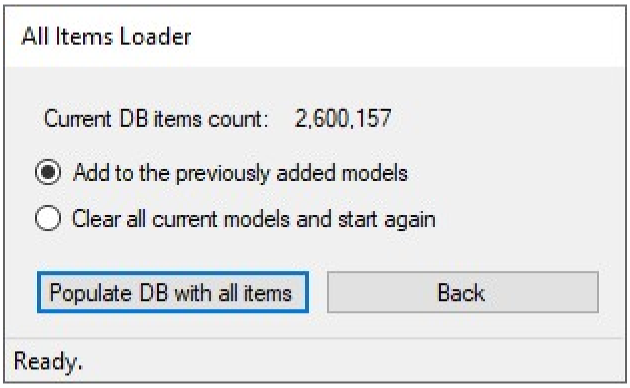


Figure A.3: ASTS interface - all items loader

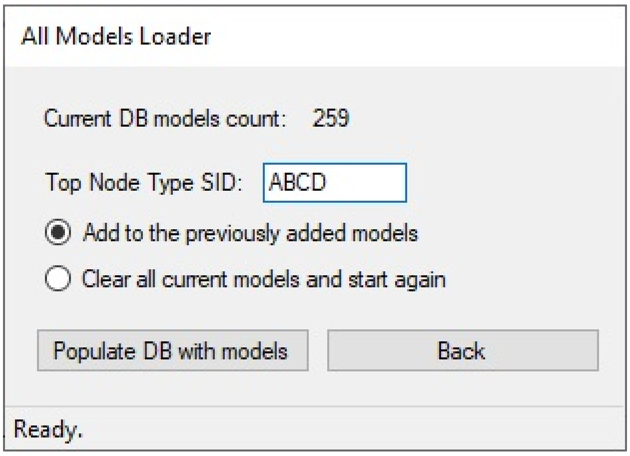


Figure A.4: ASTS interface - all models loader

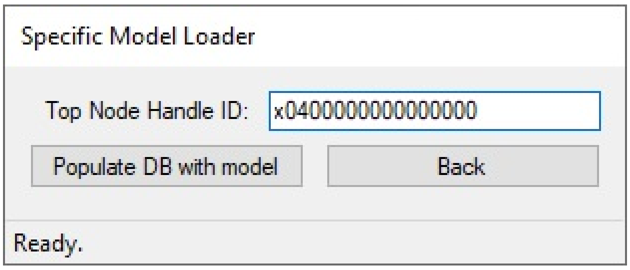


Figure A.5: ASTS interface - specific model loader

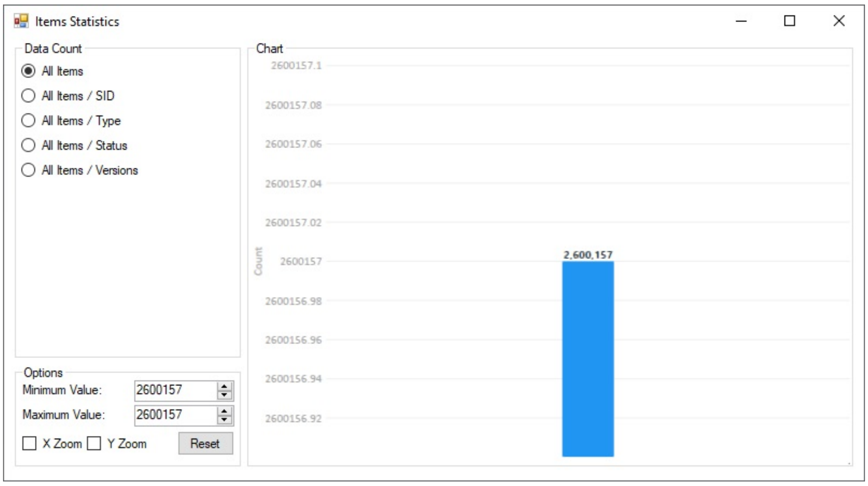


Figure A.6: ASTS items statistics - count of all items

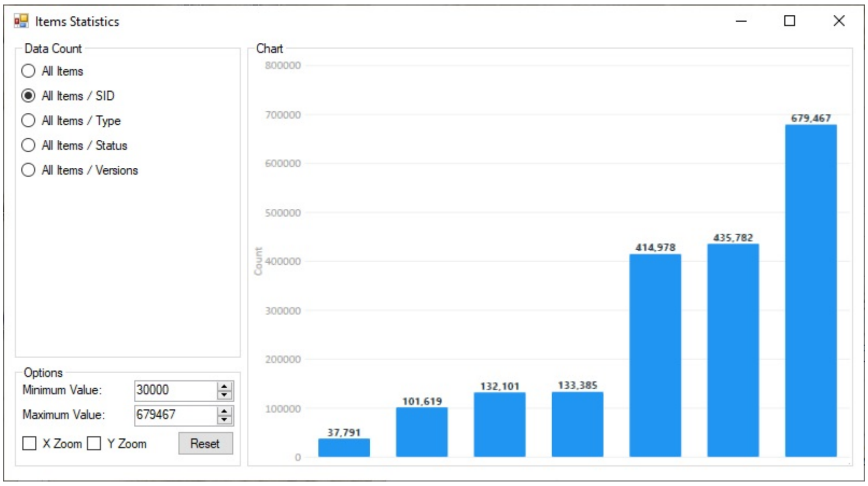


Figure A.7: ASTS items statistics - count by SID

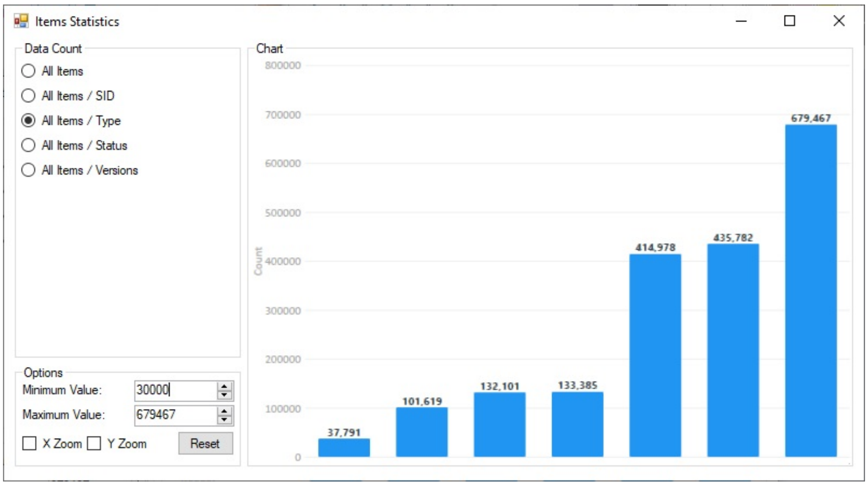


Figure A.8: ASTS items statistics - count by type

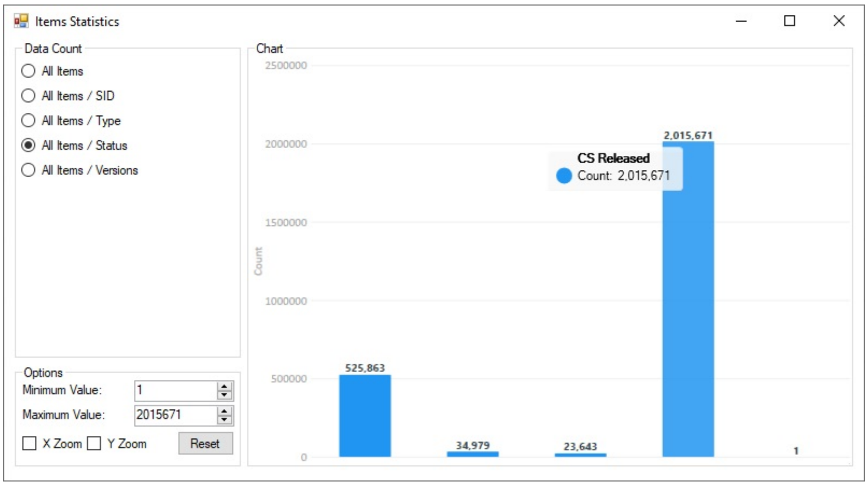


Figure A.9: ASTS items statistics - count by status

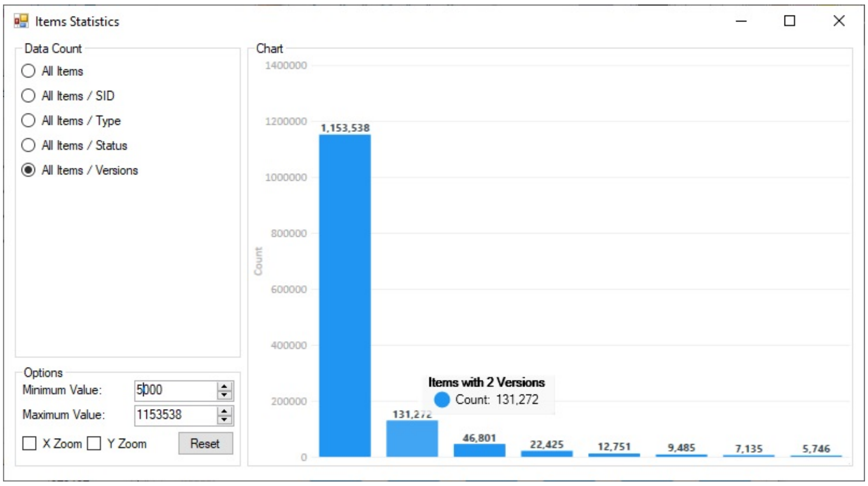


Figure A.10: ASTS items statistics - count by versions

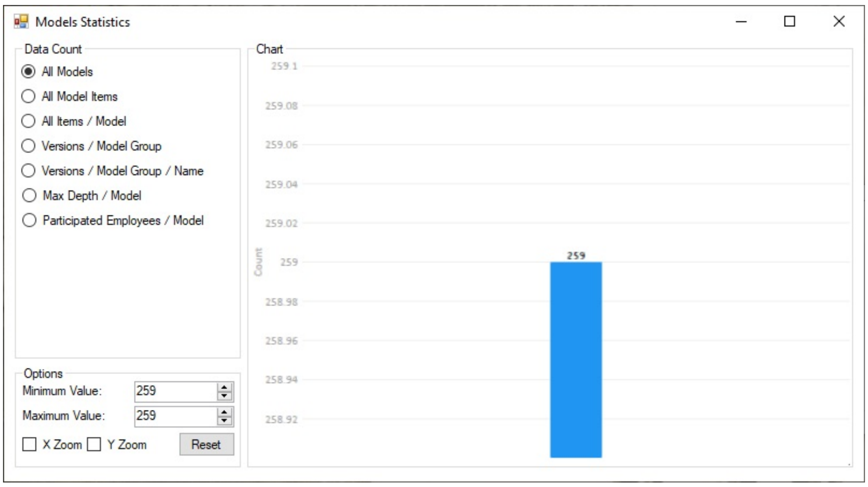


Figure A.11: ASTS models statistics - count of all models

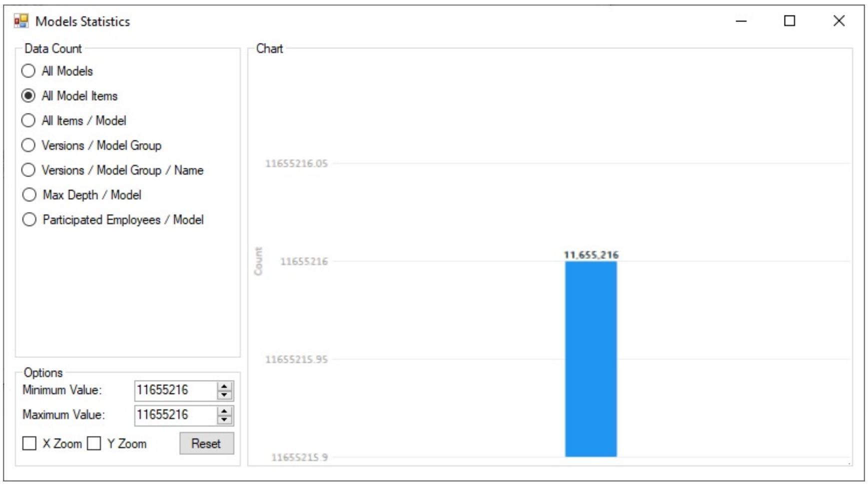


Figure A.12: ASTS models statistics - count of all model items

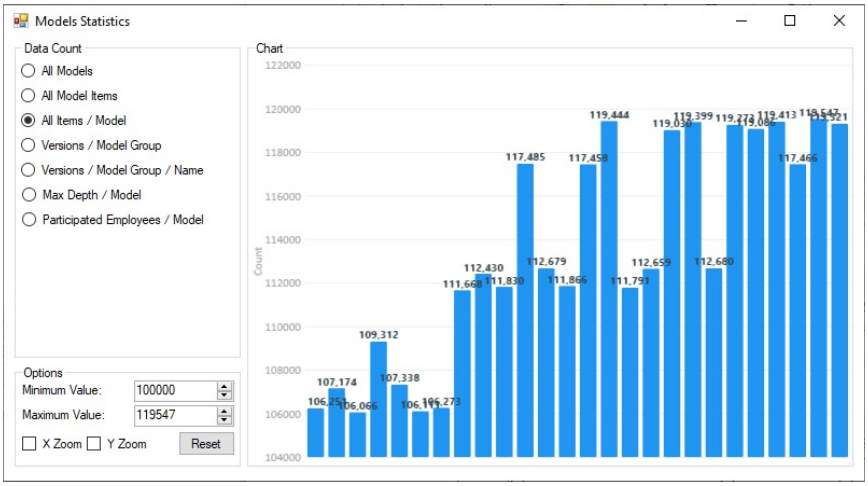


Figure A.13: ASTS models statistics - count items by model

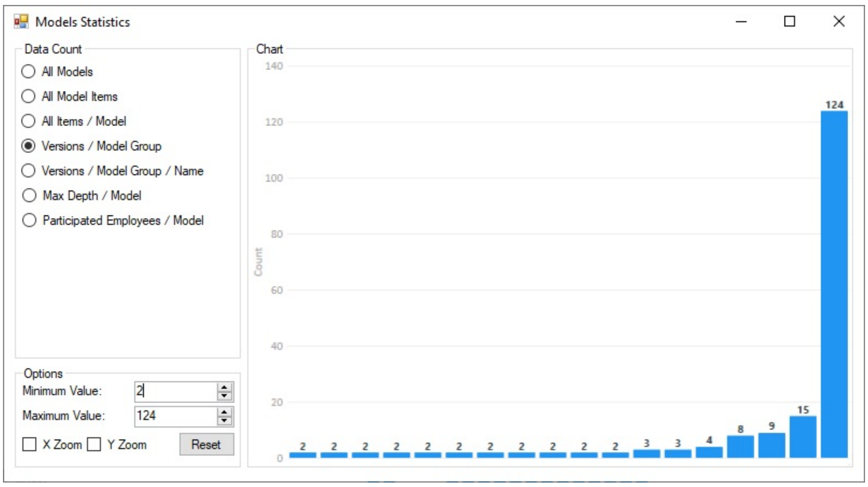


Figure A.14: ASTS models statistics - count versions by model group

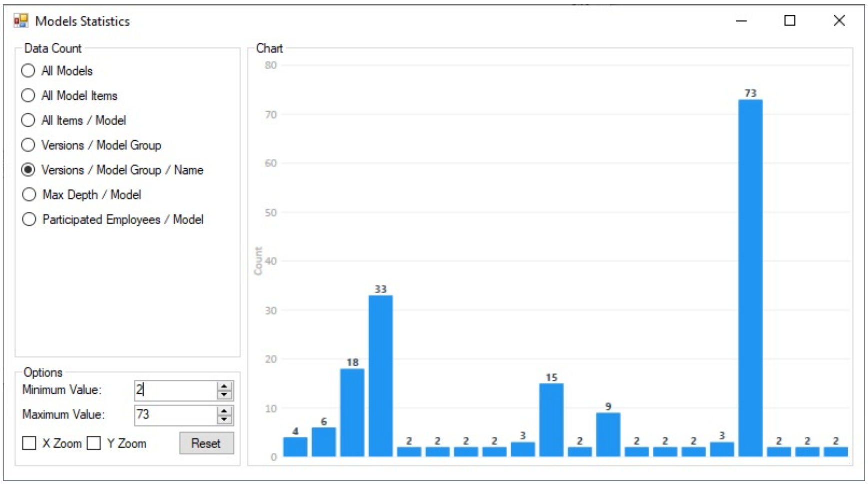


Figure A.15: ASTS models statistics - count versions by model group name

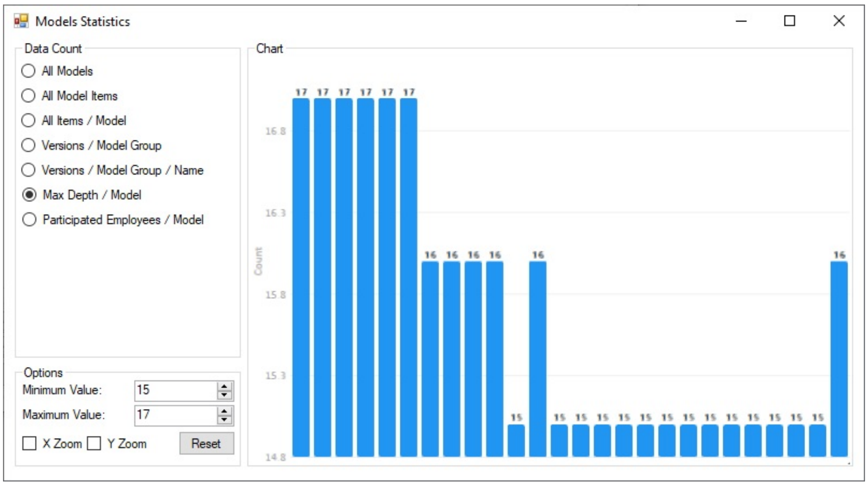


Figure A.16: ASTS models statistics - count depth by model

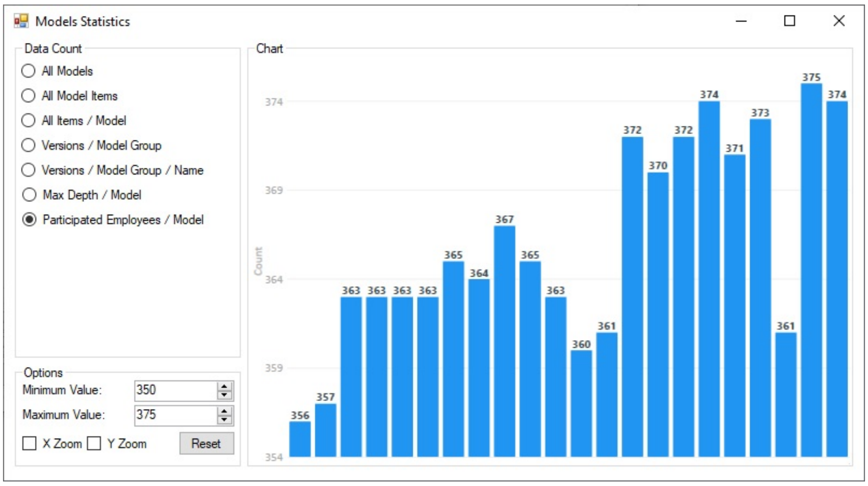


Figure A.17: ASTS models statistics - count employees by model

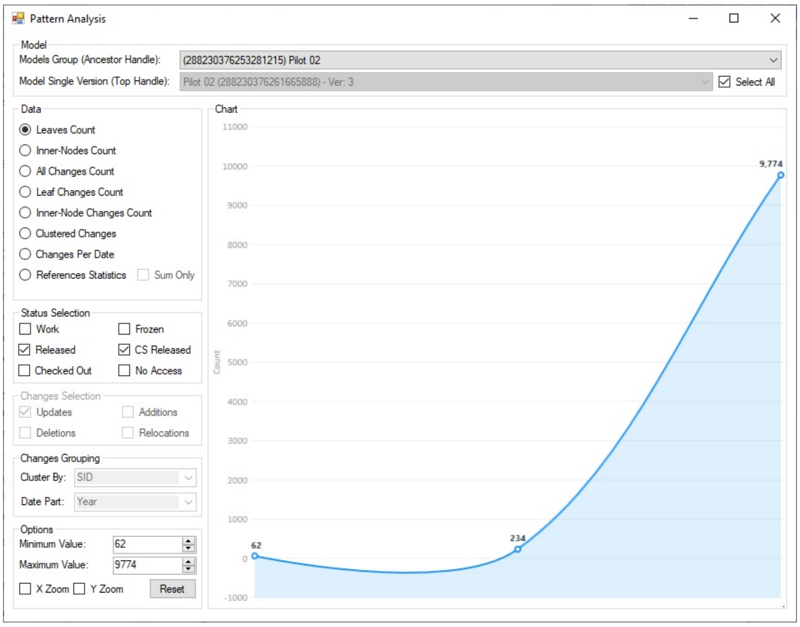


Figure A.18: ASTS patterns statistics - count of leaf nodes

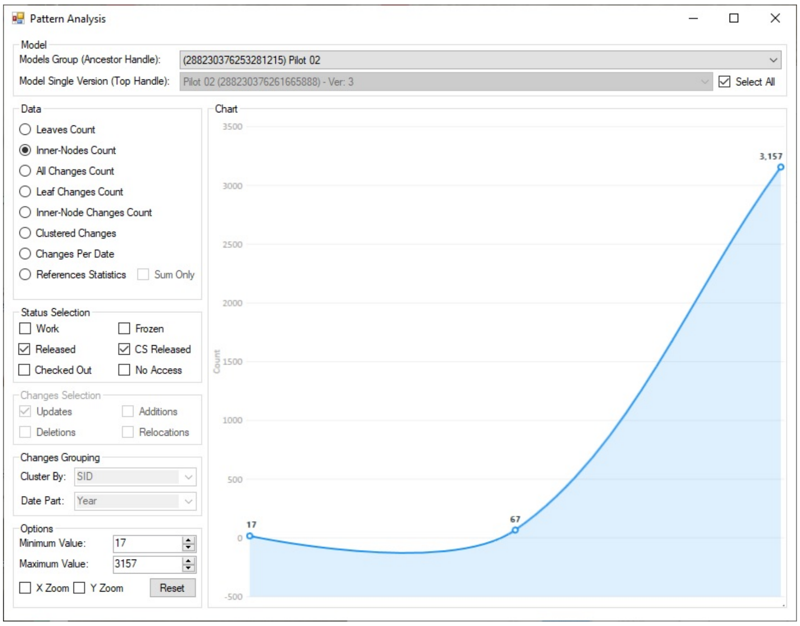


Figure A.19: ASTS patterns statistics - count of inner nodes

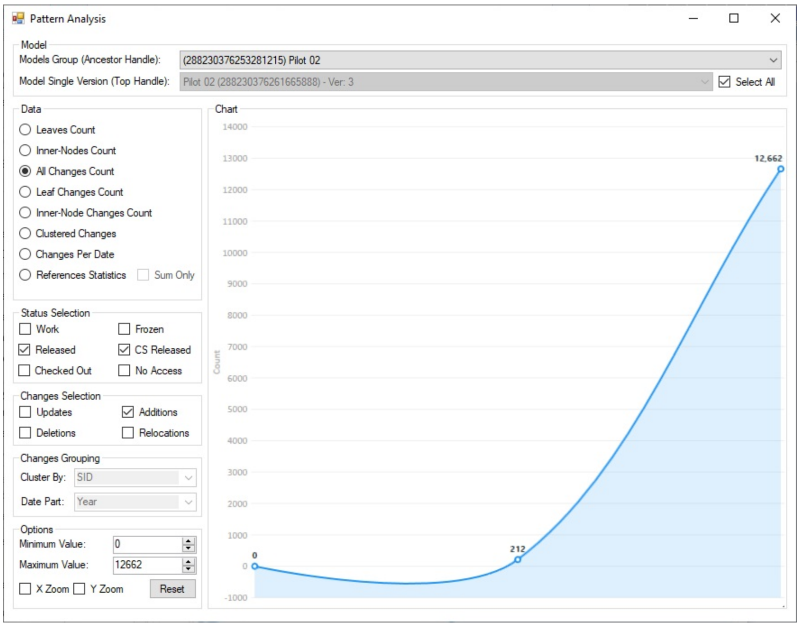


Figure A.20: ASTS patterns statistics - count of all changes

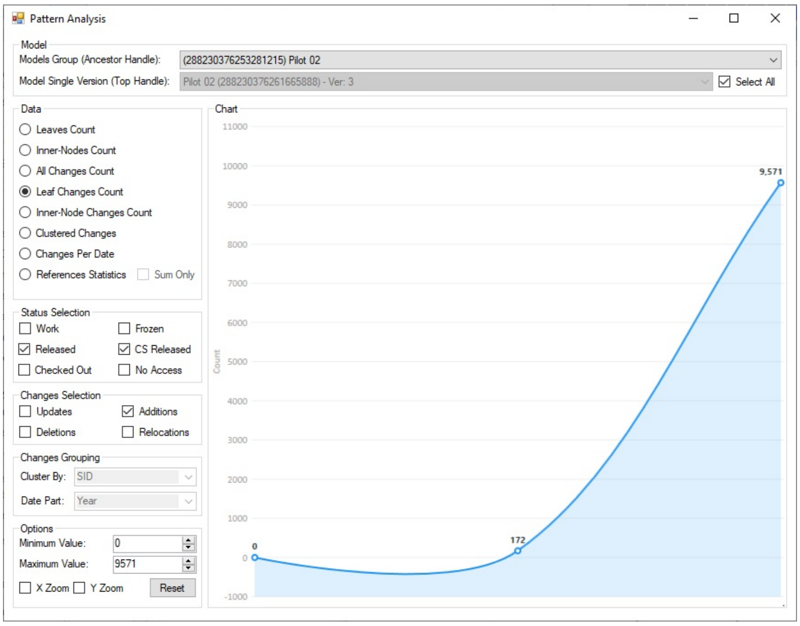


Figure A.21: ASTS patterns statistics - count of leaf node changes

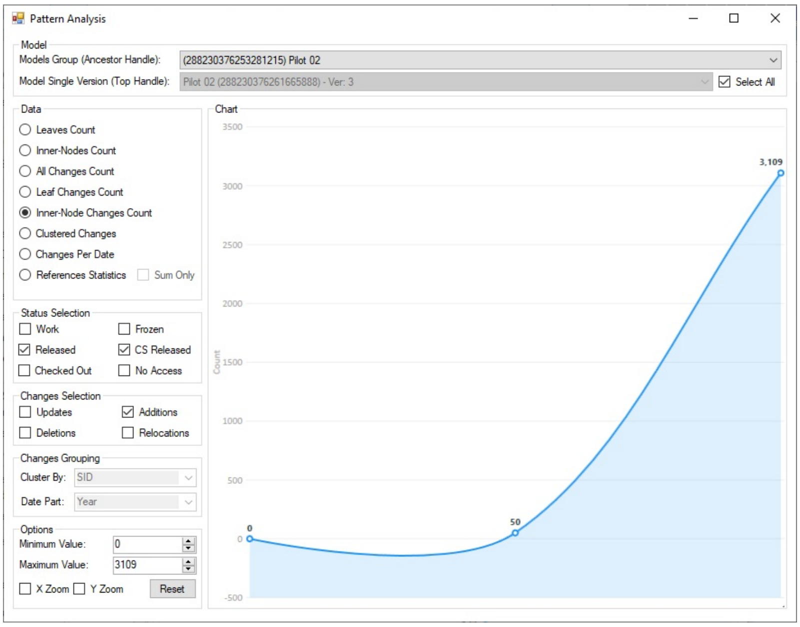


Figure A.22: ASTS patterns statistics - count of inner node changes

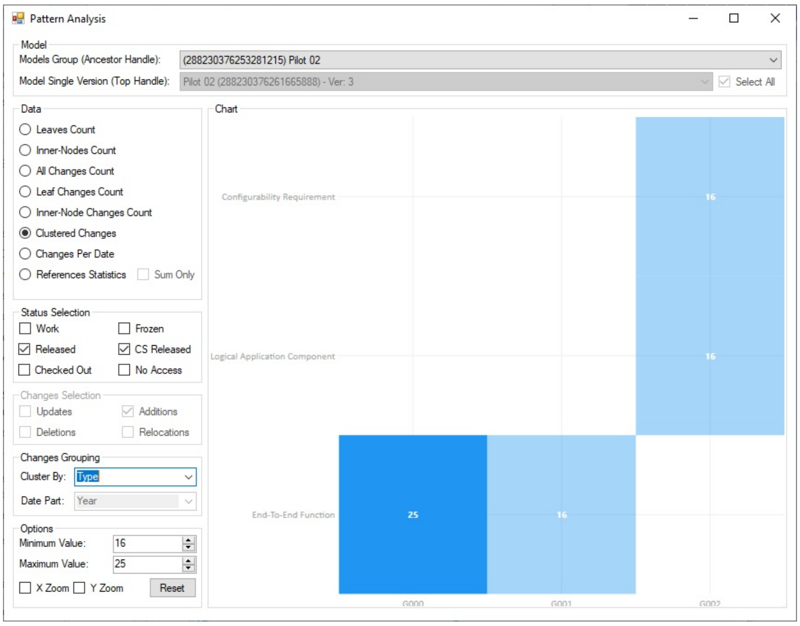


Figure A.23: ASTS patterns statistics - count of clustered changes

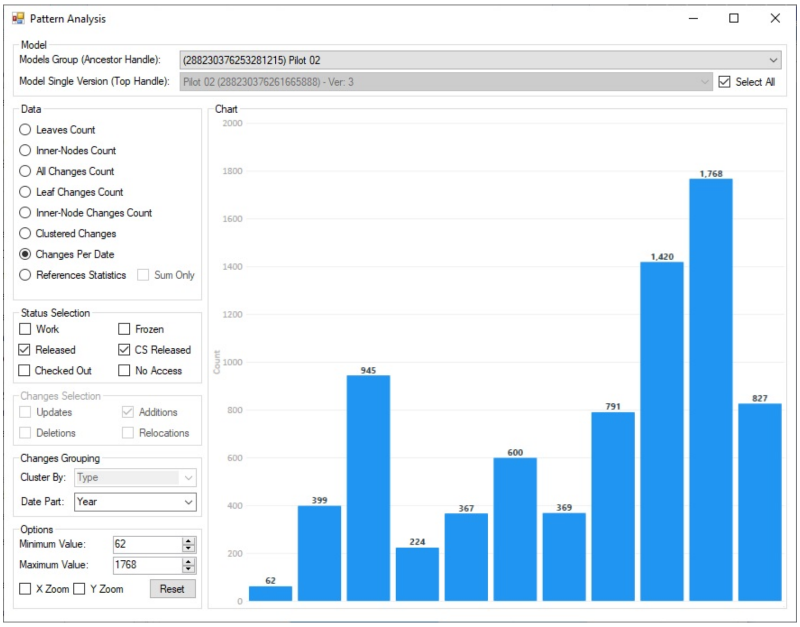


Figure A.24: ASTS patterns statistics - count of changes per date

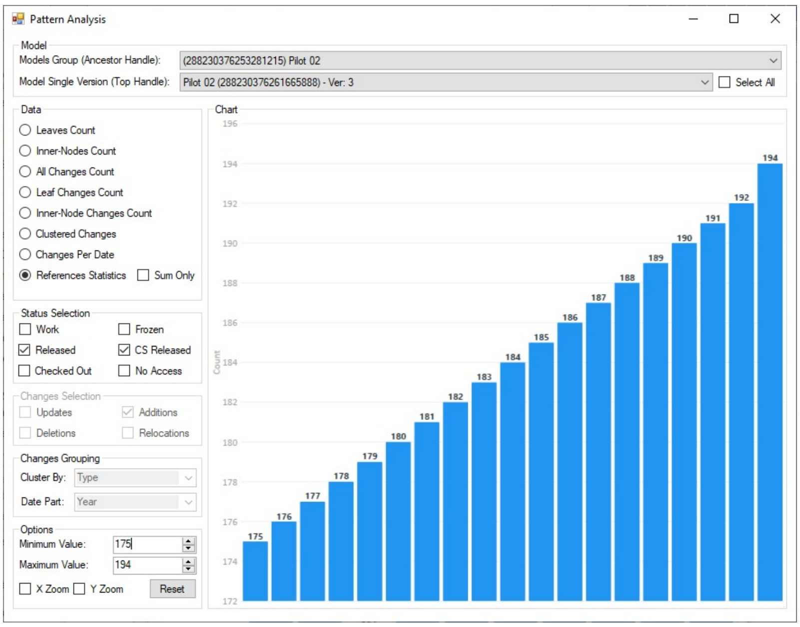


Figure A.25: ASTS patterns statistics - count of references

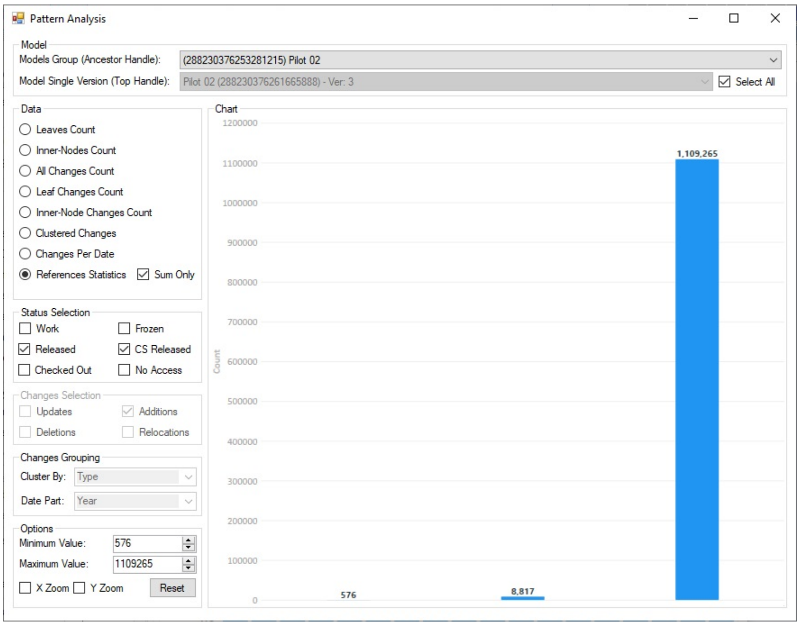


Figure A.26: ASTS patterns statistics - Sum of references

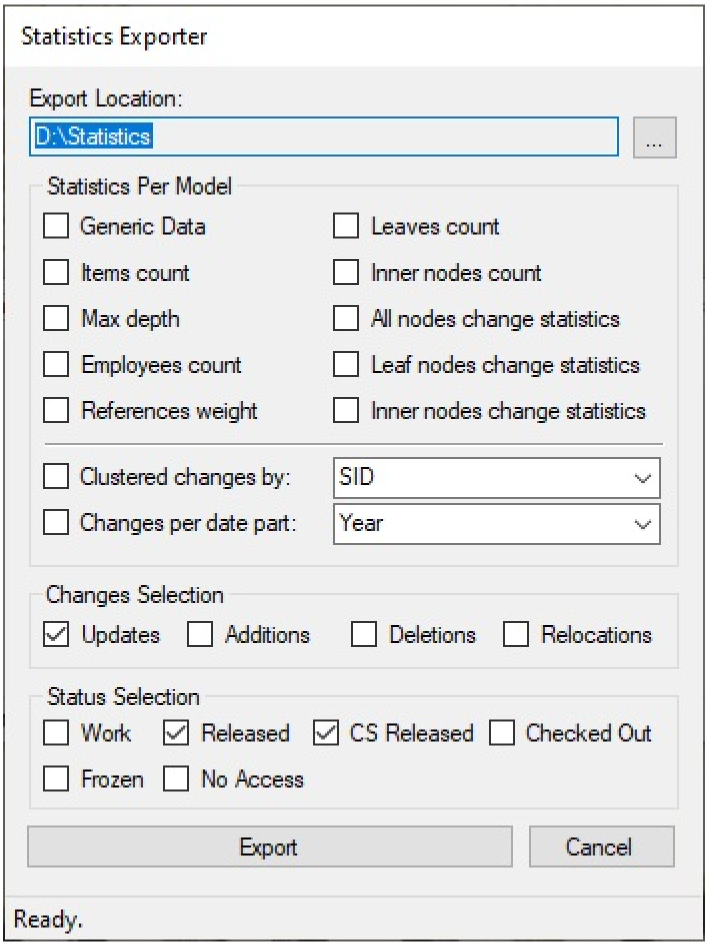


Figure A.27: ASTS exporting - statistics results

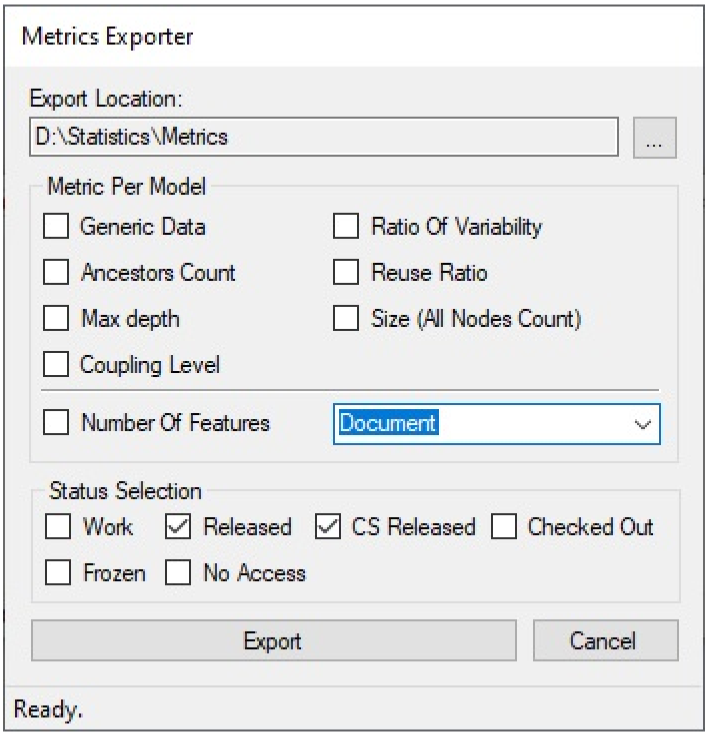


Figure A.28: ASTS exporting - metrics results

B

Data Characteristics Results

Table B.1: Data Characteristics results for model group 10 - Part 1

ID	Clust	EC	AW	MCW	CW	AM	MCM	CM	AY	MCY	CY
10	1,508.92	36,963.00	176	7,074.00	200836	48	12,227.00	20089	8	76,182.00	2008

Table B.2: Data Characteristics results for model group 10 - Part 2

ID	Root	V	MD	RW	EC	L	IN	T	LCP	INCP	LCoP	INCoP
10	YES	1	9	983,470.00	102	18,382.00	3,969.00	22,497.00	0.00%	0.00%	0.00%	0.00%
11	-	2	9	1,285,449.00	109	22,971.00	5,205.00	28,230.00	73.81%	23.73%	36.23%	51.41%
12	-	3	9	1,347,639.00	115	23,723.00	5,412.00	29,182.00	69.17%	23.54%	26.33%	39.28%
13	-	4	9	1,502,791.00	119	26,191.00	6,137.00	32,364.00	72.57%	24.46%	39.65%	57.03%
14	-	5	10	1,940,419.00	125	33,476.00	8,739.00	42,334.00	71.51%	27.31%	36.06%	52.75%
15	-	6	11	1,950,309.00	121	27,423.00	6,693.00	34,159.00	67.34%	24.36%	47.43%	70.30%
16	-	7	10	2,186,773.00	124	27,856.00	6,925.00	34,795.00	66.40%	27.65%	33.95%	56.85%
17	-	8	11	2,245,358.00	128	27,943.00	7,020.00	34,978.00	65.89%	25.74%	24.80%	38.58%
18	-	9	11	2,286,072.00	131	28,188.00	7,029.00	35,234.00	67.63%	21.68%	20.30%	26.09%

Table B.3: Data Characteristics results for model group 10 - Part 3

ID	LCu	LCa	LCd	LCr	LCt	INCu	INCa	INCd	INCr	INCt	TCu	TCa	TCd	TCr	TCt
10	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
11	4,358.00	3,297.00	589	79	8,323.00	1,549.00	926	152	49	2,676.00	6,427.00	3,762.00	620	468	11,277.00
12	4,767.00	1,046.00	395	39	6,247.00	1,693.00	278	139	16	2,126.00	7,170.00	1,224.00	444	193	9,031.00
13	5,948.00	3,212.00	1,145.00	80	10,385.00	2,419.00	759	259	63	3,500.00	9,174.00	3,534.00	1,080.00	522	14,310.00
14	7,664.00	4,136.00	220	51	12,071.00	3,313.00	1,141.00	99	57	4,610.00	11,910.00	4,360.00	74	536	16,880.00
15	8,168.00	674	3,989.00	176	13,007.00	3,269.00	232	1,060.00	144	4,705.00	12,752.00	810	4,299.00	1,454.00	19,315.00
16	7,416.00	1,058.00	969	13	9,456.00	3,233.00	326	274	104	3,937.00	11,623.00	1,025.00	1,004.00	588	14,240.00
17	5,968.00	500	446	17	6,931.00	2,413.00	158	112	25	2,708.00	9,334.00	518	441	226	10,519.00
18	5,501.00	172	48	0	5,721.00	1,825.00	7	2	0	1,834.00	8,235.00	167	49	8	8,459.00

Table B.4: Data Characteristics results for model group 19 - Part 1

ID	Clust	EC	AW	MCW	CW	AM	MCM	CM	AY	MCY	CY
19	5,545.28	97,468.00	351	17,055.00	20122	94	34,099.00	20098	11	201,340.00	2009

Table B.5: Data Characteristics results for model group 19 - Part 2

ID	Root	V	MD	RW	EC	L	IN	T	LCP	INCP	LCoP	INCoP
19	YES	1	9	596,256.00	68	7,039.00	1,311.00	8,369.00	0.00%	0.00%	0.00%	0.00%
20	-	2	9	778,720.00	80	10,511.00	2,226.00	12,752.00	79.38%	23.75%	36.89%	52.11%
21	-	3	9	1,549,622.00	117	21,033.00	5,271.00	26,371.00	76.60%	23.91%	57.09%	71.09%
22	-	4	9	1,471,758.00	118	18,213.00	4,288.00	22,523.00	74.83%	29.63%	41.80%	70.31%
23	-	5	11	1,973,831.00	127	22,712.00	5,768.00	28,807.00	74.42%	27.12%	45.76%	65.67%
24	-	6	12	2,176,896.00	126	23,242.00	6,011.00	29,579.00	64.17%	30.91%	32.60%	60.72%

Table B.5: Data Characteristics results for model group 19 - Part 2

ID	Root	V	MD	RW	EC	L	IN	T	LCP	INCP	LCoP	INCoP
25	-	7	12	2,246,208.00	128	21,281.00	5,389.00	26,991.00	65.89%	30.41%	31.93%	58.21%
26	-	8	11	2,432,516.00	136	19,750.00	4,692.00	24,457.00	72.30%	30.34%	38.17%	67.41%
27	-	7a1	12	2,499,416.00	142	24,076.00	6,393.00	30,803.00	84.45%	21.44%	16.81%	16.06%
28	-	7a2	12	2,480,198.00	146	23,025.00	5,834.00	29,185.00	57.83%	32.48%	19.27%	42.72%
29	-	7a3	11	2,557,756.00	143	22,075.00	5,612.00	27,690.00	67.16%	28.28%	27.71%	45.90%
30	-	9	11	2,453,284.00	138	19,772.00	4,727.00	24,510.00	74.96%	27.17%	19.41%	29.43%
31	-	10	11	2,759,003.00	157	20,854.00	5,158.00	26,012.00	72.97%	32.05%	29.71%	52.75%
32	-	11	11	3,595,473.00	197	27,648.00	7,704.00	35,353.00	74.67%	29.91%	32.28%	46.39%
33	-	12	11	3,754,105.00	199	28,826.00	8,187.00	37,013.00	51.63%	29.15%	23.74%	47.18%
34	-	11a1	11	3,465,938.00	195	25,682.00	7,095.00	32,777.00	57.17%	28.17%	27.18%	48.48%
35	-	11b1	11	3,616,257.00	196	27,371.00	7,833.00	35,204.00	59.91%	30.57%	21.88%	39.03%
36	-	13	11	3,779,859.00	200	29,092.00	8,366.00	37,459.00	51.01%	29.49%	23.88%	47.99%
37	-	14	10	4,051,612.00	208	30,511.00	8,761.00	39,272.00	55.92%	28.93%	29.94%	53.93%
38	-	11b2	11	3,729,116.00	199	28,290.00	8,156.00	36,446.00	59.89%	28.53%	25.34%	41.88%
39	-	11b3	13	4,002,345.00	217	30,435.00	8,999.00	39,434.00	59.15%	28.90%	24.54%	40.55%
40	-	15	11	4,181,756.00	210	31,906.00	9,366.00	41,272.00	60.08%	30.00%	35.16%	59.80%
41	-	11b4	13	4,057,426.00	218	31,066.00	9,203.00	40,269.00	59.50%	29.12%	29.66%	48.99%
42	-	11b5	13	4,083,042.00	215	31,327.00	9,307.00	40,634.00	58.67%	28.63%	21.97%	36.08%
43	-	11b6	13	4,382,449.00	225	34,979.00	10,197.00	45,176.00	65.15%	26.47%	28.73%	40.05%
44	-	16	13	4,768,759.00	230	38,199.00	11,225.00	49,424.00	56.15%	29.19%	32.38%	57.27%
45	-	11b7	13	4,418,865.00	226	35,276.00	10,252.00	45,528.00	58.28%	29.88%	29.60%	52.21%
46	-	17	13	5,214,704.00	234	41,573.00	12,375.00	53,948.00	60.87%	28.42%	41.08%	64.44%
47	-	16a1	13	4,891,123.00	232	38,604.00	11,787.00	50,391.00	60.96%	29.88%	32.80%	52.66%
48	-	18	13	5,434,929.00	243	42,164.00	12,449.00	54,613.00	58.32%	29.18%	38.34%	64.96%
49	-	17a1	13	5,215,430.00	235	41,573.00	12,375.00	53,948.00	63.13%	28.04%	22.31%	33.28%
50	-	16a2	13	4,887,867.00	231	38,569.00	11,768.00	50,337.00	60.97%	29.90%	32.80%	52.72%
51	-	18a1	13	5,429,161.00	245	41,636.00	12,267.00	53,903.00	58.81%	29.19%	39.66%	66.81%

Table B.6: Data Characteristics results for model group 19 - Part 3

ID	LCu	LCa	LCd	LCr	LCt	INCu	INCa	INCd	INCr	INCt	TCu	TCa	TCd	TCr	TCt
19	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
20	833	2,975.00	67	2	3,877.00	427	706	22	5	1,160.00	1,338.00	3,494.00	35	17	4,884.00
21	2,324.00	9,411.00	258	14	12,007.00	1,116.00	2,498.00	66	67	3,747.00	3,686.00	11,462.00	211	315	15,674.00
22	3,007.00	1,814.00	2,790.00	2	7,613.00	1,749.00	571	693	2	3,015.00	5,250.00	2,133.00	2,758.00	33	10,174.00
23	4,377.00	4,625.00	1,358.00	34	10,394.00	2,136.00	1,195.00	354	103	3,788.00	6,899.00	5,190.00	1,469.00	408	13,966.00
24	4,953.00	1,234.00	1,310.00	80	7,577.00	2,744.00	312	353	241	3,650.00	8,366.00	1,057.00	1,321.00	1,064.00	11,808.00
25	4,163.00	821	1,782.00	30	6,796.00	2,470.00	219	356	92	3,137.00	7,323.00	830	1,643.00	518	10,314.00
26	3,683.00	1,618.00	2,233.00	4	7,538.00	2,243.00	324	591	5	3,163.00	6,506.00	1,613.00	2,273.00	34	10,426.00
27	1,001.00	2,513.00	379	153	4,046.00	278	574	117	58	1,027.00	1,428.00	2,323.00	363	677	4,791.00
28	3,374.00	325	685	53	4,437.00	1,943.00	84	134	331	2,492.00	5,910.00	294	434	1,035.00	7,673.00
29	4,473.00	505	1,136.00	4	6,118.00	2,051.00	147	285	93	2,576.00	7,110.00	430	1,181.00	388	9,109.00
30	1,984.00	390	1,453.00	11	3,838.00	859	140	367	25	1,391.00	3,225.00	369	1,350.00	176	5,120.00
31	3,191.00	2,003.00	990	12	6,196.00	1,816.00	637	249	19	2,721.00	5,477.00	2,094.00	787	133	8,491.00
32	4,021.00	4,410.00	452	41	8,924.00	1,986.00	1,310.00	207	71	3,574.00	6,592.00	4,629.00	308	422	11,951.00
33	5,359.00	1,085.00	259	140	6,843.00	2,721.00	390	123	629	3,863.00	8,993.00	1,069.00	134	3,058.00	13,254.00
34	4,107.00	219	2,490.00	165	6,981.00	1,896.00	158	794	592	3,440.00	6,841.00	111	2,721.00	2,538.00	12,211.00
35	4,265.00	1,358.00	206	161	5,990.00	2,138.00	567	149	203	3,057.00	7,192.00	1,387.00	44	1,376.00	9,999.00
36	4,874.00	1,580.00	328	164	6,946.00	2,516.00	528	253	718	4,015.00	8,347.00	1,541.00	139	3,589.00	13,616.00
37	6,693.00	1,608.00	674	159	9,134.00	3,438.00	482	248	557	4,725.00	11,269.00	1,582.00	513	2,971.00	16,335.00
38	4,085.00	627	2,259.00	199	7,170.00	1,933.00	397	716	370	3,416.00	6,896.00	360	2,243.00	2,473.00	11,972.00

Table B.6: Data Characteristics results for model group 19 - Part 3

ID	LCu	LCa	LCd	LCr	LCt	INCu	INCa	INCd	INCr	INCt	TCu	TCa	TCd	TCr	TCt
39	6,004.00	1,311.00	124	29	7,468.00	3,075.00	393	21	160	3,649.00	10,241.00	1,427.00	52	905	12,625.00
40	7,081.00	2,491.00	1,360.00	287	11,219.00	3,671.00	725	618	587	5,601.00	12,098.00	2,376.00	1,218.00	2,981.00	18,673.00
41	5,540.00	1,368.00	2,119.00	187	9,214.00	2,795.00	620	639	455	4,509.00	9,542.00	1,217.00	2,000.00	2,727.00	15,486.00
42	6,499.00	133	39	212	6,883.00	3,253.00	25	6	74	3,358.00	11,101.00	77	6	547	11,731.00
43	6,824.00	3,159.00	36	32	10,051.00	3,518.00	472	5	89	4,084.00	11,739.00	3,291.00	12	385	15,427.00
44	8,643.00	2,861.00	566	298	12,368.00	4,478.00	930	345	676	6,429.00	14,945.00	2,939.00	281	3,861.00	22,026.00
45	6,717.00	553	2,681.00	489	10,440.00	3,555.00	335	884	579	5,353.00	11,855.00	276	2,763.00	3,019.00	17,913.00
46	9,502.00	6,097.00	1,050.00	428	17,077.00	4,918.00	1,878.00	468	710	7,974.00	16,357.00	6,881.00	708	4,111.00	28,057.00
47	7,965.00	968	3,488.00	243	12,664.00	4,224.00	542	1,001.00	440	6,207.00	14,077.00	782	3,812.00	2,102.00	20,773.00
48	9,602.00	4,677.00	1,462.00	424	16,165.00	5,245.00	1,351.00	650	841	8,087.00	17,010.00	5,218.00	1,065.00	4,424.00	27,717.00
49	7,239.00	688	1,282.00	65	9,274.00	3,478.00	178	367	96	4,119.00	12,379.00	464	1,398.00	449	14,690.00
50	7,951.00	968	3,495.00	238	12,652.00	4,218.00	543	1,006.00	437	6,204.00	14,061.00	782	3,823.00	2,084.00	20,750.00
51	9,687.00	4,815.00	1,614.00	398	16,514.00	5,310.00	1,397.00	650	839	8,196.00	17,236.00	5,400.00	1,118.00	4,325.00	28,079.00

Table B.7: Data Characteristics results for model group 52 - Part 1

ID	Clust	EC	AW	MCW	CW	AM	MCM	CM	AY	MCY	CY
52	10,549.08	105,840.00	384	23,710.00	20173	101	23,734.00	20171	11	150,980.00	2012

Table B.8: Data Characteristics results for model group 52 - Part 2

ID	Root	V	MD	RW	EC	L	IN	T	LCP	INCP	LCoP	INCoP
52	YES	11b8	13	4,452,560.00	229	35,456.00	10,296.00	45,752.00	0.00%	0.00%	0.00%	0.00%
53	-	11b9	13	4,487,096.00	230	35,680.00	10,402.00	46,082.00	56.88%	29.00%	22.52%	39.40%
54	-	17a1a1	13	4,906,748.00	232	37,722.00	11,853.00	49,575.00	60.53%	27.86%	42.30%	61.97%
55	-	19	13	5,589,024.00	249	43,769.00	13,131.00	56,900.00	65.71%	27.13%	38.93%	53.58%
56	-	17a1a2	13	4,972,044.00	236	38,319.00	11,984.00	50,303.00	67.92%	25.69%	38.23%	46.24%
57	-	17a1a3	13	4,956,676.00	235	38,050.00	11,904.00	49,954.00	57.16%	29.05%	22.59%	36.69%
58	-	17a1a2a1	13	4,972,230.00	235	38,332.00	11,989.00	50,321.00	57.97%	28.85%	22.17%	35.28%
59	-	20	13	5,627,815.00	251	43,887.00	13,175.00	57,062.00	65.72%	27.19%	39.40%	54.31%
60	-	19a1	14	5,564,382.00	250	42,990.00	12,819.00	55,809.00	58.86%	28.91%	22.74%	37.45%
61	-	21	14	5,780,121.00	264	45,476.00	13,642.00	59,118.00	58.41%	28.53%	26.35%	42.90%
62	-	20a1	13	5,663,994.00	257	43,783.00	12,961.00	56,744.00	60.53%	28.41%	25.06%	39.73%
63	-	22	14	5,877,323.00	271	46,276.00	13,781.00	60,057.00	61.61%	28.45%	26.74%	41.46%
64	-	21a1	14	5,794,433.00	264	44,978.00	13,278.00	58,256.00	59.08%	28.38%	24.89%	40.50%
65	-	20a2	13	5,666,011.00	257	43,820.00	12,975.00	56,795.00	61.92%	27.50%	22.74%	34.10%
66	-	22a1	14	5,903,904.00	274	46,093.00	13,620.00	59,713.00	60.77%	28.50%	27.18%	43.14%
67	-	21a2	14	5,794,920.00	264	44,993.00	13,285.00	58,278.00	60.36%	27.50%	23.05%	35.57%
68	-	22a2	14	5,904,174.00	274	46,101.00	13,624.00	59,725.00	59.10%	28.94%	23.59%	39.08%
69	-	22a1a1	14	5,904,087.00	274	46,113.00	13,630.00	59,743.00	58.37%	27.65%	20.48%	32.81%

Table B.9: Data Characteristics results for model group 52 - Part 3

ID	LCu	LCa	LCd	LCr	LCt	INCu	INCa	INCd	INCr	INCt	TCu	TCa	TCd	TCr	TCt
52	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Table B.9: Data Characteristics results for model group 52 - Part 3

ID	LCu	LCa	LCd	LCr	LCt	INCu	INCa	INCd	INCr	INCt	TCu	TCa	TCd	TCr	TCt
53	7,449.00	394	175	18	8,036.00	3,806.00	151	34	107	4,098.00	13,114.00	422	112	481	14,129.00
54	8,700.00	4,004.00	2,861.00	391	15,956.00	4,628.00	1,376.00	609	732	7,345.00	15,209.00	4,375.00	2,716.00	4,062.00	26,362.00
55	9,823.00	6,183.00	941	94	17,041.00	5,206.00	1,245.00	311	273	7,035.00	17,085.00	6,872.00	751	1,225.00	25,933.00
56	7,639.00	967	5,954.00	91	14,651.00	3,823.00	318	1,215.00	185	5,541.00	13,198.00	779	6,623.00	970	21,570.00
57	8,362.00	53	173	6	8,594.00	4,294.00	13	20	40	4,367.00	14,698.00	48	161	128	15,035.00
58	8,262.00	185	52	0	8,499.00	4,177.00	21	12	20	4,230.00	14,417.00	161	47	36	14,661.00
59	10,018.00	6,148.00	1,022.00	105	17,293.00	5,294.00	1,254.00	319	289	7,156.00	17,417.00	6,840.00	792	1,265.00	26,314.00
60	9,018.00	224	520	14	9,776.00	4,581.00	67	87	66	4,801.00	15,688.00	208	399	313	16,608.00
61	9,851.00	1,636.00	431	64	11,982.00	5,107.00	272	85	389	5,853.00	16,918.00	1,510.00	388	1,699.00	20,515.00
62	9,306.00	494	1,149.00	22	10,971.00	4,694.00	123	207	125	5,149.00	16,158.00	450	975	542	18,125.00
63	9,941.00	1,803.00	521	110	12,375.00	5,088.00	324	132	170	5,714.00	17,107.00	1,579.00	470	929	20,085.00
64	9,966.00	331	813	87	11,197.00	4,925.00	109	172	172	5,378.00	17,246.00	309	594	804	18,953.00
65	8,629.00	293	1,041.00	1	9,964.00	4,239.00	31	155	0	4,425.00	14,870.00	195	994	34	16,093.00
66	10,092.00	1,977.00	366	94	12,529.00	5,224.00	416	51	185	5,876.00	17,524.00	1,997.00	235	861	20,617.00
67	9,195.00	92	913	173	10,373.00	4,378.00	27	264	57	4,726.00	15,681.00	52	975	477	17,185.00
68	9,809.00	913	89	63	10,874.00	4,936.00	264	27	97	5,324.00	16,965.00	975	50	408	18,398.00
69	9,414.00	22	6	0	9,442.00	4,464.00	8	0	0	4,472.00	16,151.00	22	2	1	16,176.00

Table B.10: Data Characteristics results for model group 70 - Part 1

ID	Clust	EC	AW	MCW	CW	AM	MCM	CM	AY	MCY	CY
70	361,434.86	7,518,708.00	528	340,095.00	20173	126	348,492.00	20171	11	607,208.00	2012

Table B.11: Data Characteristics results for model group 70 - Part 2

ID	Root	V	MD	RW	EC	L	IN	T	LCP	INCP	LCoP	INCoP
70	YES	23	14	6,030,747.00	281	48,093.00	14,429.00	62,522.00	0.00%	0.00%	0.00%	0.00%
71	-	24	14	6,208,061.00	292	50,281.00	15,385.00	65,666.00	59.85%	28.97%	27.25%	43.12%
72	-	23a1	14	6,016,870.00	284	47,596.00	14,185.00	61,781.00	60.16%	28.67%	27.62%	44.16%
73	-	24a1	14	6,180,649.00	292	49,539.00	14,994.00	64,533.00	59.91%	29.16%	26.65%	42.85%
74	-	25	14	6,346,067.00	293	51,810.00	16,097.00	67,907.00	59.77%	28.03%	27.16%	41.00%
75	-	23a1a1	14	6,018,040.00	285	47,665.00	14,220.00	61,885.00	62.48%	29.06%	29.97%	46.73%
76	-	25a1	14	6,297,810.00	293	51,164.00	15,709.00	66,873.00	61.13%	29.53%	30.70%	48.29%
77	-	26	14	6,527,874.00	298	54,174.00	16,997.00	71,171.00	60.28%	27.69%	27.57%	40.37%
78	-	24a2	14	6,181,078.00	292	49,544.00	14,998.00	64,542.00	61.84%	28.31%	30.69%	46.41%
79	-	24a3	14	6,181,671.00	292	49,553.00	15,003.00	64,556.00	57.53%	27.33%	20.61%	32.34%
80	-	23a1a2	14	6,018,070.00	286	47,668.00	14,220.00	61,888.00	60.70%	28.25%	24.90%	38.85%
81	-	26a1	14	6,466,492.00	299	53,307.00	16,628.00	69,935.00	62.58%	29.26%	34.65%	51.94%
82	-	27	14	6,884,202.00	307	61,114.00	18,401.00	79,515.00	65.50%	24.29%	32.77%	40.36%
83	-	24a4	14	6,181,779.00	292	49,555.00	15,005.00	64,560.00	67.72%	25.47%	44.44%	55.21%
84	-	27a1	14	6,858,813.00	307	60,801.00	18,223.00	79,024.00	66.20%	25.88%	39.83%	51.95%
85	-	28	13	7,046,770.00	312	62,656.00	18,935.00	81,591.00	61.29%	27.62%	26.52%	39.55%
86	-	26a2	15	6,466,497.00	299	53,308.00	16,633.00	69,941.00	64.98%	24.92%	38.43%	47.24%
87	-	23a1a3	14	6,018,064.00	286	47,668.00	14,220.00	61,888.00	65.53%	28.89%	31.97%	47.25%
88	-	24a5	14	6,182,008.00	292	49,558.00	15,009.00	64,567.00	60.30%	28.81%	26.79%	42.27%
89	-	28a1	13	7,035,923.00	312	62,538.00	18,900.00	81,438.00	66.78%	26.07%	41.85%	54.06%
90	-	29	13	7,120,899.00	315	63,822.00	19,236.00	83,058.00	59.04%	27.73%	23.41%	36.49%
91	-	29a1	13	7,111,924.00	315	63,658.00	19,275.00	82,933.00	58.32%	27.66%	21.90%	34.29%

Table B.11: Data Characteristics results for model group 70 - Part 2

ID	Root	V	MD	RW	EC	L	IN	T	LCP	INCP	LCoP	INCoP
92	-	30	13	7,237,305.00	316	65,897.00	20,011.00	85,908.00	59.86%	28.03%	25.47%	39.26%
93	-	26a3	15	6,466,689.00	299	53,320.00	16,640.00	69,960.00	66.58%	25.20%	43.30%	52.52%
94	-	28a2	13	7,035,974.00	312	62,538.00	18,906.00	81,444.00	65.27%	25.03%	35.39%	44.90%
95	-	26a4	15	6,467,045.00	299	53,326.00	16,656.00	69,982.00	64.90%	24.94%	38.11%	46.89%
96	-	28a3	13	7,036,070.00	312	62,540.00	18,917.00	81,457.00	65.25%	25.05%	35.39%	44.92%
97	-	30a1	13	7,227,224.00	318	65,677.00	20,062.00	85,739.00	60.57%	28.52%	27.58%	42.51%
98	-	31	13	7,293,820.00	321	66,927.00	20,334.00	87,261.00	59.82%	27.54%	23.85%	36.14%
99	-	31a1	13	7,296,101.00	321	66,949.00	20,366.00	87,315.00	57.71%	27.81%	21.77%	34.49%
100	-	32	13	7,424,643.00	322	69,388.00	21,083.00	90,471.00	59.86%	27.31%	27.11%	40.70%
101	-	29a2	13	7,111,953.00	315	63,660.00	19,272.00	82,932.00	62.71%	26.00%	31.53%	43.20%
102	-	32a1	13	7,406,140.00	323	69,198.00	21,082.00	90,280.00	61.96%	27.72%	32.30%	47.44%
103	-	33	13	7,424,318.00	316	70,268.00	21,717.00	91,985.00	60.43%	28.40%	27.95%	42.50%
104	-	29a3	13	7,112,126.00	315	63,668.00	19,278.00	82,946.00	64.31%	26.51%	35.98%	48.99%
105	-	31a2	13	7,296,276.00	321	66,957.00	20,372.00	87,329.00	60.42%	28.01%	27.35%	41.68%
106	-	33a1	13	7,533,510.00	324	72,129.00	22,307.00	94,436.00	60.73%	28.12%	31.15%	46.63%
107	-	34	13	7,505,795.00	323	71,658.00	22,810.00	94,468.00	57.97%	30.25%	27.88%	45.70%
108	-	31a3	13	7,296,303.00	321	66,961.00	20,373.00	87,334.00	63.77%	27.54%	33.24%	47.17%
109	-	32a2	13	7,406,368.00	323	69,201.00	21,082.00	90,283.00	59.97%	27.47%	27.68%	41.62%
110	-	31a4	13	7,296,550.00	321	66,963.00	20,373.00	87,336.00	60.47%	26.58%	26.71%	38.59%
111	-	33a2	13	7,533,711.00	324	72,129.00	22,307.00	94,436.00	60.73%	28.10%	31.11%	46.53%
112	-	34a1	13	7,612,849.00	333	73,418.00	23,415.00	96,833.00	56.82%	31.06%	25.64%	43.94%
113	-	35	13	7,543,487.00	326	72,488.00	23,244.00	95,732.00	59.05%	27.87%	26.42%	38.88%
114	-	33a3	13	7,533,725.00	324	72,130.00	22,307.00	94,437.00	61.85%	27.88%	27.27%	39.76%
115	-	36	13	7,649,837.00	326	80,800.00	25,451.00	106,251.00	62.89%	28.30%	36.93%	52.76%
116	-	37	13	7,657,889.00	331	81,293.00	25,881.00	107,174.00	58.22%	28.34%	23.70%	36.23%
117	-	36a1	13	7,640,452.00	327	80,630.00	25,436.00	106,066.00	58.37%	28.18%	22.29%	34.12%
118	-	34a2	13	7,612,927.00	333	73,419.00	23,418.00	96,837.00	64.19%	25.66%	36.23%	45.40%
119	-	34a3	13	7,612,919.00	333	73,420.00	23,418.00	96,838.00	56.59%	27.73%	21.44%	32.94%
120	-	38	13	7,672,727.00	339	82,597.00	26,715.00	109,312.00	63.61%	27.20%	37.73%	49.87%
121	-	37a1	13	7,661,383.00	333	81,383.00	25,955.00	107,338.00	60.47%	27.23%	25.64%	36.20%
122	-	36a2	13	7,641,412.00	327	80,660.00	25,451.00	106,111.00	58.13%	27.95%	22.37%	34.09%
123	-	36a3	13	7,645,897.00	328	80,795.00	25,478.00	106,273.00	56.09%	27.87%	20.17%	31.78%
124	-	39	13	7,912,025.00	338	85,745.00	25,923.00	111,668.00	66.83%	25.45%	38.05%	47.92%
125	-	40	13	7,925,233.00	346	86,336.00	26,094.00	112,430.00	57.58%	28.97%	22.03%	36.67%
126	-	39a1	13	7,917,170.00	342	85,842.00	25,988.00	111,830.00	57.00%	29.36%	20.64%	35.10%
127	-	41	13	8,051,500.00	360	90,220.00	27,265.00	117,485.00	61.43%	27.94%	29.51%	44.42%
128	-	40a1	13	7,933,098.00	346	86,514.00	26,165.00	112,679.00	60.56%	27.38%	23.75%	35.51%
129	-	39a2	13	7,917,662.00	343	85,863.00	26,003.00	111,866.00	57.31%	29.44%	20.79%	35.27%
130	-	41a1	13	8,049,134.00	361	90,202.00	27,256.00	117,458.00	61.25%	27.89%	29.69%	44.74%
131	-	42	13	8,056,292.00	372	91,607.00	27,837.00	119,444.00	59.03%	27.61%	21.40%	32.94%
132	-	39a3	13	7,914,745.00	344	85,804.00	25,987.00	111,791.00	60.90%	29.29%	27.06%	42.98%
133	-	40a2	13	7,932,339.00	346	86,503.00	26,156.00	112,659.00	57.34%	29.02%	22.27%	37.28%
134	-	43	13	8,024,592.00	370	91,207.00	27,823.00	119,030.00	62.08%	27.33%	30.25%	43.67%
135	-	42a1	13	8,055,472.00	372	91,564.00	27,835.00	119,399.00	59.20%	27.38%	20.23%	30.77%
136	-	40a3	13	7,931,997.00	348	86,522.00	26,158.00	112,680.00	61.58%	27.77%	25.74%	38.40%
137	-	44	13	8,016,771.00	374	91,364.00	27,909.00	119,273.00	62.20%	27.67%	31.03%	45.19%
138	-	43a1	13	8,024,638.00	371	91,249.00	27,837.00	119,086.00	58.74%	27.73%	19.46%	30.11%
139	-	42a2	13	8,055,448.00	373	91,569.00	27,844.00	119,413.00	59.25%	27.36%	20.24%	30.73%
140	-	41a2	13	8,049,147.00	361	90,209.00	27,257.00	117,466.00	59.45%	27.51%	21.22%	32.50%
141	-	45	13	8,014,442.00	375	91,288.00	27,607.00	119,547.00	60.00%	27.82%	24.55%	37.65%
142	-	44a1	13	8,016,760.00	374	91,355.00	27,871.00	119,321.00	58.66%	27.09%	19.45%	29.44%

Table B.12: Data Characteristics results for model group 70 - Part 3

ID	LCu	LCa	LCd	LCr	LCt	INCu	INCa	INCd	INCr	INCt	TCu	TCa	TCd	TCr	TCt
70	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
71	11,855.00	1,665.00	179	5	13,704.00	5,858.00	643	49	84	6,634.00	20,423.00	2,018.00	149	308	22,898.00
72	10,567.00	560	1,925.00	94	13,146.00	5,231.00	163	667	203	6,264.00	18,389.00	515	2,023.00	925	21,852.00
73	11,166.00	1,748.00	261	25	13,200.00	5,532.00	688	78	127	6,425.00	19,293.00	2,079.00	192	468	22,032.00
74	11,313.00	1,792.00	655	310	14,070.00	5,567.00	656	173	203	6,599.00	19,553.00	1,850.00	539	1,600.00	23,542.00
75	10,078.00	754	3,340.00	114	14,286.00	5,030.00	177	1,255.00	183	6,645.00	17,573.00	586	3,747.00	959	22,865.00
76	11,912.00	3,247.00	494	54	15,707.00	5,984.00	1,291.00	120	191	7,586.00	20,700.00	3,876.00	279	838	25,693.00
77	12,173.00	1,916.00	551	296	14,936.00	5,876.00	644	164	177	6,861.00	20,823.00	1,974.00	539	1,442.00	24,778.00
78	10,714.00	728	3,458.00	306	15,206.00	5,254.00	195	1,256.00	256	6,961.00	18,657.00	604	3,845.00	1,485.00	24,591.00
79	10,207.00	5	0	0	10,212.00	4,847.00	0	0	5	4,852.00	17,661.00	2	0	88	17,751.00
80	9,731.00	329	1,759.00	51	11,870.00	4,713.00	96	687	29	5,525.00	16,802.00	247	2,083.00	423	19,555.00
81	12,617.00	5,037.00	725	92	18,471.00	6,272.00	1,965.00	160	240	8,637.00	21,815.00	6,067.00	468	1,167.00	29,517.00
82	12,267.00	7,080.00	382	297	20,026.00	5,806.00	1,355.00	125	141	7,427.00	21,018.00	7,962.00	324	1,270.00	30,574.00
83	10,682.00	767	10,267.00	305	22,021.00	5,237.00	205	2,590.00	252	8,284.00	18,586.00	594	11,853.00	1,486.00	32,519.00
84	13,034.00	10,270.00	600	313	24,217.00	6,489.00	2,584.00	149	244	9,466.00	22,501.00	11,953.00	378	1,751.00	36,583.00
85	13,640.00	1,740.00	1,195.00	44	16,619.00	6,671.00	463	295	60	7,489.00	23,550.00	1,833.00	1,326.00	406	27,115.00
86	11,779.00	363	8,189.00	157	20,488.00	5,765.00	127	1,711.00	254	7,857.00	20,630.00	247	9,265.00	1,387.00	31,529.00
87	9,399.00	725	5,038.00	78	15,240.00	4,545.00	160	1,966.00	48	6,719.00	16,169.00	468	6,069.00	552	23,258.00
88	11,162.00	1,763.00	329	25	13,279.00	5,434.00	688	96	127	6,345.00	19,214.00	2,086.00	247	474	22,021.00
89	13,691.00	11,435.00	710	339	26,175.00	6,805.00	2,972.00	189	252	10,218.00	23,522.00	13,309.00	482	1,883.00	39,196.00
90	13,900.00	872	151	20	14,943.00	6,620.00	263	99	37	7,019.00	23,872.00	923	174	339	25,308.00
91	13,812.00	31	96	1	13,940.00	6,554.00	35	13	8	6,610.00	23,810.00	41	26	24	23,901.00
92	14,526.00	1,931.00	266	58	16,781.00	7,099.00	581	118	59	7,857.00	25,114.00	2,215.00	309	397	28,035.00
93	11,746.00	490	10,670.00	183	23,089.00	5,768.00	226	2,481.00	264	8,739.00	20,575.00	391	12,170.00	1,545.00	34,681.00
94	13,340.00	8,154.00	341	298	22,133.00	6,496.00	1,711.00	111	171	8,489.00	22,929.00	9,286.00	215	1,479.00	33,909.00
95	11,674.00	346	8,154.00	150	20,324.00	5,744.00	119	1,711.00	236	7,810.00	20,453.00	223	9,286.00	1,356.00	31,318.00
96	13,339.00	8,153.00	343	298	22,133.00	6,504.00	1,711.00	111	171	8,497.00	22,941.00	9,286.00	215	1,480.00	33,922.00
97	14,675.00	2,782.00	581	76	18,114.00	7,331.00	903	200	95	8,529.00	25,524.00	3,208.00	479	695	29,906.00
98	14,805.00	1,027.00	113	19	15,964.00	7,054.00	175	55	65	7,349.00	25,395.00	918	72	300	26,685.00
99	14,533.00	24	16	0	14,573.00	7,003.00	11	7	3	7,024.00	25,212.00	21	12	8	25,253.00
100	15,552.00	2,565.00	603	89	18,809.00	7,564.00	754	135	127	8,580.00	26,911.00	3,064.00	609	837	31,421.00
101	13,651.00	844	5,351.00	229	20,075.00	6,358.00	252	1,571.00	144	8,325.00	23,365.00	904	6,328.00	1,417.00	32,014.00
102	15,762.00	5,434.00	983	174	22,353.00	7,888.00	1,606.00	268	239	10,001.00	27,299.00	6,401.00	901	1,476.00	36,077.00
103	15,505.00	2,304.00	1,798.00	33	19,640.00	7,642.00	907	561	119	9,229.00	26,985.00	2,760.00	2,235.00	518	32,498.00
104	13,597.00	1,995.00	7,083.00	234	22,909.00	6,346.00	596	2,356.00	146	9,444.00	23,256.00	2,348.00	8,580.00	1,440.00	35,624.00
105	15,075.00	2,838.00	320	82	18,315.00	7,441.00	804	133	114	8,492.00	26,047.00	3,245.00	339	683	30,314.00
106	16,263.00	5,190.00	897	118	22,468.00	8,257.00	1,740.00	176	229	10,402.00	28,502.00	6,362.00	874	1,258.00	36,996.00
107	16,466.00	1,262.00	2,220.00	29	19,977.00	9,033.00	621	653	117	10,424.00	29,983.00	1,334.00	2,668.00	475	34,460.00
108	14,182.00	2,288.00	5,595.00	190	22,255.00	6,689.00	638	2,156.00	126	9,609.00	24,388.00	2,584.00	6,697.00	1,228.00	34,897.00
109	15,637.00	2,659.00	749	109	19,154.00	7,659.00	793	154	168	8,774.00	27,123.00	3,140.00	607	1,070.00	31,940.00
110	14,285.00	749	2,657.00	193	17,884.00	6,792.00	154	793	123	7,862.00	24,565.00	607	3,138.00	1,265.00	29,575.00
111	16,232.00	5,189.00	898	117	22,436.00	8,235.00	1,740.00	176	229	10,380.00	28,449.00	6,361.00	875	1,256.00	36,941.00
112	16,746.00	1,432.00	598	47	18,823.00	9,282.00	736	142	128	10,288.00	30,682.00	1,520.00	382	542	33,126.00
113	16,204.00	882	2,030.00	34	19,150.00	8,133.00	242	584	78	9,037.00	28,694.00	829	2,504.00	402	32,429.00
114	15,049.00	2,422.00	2,152.00	49	19,672.00	7,180.00	687	942	60	8,869.00	26,191.00	2,811.00	2,304.00	501	31,807.00
115	17,142.00	10,209.00	2,410.00	75	29,836.00	9,597.00	2,966.00	681	184	13,428.00	31,593.00	12,181.00	2,792.00	878	47,444.00
116	17,270.00	1,160.00	812	21	19,263.00	8,724.00	494	125	33	9,376.00	30,882.00	1,397.00	613	197	33,089.00
117	16,158.00	643	1,142.00	32	17,975.00	8,056.00	123	490	9	8,678.00	28,809.00	534	1,367.00	83	30,793.00
118	15,608.00	2,079.00	8,847.00	65	26,599.00	7,704.00	578	2,270.00	80	10,632.00	27,637.00	2,541.00	10,721.00	537	41,436.00
119	15,743.00	1	0	0	15,744.00	7,715.00	0	0	0	7,715.00	27,822.00	1	0	0	27,823.00
120	17,263.00	11,204.00	2,635.00	59	31,161.00	8,934.00	3,539.00	686	164	13,323.00	30,872.00	14,199.00	3,093.00	826	48,990.00
121	16,234.00	1,688.00	2,934.00	9	20,865.00	8,124.00	244	997	32	9,397.00	28,980.00	1,663.00	3,673.00	188	34,504.00
122	16,114.00	683	1,212.00	35	18,044.00	8,012.00	121	522	22	8,677.00	28,722.00	529	1,441.00	348	31,040.00
123	16,183.00	105	6	0	16,294.00	8,082.00	8	1	5	8,096.00	28,935.00	101	0	15	29,051.00

Table B.12: Data Characteristics results for model group 70 - Part 3

ID	LCu	LCa	LCd	LCr	LCt	INCu	INCa	INCd	INCr	INCt	TCu	TCa	TCd	TCr	TCt
124	21,129.00	8,277.00	3,198.00	23	32,627.00	9,411.00	1,726.00	1,177.00	109	12,423.00	35,684.00	9,234.00	3,391.00	511	48,820.00
125	17,156.00	812	744	308	19,020.00	8,478.00	580	404	107	9,569.00	30,105.00	974	599	1,354.00	33,032.00
126	16,140.00	717	726	131	17,714.00	8,098.00	409	543	73	9,123.00	28,655.00	588	880	955	31,078.00
127	20,830.00	4,397.00	1,041.00	354	26,622.00	9,601.00	1,783.00	545	181	12,110.00	34,939.00	5,581.00	845	1,973.00	43,338.00
128	16,555.00	359	3,572.00	64	20,550.00	7,961.00	126	1,181.00	22	9,290.00	28,823.00	300	4,589.00	223	33,935.00
129	16,053.00	771	894	131	17,849.00	8,041.00	442	613	74	9,170.00	28,504.00	630	1,047.00	963	31,144.00
130	20,864.00	4,422.00	1,085.00	407	26,778.00	9,633.00	1,791.00	559	212	12,195.00	34,992.00	5,610.00	881	2,236.00	43,719.00
131	17,626.00	1,654.00	231	92	19,603.00	8,330.00	677	102	61	9,170.00	30,330.00	2,240.00	230	408	33,208.00
132	15,854.00	1,206.00	6,024.00	138	23,222.00	8,054.00	607	2,425.00	84	11,170.00	28,231.00	1,013.00	7,813.00	1,076.00	38,133.00
133	17,257.00	901	727	382	19,267.00	8,576.00	610	428	136	9,750.00	30,286.00	1,047.00	574	1,696.00	33,603.00
134	20,595.00	5,582.00	1,262.00	153	27,592.00	9,455.00	2,059.00	387	249	12,150.00	34,448.00	7,315.00	1,300.00	1,386.00	44,449.00
135	17,342.00	719	450	9	18,520.00	8,140.00	183	222	19	8,564.00	29,773.00	779	531	201	31,284.00
136	16,417.00	622	5,219.00	11	22,269.00	7,952.00	220	1,862.00	10	10,044.00	28,642.00	566	6,859.00	96	36,163.00
137	20,871.00	5,819.00	1,501.00	158	28,349.00	9,597.00	2,244.00	500	271	12,612.00	34,903.00	7,604.00	1,533.00	1,536.00	45,576.00
138	17,176.00	296	278	3	17,753.00	8,005.00	156	215	6	8,382.00	29,534.00	317	348	23	30,222.00
139	17,322.00	724	475	9	18,530.00	8,120.00	189	229	19	8,557.00	29,734.00	785	557	200	31,276.00
140	17,225.00	257	1,654.00	3	19,139.00	8,055.00	103	687	13	8,858.00	29,606.00	253	2,251.00	86	32,196.00
141	18,320.00	2,478.00	1,437.00	176	22,411.00	8,567.00	1,072.00	551	203	10,393.00	31,278.00	3,203.00	1,651.00	1,221.00	37,353.00
142	17,286.00	275	209	0	17,770.00	7,978.00	184	43	0	8,205.00	29,633.00	430	229	0	30,292.00

Table B.13: Data Characteristics results for model group 163 - Part 1

ID	Clust	EC	AW	MCW	CW	AM	MCM	CM	AY	MCY	CY
163	123.75	216	159	972	201023	43	1,523.00	200910	7	7,638.00	2009

Table B.14: Data Characteristics results for model group 163 - Part 2

ID	Root	V	MD	RW	EC	L	IN	T	LCP	INCP	LCoP	INCoP
163	YES	1	11	960,869.00	88	7,064.00	1,431.00	8,498.00	0.00%	0.00%	0.00%	0.00%
164	-	2	11	1,072,586.00	94	7,751.00	1,540.00	9,481.00	85.51%	16.67%	10.13%	9.94%
165	-	3	11	962,452.00	89	7,074.00	1,427.00	8,522.00	86.05%	16.32%	11.25%	10.58%

Table B.15: Data Characteristics results for model group 163 - Part 3

ID	LCu	LCa	LCd	LCr	LCt	INCu	INCa	INCd	INCr	INCt	TCu	TCa	TCd	TCr	TCt
163	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
164	93	689	3	0	785	16	123	14	0	153	111	801	6	0	918
165	94	13	689	0	796	16	11	124	0	151	112	12	801	0	925

Table B.16: Data Characteristics results for model group 203 - Part 1

ID	Clust	EC	AW	MCW	CW	AM	MCM	CM	AY	MCY	CY
203	489.09	2,862.00	433	1,454.00	20173	113	2,040.00	20149	11	8,833.00	2014

Table B.17: Data Characteristics results for model group 203 - Part 2

ID	Root	V	MD	RW	EC	L	IN	T	LCP	INCP	LCoP	INCoP
203	YES	1	12	2,570,693.00	242	18,321.00	4,267.00	22,591.00	0.00%	0.00%	0.00%	0.00%
204	-	2	12	2,573,581.00	242	18,532.00	4,284.00	22,823.00	67.30%	20.17%	8.23%	10.67%
205	-	3	12	2,596,623.00	247	19,135.00	4,476.00	23,647.00	68.16%	21.89%	9.99%	13.72%

Table B.18: Data Characteristics results for model group 203 - Part 3

ID	LCu	LCa	LCd	LCr	LCt	INCu	INCa	INCd	INCr	INCt	TCu	TCa	TCd	TCr	TCt
203	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
204	1,243.00	206	35	41	1,525.00	360	41	36	20	457	1,801.00	204	47	214	2,266.00
205	1,404.00	455	45	8	1,912.00	423	150	32	9	614	2,048.00	537	38	182	2,805.00

Table B.19: Data Characteristics results for model group 214 - Part 1

ID	Clust	EC	AW	MCW	CW	AM	MCM	CM	AY	MCY	CY
214	11,146.45	34,344.00	515	15,986.00	20173	126	16,954.00	20171	11	32,999.00	2012

Table B.20: Data Characteristics results for model group 214 - Part 2

ID	Root	V	MD	RW	EC	L	IN	T	LCP	INCP	LCoP	INCoP
214	YES	3	17	4,402,192.00	331	35,241.00	11,532.00	46,773.00	0.00%	0.00%	0.00%	0.00%
215	-	4	17	4,402,290.00	331	35,238.00	11,526.00	46,764.00	59.78%	27.15%	14.78%	20.52%
216	-	5	17	4,516,613.00	342	37,476.00	12,098.00	49,574.00	63.67%	27.29%	20.34%	27.00%
217	-	6	17	4,517,177.00	344	37,553.00	12,123.00	49,676.00	59.77%	27.73%	14.89%	21.40%
218	-	7	17	4,516,577.00	344	37,599.00	12,133.00	49,732.00	59.71%	27.51%	14.86%	21.22%
219	-	8	17	4,516,617.00	345	37,604.00	12,110.00	49,739.00	59.96%	26.91%	14.55%	20.27%

Table B.21: Data Characteristics results for model group 214 - Part 3

ID	LCu	LCa	LCd	LCr	LCt	INCu	INCa	INCd	INCr	INCt	TCu	TCa	TCd	TCr	TCt
214	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
215	5,198.00	3	6	0	5,207.00	2,355.00	2	8	0	2,365.00	8,699.00	1	10	0	8,710.00
216	5,315.00	2,258.00	48	0	7,621.00	2,601.00	618	47	0	3,266.00	9,095.00	2,824.00	49	1	11,969.00
217	5,494.00	83	15	0	5,592.00	2,572.00	20	2	0	2,594.00	9,267.00	83	4	2	9,356.00
218	5,535.00	49	4	0	5,588.00	2,561.00	12	2	0	2,575.00	9,295.00	60	4	0	9,359.00
219	5,468.00	2	0	0	5,470.00	2,435.00	0	20	0	2,455.00	9,101.00	1	20	0	9,122.00

Table B.22: Data Characteristics results for model group 233 - Part 1

ID	Clust	EC	AW	MCW	CW	AM	MCM	CM	AY	MCY	CY
233	18.25	25	429	649	20173	121	662	20171	11	1,768.00	2016

Table B.23: Data Characteristics results for model group 233 - Part 2

ID	Root	V	MD	RW	EC	L	IN	T	LCP	INCP	LCoP	INCoP
233	YES	1	6	576	5	62	17	79	0.00%	0.00%	0.00%	0.00%
234	-	2	7	8,817.00	19	234	67	301	80.99%	26.03%	83.76%	94.03%
235	-	3	12	1,109,265.00	179	9,774.00	3,157.00	12,954.00	75.50%	24.67%	98.64%	99.78%

Table B.24: Data Characteristics results for model group 233 - Part 3

ID	LCu	LCa	LCd	LCr	LCt	INCu	INCa	INCd	INCr	INCt	TCu	TCa	TCd	TCr	TCt
233	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
234	14	172	10	0	196	13	50	0	0	63	30	212	0	0	242
235	34	9,571.00	36	0	9,641.00	15	3,109.00	26	0	3,150.00	53	12,662.00	54	0	12,769.00

Table B.25: Data Characteristics results for model group 236 - Part 1

ID	Clust	EC	AW	MCW	CW	AM	MCM	CM	AY	MCY	CY
236	18,067.49	120,321.00	525	116,464.00	20173	126	120,481.00	20171	11	189,360.00	2017

Table B.26: Data Characteristics results for model group 236 - Part 2

ID	Root	V	MD	RW	EC	L	IN	T	LCP	INCP	LCoP	INCoP
236	YES	1	13	4,683,584.00	318	40,961.00	12,520.00	53,481.00	0.00%	0.00%	0.00%	0.00%
237	-	2	16	5,466,969.00	329	47,089.00	14,996.00	62,085.00	73.04%	23.59%	21.82%	22.13%
238	-	3	16	6,753,598.00	335	66,762.00	21,512.00	88,274.00	70.73%	26.00%	41.43%	47.26%
239	-	4	15	6,948,470.00	356	71,971.00	22,958.00	94,929.00	61.87%	27.82%	28.50%	40.17%
240	-	3a1	16	6,758,528.00	335	66,826.00	21,541.00	88,367.00	63.22%	27.28%	28.30%	37.89%
241	-	4a1	15	6,949,621.00	357	71,959.00	22,957.00	94,916.00	61.54%	27.71%	28.23%	39.84%
242	-	5	15	6,959,911.00	363	73,569.00	23,475.00	97,044.00	60.08%	27.08%	22.36%	31.58%
243	-	6	15	6,876,913.00	363	73,206.00	23,492.00	96,698.00	60.64%	26.97%	22.66%	31.41%
244	-	5a1	15	6,959,547.00	363	73,570.00	23,477.00	97,047.00	61.41%	26.23%	21.97%	29.40%
245	-	6a1	15	6,876,910.00	363	73,234.00	23,507.00	96,741.00	60.71%	26.99%	22.71%	31.46%
246	-	7	15	6,892,771.00	365	73,650.00	23,628.00	97,278.00	59.91%	27.10%	20.32%	28.64%
247	-	5a2	15	6,959,541.00	364	73,569.00	23,478.00	97,047.00	61.80%	26.98%	22.42%	30.68%
248	-	8	15	6,888,768.00	367	73,546.00	23,418.00	97,905.00	61.03%	27.54%	23.84%	33.79%
249	-	7a1	15	6,892,920.00	365	73,622.00	23,619.00	97,334.00	59.05%	26.38%	18.94%	26.36%
250	-	6a2	15	6,876,908.00	363	73,226.00	23,479.00	96,741.00	60.23%	26.55%	19.78%	27.19%

Table B.27: Data Characteristics results for model group 236 - Part 3

ID	LCu	LCa	LCd	LCr	LCt	INCu	INCa	INCd	INCr	INCt	TCu	TCa	TCd	TCr	TCt
236	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
237	6,664.00	3,612.00	0	0	10,276.00	2,387.00	932	0	0	3,319.00	10,475.00	3,594.00	0	0	14,069.00
238	10,548.00	16,682.00	309	121	27,660.00	4,506.00	5,131.00	431	99	10,167.00	17,270.00	20,664.00	421	754	39,109.00
239	14,581.00	5,269.00	570	89	20,509.00	6,718.00	1,730.00	358	416	9,222.00	24,613.00	6,503.00	494	1,539.00	33,149.00

Table B.27: Data Characteristics results for model group 236 - Part 3

ID	LCu	LCa	LCd	LCr	LCt	INCu	INCa	INCd	INCr	INCt	TCu	TCa	TCd	TCr	TCt
240	13,105.00	519	5,181.00	106	18,911.00	6,027.00	360	1,709.00	65	8,161.00	22,500.00	484	6,482.00	448	29,914.00
241	14,504.00	5,179.00	531	103	20,317.00	6,645.00	1,713.00	365	424	9,147.00	24,474.00	6,464.00	494	1,580.00	33,012.00
242	14,397.00	1,807.00	208	35	16,447.00	6,567.00	651	127	68	7,413.00	24,444.00	2,311.00	172	447	27,374.00
243	14,069.00	1,096.00	1,308.00	119	16,592.00	6,483.00	446	337	112	7,378.00	23,963.00	1,386.00	1,461.00	550	27,360.00
244	13,722.00	1,300.00	1,087.00	53	16,162.00	6,099.00	327	433	44	6,903.00	23,188.00	1,451.00	1,376.00	302	26,317.00
245	14,066.00	1,135.00	1,315.00	117	16,633.00	6,494.00	455	333	114	7,396.00	23,968.00	1,434.00	1,457.00	540	27,399.00
246	14,114.00	609	229	11	14,963.00	6,417.00	224	106	20	6,767.00	23,927.00	715	193	139	24,974.00
247	13,733.00	1,257.00	1,459.00	45	16,494.00	6,114.00	401	640	47	7,202.00	23,219.00	1,330.00	1,830.00	312	26,691.00
248	14,306.00	1,559.00	1,483.00	187	17,535.00	6,551.00	654	586	122	7,913.00	24,264.00	1,902.00	1,696.00	868	28,730.00
249	13,615.00	213	111	2	13,941.00	5,987.00	190	43	7	6,227.00	22,964.00	350	105	190	23,609.00
250	13,585.00	264	619	14	14,482.00	6,008.00	125	235	16	6,384.00	22,961.00	246	735	101	24,043.00

C

Pattern Results

ID	**P1**	**P2**	**P3**	**P4**	**P5**	**P6**	**P7**	**P8**
10	43.71560653	0	0	0	0	0	202473	0
11	45.53485654	0.6005585273	0.04375245072	0.3994686504	3015.642723	1375.787896	508140	43.54208289
12	46.18048797	0.562328661	0.04365863495	0.3094715921	1645.028411	835.158167	787914	35.58923309
13	46.43403164	0.5872956109	0.04637910263	0.4421579533	4117.758963	1996.089294	1165104	52.61679644
14	45.83594747	0.5654771511	0.05637686435	0.3987338782	4352.641923	2431.868635	2116700	49.84173478
15	57.0950262	0.540620168	0.04772880841	0.5654439533	6169.348685	3307.489168	2254494	68.41871835
16	62.84733439	0.5316176449	0.05502478603	0.4092542032	3209.93452	2238.262671	2435650	50.7475212
17	64.19343587	0.5263801471	0.0516673686	0.3007318886	1719.169774	1044.624501	3078064	38.49368174
18	64.88255662	0.5410722186	0.04325256821	0.240080604	1161.126756	478.5255371	3488166	31.45055912

Table C.1: Pattern base formula values for model group 10

ID	P1	P2	P3	P4	P5	P6	P7	P8
19	71.24578803	0	0	0	0	0	75321	0
20	61.06649937	0.6543134953	0.0414599897	0.3829987453	1430.03796	604.492363	229536	30.63989962
21	58.76235258	0.6109832317	0.047782654	0.5943650222	6854.374031	2663.632897	712017	69.5407076
22	65.34466989	0.6050891245	0.05641883616	0.4517160236	3182.219788	2119.921875	810828	53.30249079
23	68.51914465	0.5867701625	0.05430816786	0.4848127191	4756.746918	2487.680999	1584385	61.57121533
24	73.59599716	0.5042094165	0.06281737158	0.3992021367	2470.137209	2216.353352	2129688	50.29946922
25	83.2206291	0.5195164452	0.06072626914	0.3821273758	2170.274705	1826.084431	2267244	48.9123041
26	99.46093143	0.583851404	0.05820178325	0.426299219	2877.035139	2132.261083	2959297	57.97669379
27	81.14196669	0.6600715681	0.04448933982	0.1555367984	679.935039	164.9818552	2957088	22.08622537
28	84.98194278	0.4562093393	0.06492165268	0.2629090286	855.025798	1064.460747	3151980	38.38471818
29	92.3711087	0.5354470461	0.05731520673	0.3289635247	1695.579796	1182.42623	3045900	47.04178404
30	100.0931865	0.6047032461	0.05239616005	0.2088943288	745.00526	409.3253649	3235320	28.82741738
31	106.0665462	0.5850166035	0.06354440147	0.3264262648	1840.913782	1435.409267	3719716	51.24892357
32	101.7020621	0.583972993	0.06516888682	0.3380476904	2880.417245	1658.031672	5444362	66.59539502
33	101.4266609	0.4020959222	0.06446860087	0.3580904007	1624.458787	1822.739587	9364289	71.25998973
34	105.7429905	0.4479463965	0.06098041983	0.3725478232	1897.607702	1667.878788	5408205	72.64682552
35	102.7229008	0.4657672051	0.0680260078	0.2840302238	1310.880129	1193.061279	6195904	55.66992387
36	100.9065645	0.3961892029	0.06585635469	0.3634907499	1658.425547	1926.873655	9889176	72.69814998
37	103.1679568	0.4344254816	0.06452876232	0.4159452027	2734.422208	2548.296427	9818000	86.51660216
38	102.3189376	0.4648742858	0.06385258739	0.3284859793	1817.211029	1430.732712	6815402	65.36870987
39	101.4947761	0.4565363859	0.06595775973	0.320155196	1832.463414	1479.631181	9227556	69.47367754
40	101.3218647	0.4644691749	0.06806911655	0.4524374879	3944.899423	3349.476938	11803792	95.01187246
41	100.7580521	0.4590113727	0.06654256806	0.3845638084	2732.820318	2209.179724	9946443	83.83491023
42	100.4833883	0.4523472616	0.0655640533	0.288699119	1512.295751	1211.578812	10564840	62.07031058
43	97.00834514	0.5044607813	0.05975426358	0.3414866301	2888.092884	1635.682652	12333048	76.83449177
44	96.48670686	0.4339882232	0.06629125631	0.4456539333	4004.487657	3682.141737	17347824	102.5004047
45	97.05818397	0.4515781646	0.0672913037	0.3934501845	3089.738066	2795.026239	13021008	88.9197417
46	96.6616742	0.4690362001	0.06519358415	0.5200748869	7014.743439	5138.155636	21039720	121.6975235
47	97.06342402	0.4670367019	0.06989286303	0.412236312	4154.411356	3268.58819	18342324	95.63882439
48	99.51712962	0.4502723282	0.06650888305	0.5075165254	6197.401219	5253.39939	22719008	123.3265157
49	96.67513161	0.4864982834	0.06431908462	0.2722992511	2068.820533	1371.002909	21741044	63.99032402
50	97.10286668	0.4671884874	0.06989868719	0.4122216262	4150.304753	3270.701564	18977049	95.22319566
51	100.7209432	0.4542832316	0.0664271686	0.5209172031	6549.91344	5476.026412	23124387	127.6247148

Table C.2: Pattern base formula values for model group 19

ID	P1	P2	P3	P4	P5	P6	P7	P8
52	97.31946144	0	0	0	0	0	594776	0
53	97.37198906	0.4403743641	0.06547056047	0.3066056161	1809.901794	1614.459142	1198132	70.5192917
54	98.97625819	0.4605509259	0.06661606969	0.5317599597	6749.216266	4551.508057	1933425	123.3683106
55	98.22537786	0.5054715006	0.06260324954	0.4557644991	6634.734195	3769.037012	5177900	113.4853603
56	98.8418981	0.5174130803	0.06119922449	0.4288014631	5601.706751	2561.972714	2615756	101.1971453
57	99.22480682	0.4353878531	0.06921534822	0.3009768987	1941.046938	1602.040407	3896412	70.72957121
58	98.81023827	0.4415871753	0.06874014926	0.291349536	1884.404701	1492.443073	3270865	68.46714096
59	98.62631874	0.5054432212	0.0627895103	0.4611475237	6814.041721	3886.780721	6676254	115.7480285
60	99.70402623	0.4534266698	0.06639941858	0.2975864108	2223.079228	1798.081052	6250608	74.3966027
61	97.77260733	0.449283344	0.06583628473	0.3470178287	3157.013018	2511.186703	9931824	91.61270679
62	99.81661497	0.4670396681	0.06488785835	0.3194170309	2749.077062	2045.536687	7376720	82.09017694
63	97.86241404	0.4747506299	0.06528080458	0.3344322893	3309.288292	2369.189173	12611970	90.63115041
64	99.46499931	0.4561242835	0.06467476182	0.3253398792	2787.425163	2178.256063	10602592	85.8897281
65	99.7624967	0.477704109	0.06281646986	0.2833524078	2265.661707	1509.104046	8121685	72.8215688
66	98.87133455	0.4690909161	0.06500765991	0.3452681996	3405.632981	2535.049633	13375712	94.60348668
67	99.43580768	0.4660099117	0.0626904086	0.2948797145	2391.463761	1681.225141	11422488	77.84824462
68	98.85598995	0.4562185099	0.06601093873	0.3080452072	2564.887443	2080.51791	15050700	84.40438677
69	98.82474934	0.4505356984	0.06307241868	0.2707597543	1933.323878	1467.262216	14218834	74.18817267

Table C.3: Pattern base formula values for model group 52

ID	P1	P2	P3	P4	P5	P6	P7	P8
70	96.45799878	0	0	0	0	0	875308	0
71	94.5399598	0.4582612581	0.06787890916	0.3487040478	3735.001611	2860.575626	5515944	101.8215819
72	97.39029799	0.463466084	0.0658165273	0.353700976	3630.921002	2766.140007	1729868	100.4510772
73	95.77501433	0.4599232758	0.06775710791	0.3414067221	3517.22885	2753.142924	6324234	99.69076287
74	93.4523245	0.455984195	0.06644543859	0.3466800183	3820.978576	2705.274337	11408376	101.5772454
75	97.24553607	0.4812310511	0.06677870314	0.3694756403	4281.753824	3105.205696	2599170	105.3005575
76	94.17567628	0.4677266444	0.06935787115	0.3842058828	4821.942166	3663.339232	12170886	112.5723237
77	91.72098186	0.4588343167	0.06612875969	0.3481474196	4117.918116	2769.507619	13949516	103.747931
78	95.76830591	0.4746652565	0.0657788648	0.3810077159	4667.011868	3230.79884	7228704	111.254253
79	95.75672285	0.4415921267	0.06352423805	0.2749705682	2104.513228	1569.146437	8134056	80.29140591
80	97.24130688	0.4675341961	0.06491837053	0.3159740176	2955.796341	2146.668425	3465728	90.36856903
81	92.46431687	0.4769884422	0.06957226475	0.4220633445	6400.24464	4486.274296	14686350	126.19694
82	86.57740049	0.5034236303	0.05621516953	0.384506068	6562.173577	2997.68105	21150990	118.0433629
83	95.75246283	0.5197850852	0.05920731767	0.5037019827	9785.580486	4573.452582	9038400	147.0809789
84	86.79404991	0.5093223546	0.05966890244	0.4629353108	9645.615845	4917.146244	22126720	142.1211404
85	86.36700126	0.4706691017	0.06409693684	0.3323283205	4408.056068	2961.981569	22274343	103.686436
86	92.45645616	0.4952790073	0.05926322846	0.4507942409	7874.205448	3711.444057	16785840	134.787478
87	97.24120993	0.5046997428	0.06637819265	0.3758079111	4872.400772	3174.751125	4332160	107.4810626
88	95.74562857	0.4628406526	0.06697854964	0.3410565769	3558.090339	2682.325605	9943318	99.58852045
89	86.39606817	0.5128163108	0.0605004847	0.4812986566	10955.4291	5524.207619	23291268	150.1651809
90	85.73405331	0.4537001376	0.06423189216	0.3047027378	3498.687741	2561.154138	26993850	95.98136242
91	85.75505529	0.4476847657	0.06427652637	0.288196496	3052.618681	2266.775616	28031354	90.78189623
92	84.24483168	0.4591444214	0.0652816881	0.3263374773	4273.365419	3084.925741	32387316	103.1226428
93	92.43409091	0.5074039598	0.05993405319	0.4957261292	9998.160559	4589.550541	17839800	148.2221126
94	86.39032955	0.5011989986	0.05811417938	0.4163474289	7833.152467	3811.653496	24351756	129.9003978
95	92.41011975	0.4945017409	0.05935282248	0.4475150753	7746.03338	3662.10975	18895140	133.8070075
96	86.37772076	0.5009429856	0.05817119975	0.416440576	7832.901967	3816.620447	25414584	129.9294597
97	84.29330876	0.4639710973	0.0667322238	0.3488027619	4995.919363	3625.9516	33438210	110.9192783
98	83.58625274	0.4588340977	0.06417467439	0.3058067178	3807.869709	2656.034278	35166183	98.16395641
99	83.56068259	0.4424775312	0.06487664834	0.2892172021	3172.150876	2422.497103	36323040	92.83872187
100	82.06655171	0.4591141551	0.06363415818	0.3473046612	5098.554231	3491.742162	42340428	111.8321009
101	85.75643901	0.4813490385	0.06042949286	0.3860271065	6330.594172	3596.182285	29109132	121.5985386
102	82.03522375	0.4749057126	0.06473412312	0.3996123172	7220.679918	4744.331705	43424680	129.0747785
103	80.7122683	0.4616633823	0.0670472285	0.3532967332	5489.406273	3922.016899	46636395	111.6417677
104	85.74405035	0.4936159794	0.06161405967	0.4294842428	8243.10927	4626.472456	30192344	135.2875365
105	83.54929061	0.4632347986	0.06534944742	0.3471240939	5009.770823	3539.861771	37464141	111.4268342
106	79.77370918	0.4638547114	0.06641492131	0.3917573807	6998.72484	4850.567266	49106720	126.9293913
107	79.45330694	0.4397389735	0.07303981995	0.3647796079	5569.23901	4763.690311	52807612	117.8238134
108	83.54481645	0.4889653497	0.06423352167	0.3995809192	7396.619301	4532.120012	38601628	128.2654751
109	82.0350232	0.4596539112	0.06414584721	0.3537764585	5301.595584	3651.602125	44599802	114.2697961
110	83.54573143	0.4636406572	0.06201117693	0.3386346982	4776.331048	3033.968684	39737880	108.7017381
111	79.7758376	0.4638836987	0.06637312865	0.3911749756	6978.8032	4830.071278	50334388	126.7406921
112	78.61833259	0.4308231257	0.07509875429	0.3420941208	4825.864624	4520.305104	55388476	113.9173422
113	78.79796724	0.4471407046	0.06766194226	0.3387477541	5059.078744	3513.481716	58492252	110.4317679
114	79.7751411	0.4723887614	0.06586442898	0.3368065483	5365.140496	3526.209755	51562602	109.1253216
115	71.99778826	0.4782309022	0.06779565487	0.4465275621	11017.16455	7084.640446	66300624	145.5679852
116	71.4528617	0.4415745075	0.06842669579	0.308740926	4564.515629	3396.676172	72449624	102.1932465
117	72.03488394	0.4437489781	0.06758343621	0.2903192352	4007.201104	2960.673219	67564042	94.93438991
118	78.61589062	0.486692466	0.06205054761	0.4278942966	9636.562756	4827.031514	56649645	142.4888008
119	78.61499618	0.4290221294	0.06705574083	0.287314897	3376.103732	2541.68695	57909124	95.67586072
120	70.19107692	0.4806183855	0.06646330395	0.4481667155	11755.97081	6644.294554	76737024	151.9285165
121	71.37624141	0.4584892317	0.06585478193	0.3214518623	5349.375484	3402.181044	73955882	107.0434702
122	72.01338221	0.4418846506	0.06704900362	0.2925238665	4036.522886	2958.246395	68972150	95.65530435
123	71.94580938	0.426410775	0.06681158978	0.2733620016	3286.025571	2572.620143	70458999	89.66273654
124	70.85310922	0.5131678437	0.05907248383	0.4371888097	12414.96448	5953.436292	79842620	147.7698177
125	70.49037623	0.4421660111	0.06723418303	0.293800587	4190.145478	3509.073389	86233810	101.6550031
126	70.7964768	0.4375272236	0.0682180256	0.2779039614	3655.387759	3202.598469	81412240	95.04315479
127	68.53215304	0.4717286086	0.06484826464	0.3688811338	7855.585059	5378.767651	96220215	132.7972082
128	70.40440543	0.4649512085	0.06356903452	0.3011652571	4881.319786	3298.455953	87889620	104.2031789
129	70.77809165	0.439893402	0.06844162174	0.2784045197	3710.408453	3233.815329	82892706	95.49275025
130	68.52776312	0.4703720233	0.0647278384	0.3722096409	7949.505377	5456.340806	97725056	134.3676804
131	67.44827702	0.4527350744	0.06435535731	0.2780214996	4194.849837	3020.760139	102482952	103.4239979
132	70.79948296	0.467411443	0.06809284894	0.3411097494	6284.803552	4801.204448	84290414	117.3417538
133	70.41016696	0.4402519851	0.06736464112	0.2982717759	4291.380519	3634.44334	89338587	103.2020345
134	67.41655045	0.4756559394	0.06389425421	0.3734268672	8347.149495	5305.772203	106769910	138.1679409
135	67.46682971	0.4539863262	0.06381825391	0.2620122447	3745.908872	2634.887588	103996529	97.46855501
136	70.39400958	0.4728419236	0.06447627661	0.3209353923	5731.586891	3856.637969	90820080	111.6855165
137	67.21362756	0.4764688352	0.06475150818	0.3821149799	8796.30709	5699.327959	110088979	142.9110025
138	67.3852342	0.4501071975	0.06483151595	0.2537829804	3453.944799	2523.9043	108368260	94.15348572
139	67.4587189	0.4543191855	0.06379554375	0.2619145319	3749.750461	2629.731684	105561092	97.69412041
140	68.52320672	0.456514958	0.06384099265	0.2740878212	4060.585097	2878.679385	99258770	98.94570344
141	67.04009302	0.4581532356	0.06425337915	0.3124545158	5501.850418	3912.574673	113450103	117.1704434
142	67.18649693	0.4491329495	0.06326832023	0.2538698134	3456.547534	2415.486527	111684456	94.9473102

Table C.4: Pattern base formula values for model group 70

ID	P1	P2	P3	P4	P5	P6	P7	P8
163	113.0700165	0	0	0	0	0	93478	0
164	113.1300496	0.699085937	0.02707168723	0.09682522941	79.50264482	15.20064935	208582	9.101571564
165	112.9373387	0.7143233729	0.0273349106	0.1085425956	89.56969183	15.9782761	281226	9.660291011
166	3.214285714	0.5350201101	0.0359456776	606.3571429	5546025	675925.3333	224	1819.071429

Table C.5: Pattern base formula values for model group 163

ID	P1	P2	P3	P4	P5	P6	P7	P8
203	113.7927936	0	0	0	0	0	271092	0
204	112.7626079	0.5464614113	0.03785585212	0.09928580818	125.4923915	48.75093371	547752	24.02716558
205	109.8077135	0.5515786373	0.04143330072	0.1186196981	191.0501176	84.22609473	851292	29.29906542

Table C.6: Pattern base formula values for model group 203

ID	P1	P2	P3	P4	P5	P6	P7	P8
214	94.1182306	0	0	0	0	0	2385423	0
215	94.13843983	0.4504732658	0.0669237015	0.1862543837	769.4207674	485.2702585	3179952	61.65020101
216	91.10850446	0.4813415615	0.06659136714	0.2414370436	1549.782287	881.6958175	4213790	82.57146892
217	90.93278444	0.4518299014	0.06766175299	0.1883404461	832.7021543	555.0471006	5066952	64.78911346
218	90.81832623	0.4514059919	0.06712434467	0.1881886914	830.4940025	546.495096	5918108	64.73690984
219	90.80634914	0.4533506606	0.06552522519	0.1833973341	795.6839698	497.6899257	6764504	63.27208026

Table C.7: Pattern base formula values for model group 214

ID	P1	P2	P3	P4	P5	P6	P7	P8
233	7.291139241	0	0	0	0	0	474	0
234	29.2923588	0.629636748	0.05794733807	0.803986711	164.1709402	59.23880597	4214	15.27574751
235	85.6310792	0.5696834959	0.06012074533	0.9857186969	9509.809802	3143.015521	466344	176.4436468

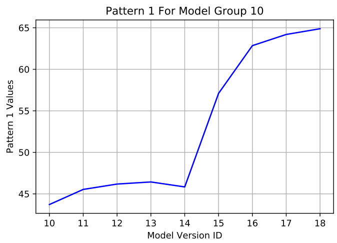
Table C.8: Pattern base formula values for model group 233

ID	P1	P2	P3	P4	P5	P6	P7	P8
236	87.57472747	0	0	0	0	0	695253	0
237	88.05619715	0.5539794416	0.05698135456	0.2266086816	2242.480749	734.5799547	1986720	74.55425626
238	76.50721617	0.5348992592	0.06335254922	0.443040986	11459.74656	4805.126859	4237152	148.4187303
239	73.19649422	0.4690646283	0.06728059629	0.3491978215	5844.285629	3704.385574	7119675	124.3144245
240	76.48248781	0.4780742589	0.06650352078	0.3385200358	5351.598495	3091.867648	5655488	113.404212
241	73.21864596	0.4665878612	0.06701662446	0.3478022673	5736.328868	3644.535828	8542440	124.1654094
242	71.71912741	0.4554855389	0.06550774488	0.2820782326	3676.872174	2340.897508	10189620	102.3943984
243	71.11742745	0.4591047983	0.06551263359	0.2829427703	3760.545092	2317.166865	14504700	102.7082256
244	71.7131596	0.4655618265	0.06345443452	0.2711778829	3550.499443	2029.706053	11645640	98.43757149
245	71.08578576	0.4595555956	0.06559169065	0.2832201445	3777.708291	2327.001149	15962265	102.8089125
246	70.8564218	0.4536163363	0.06581431996	0.25672814	3039.937122	1938.051845	18969210	93.70577109
247	71.71309778	0.4684614768	0.06527806244	0.2750316857	3697.916731	2209.251384	13101345	100.1115336
248	70.36175885	0.4584841536	0.06587952659	0.2934477299	4180.733487	2673.822231	22028625	107.6953169
249	70.81718618	0.4466418101	0.06400268717	0.2425565578	2639.856035	1641.709175	20440140	88.53314361
250	71.08576508	0.4559262796	0.06444262838	0.248529579	2864.123727	1735.825887	17413380	90.21623717

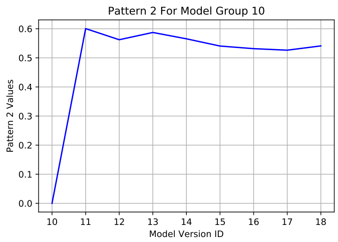
Table C.9: Pattern base formula values for model group 236

D

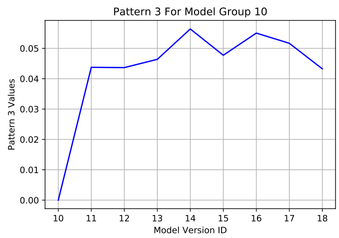
Pattern Charts



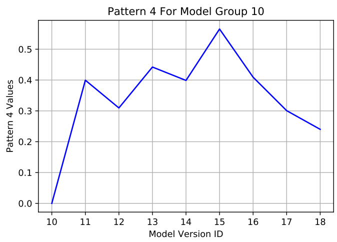
(a) P1 - Increasing references of items



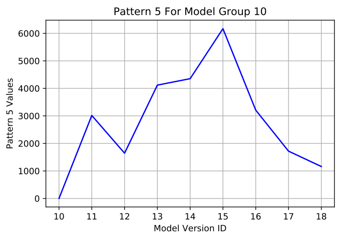
(b) P2 - Increasing leaf nodes and their changes



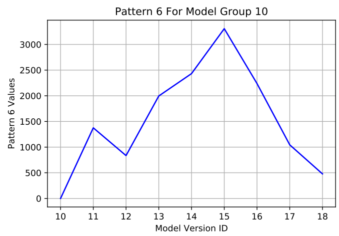
(c) P3 - Increasing inner nodes and their changes



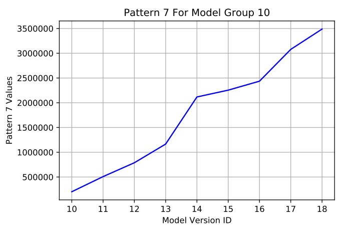
(d) P4 - Increasing changes of items



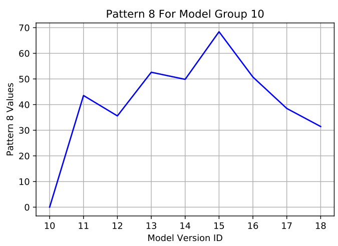
(e) P5 - Increasing leaf changes and their coverage



(f) P6 - Increasing inner changes and their coverage

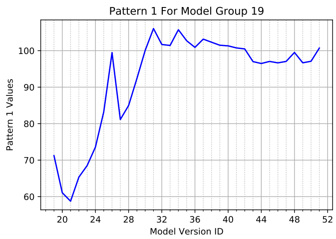


(g) P7 - Increasing versions, depths and items

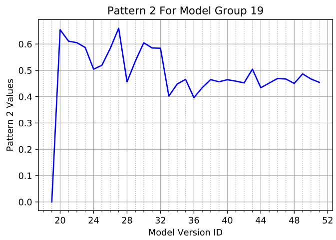


(h) P8 - Increasing employees and their changes on items

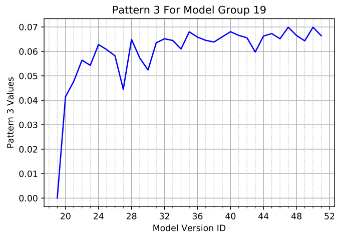
Figure D.1: Pattern base formula values for model group 10



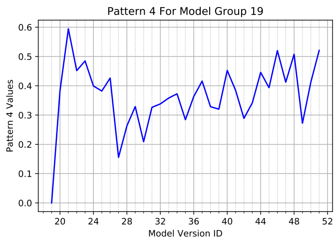
(a) P1 - Increasing references of items



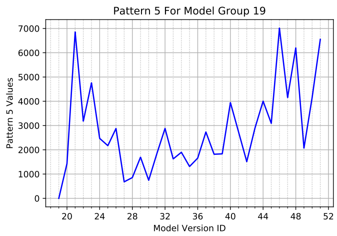
(b) P2 - Increasing leaf nodes and their changes



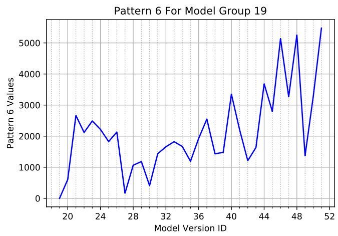
(c) P3 - Increasing inner nodes and their changes



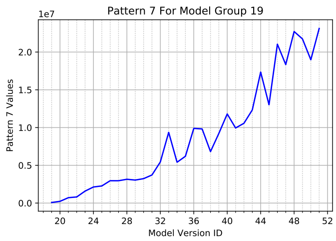
(d) P4 - Increasing changes of items



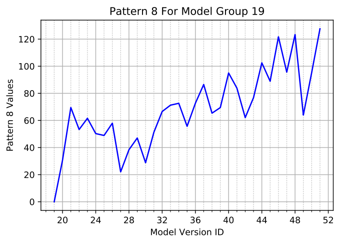
(e) P5 - Increasing leaf changes and their coverage



(f) P6 - Increasing inner changes and their coverage

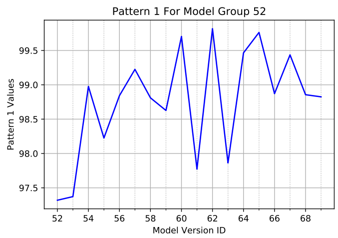


(g) P7 - Increasing versions, depths and items

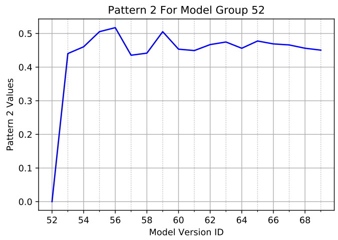


(h) P8 - Increasing employees and their changes on items

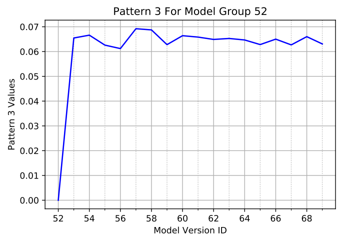
Figure D.2: Pattern base formula values for model group 19



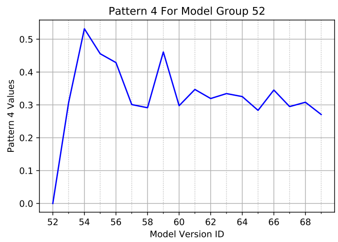
(a) P1 - Increasing references of items



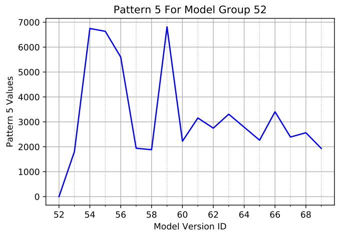
(b) P2 - Increasing leaf nodes and their changes



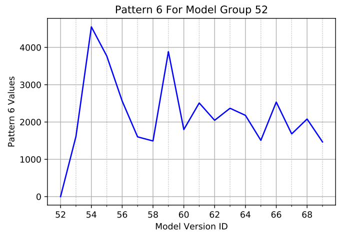
(c) P3 - Increasing inner nodes and their changes



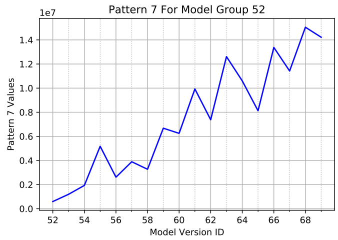
(d) P4 - Increasing changes of items



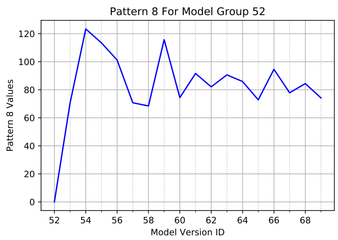
(e) P5 - Increasing leaf changes and their coverage



(f) P6 - Increasing inner changes and their coverage

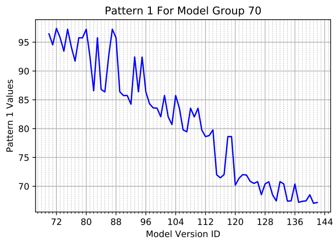


(g) P7 - Increasing versions, depths and items

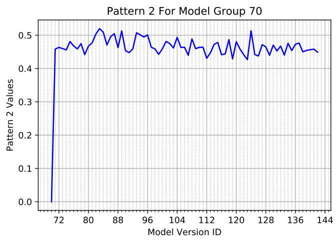


(h) P8 - Increasing employees and their changes on items

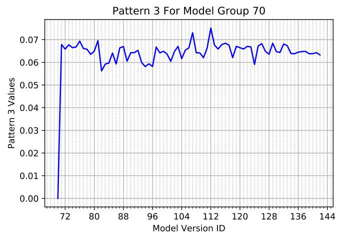
Figure D.3: Pattern base formula values for model group 52



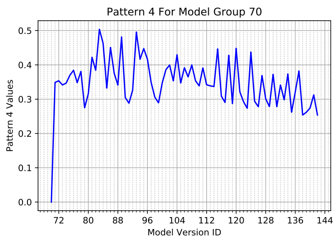
(a) P1 - Increasing references of items



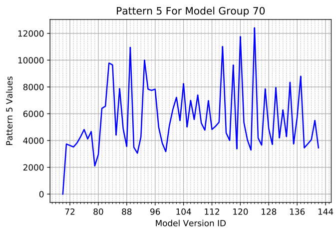
(b) P2 - Increasing leaf nodes and their changes



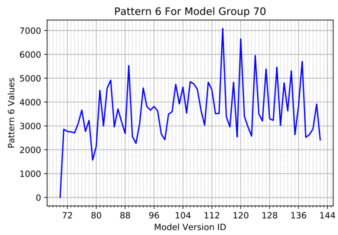
(c) P3 - Increasing inner nodes and their changes



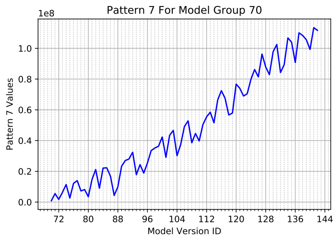
(d) P4 - Increasing changes of items



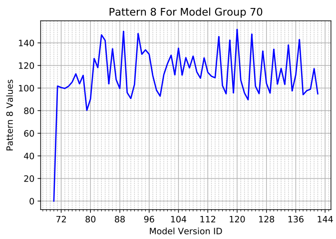
(e) P5 - Increasing leaf changes and their coverage



(f) P6 - Increasing inner changes and their coverage

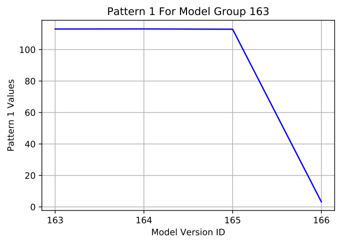


(g) P7 - Increasing versions, depths and items

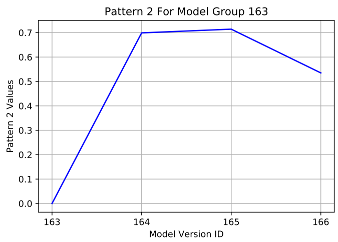


(h) P8 - Increasing employees and their changes on items

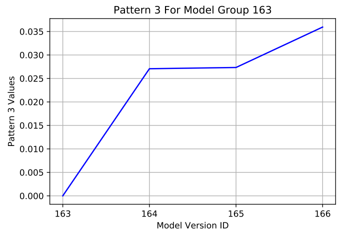
Figure D.4: Pattern base formula values for model group 70



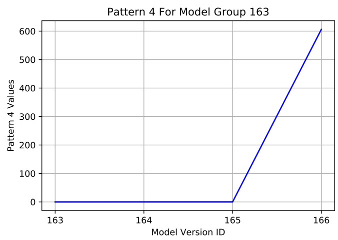
(a) P1 - Increasing references of items



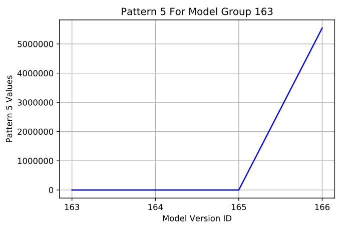
(b) P2 - Increasing leaf nodes and their changes



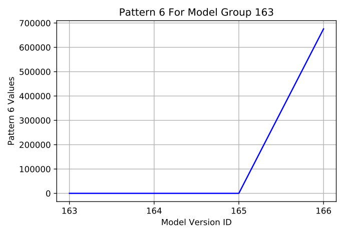
(c) P3 - Increasing inner nodes and their changes



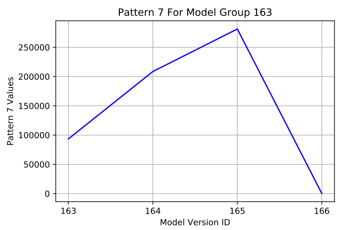
(d) P4 - Increasing changes of items



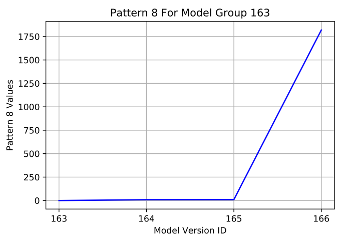
(e) P5 - Increasing leaf changes and their coverage



(f) P6 - Increasing inner changes and their coverage

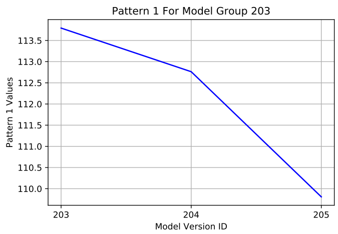


(g) P7 - Increasing versions, depths and items

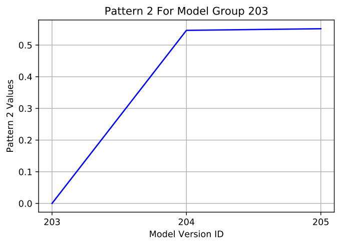


(h) P8 - Increasing employees and their changes on items

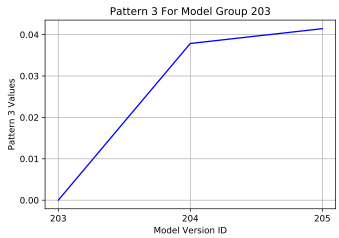
Figure D.5: Pattern base formula values for model group 163



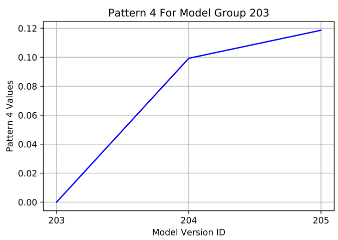
(a) P1 - Increasing references of items



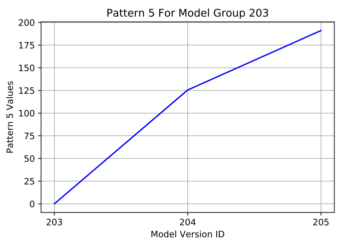
(b) P2 - Increasing leaf nodes and their changes



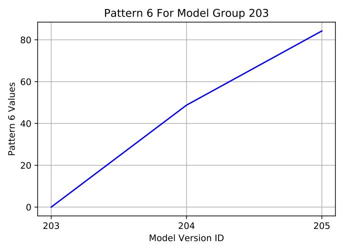
(c) P3 - Increasing inner nodes and their changes



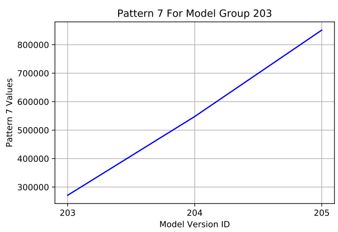
(d) P4 - Increasing changes of items



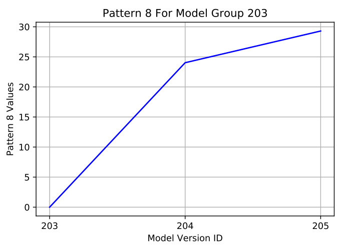
(e) P5 - Increasing leaf changes and their coverage



(f) P6 - Increasing inner changes and their coverage

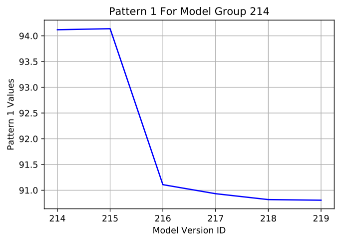


(g) P7 - Increasing versions, depths and items

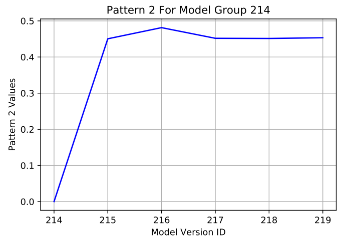


(h) P8 - Increasing employees and their changes on items

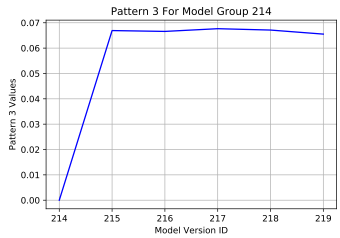
Figure D.6: Pattern base formula values for model group 203



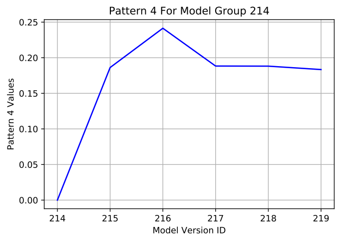
(a) P1 - Increasing references of items



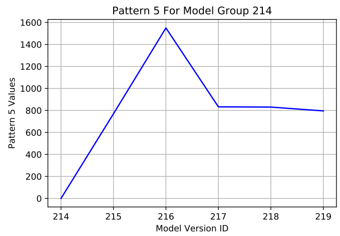
(b) P2 - Increasing leaf nodes and their changes



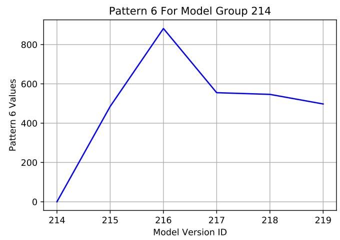
(c) P3 - Increasing inner nodes and their changes



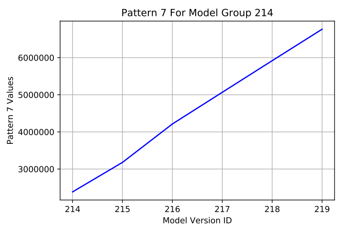
(d) P4 - Increasing changes of items



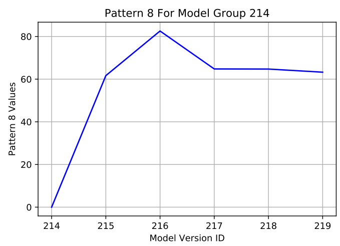
(e) P5 - Increasing leaf changes and their coverage



(f) P6 - Increasing inner changes and their coverage

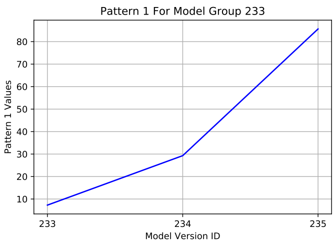


(g) P7 - Increasing versions, depths and items

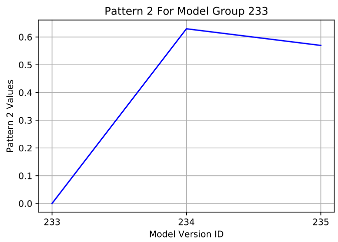


(h) P8 - Increasing employees and their changes on items

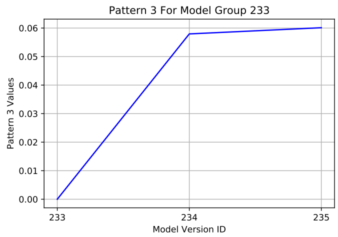
Figure D.7: Pattern base formula values for model group 214



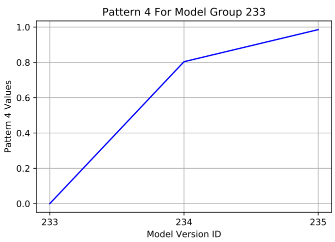
(a) P1 - Increasing references of items



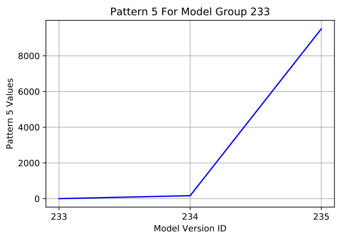
(b) P2 - Increasing leaf nodes and their changes



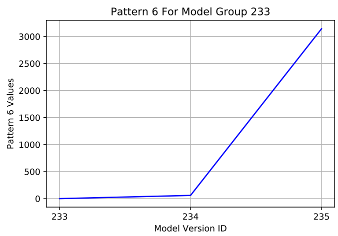
(c) P3 - Increasing inner nodes and their changes



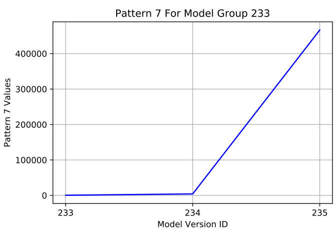
(d) P4 - Increasing changes of items



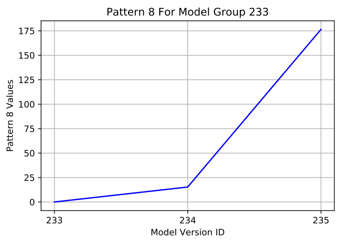
(e) P5 - Increasing leaf changes and their coverage



(f) P6 - Increasing inner changes and their coverage

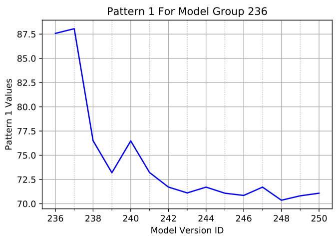


(g) P7 - Increasing versions, depths and items

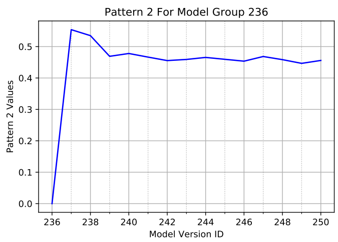


(h) P8 - Increasing employees and their changes on items

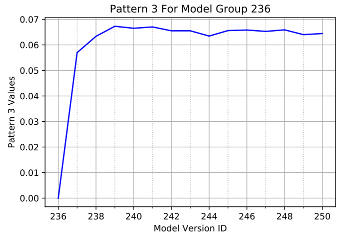
Figure D.8: Pattern base formula values for model group 233



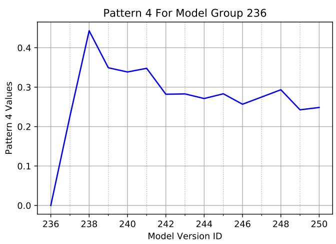
(a) P1 - Increasing references of items



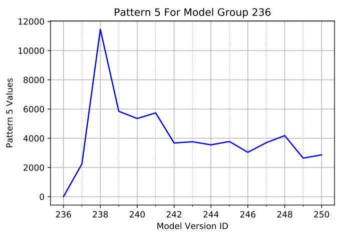
(b) P2 - Increasing leaf nodes and their changes



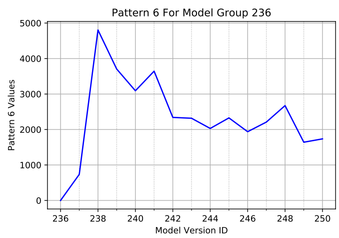
(c) P3 - Increasing inner nodes and their changes



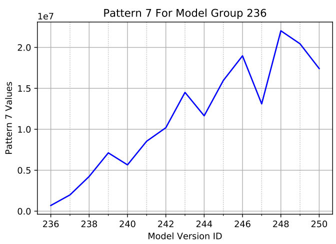
(d) P4 - Increasing changes of items



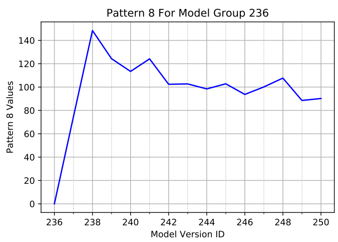
(e) P5 - Increasing leaf changes and their coverage



(f) P6 - Increasing inner changes and their coverage



(g) P7 - Increasing versions, depths and items



(h) P8 - Increasing employees and their changes on items

Figure D.9: Pattern base formula values for model group 236

E
Metric Results

ID	M1	M2	M3	M4	M5	M6	M7	M8	M9
10	9	22497	4	0.9999552593	6	1055098	646	0	8474
11	9	28230	4	0.9999645088	5	1378968	704	0	10518
12	9	29182	4	0.999965677	5	1448830	724	0	10872
13	9	32364	4	0.9999690671	5	1626330	765	0	11796
14	10	42334	4	0.9999763117	5	2133533	858	0	15600
15	11	34159	4	0.9999706882	5	2156138	790	0	12728
16	10	34795	4	0.9999712487	5	2440513	796	0	13225
17	11	34978	4	0.9999713983	5	2521461	791	0	13359
18	11	35234	4	1	5	2563445	791	0	13359

Table E.1: Metric measurements for model group 10

ID	M1	M2	M3	M4	M5	M6	M7	M8	M9
19	9	8369	5	0.9998802395	5	625278	116	0	2335
20	9	12752	5	0.9999214886	5	823597	222	0	4030
21	9	26371	4	0.999961983	5	1695811	565	0	9357
22	9	22523	4	0.9999555575	6	1602736	551	0	7890
23	11	28807	4	0.9999648876	5	2190409	622	0	10014
24	12	29579	4	0.9999658155	5	2434208	600	0	10495
25	12	26991	4	0.9999625047	6	2533030	628	0	9682
26	11	24457	4	0.9999590868	5	2778341	533	0	9074
27	12	30803	4	0.9999671798	6	2840266	636	0	11385
28	12	29185	4	0.9999653488	6	2833420	608	0	10879
29	11	27690	4	0.999963882	5	2942650	590	0	10632
30	11	24510	4	0.999959182	5	2806386	510	0	9094
31	11	26012	4	0.9999615562	5	3251256	567	0	10072
32	11	35353	3	0.9999717131	5	4371851	881	0	14846
33	11	37013	3	0.9999729825	5	4600747	868	0	15720
34	11	32777	3	0.9999694908	5	4202567	875	0	13594
35	11	35204	3	0.9999715941	5	4394166	882	0	14764
36	11	37459	3	0.9999733034	5	4639716	868	0	15966
37	10	39272	3	0.9999745366	5	5013097	937	0	17146
38	11	36446	3	0.9999725621	5	4549806	873	0	15448
39	13	39434	3	0.9999746412	5	4919198	987	0	16896
40	11	41272	3	0.9999757705	5	5182362	953	0	18311
41	13	40269	3	0.999975167	5	4988986	989	0	17320
42	13	40634	3	0.9999753901	5	5022253	1005	0	17509
43	13	45176	3	0.9999778644	5	5367767	995	0	18230
44	13	49424	3	0.9999797669	5	5930077	1007	0	20897
45	13	45528	3	0.9999780355	5	5414132	997	0	18429
46	13	53948	3	0.9999814636	5	6536485	1037	0	22421
47	13	50391	3	0.9999801552	5	6100209	1034	0	21246
48	13	54613	3	0.9999816893	5	6857073	1069	0	23123
49	13	53948	3	0.9999814636	5	6537700	1037	0	22421
50	13	50337	3	0.9999801339	5	6096076	1034	0	21215
51	13	53903	3	0.9999814482	5	6843675	1089	0	22643

Table E.2: Metric measurements for model group 19

ID	M1	M2	M3	M4	M5	M6	M7	M8	M9
52	13	45752	3	0.999978143	5	5462503	1000	0	18531
53	13	46082	3	0.9999782996	5	5507918	1001	0	18582
54	13	49575	3	0.9999798285	5	6204264	1037	0	22153
55	13	56900	3	0.9999824253	5	7037596	1097	0	24412
56	13	50303	3	0.9999801205	5	6282176	1044	0	22670
57	13	49954	3	0.9999799816	5	6263723	1044	0	22492
58	13	50321	3	0.9999801276	5	6282416	1044	0	22672
59	13	57062	3	0.9999824752	5	7094622	1100	0	24491
60	14	55809	3	0.9999820817	5	7009206	1089	0	23704
61	14	59118	3	0.9999830847	5	7277280	1190	0	25495
62	13	56744	3	0.999982377	5	7122682	1126	0	24000
63	14	60057	3	0.9999833492	5	7390158	1217	0	25835
64	14	58256	3	0.9999828344	5	7279592	1201	0	24753
65	13	56795	3	0.9999823928	5	7123954	1126	0	24013
66	14	59713	3	0.9999832532	5	7415962	1278	0	25243
67	14	58278	3	0.9999828409	5	7280164	1201	0	24759
68	14	59725	3	0.9999832566	5	7416334	1278	0	25248
69	14	59743	3	0.9999832616	5	7416026	1278	0	25246

Table E.3: Metric measurements for model group 52

ID	M1	M2	M3	M4	M5	M6	M7	M8	M9
70	14	62522	3	0.9999840056	5	7594877	1433	0	27085
71	14	65666	3	0.9999847714	5	7824177	1594	0	28565
72	14	61781	3	0.9999838138	5	7568750	1460	0	26404
73	14	64533	3	0.9999845041	5	7777499	1591	0	27691
74	14	67907	3	0.999985274	5	8017475	1668	0	29586
75	14	61885	3	0.999983841	5	7569140	1460	0	26434
76	14	66873	3	0.9999850463	5	7935498	1643	0	28805
77	14	71171	3	0.9999859493	5	8247716	1718	0	31069
78	14	64542	3	0.9999845062	5	7777891	1591	0	27693
79	14	64556	3	0.9999845096	5	7778708	1591	0	27695
80	14	61888	3	0.9999838418	5	7569140	1460	0	26435
81	14	69935	3	0.999985701	5	8157807	1693	0	30156
82	14	79515	3	0.9999874238	5	8665798	1745	0	31425
83	14	64560	3	0.9999845105	5	7778679	1591	0	27697
84	14	79024	3	0.9999873456	5	8624973	1740	0	31054
85	13	81591	3	0.9999877437	5	8878516	1787	0	32016
86	15	69941	3	0.9999857022	5	8158018	1693	0	30159
87	14	61888	3	0.9999838418	5	7569140	1460	0	26435
88	14	64567	3	0.9999845122	5	7778970	1591	0	27700
89	13	81438	3	0.9999877207	5	8864042	1787	0	31891
90	13	83058	3	0.9999879602	5	8967229	1841	0	32662
91	13	82933	3	0.9999879421	5	8960264	1841	0	32512
92	13	85908	3	0.9999883596	5	9119936	1850	0	33733
93	15	69960	3	0.9999857061	5	8158085	1693	0	30161
94	13	81444	3	0.9999877216	5	8864109	1787	0	31893
95	15	69982	3	0.9999857106	5	8159038	1693	0	30174
96	13	81457	3	0.9999877236	5	8864965	1787	0	31898
97	13	85739	3	0.9999883367	5	9112773	1870	0	33475
98	13	87261	3	0.9999885401	5	9193075	1891	0	34082
99	13	87315	3	0.9999885472	5	9197211	1891	0	34107
100	13	90471	3	0.9999889467	5	9351155	1931	0	34717
101	13	82932	3	0.9999879419	5	8960168	1841	0	32514
102	13	90280	3	0.9999889233	5	9327401	1936	0	34539
103	13	91985	3	0.9999891287	5	9343117	1968	0	35387
104	13	82946	3	0.999987944	5	8960322	1841	0	32525
105	13	87329	3	0.9999885491	5	9197365	1891	0	34118
106	13	94436	3	0.9999894108	5	9481382	1969	0	35472
107	13	94468	3	0.9999894144	5	9489833	2007	0	36405
108	13	87334	3	0.9999885497	5	9197059	1891	0	34123
109	13	90283	3	0.9999889237	5	9327852	1936	0	34540
110	13	87336	3	0.99998855	5	9197583	1891	0	34123
111	13	94436	3	0.9999894108	5	9481577	1969	0	35472
112	13	96833	3	0.9999896729	5	9628697	2007	0	36286
113	13	95732	3	0.9999895542	5	9545208	2011	0	36922
114	13	94437	3	0.9999894109	5	9481903	1969	0	35473
115	13	106251	3	0.9999905883	5	9665908	2011	0	38391
116	13	107174	3	0.9999906694	5	9678307	2015	0	38777
117	13	106066	3	0.9999905719	5	9656117	2011	0	38173
118	13	96837	3	0.9999896734	5	9628864	2007	0	36288
119	13	96838	3	0.9999896735	5	9628846	2007	0	36289
120	13	109312	3	0.9999908519	5	9710033	2014	0	39767
121	13	107338	3	0.9999906836	5	9683095	2015	0	38803
122	13	106111	3	0.9999905759	5	9657333	2011	0	38222
123	13	106273	3	0.9999905903	5	9662058	2011	0	38245
124	13	111668	3	0.9999910449	5	9970781	2014	0	38156
125	13	112430	3	0.9999911056	5	9993692	2029	0	38248
126	13	111830	3	0.9999910579	5	9978031	2014	0	38223
127	13	117485	3	0.9999914883	5	10135716	2019	409	38768
128	13	112679	3	0.9999911252	5	9998180	2029	0	38337
129	13	111866	3	0.9999910607	5	9978399	2014	0	38237
130	13	117458	3	0.9999914863	5	10132655	2010	409	38751
131	13	119444	3	0.9999916279	5	10144264	2009	1123	38755
132	13	111791	3	0.9999910547	5	9975336	2013	0	38206
133	13	112659	3	0.9999911237	5	9997679	2028	0	38328
134	13	119030	3	0.9999915988	5	10102795	1924	1164	38436
135	13	119399	3	0.9999916247	5	10143440	2007	1123	38747
136	13	112680	3	0.9999911253	5	9997281	2028	0	38348
137	13	119273	3	0.9999916159	5	10088412	1935	1178	38501
138	13	119086	3	0.9999916027	5	10102198	1924	1164	38471
139	13	119413	3	0.9999916257	5	10143540	2007	1123	38757
140	13	117466	3	0.9999914869	5	10132611	2010	409	38759
141	13	119547	3	1	5	10082738	1935	1178	38432
142	13	119321	3	1	5	10088347	1935	1178	38495

Table E.4: Metric measurements for model group 70

ID	M1	M2	M3	M4	M5	M6	M7	M8	M9
163	11	8498	5	0.9998822837	6	1064925	275	0	2910
164	11	9481	5	1	6	1191420	324	0	3177
165	11	8522	5	1	6	1066838	276	0	2910
166	4	14	3	1	3	48	0	0	5

Table E.5: Metric measurements for model group 163

ID	M1	M2	M3	M4	M5	M6	M7	M8	M9
203	12	22591	4	0.9999557287	5	3045879	920	0	8008
204	12	22823	4	0.9999561711	5	3046460	922	0	8160
205	12	23647	4	1	5	3074297	922	0	8593

Table E.6: Metric measurements for model group 203

ID	M1	M2	M3	M4	M5	M6	M7	M8	M9
214	17	46773	3	0.9999786201	9	5551427	1271	0	19996
215	17	46764	3	0.999978616	9	5551524	1271	0	19997
216	17	49574	3	0.9999798281	9	5688416	1275	0	20022
217	17	49676	3	0.9999798696	9	5688910	1275	0	20101
218	17	49732	3	0.9999798922	9	5687533	1275	0	20143
219	17	49739	3	1	9	5687559	1275	0	20148

Table E.7: Metric measurements for model group 214

ID	M1	M2	M3	M4	M5	M6	M7	M8	M9
233	6	79	5	0.9873417722	4	506	1	0	22
234	7	301	4	0.9966777409	4	10397	2	0	56
235	12	12954	3	1	6	1319511	298	0	4598

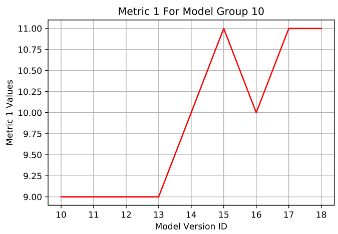
Table E.8: Metric measurements for model group 233

ID	M1	M2	M3	M4	M5	M6	M7	M8	M9
236	13	53481	3	0.9999813018	6	5739631	1661	0	20933
237	16	62085	3	0.999983893	6	6819805	1791	0	25300
238	16	88274	3	0.9999886716	5	8534796	1893	0	32216
239	15	94929	3	0.9999894658	5	8762381	1859	517	33253
240	16	88367	3	0.9999886836	5	8536141	1893	0	32237
241	15	94916	3	0.9999894644	5	8762473	1847	517	33250
242	15	97044	3	0.9999896954	5	8774608	1832	1104	33557
243	15	96698	3	0.9999896585	5	8671305	1630	1321	32966
244	15	97047	3	0.9999896957	5	8774435	1832	1104	33560
245	15	96741	3	0.9999896631	5	8670903	1630	1321	32987
246	15	97278	3	0.9999897202	5	8682808	1742	1335	33212
247	15	97047	3	0.9999896957	5	8774442	1832	1104	33560
248	15	97905	3	1	5	8674688	1742	1335	33221
249	15	97334	3	1	5	8682713	1742	1335	33227
250	15	96741	3	1	5	8670899	1630	1321	32987

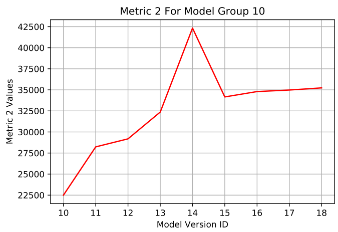
Table E.9: Metric measurements for model group 236

F

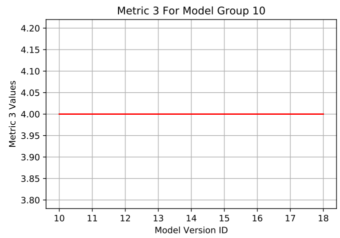
Metric Charts



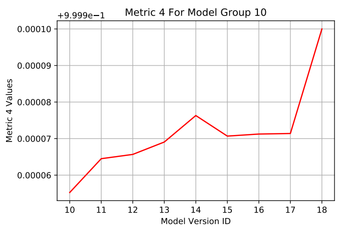
(a) M1 - Depth of Tree



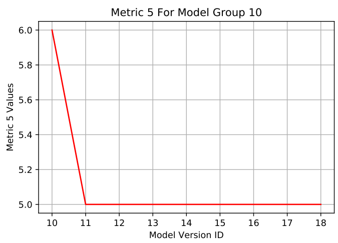
(b) M2 - Size or Lines Of Code



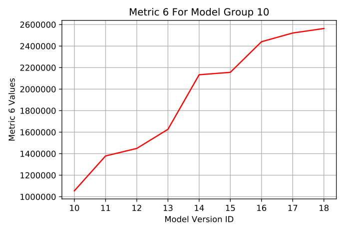
(c) M3 - Ratio Of Variability



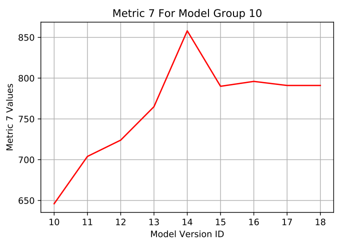
(d) M4 - Reuse Ratio



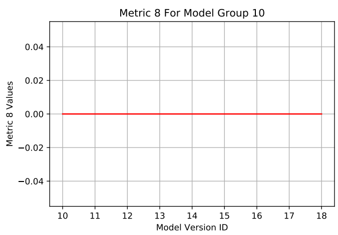
(e) M5 - Number of Ancestors



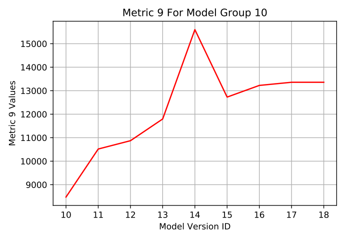
(f) M6 - Coupling Between Objects



(g) M7 - Number of Features (Use Cases)

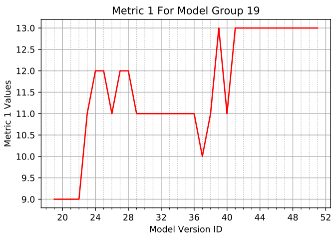


(h) M8 - Number of Features (Requirements)

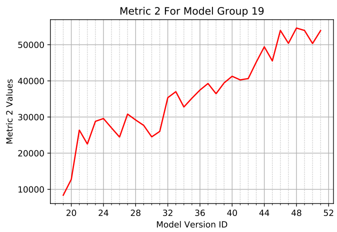


(i) M9 - Number of Features (Functional Requirements)

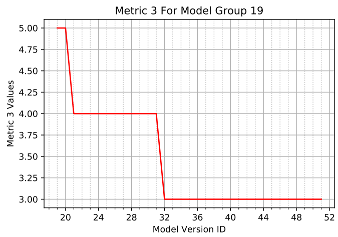
Figure F.1: Metric measurements for model group 10



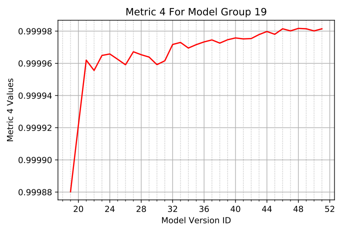
(a) M1 - Depth of Tree



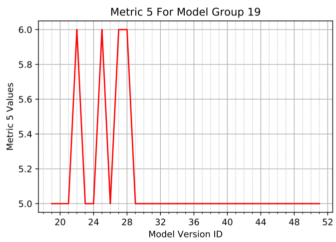
(b) M2 - Size or Lines Of Code



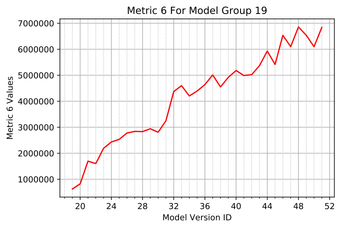
(c) M3 - Ratio Of Variability



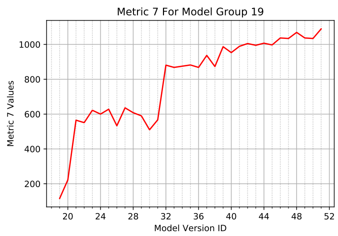
(d) M4 - Reuse Ratio



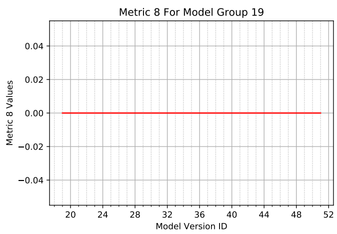
(e) M5 - Number of Ancestors



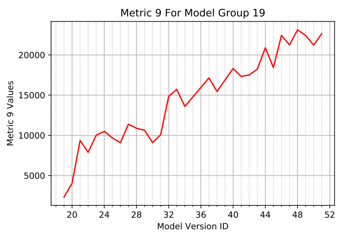
(f) M6 - Coupling Between Objects



(g) M7 - Number of Features (Use Cases)

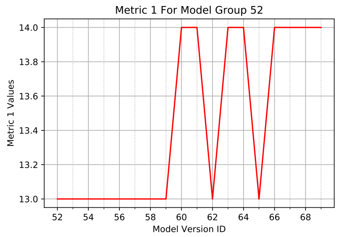


(h) M8 - Number of Features (Requirements)

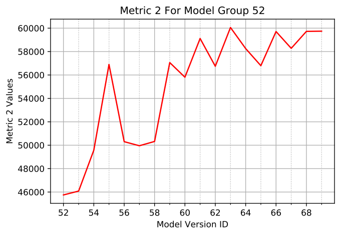


(i) M9 - Number of Features (Functional Requirements)

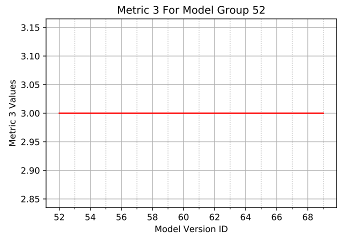
Figure F.2: Metric measurements for model group 19



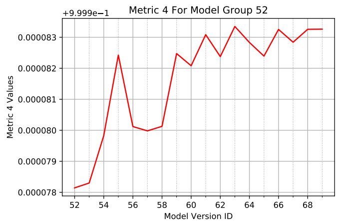
(a) M1 - Depth of Tree



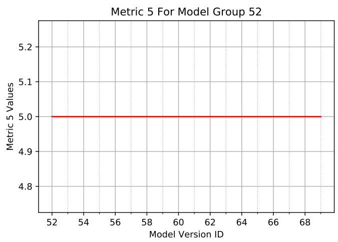
(b) M2 - Size or Lines Of Code



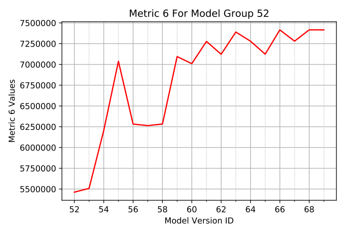
(c) M3 - Ratio Of Variability



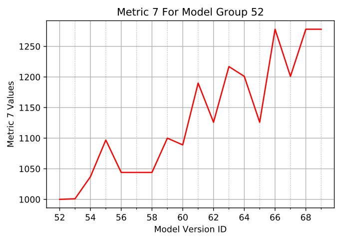
(d) M4 - Reuse Ratio



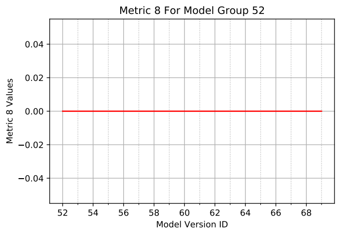
(e) M5 - Number of Ancestors



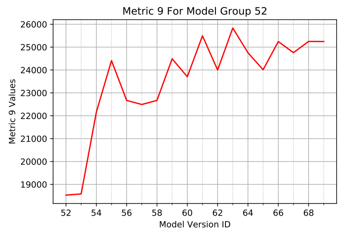
(f) M6 - Coupling Between Objects



(g) M7 - Number of Features (Use Cases)

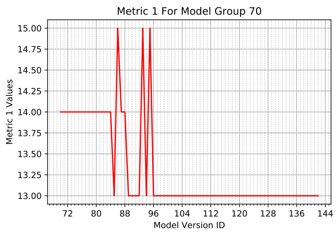


(h) M8 - Number of Features (Requirements)

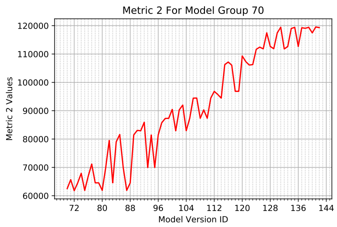


(i) M9 - Number of Features (Functional Requirements)

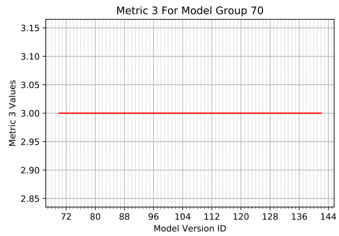
Figure F.3: Metric measurements for model group 52



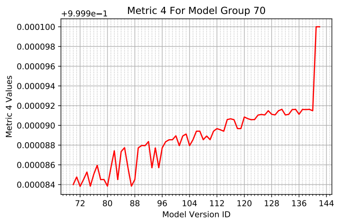
(a) M1 - Depth of Tree



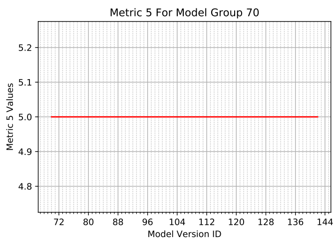
(b) M2 - Size or Lines Of Code



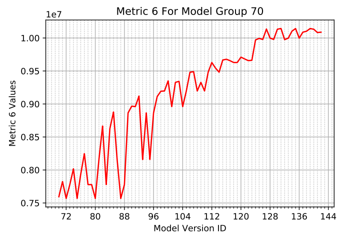
(c) M3 - Ratio Of Variability



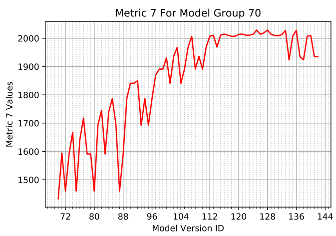
(d) M4 - Reuse Ratio



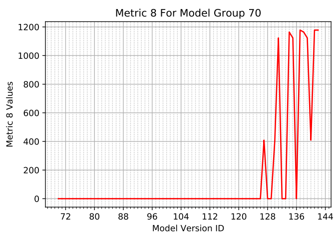
(e) M5 - Number of Ancestors



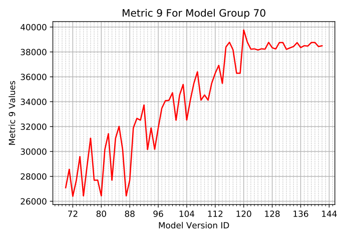
(f) M6 - Coupling Between Objects



(g) M7 - Number of Features (Use Cases)

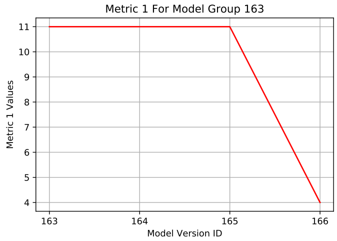


(h) M8 - Number of Features (Requirements)

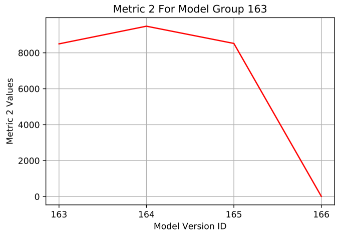


(i) M9 - Number of Features (Functional Requirements)

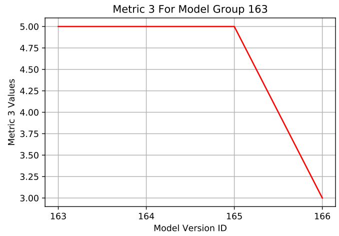
Figure F.4: Metric measurements for model group 70



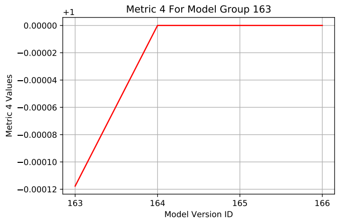
(a) M1 - Depth of Tree



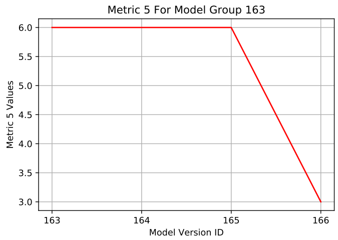
(b) M2 - Size or Lines Of Code



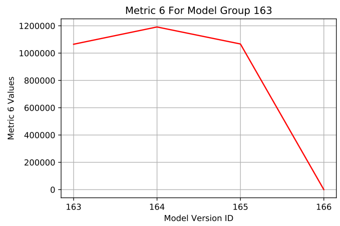
(c) M3 - Ratio Of Variability



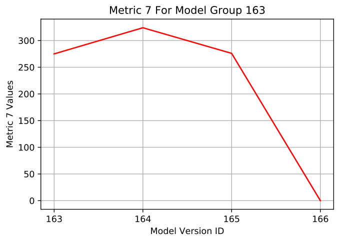
(d) M4 - Reuse Ratio



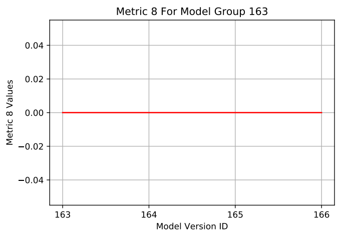
(e) M5 - Number of Ancestors



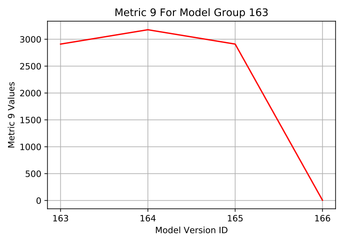
(f) M6 - Coupling Between Objects



(g) M7 - Number of Features (Use Cases)

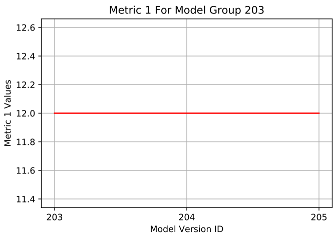


(h) M8 - Number of Features (Requirements)

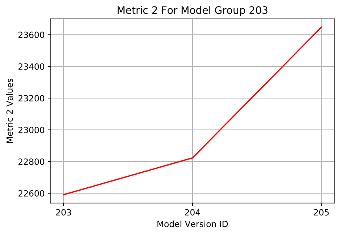


(i) M9 - Number of Features (Functional Requirements)

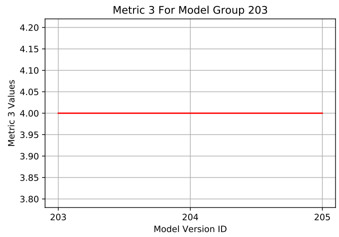
Figure F.5: Metric measurements for model group 163



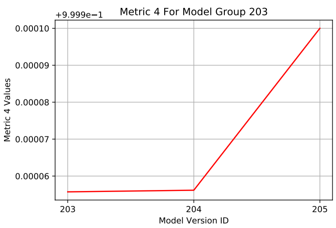
(a) M1 - Depth of Tree



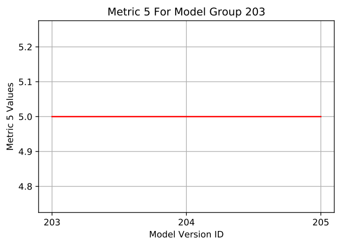
(b) M2 - Size or Lines Of Code



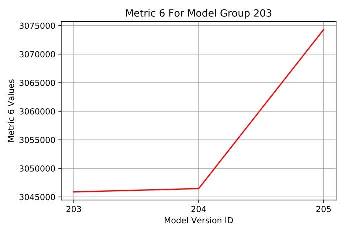
(c) M3 - Ratio Of Variability



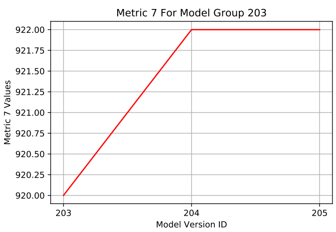
(d) M4 - Reuse Ratio



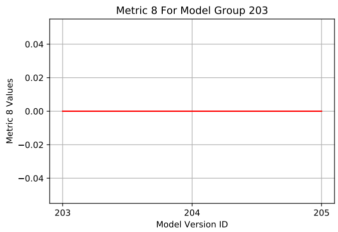
(e) M5 - Number of Ancestors



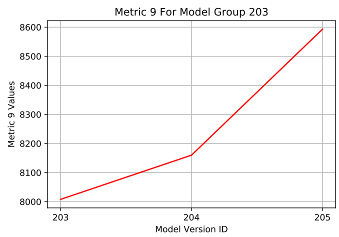
(f) M6 - Coupling Between Objects



(g) M7 - Number of Features (Use Cases)

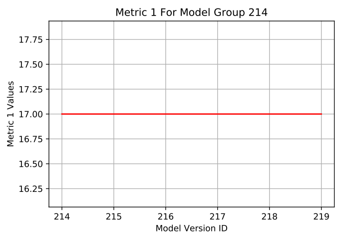


(h) M8 - Number of Features (Requirements)

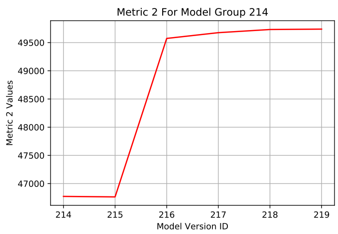


(i) M9 - Number of Features (Functional Requirements)

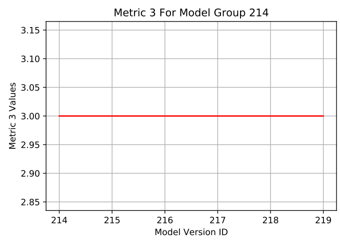
Figure F.6: Metric measurements for model group 203



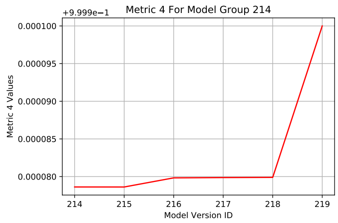
(a) M1 - Depth of Tree



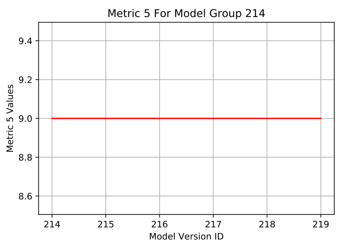
(b) M2 - Size or Lines Of Code



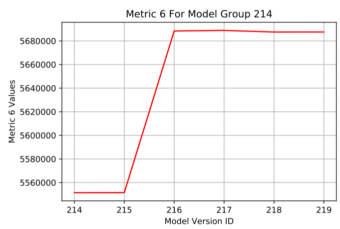
(c) M3 - Ratio Of Variability



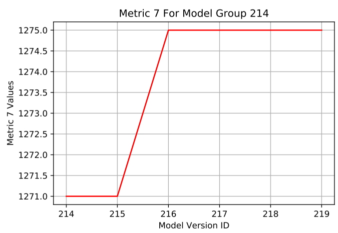
(d) M4 - Reuse Ratio



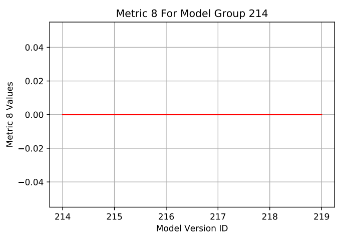
(e) M5 - Number of Ancestors



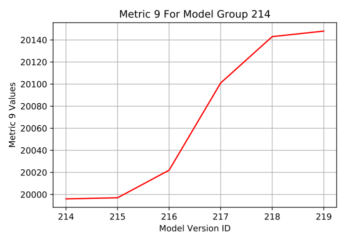
(f) M6 - Coupling Between Objects



(g) M7 - Number of Features (Use Cases)

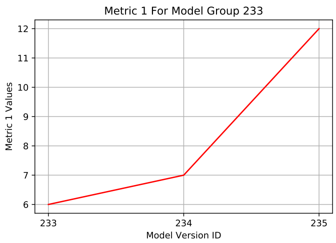


(h) M8 - Number of Features (Requirements)

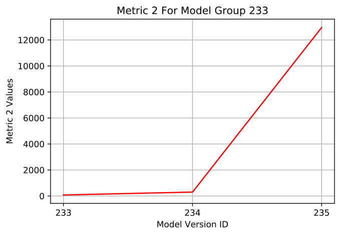


(i) M9 - Number of Features (Functional Requirements)

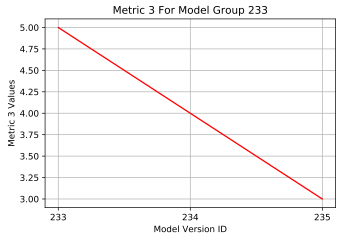
Figure F.7: Metric measurements for model group 214



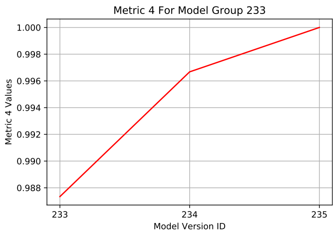
(a) M1 - Depth of Tree



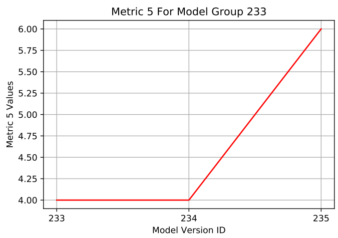
(b) M2 - Size or Lines Of Code



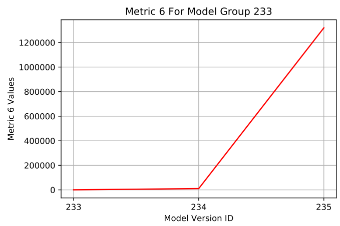
(c) M3 - Ratio Of Variability



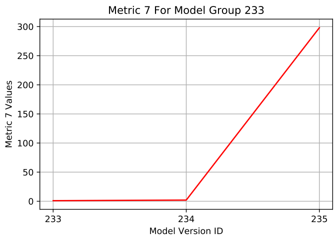
(d) M4 - Reuse Ratio



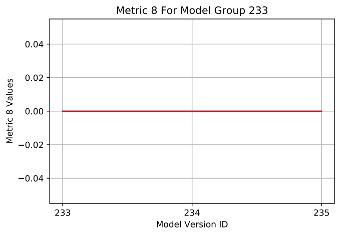
(e) M5 - Number of Ancestors



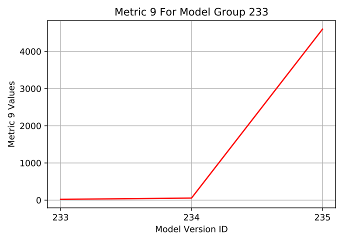
(f) M6 - Coupling Between Objects



(g) M7 - Number of Features (Use Cases)

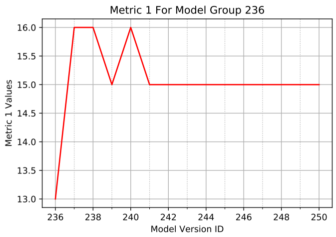


(h) M8 - Number of Features (Requirements)

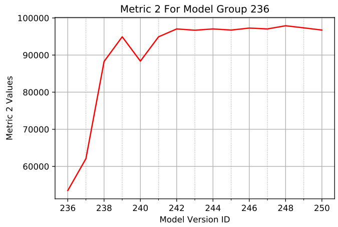


(i) M9 - Number of Features (Functional Requirements)

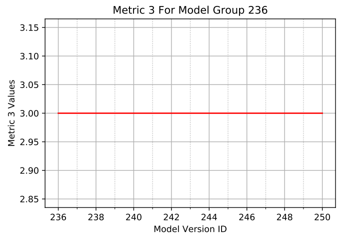
Figure F.8: Metric measurements for model group 233



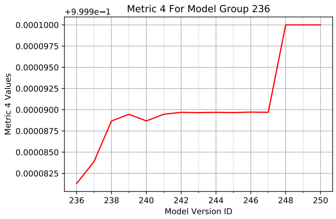
(a) M1 - Depth of Tree



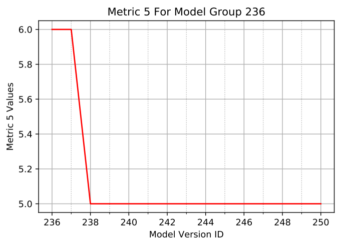
(b) M2 - Size or Lines Of Code



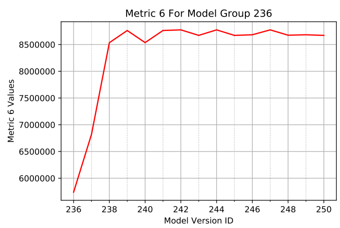
(c) M3 - Ratio Of Variability



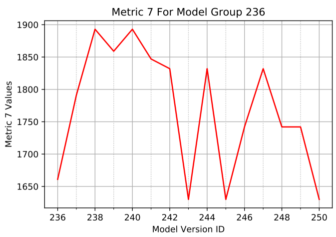
(d) M4 - Reuse Ratio



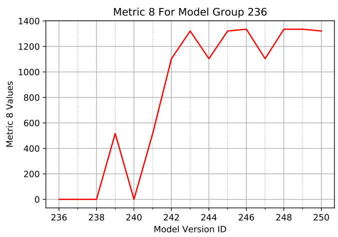
(e) M5 - Number of Ancestors



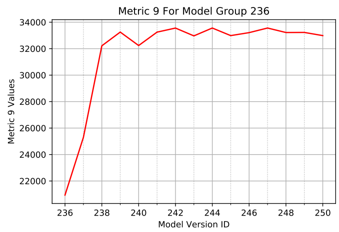
(f) M6 - Coupling Between Objects



(g) M7 - Number of Features (Use Cases)



(h) M8 - Number of Features (Requirements)

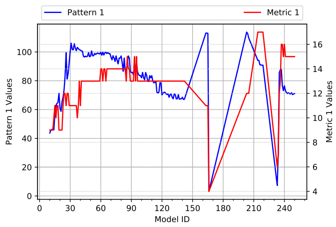


(i) M9 - Number of Features (Functional Requirements)

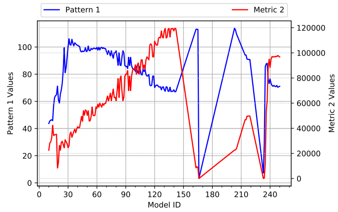
Figure F.9: Metric measurements for model group 236

G

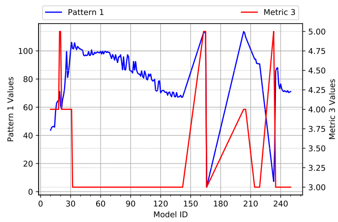
Pattern and Metric Correlations



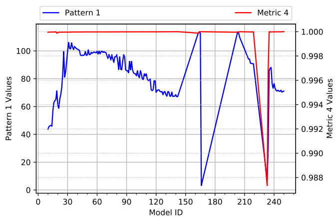
(a) P1 Vs. M1



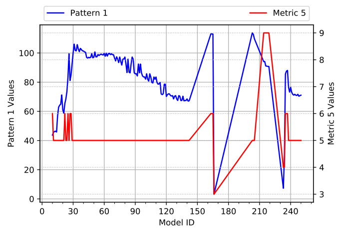
(b) P1 Vs. M2



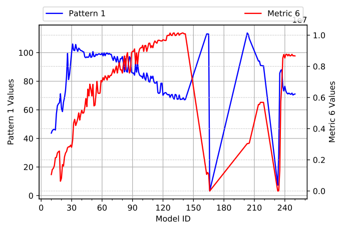
(c) P1 Vs. M3



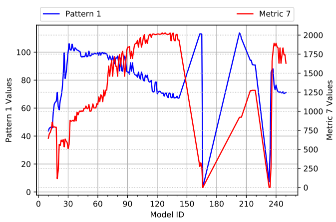
(d) P1 Vs. M4



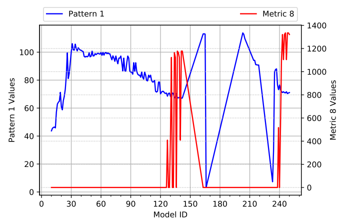
(e) P1 Vs. M5



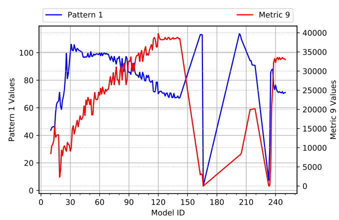
(f) P1 Vs. M6



(g) P1 Vs. M7

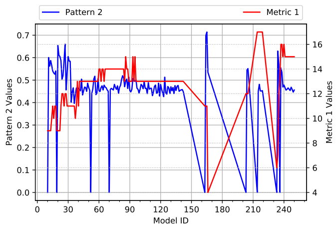


(h) P1 Vs. M8

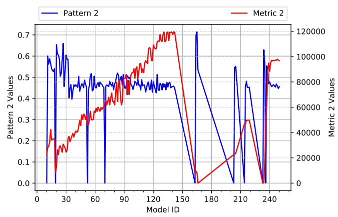


(i) P1 Vs. M9

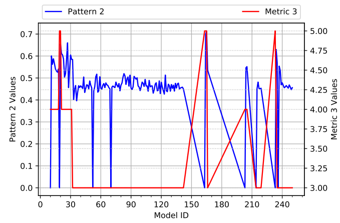
Figure G.1: Pattern 1 correlations with available metrics



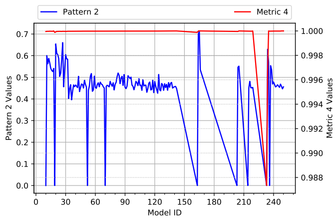
(a) P2 Vs. M1



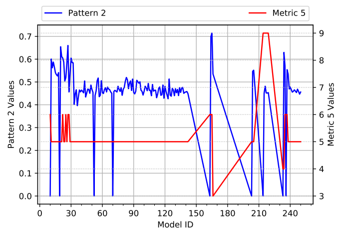
(b) P2 Vs. M2



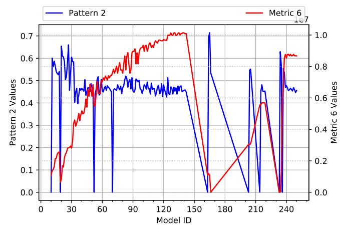
(c) P2 Vs. M3



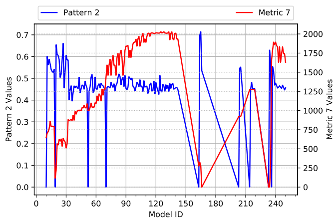
(d) P2 Vs. M4



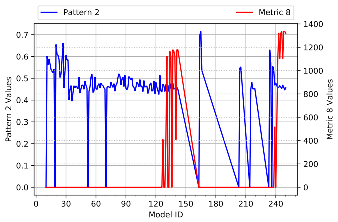
(e) P2 Vs. M5



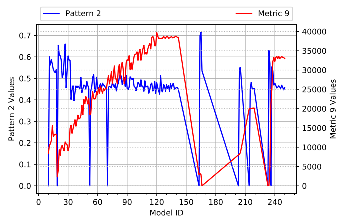
(f) P2 Vs. M6



(g) P2 Vs. M7

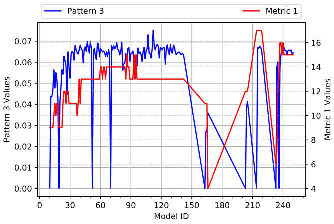


(h) P2 Vs. M8

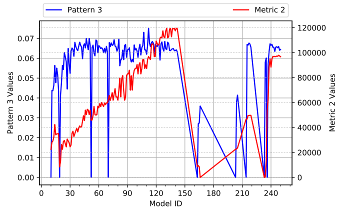


(i) P2 Vs. M9

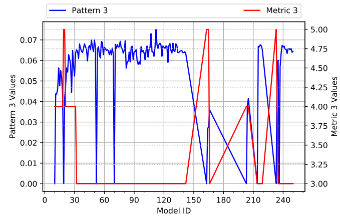
Figure G.2: Pattern 2 correlations with available metrics



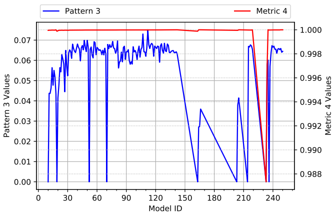
(a) P3 Vs. M1



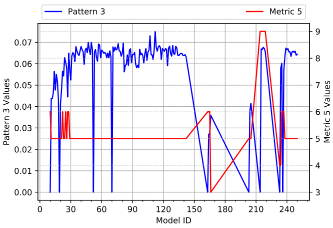
(b) P3 Vs. M2



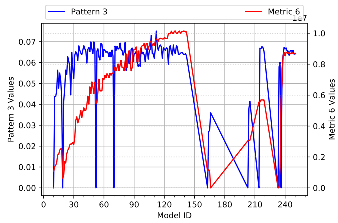
(c) P3 Vs. M3



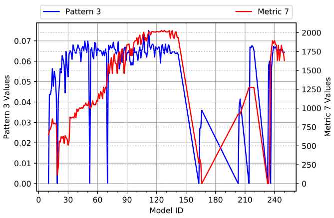
(d) P3 Vs. M4



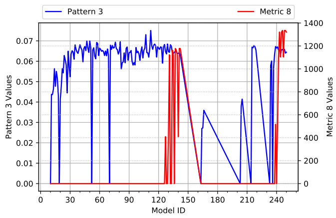
(e) P3 Vs. M5



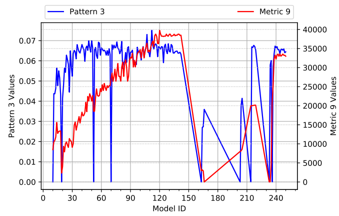
(f) P3 Vs. M6



(g) P3 Vs. M7

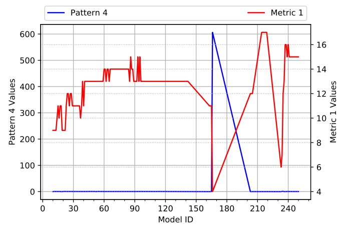


(h) P3 Vs. M8

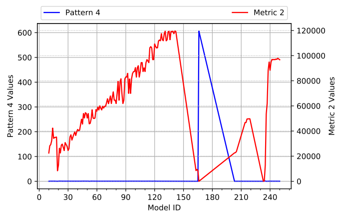


(i) P3 Vs. M9

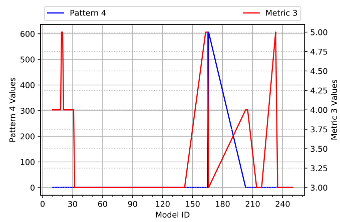
Figure G.3: Pattern 3 correlations with available metrics



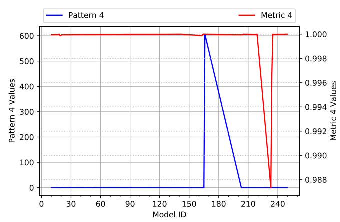
(a) P4 Vs. M1



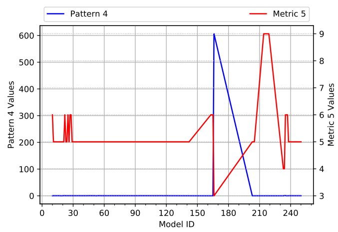
(b) P4 Vs. M2



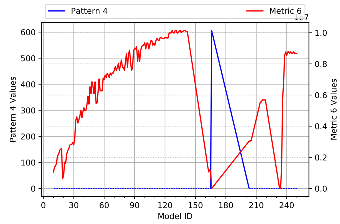
(c) P4 Vs. M3



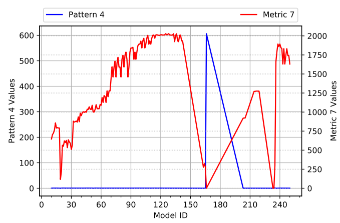
(d) P4 Vs. M4



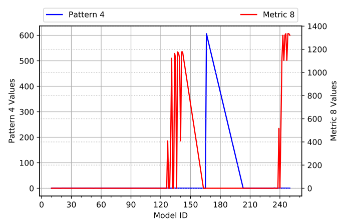
(e) P4 Vs. M5



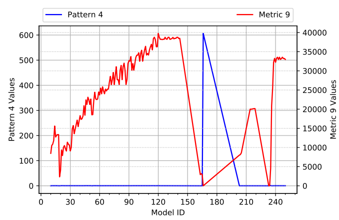
(f) P4 Vs. M6



(g) P4 Vs. M7

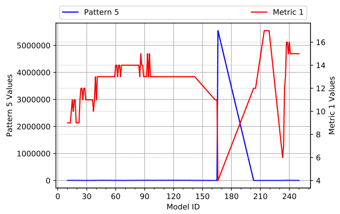


(h) P4 Vs. M8

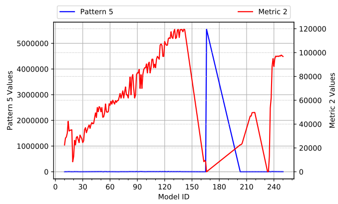


(i) P4 Vs. M9

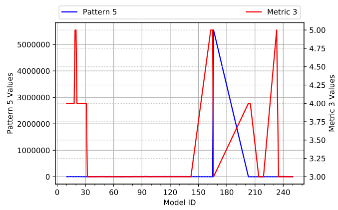
Figure G.4: Pattern 4 correlations with available metrics



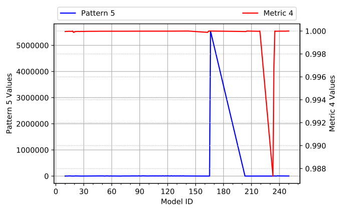
(a) P5 Vs. M1



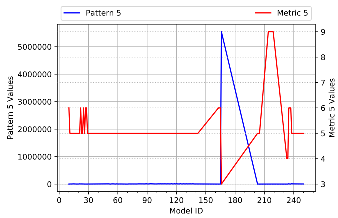
(b) P5 Vs. M2



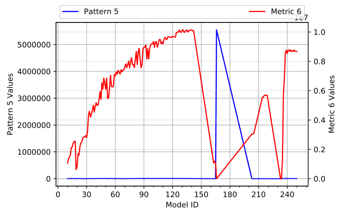
(c) P5 Vs. M3



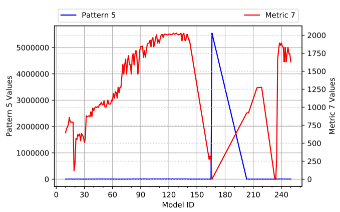
(d) P5 Vs. M4



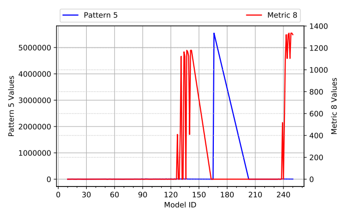
(e) P5 Vs. M5



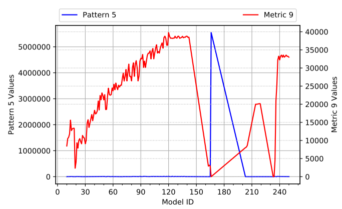
(f) P5 Vs. M6



(g) P5 Vs. M7

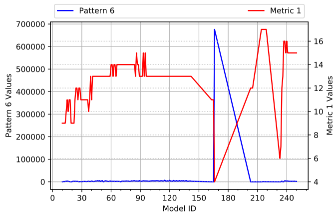


(h) P5 Vs. M8

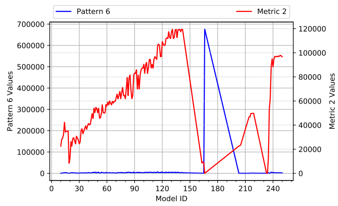


(i) P5 Vs. M9

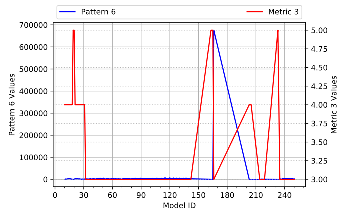
Figure G.5: Pattern 5 correlations with available metrics



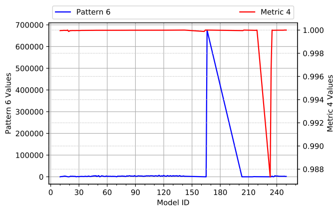
(a) P6 Vs. M1



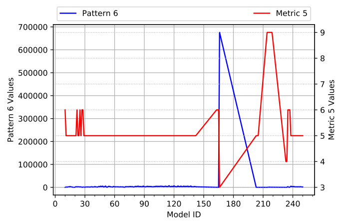
(b) P6 Vs. M2



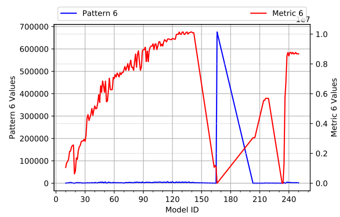
(c) P6 Vs. M3



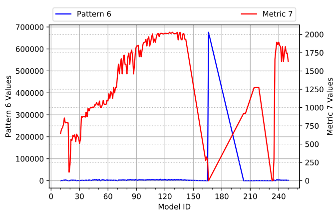
(d) P6 Vs. M4



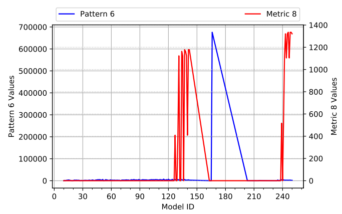
(e) P6 Vs. M5



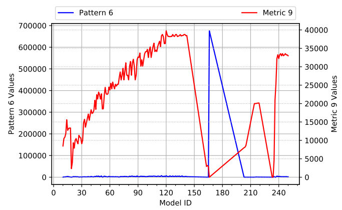
(f) P6 Vs. M6



(g) P6 Vs. M7

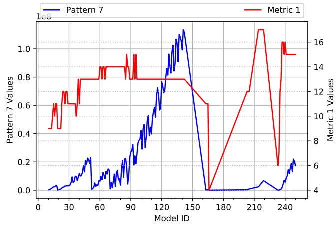


(h) P6 Vs. M8

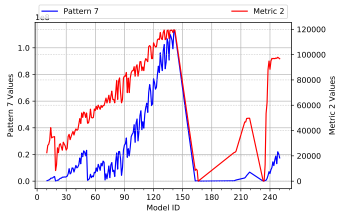


(i) P6 Vs. M9

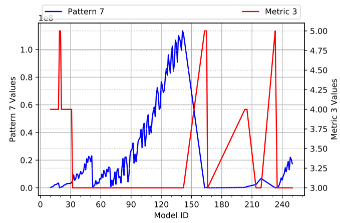
Figure G.6: Pattern 6 correlations with available metrics



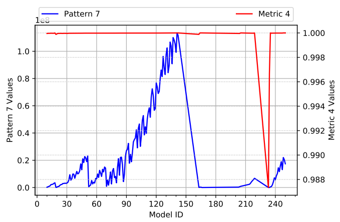
(a) P7 Vs. M1



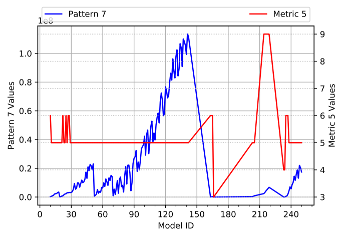
(b) P7 Vs. M2



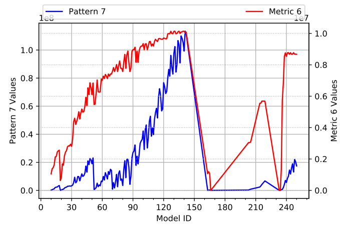
(c) P7 Vs. M3



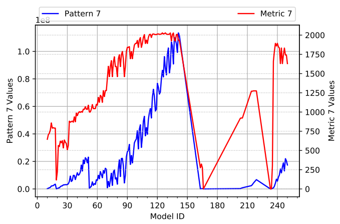
(d) P7 Vs. M4



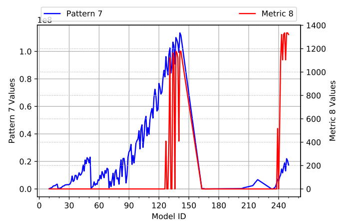
(e) P7 Vs. M5



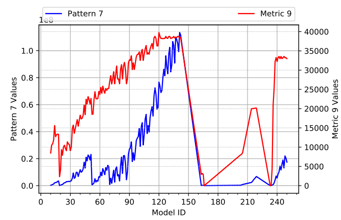
(f) P7 Vs. M6



(g) P7 Vs. M7

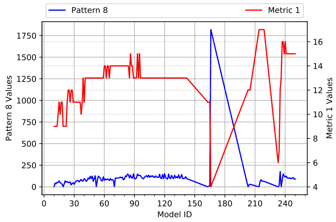


(h) P7 Vs. M8

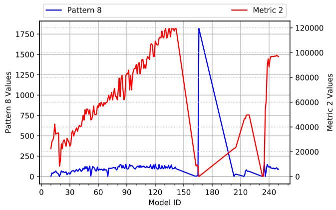


(i) P7 Vs. M9

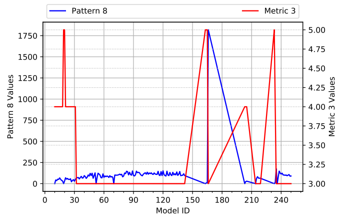
Figure G.7: Pattern 7 correlations with available metrics



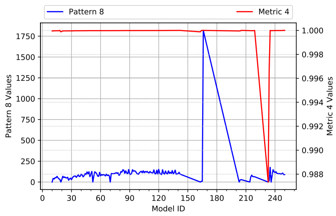
(a) P8 Vs. M1



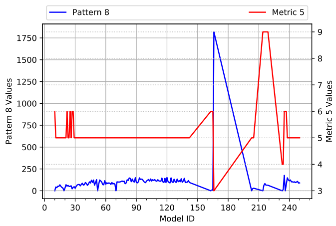
(b) P8 Vs. M2



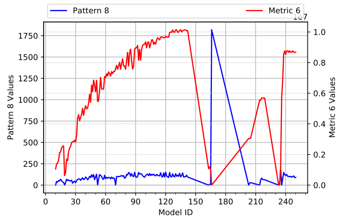
(c) P8 Vs. M3



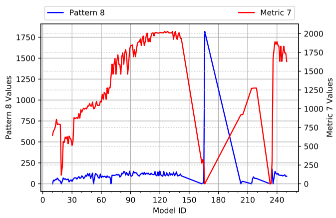
(d) P8 Vs. M4



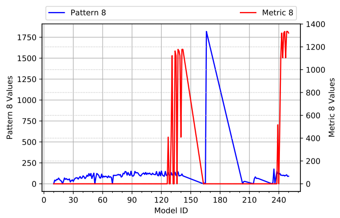
(e) P8 Vs. M5



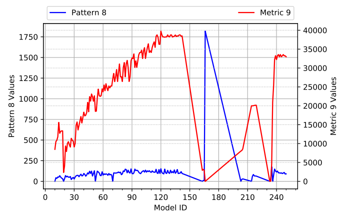
(f) P8 Vs. M6



(g) P8 Vs. M7



(h) P8 Vs. M8

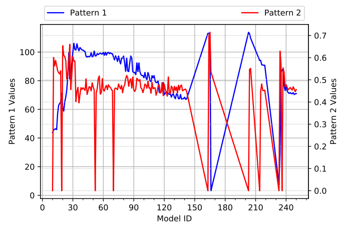


(i) P8 Vs. M9

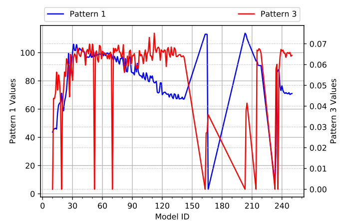
Figure G.8: Pattern 8 correlations with available metrics

H

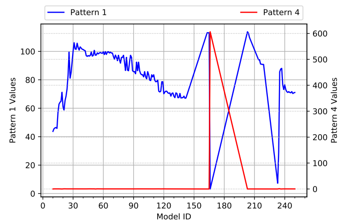
Pattern Correlations Together



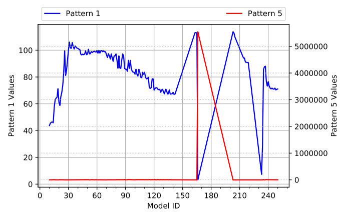
(a) P1 Vs.P2



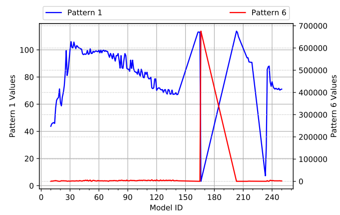
(b) P1 Vs.P3



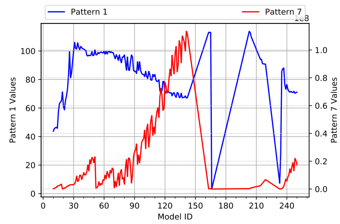
(c) P1 Vs.P4



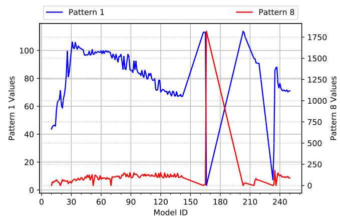
(d) P1 Vs.P5



(e) P1 Vs.P6

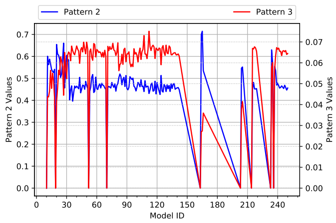


(f) P1 Vs.P7

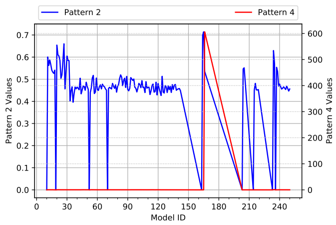


(g) P1 Vs.P8

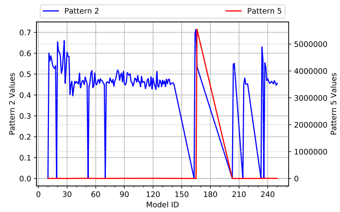
Figure H.1: Pattern 1 correlations with the rest of patterns



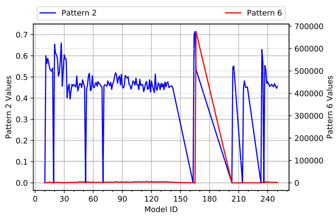
(a) P2 Vs.P3



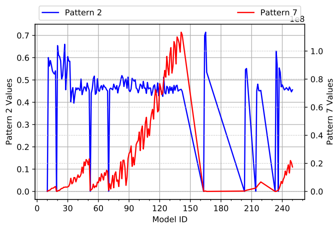
(b) P2 Vs.P4



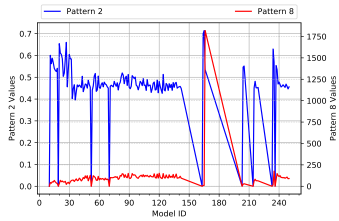
(c) P2 Vs.P5



(d) P2 Vs.P6

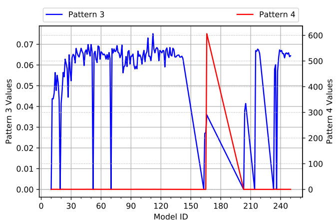


(e) P2 Vs.P7

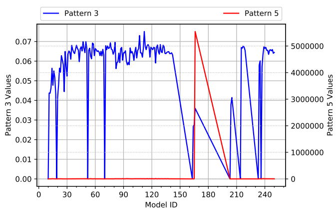


(f) P2 Vs.P8

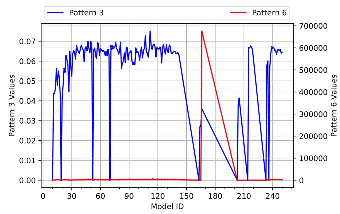
Figure H.2: Pattern 2 correlations with the rest of patterns



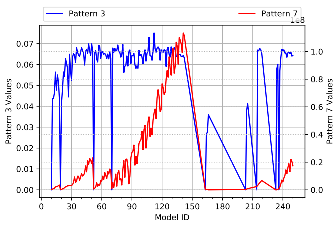
(a) P3 Vs.P4



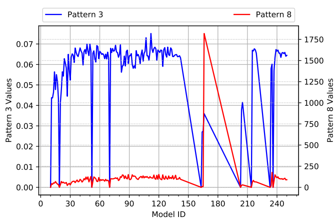
(b) P3 Vs.P5



(c) P3 Vs.P6

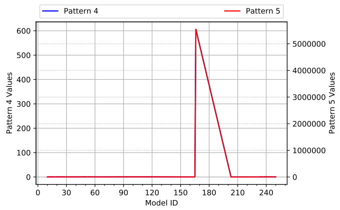


(d) P3 Vs.P7

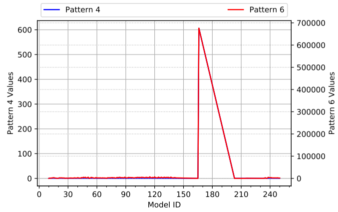


(e) P3 Vs.P8

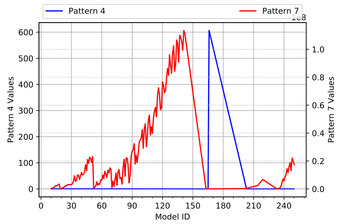
Figure H.3: Pattern 3 correlations with the rest of patterns



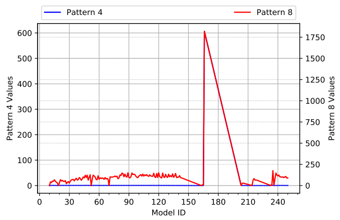
(a) P4 Vs.P5



(b) P4 Vs.P6

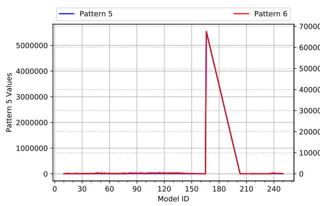


(c) P4 Vs.P7

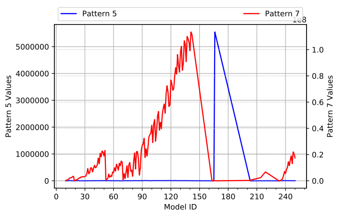


(d) P4 Vs.P8

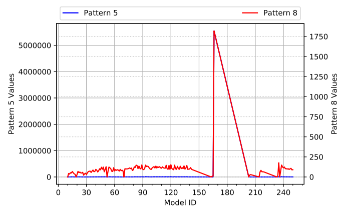
Figure H.4: Pattern 4 correlations with the rest of patterns



(a) P5 Vs.P6

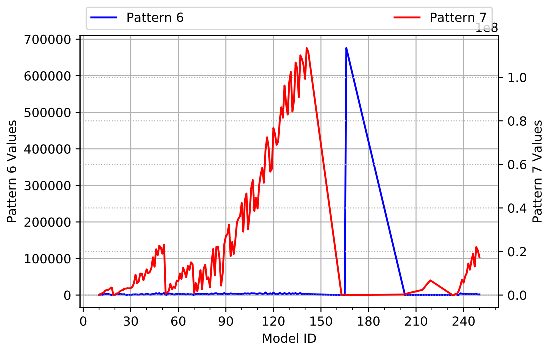


(b) P5 Vs.P7

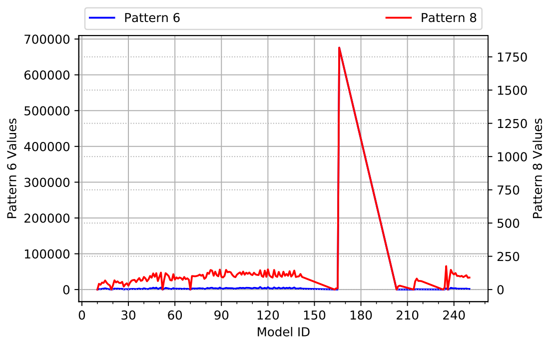


(c) P5 Vs.P8

Figure H.5: Pattern 5 correlations with the rest of patterns

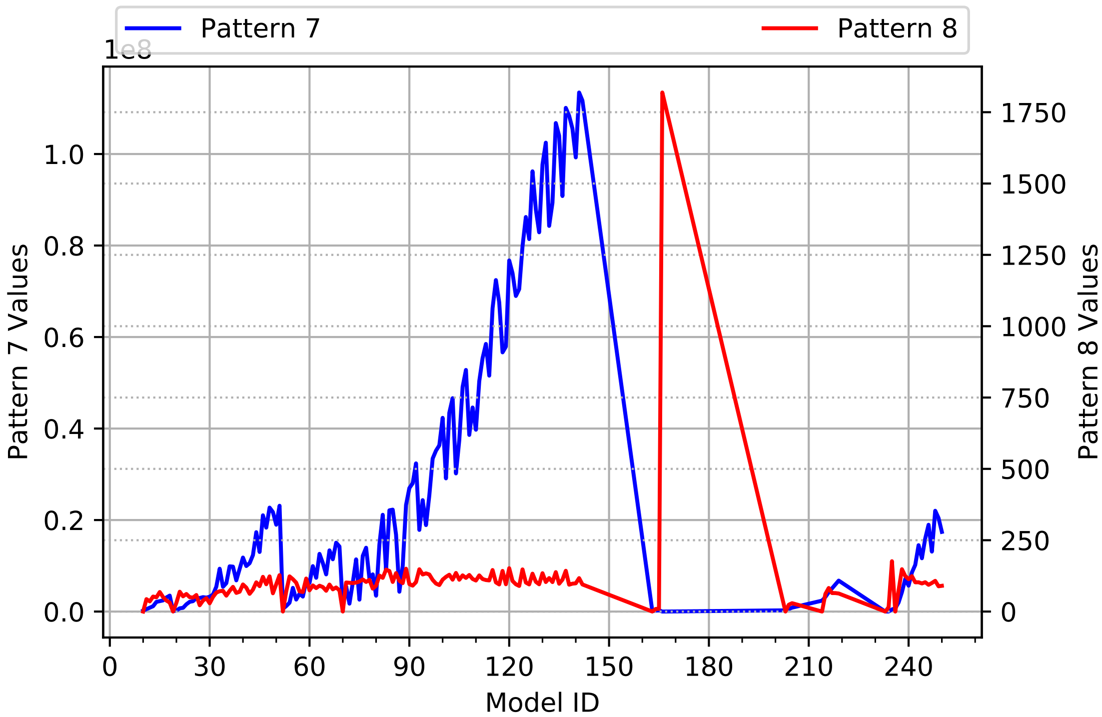


(a) P6 Vs.P7



(b) P6 Vs.P8

Figure H.6: Pattern 6 correlations with the rest of patterns



(a) P7 Vs.P8

Figure H.7: Pattern 7 correlations with the rest of patterns

I

Interview Transcripts

First Interview

Abdullah: OK. So the first question is: Are you willing to participate in this interview?

Interviewee: Yes!

Abdullah: OK cool. We have printed some consents in there. [It's] for telling you that we are going to deal with this confidentially and that your identity would not be revealed to anyone.

Interviewee: Yeah.

Sinan: We will make two copies of it. We will keep a copy with you.

Interviewee: Like that?

Abdullah: Yeah, okay. So, well in this interview, we will discuss as much as we can of the situations we analysed in the data that basically indicate the level of maintenance efforts you applied on the model. [So] our analyzation was focused on that area and we will try to discuss as much as possible of the situations we found. When we say maintenance efforts, we mean all changes applied on the models in order to enhance them or upgrade them or stabilise them. So all kind of activities applied on the data would be considered maintainers efforts.
[Yeah], for each situation, we will discuss [like] a set of characteristics and behaviours that address these maintenance efforts in our opinion and we want your help to confirm if this is correct or not.
OK, so I will start first by presenting the things we've done regarding the data. [So], basically through SystemWeaver API we gathered so many data about the models and we ended with around 259 models.
[And] by a model, we mean that each version of each model was available in the data. So some models have many versions and we would call these versions together a model group. [And] in this list, we have all the models with their handles and names and versions besides some information about the data, internal information. Let's start with here, [like] for example, we have models starting from here to here. The word "Yes" shows that this was the first version in the model group and the next lines are only an (X) versions of this model group. If we [can] show the name

for you, [like] for example, we have this [Group Model 10] with this handle. It had version 1 until version 9. So it has 9 versions in the database.
[OK], for each version we applied some of the metrics in order to analyse the data and see the aspects or different aspects of the data. I will go through them in a fast way just to explain a little bit.
So, for each version of each model group, we calculated the Max Depth, which is the deepest level of items [and] we also calculated something called References Weight by basically seeing them for each version. We have some items that are shared with other versions in other models or in the same group model. [So] for each item that was shared we would see how many times it was shared and then we will calculate the reference weight by multiplying those numbers. [like] For example, if we had a model or a version that has three items and each item is used in two different models in total.The weight would be 3 x 2 and will be 6 overall. So, this version would have a weight of 6 [So], This is just [you know] a formula that we've come up with to take a number that we can compare versions against.
We also calculated the employees count for each version. So, for example in this version, we had 98 employees working while in other versions We have more or less. We also counted the leaves, which is [like] the child nodes of a model and as well, the inner nodes count and the total items count. We calculated also the amount of updates applied. The additions, deletions and relocations. But in order to count these numbers, we had to compare with the first version. So in the models that have only one version, the amount of changes will be always 0 because there was no other version to see if there were changes or not. But with more versions We could manage to compute some numbers. These changes are for all types of nodes.
We calculate the changes on leave nodes as well and changes on inner nodes and based on that we calculated some percentages [like] out of all changes: What were the percentages of changes applied on leaves? Or what were the percentages applied on inner nodes?
[and] There is [like] this coverage percentage, [like], how many or what is the percentage of leaves affected by the changes on leaves? [So] if I, for example, have 100 changes and I have 100 leaves [so] it will be like all leaves were changed in a certain way. Same thing for inner nodes coverage.
We also did some analysation about the types that are changing together in each model group and not the version. So for each set of versions that form a group or a model group. We managed to find out the types that are changing together. For example, [Group Model 10] were changing together most of the time or [Group Model 19] were changing with [Group Model 52]. [So], this kind of information we [kind of] used in here in statistics to see that the largest number of changes happening in a given model, just an indication of the amount of changes applied.
We also have counted the amount of changes applied by some people or employees and we took the maximum number of changes. So for example in this model [this line], we have [EMPLOYEE NAME] having around 36,000 changes applied in total in all versions of the model.

Interviewee: for one guy!

Abdullah: This is, no, actually like there's so many changes but this guy had the most number of changes on all versions.

Interviewee: but he didn't even have the 36 thousand? one guy!

Abdullah: Yeah, actually he did so many changes but it might be like little changes that accumulated through time. So this number is calculated in a specific way that may not really be explained correctly. Like here those changes by employees. for example in this version we had a list of employees and the number of changes they have and then we summed up these changes for the whole model So if your model has 9 versions we summed up these numbers for the 9 versions and then we got a result. But we only picked the highest result to show. Only the employees that were changing a lot probably.
We also calculated something related to weeks, months and years by seeing which month was [like] the month of the most changes applied on this model or which year was the year with the most changes applied on model.
So these are the metrics we used to analyse the data which formed the base to our analyzation of the patterns or what we call situations.
[OK, so]. In this sheet, we had the same list of the models, but then we went through creating formulas using those metrics we just introduced or combining two or more metrics and seeing if we have some results explaining maintainability efforts or maintenance efforts applied on the models.
I will explain that through time. But what we want to focus on is a list of a few group models, they are around 9 or 10 groups of models only and we will try to cover as much as possible of the situations we discovered.
[So, okay] Hope I didn't really [like] introduce so much information. It sounds a little bit difficult, but I will take it easily from [like] here.
[OK, so. yeah] The first situation we tried to analyse, was that if we took probably the references weight of each version of the models and combined it with the total number of items in that version of the model, we might get an indication of the maintenance effort applied. So basically when you create a version of a model, through time, you will have more changes probably, and then with each version it will get more complicated and you will end up with applying many changes. So, by having those two metrics together we might get a value representing the maintenance efforts.
[OK] in order to actually present results. We compared each version with the base version of each group model. so let's start with this model called [Group Model 10], which had 9 versions and the base model is this handle. If you can remember the model we can just discuss it. If not, we can open it on your laptop.

Interviewee: It's a very old model we saw in the slides that you have and this is of type of [TYPE OF MODELS].

Interviewee: [Entering the model ID on their laptop]

Abdullah: if the network worked on my PC, it would have been a lot easier to just copy it and open it up on my PC.

Interviewee: This is old.

Abdullah: Yeah it is old, but does it have 9 versions as we indicated? exactly the one we are talking about? So the name is [Group Model 10] and it has 9 versions?

Interviewee: Yes.

Abdullah: OK, cool. Well, basically we found out that for this first situation the model kept getting more complicated.So the last three versions are so complicated compared to the first one. And in the middle, it was kind of a little bit complicated.

Interviewee: Yeah.

Abdullah: Do you think that this is correct?

Interviewee: Yes, it's correct because it has evolved and when you're coming to the latest versions.

Abdullah: OK, so it seems that for this model, it's kind of correct. The last three model seems to have more maintenance efforts?

Interviewee: Yes, and the reason why it gets more complicated is that the model is evolving and you look at these versions over a period of one year, I think so, approximately one year or one and a half. So, it's natural that it may get more complicated because you have included more things. You probably have more people working here during this year. What is interesting to see is that when you're looking at the next group, it seems that it picks up where the last one finished.

Abdullah: OK, you mean in the same model? Like each version is continuing based on the last one and more stuff are being added?

Interviewee: Yes, and then something seems to happen between these two groups too. So from version 9 of the first one you going into the first one of the next one, probably, because you can see what it says the [Group Model 19] in the other one is [Group Model 10] and then they added a [SUFFIX]. [OK], so it's probably exactly the same model evolving. So you have exactly the same model today as well. [OK], so you could follow this model until this present day, but they have on the way, they have had .. called a destructive version change and that was version 9 then they start picking up from something else.

Abdullah: OK. So basically for these 9 versions, they didn't try to maybe enhance or make it less complicated?

Sinan: You can't say complicated. You can say that is hard to be changed. Just like this. So because now this situation that we explain exactly it's it's more hard to be maintained. So maybe to add something or to do something or change. [So] this is our point exactly. [So] if we look for this the version, maybe 7, [okay], it started to be more harder to be.

Abdullah: This is only compared to the first version all the time.

Interviewee: Yeah, something happens in version 7.

Sinan: Yeah. this is maybe it's in this situation. We can say if we can explain a deal about situation. So maybe now the weather is just good or bad. That's our Point here. [So] if good it's not related to our metrics. Now we should just look into this situation and say is it good or bad now? If you can't judge it?

Abdullah: Yeah. I mean, what sinan is trying to say, [like] do you see that this is a correct representation? [like] The last three models where harder to maintain compared to the first one, is that yes or no? For an estimation which just like you don't need to be really [specific].

Interviewee: The question is why it's become harder at that point?

Abdullah: The questions is did it really became harder? We just wanted to see if our results are correct or not. [So] basically it's logical that it got harder but is that the truth?

Sinan: Maybe just someone made some refactoring and made it easier to be understood or something like this.

Interviewee: I see, then we need to compare because you have a shift from version 6 to 7 and 5 to 7 .. I see differences in the model.

Abdullah: We are focusing on this one because it was the only one that is perfectly increasing in these numbers while other models were going ups and downs, so we want to compare and see if our situation is correct or not or if this was a special case? If you're not sure [just like] we can skip it. We don't really want you to be busy in finding an answer. It should be [like] a simple yes or no based on your expectations or experience. You don't really need to prove it for us [but] just give us like: Yes! this is something that's logical or I would agree with this or not. [So] the main question would be that we see here that the maintenance efforts are increasing through versions. Do you see that as the reality or not?

Interviewee: I want to, but part of me should say that the complexity went down.

Abdullah: Went down!?

Interviewee: about that point. So when you say getting more complicated, I would say that we became less complicated, because I see a shift in the model at that time.

Abdullah: Yeah, I mean like our pattern is not true or false. We're just asking for the reality. So we might find other patterns that are actually giving what you're saying. [So] that's why we just want to see if it's correct or not.

Interviewee: It's very hard to say because it's so long time ago and what happens in the models. But you can see from the version 5 to version 6, we see a big difference that they all of a sudden removed all the domain allocations and domain allocations are the basis for making this into an architecture, so I don't know why [so], for me, this version ,5, is kind of the last in the chain of doing in this way. [So] I would be surprised if you couldn't find a new architecture picking up from version 5 of this.

Abdullah: So basically you're saying that version 6 should be more maintainable or with less effort compared to 5?

Interviewee: I can see difference in the model that they have taken away complicated part of the model, but they also added another part that is kind of complicated. So you have a shift but I would say that you cannot build a [PRODUCT NAME] from version 6. You had a complete data in version 5. But in version 6 they seem to have done something in the development organisations that they made a shift so I would say that somewhere around version 6 they have done something, they have reorganised themselves and looked in the model in a different way.

Abdullah: OK. So if we took only the first five versions, would you see that the efforts were increasing through time?

Interviewee: I would say the same and yours numbers stating the same. [OK. So] yeah, so they rely as I can see it.

Abdullah: OK. Basically we can probably confirm that from version 1 to 5. There's an increase in each version in the complexity?

Interviewee: Slightly slightly. Not much.

Abdullah: The next column actually is comparing each version with the previous one. so we can see here between 5 and 6 something you're talking about. In 6 it was more difficult to maintain compared to the 5 one, is that correct?

Interviewee: They have made a big change in the model.

Abdullah: OK. So many changes?

Interviewee: Not so many, a big change, a conceptual change.

Abdullah: OK.

Interviewee: They have taken away while one major part of the model and added another major part of the model.

Abdullah: and they start building upon that so like in version 7 they continued after the changes presented in version 6. right?. So here we can see that in 7. It was easier to change compared to 6 because in 6 they presented larger changes.

Interviewee: Yes.

Abdullah: So does this sound correct to you?

Interviewee: Yeah. when I looked at it, so might be I cannot say the numbers, but there happened something and you have seen it go from green to red.

Abdullah: exactly.

Interviewee: then something big happened, and you went from 104% to 130% in the previous column. So something happens at that point. So you have identified something.

Abdullah: To be sure we want to compare this pattern to another model. So I want to pick something that's maybe newer. So let's start by the name, do you think that [Group Model 19] is a new one?

Interviewee: That is I would say might be the one that picked up from version 5.

Abdullah: OK. Yeah, I don't know. Yeah, so maybe we can go with this because this is the largest one we studied actually called [Group Model 70].

Interviewee: Yes.

Abdullah: Are you familiar with this?

Interviewee: it's the same model that we talked about. We talked about the same model the the big model that they use to build the [PRODUCT]. so it has increased because they added more parts of the system and more parts of the system for the [PRODUCT]. So if you go from 100 function, you go to 150 functions. So it's increasing in that sense that is more data and they also might have done changes in the modelling principals, so they they might have introduced as we saw in version 5 to 6, they've probably re-made some things in that I cannot really say what it is.

Abdullah: I would say that all the models we picked are related to the architecture of [PRODUCT NAME] so they might be related together as you're saying.

Interviewee: it's the same [PRODUCT]. It's the same model with like evolving.

Abdullah: Yeah, so, I guess I can see .. [LOOKING INTO MODELS]

Interviewee: The [Group Model 70] that is not the [PRODUCT NAME]. So that it is a completely different system.

Abdullah: Maybe we can take that?

Interviewee: Yeah. See, they were in for a short while and then they cancelled the project so that nothing that they have proceeded with. I would say that you couldn't make any assumptions.

Abdullah: but I mean if we took these four versions.Would you agree that it was [Like] kind of similar here, you can see like 100% and 99%. So there was not much changes. It was the same version just like copied again and again?

Interviewee: Yeah, they did small changes and then you probably in the green one they abandoned the model.

Abdullah:I would like to take something. That's maybe you can go with this [Group Model 236].

Interviewee: This is, this is very new.

Abdullah: OK.

Interviewee: So this is what we're working with today.

Abdullah: OK. Yeah well, let's go with it then! For this model, we can see that it started with so many changes and through time it got. Stabilised maybe?

Interviewee: Yes.

Abdullah: So like in the last version here we can see there are less changes compared to when they started, does that sound correct?

Interviewee: Yes, because before you had the [Group Model 70], we have actually a [Group Model 70] and [Group Model 236] the [LETTER] in the name. So one of the other platforms are the [Group Model 70], so today you have two parallel systems one is [Group Model 70] and one is [Group Model 236]. So that that is probably when they established a [Group Model 236] that letter means that they took the [Group Model 70] platform split into 2. So [Group Model 236] is copy of

[Group Model 70], but with a lot of changes, so they established it, I guess that you see the establishment of the model was the first two versions.

Abdullah: Yeah exactly. Was two versions and then changes kept decreasing through time, or [like] the amount of enhancement or changes got less and less through time.

Interviewee: Yes.

Abdullah: OK, but if we compare each version with the previous one, we can see that there is a slight increase in here like between version 4 and then they went back to 3a1 so do think that the 3a1 got so many changes compared to the 4?

Interviewee: The comparison shouldn't be done to the 4 [it's interesting to see ..], You should compare with the 3, and then it's interesting to see the difference between 4 and 3a1 because that is actually, parallel work in organisation. So, you have to open both versions at the same time, [So] you work with version 4 and at the same time version 3a probably .

Abdullah: OK. If we want to compare 3a to 3, we would see close numbers like it would be [like] 76.5% and 76,4%. So actually in 3a was little bit of less changes, compared to the changes applied on 3, does this sound correct?

Interviewee: it's the same system in the 3a1, so it was a small modification. and then you have the major modifications of version 4, because the versions number 1 2 3 4 5 6 7 8 we call the main track the main [PRODUCT] of development, so that is going to start a production somewhere in the future and the 3a1, 4a1, 5a1, that is what they call production branches. That is something that they build the [PRODUCT] and then they do modification of that branch. So they branch out, build it and then they get feedback in testing and so forth back into the main track. So, when you're looking at the version chain you couldn't compare 3a1 with 4. It says something about the 4 to 3.

Abdullah: So can we compare the 4 to 3 or even with 2. Yeah, like do you see that the version 3 had less changes compared to the 2 and then they slightly increase the changes in version 4?

Interviewee: This is I think that what they say that is difficult to, it's difficult to say is that if the statistic way.

Abdullah: Because it's kind of close numbers So yeah, there's no big shifts.

Interviewee: Yeah, I would, I would expect that you have very small changes between the versions all the time, because you do small fixes all the time you change in one part of the system where you can, small things in many parts of the system, but you don't have any revolutionary things as you have when you established the

[Group Model 236].

Abdullah: Yeah, so see this is actually good. I guess we can move to another pattern. Actually, it's almost 2:30. So we wanted to ask if you're available for more than one hour or should we book something else?

Interviewee: I'm available.

Abdullah: OK, I will go, probably, to the last two patterns and talk a little bit about them. So we thought that the number of versions and the depth of the model besides the node counts might indicate maintenance efforts [like] so when we increase the version and when we change the depth, when we have more depth probably, and we will have more nodes in a model, for me, I would say that it's it requires more effort to maintain. Do you think this is correct?

Interviewee: Yes. That is what I think, correct. The depth, because when you when you having a depth in the model that means in a platform like SystemWeaver, if you changing the leaf you need to change everything above, so if you have a more shallow model, you don't have to change all the items on your way up to the top. So, the structure include introduced levels where you need to update so that you can update the interesting part because the details are often in the leaf, so the details that you want to work with using the leaves. Changing one leaf, that means that you need to change the upper things and then depending on how you have in your system. If you're changing one leaf, maybe you need to change another leaf in another part of the tree. So, this is, more depth you have the more high probability is that you have spread your information laterally, on the lateral. Not on the vertical. So if you have combined, if you have a function, that is spreading not vertically in this but laterally [so] you need to change many different leaves to change one single function, then you get another with a smaller depth you don't need to change in that number places so that it's hard to say anything about it.

Abdullah: Yeah, but we would take the same old version we discussed first and see if this is working or not. For this situation, we can see that from version number 4, we had some difficulties or lots of efforts applied on the model and we are comparing always the the version with its previous version so it's always with predecessor. We can see that the changes are getting less through time. So the last version had less changes than the one before, but the one before had more changes than probably the one previously so we have like different numbers.

Interviewee: Yeah.

Abdullah: Does this sound correct to you?

Interviewee: It could be a bit because you have you have a change from 0 to 148 percent!

Abdullah: Yeah, this is because usually at first we don't have that much of nodes or versions. the version here might be [like] version 0 so we have a result of zero. Yeah. But we are probably interested in those values that are above zero. What I'm trying to say, is that in here like the first pattern we discussed there was an increase in maintenance effort through time, but this pattern is showing that: No, there's like a decrease in it.

Interviewee: What was the pattern 7 compared to the 1st pattern?

Abdullah: Yeah, the the the pattern 7 is we saying that when we increase the version and the total number of nodes, then there might be an indication of more changes. So we're just seeing if the version number and the max depth and the nodes count might indicate the change, and it may not. I mean, clearly here, we see different results to the ones we already discussed. So I would say that this pattern, maybe is not the best one to use to indicate changes because it's giving us different results compared to the one [we already approved]..

Interviewee: Can we look at that model, was that the first one that we looked at?

Abdullah: it is actually the first one.

Interviewee: and we said that the version 5 something happened?

Abdullah: exactly.

Interviewee: What was the row when we got the 148

Abdullah: So basically this is the 4 and 5 or 5 and 6. Yeah. So it seems that 6 having more changes compared to 5 but only a slight of changes but in the first pattern. We would say that there were so many changes compared to 5.

Interviewee: And that model was little kind of tricky because they switched from one thing to another and it was not complete models, so I don't really know what happened.

Abdullah: But actually we may not take these numbers as a real indication if I want to compare those two patterns I would say that: Yeah, there are more changes in version 6 compared to 5 and both patterns are saying this but in different numbers. So, is that the situation? like the version 6 had more changes compared to 5? because you said that there was big changes at 6, the version 6, right? if I remember correctly.

Interviewee: Yes.

Abdullah: So I guess the better is also describing things but in different numbers, so the threshold of this pattern might be different than the threshold of the first pattern, but they're both giving us the same result in different numbers.

Sinan: Can .. ask about efforts more than changes .. you just.

Abdullah: I mean, even for the last pattern you can see that numbers more changes compared to the previous one. So the patterns we kind of calculated are agreeing on this if you compare each pattern with they have more except for this one, so maybe we cannot include pattern 3 because it's not giving us the truth [UNCLEAR DISCUSSION BETWEEN ABDULLAH AND SINAN]

Interviewee: I don't know if we dare to say anything about this old model, because there was a cleanup activity back in 2009.

Abdullah: OK, then maybe we can focus on model you're more ...

Interviewee: Yeah, I think that we should focus on the more later on. You don't have the date in this, the date is saying very much because I guess that there was a structure combining different architectural, because in the beginning they had a parallel architecture, they had one reference architecture and one kind of instance architecture and the idea was to keep these architecture alive and may make changes in both. So, you have the reusable stuff in reference and then the instantiated in kind of flexible building [PRODUCTS], and now we only see one thread of the architectural building [PRODUCTS]. As we have today we have the [Group Model 236] and I said we have [Group Model 70]. As well as [Group Model 70] and [Group Model 236]. So that means, that when you establish the [Group Model 236] you get lot of work and then when you're done you could see in [Group Model 70], You see something in [Group Model 236] is established. You see changes in the [Group Model 70] but not that Many but ..

Abdullah: if we went back to [Group Model 236], which is the most recent one, we can see that there are some peaks in here like for example if I want to compare version 8. To version 7a is that possible to say? or do you prefer to compare two sequenced versions like 6 to 5? OK, So in 6 we can see that we have more changes compared to 5. Yeah, and maybe in four [or like not] the only possible way to compare the 6 and 5. In our first pattern, we could see that 6 and 5 had kind of similar changes, not that much of a difference, but here the pattern is saying that there is!

Interviewee: What was the difference in the patterns?

Abdullah: The first one was about references and the total amount of nodes. The total count of nodes [Yeah], but here we're just taking the version and the depth and the total count of nodes.

Sinan: This, the first was just references and we just considered references and the total number of nodes

Interviewee: in the first one?

Abdullah: Yeah.

Sinan: and then the second one is taking the model just the depth and its total count of nodes.

Abdullah: and also the number of version. I can see that there is some confusion in this pattern. So, maybe it's not the right one to use. There's probably a very slight connection or very little connection between the number of versions, the depth, and the count with the maintainability. Do you agree with that?

Interviewee: I struggled with trying to see what kind of things we're looking at because when looking at two versions of the model, you can have things like indication not much happened or your introduced a new functionality that you have decision to introduce a new kind of functionality and a lot of people do a lot of changes and you can see, if you're closing in to start a production of the [PRODUCT], so saying these cases you probably going to see a variation in changes, you can also see that. You have so [much] data, so it doesn't match but if you have, if you have a development loop of 16 weeks and then you go to 8 weeks. [So] that means that this top model is open for 16 weeks, that means that you have a lot of changes, but if you closing down the loop to 8 weeks you don't have time to do that many changes. So, it's also depending on the process how long the loop is open, because I think that the amount of work that is performed is kind of equal all the time. Then, the parents, then if you have more functions then you have more changes. If you have closing into production, first, you have, probably a lot of changes and then you have fewer changes because you want to have stability for the release of the product, and then of course the loop time is also important. so there is more things into this ..

Abdullah: Yeah more than this, factors or metrics or, okay.

Abdullah: I will move to a maybe a simpler pattern to understand which is pattern number 4. basically in this pattern we would compute the ratio between the total number of changes and the total number of nodes we have in a model Yeah. So basically just like the total number of changes applied and always compared with the total number of nodes and we will try to see how it reflects the maintenance efforts and this [Group Model 236], which is the newest one.

Interviewee: Yeah.

Abdullah: Basically, we'll just compare each version with the one before and the results are here in this column Q. We can see like in version 3 and 4, there was so many changes at [the] first. Like probably in version 3 but in version 4 the maintenance efforts decreased.

Interviewee: yeah.

Abdullah: do you consider this correct?

Interviewee: Yeah, because we concluded that this probably because it was established in the first two versions.

Abdullah: And then probably just little changes in each version, we can see here that the change is not big in each new version. So we have kind of smaller changes in each version. Does this sound logical?

Interviewee: Yeah, I think it's .. the number changes is probably constant over time once you have established the model, then you can see that if you introduce new functionality, then you're going to see an increase,

Abdullah: okay. I will try to probably prove that point about the new functionality if we take a look at another model.

Interviewee: I think the [Group Model 70] and the [Group Model 236], those two are probably the two parallel the [Group Model 70] and the [Group Model 236].

Abdullah: Ah, because the [Group Model 70] has so many changes.

Interviewee: Yes.

Abdullah: We can see here versions. So we have around 70 versions,

Interviewee: Yes, so if you would have the date. You should see where they split.

Abdullah: OK, I see but I mean looking at this [Group Model 70] at some point between version 39 and 40, There was so much maintenance efforts applied on 39 while less maintenance of effort on 40. Do you think that this version the 31 had [like] introduced some new features maybe the middle if you would like we can give you the the handle so you can check the model and the changes. I mean answering this question would prove probably that the pattern is correct or not.

Interviewee: Yeah, and interesting in this is to see if where we have the point where they split it.

Abdullah: Yeah. [PROVIDING THE HANDLE ID TO INTERVIEWEE]

Abdullah: it should be the [Group Model 70] version 13.

Interviewee: Takes a while to open.

Abdullah: Yeah, it's a large model. I guess it's the largest we started with 70 versions.

Interviewee: Yeah, and this but this is also that the the only model so we talked about. You're probably haven't looked into the test model and rebuilds and those models.

Abdullah: we actually included all items and all types, so probably they are included inside.

Interviewee: Yeah, if we look at the 39, version 39, it says in the version text: "refactored". So that means that we have something.

Abdullah: so many changes.

Interviewee: Yeah.

Abdullah: so it was a point of refactoring actually.

Interviewee: and the variability model was before said you have why? So between Y and Z we did the refactoring on the variability and the variability module before this version 39 was inducing many changes for no reason, administrative changes. So what you want, you probably should see that you have more changes in each version before 39 compared to after.

Abdullah: compared to after?

Interviewee: yeah.

Abdullah: but at the version 39 there was so many changes, right?

Interviewee: Yeah that .. there .. everything. Because it was refactored.

Abdullah: in version 40 we had so less changes compared to 39. So ..that might be correct

Interviewee: yeah, and then then you have should have a lower number of 40, 41. 41 was a big one.

Abdullah: Actually it's because we compared with the previous ones, So 41 is compared to 39, but if we want to compare to 40 we can look at these two numbers.

Interviewee: Yeah, but you also had at this point in time. We also got the [Group Model 236] emerged.

Abdullah: OK, so [like] between 40 and 4?

Interviewee: somewhere in the neighbourhood.

Abdullah: This also seems to be a little bit different if we go to the version 26a3.

Interviewee: Just a little bit, but I can see when I go from the 39 I get in something that we call a [PRODUCT] architecture compare area. So at that time there was a reason to compare these two. It's there was a comparison between the version 39 of [Group Model 70] and version 2 of [Group Model 236]. So those two you can consider kind of a pair and from that point they are they are going together. So then you get a link between the [Group Model 236] platform in the [Group Model 70] at that point. That means [Group Model 70] got so complex, So they when they tried to introduce new [PRODUCTS] in the same platform. There was a lot of Complexity that they need and they couldn't create the systems. So they decide to split into two systems, actually the two separate development lines for this, that also means that you kind of up to the point 38 of the [Group Model 70] then you have one development team for the [Group Model 70] then from that point, from the 39 on-wards you have kind of the same team dealing with two models or two teams dealing with one model each.

Abdullah: OK. This is actually really good.

Interviewee: And then you also had a refactoring on the variability. that was refactoring going into change. Approximately 10,000 items 20,000 items that were changed in overnight. You alsohave if you look at the comparison here that you introduce the new model in 39 that you didn't have before so that means that you have a lot of changes in the new parallel model, and then you can see that you want to [have] keep the changes change rate low, but by introducing a new model where you gather all the kind of instantiation information or variability information or usage information. Then you can get the number of changes in your platform get that down so that you do that it changes in a parallel model instead of in the main model so that you can reuse more but in these numbers you have this variability model also included, so means that you cannot see probably cannot see the effects of that. There is a parallel model from from 39 and on-wards dealing with variability. That was pretty before 39 was included in the main model.

Abdullah: Hmm. So they Introduce probably more changes in 39 to do this transition.

Interviewee: they started earlier to do it but then the change, actual change in items was made in this period of time.

Abdullah: based on this information, I would like to ask about the last pattern we try to analyse which is pattern 8. we have this idea that sounds logical to us. Like if we consider the number of employees working on Model or a version of model and the ratio of changes compared to the total number of nodes Then we might get an indication of the efforts. Like for example, let's say you have 20 employees working on a version model and then you have this amount of changes and this amount of nodes or total nodes. From this model we are discussing right now. Which is the [Group Model 70]. This pattern was telling the same thing you're saying about the if the 39 like we have lots of changes or lots of things happening in 39 compared to other models and this confirms actually to the pattern we were discussing moments ago, which was the pattern 4 but in order to prove that this pattern may be giving us a correct result. I would like to see if it's possible to compare these versions together, the 34a2 and 34a3 maybe. According to our pattern, in 34a2 there was more changes than the 34a3, doesn't this sound correct?

Interviewee: Sounds logical. Yes. Because that is what the thing we talked about, the production branch, and that means that you have the 34a1 that is in parallel with 35 and then they have done changes in that branch and probably don't have 34a4. So it ends at 34a3. And they made small changes from the a2 to a3 so that they could get the [PRODUCT] to start. when you want it to start and it probably didn't start, so it needed some fixes in a queue, but not that many.

Abdullah: Yeah, but if we looked at 36 and 37 we can see that in 36 there was more changes Compared to 37, can we agree with this or is it correct or?

Interviewee: it depends on, because we introduced this change variability, slightly earlier.

Abdullah: the pattern number 4 is also agreeing with this which is the one we discussed before this one. So in pattern 4 we are seeing also more changes and 36 and compared to 37. So we just want to see if this pattern it is also saying the truth.

Interviewee: do you want to know what happened in 36?

Abdullah: if there's like an explanation like why 36 is more complicated than 37 in terms of maintenance efforts.

Interviewee: We have a refactoring also in 35, 36,

Abdullah: okay.

Interviewee: So the 35 and 36. I would say 35 and 36 are the same. those two are identical in content.

Abdullah: Identical in content ?

Interviewee: Yes.

Abdullah: OK, the content might be identical but do you think. The same number of employees were working on these two different versions,

Interviewee: I would say that the 36 ..

Abdullah: is mainly a copy from 35?

Interviewee: Yeah,

Abdullah: but this pattern is showing that in 35 there was less changes than 36 but this is because in this pattern we're taking the number of employees into consideration

Interviewee: if you take 36 is as I can see an exact copy of 35, it was a refactoring. So I would say very few people were involved in 35 to change that one. So there has been a change from 35 to 36. I take this on the names because we have the 35 called x0-refactored. OK, and we have an x0 as well.

Abdullah: Is there any chance that maybe more people were allocated to work on the newer version? So 36 got more people involved. Maybe as a preparation for [like] the next version.

Interviewee: Yeah, yes, because we are, we are in the despair of what we did refactored on the variability model, so it's very hard to say what what happened.

Abdullah: Maybe we can take two different versions like 39 and 40. Yeah, and here you said that they presented the changes. So this also confirms What we said.

Interviewee: The 35 and 36. Yeah, it's exactly the same content! the only difference is that you have variability model in the 36 that has been introduced. Introduced in the 36. So the 35 has an old variability Model and 36 a new one.

Abdullah: Which means they introduced changes in 36.

Interviewee: in 36, they introduced changes by refactoring script, but this probably not affecting versions of the details, just adding a model. So it's in that case. There was a large impact of the model and change it but you don't see it in version change here, so the content of 35 and 36 is exactly the same.

Abdullah: Well, actually we would you said really explains the numbers here to me. So this is good. Just looking if I can use another ..

Interviewee: and then in that. if you take version 38. in version 38. It got a name [SIMILAR to Group Model 70] that means that the [Group Model 236] was invented in that case, that in that point in time at 38. So the 38 is meeting version one of the [Group Model 236].

Abdullah: OK and here probably there was also a lot of changes?

Interviewee: Yeah at that point in time with the. Changed it because if you have the two parallel [PRODUCTS] you were forced to do updates in the old [PRODUCT] as well. So that taken care of the duplication, and I think it took a couple of versions in [Group Model 70] to get Stability under.

Abdullah: [DISCUSSING WITH SINAN] if you can notice here, the multiple patterns are actually saying the same thing so and this is actually conforming to what he's saying except for this pattern that we had some troubles with, so I guess this is not correct, but the rest of patterns are correct. Let's try to see if Pattern 2 is really not correct by analyzing one case maybe just to see if it's not correctly or not.

OK. There's this interesting pattern we want to discuss. [Umm Yeah], in pattern 2 we actually thought that if we took the percentage of leaves [like] the percentage of leaves out of all nodes we have and also the percentage of changes applied on leaves we might get an indication of the maintenance efforts. So basically if you have a 100 nodes and you have 50% of them as leaves and then you applied like 20 changes on leaves So 20% or 20 changes on the 50 nodes of leaves then basically we're trying to calculate something here, but it's related to the percentage of leaves we have in a model and the percentage of changes applied on leaves. [LAUGHING WITH INTERVIEWEE] It's kind of complicated. OK, so let me see if I can say it in easier words. So the leaves percentage out of all nodes and their respective change percentage out of all changes. As you are trying to compare. Like we have all nodes. and there's a percentage of these nodes as leaves and then we have all changes and the percentage of these changes are only applied on leaves.

Interviewee: Yeah.

Abdullah: So we've taken those together like the percentage of leaves and the percentage of changes related to leaves in order to see if it might give us an indication of efforts needed. The interesting thing is that in this pattern. We're getting different results than the one we discussed earlier. So if we go to the [Group Model 236], this pattern, for example is saying that, let me see if I can take a look .. Yeah, I guess we can look…

Interviewee: So what we talk about is that the changes in leaves and changes in non leaves.

Abdullah: Yeah, they're actually changes on leaves and the percentage of Leaves we have. And we want to see if this gives an idea or not. [Let's try it here]. I will explain more just a moment. I would compare to a model we already discussed and see if this is correct.

Abdullah: So in the [Group Model 70], we said that at 39 we introduced changes and then there was another version, So we agreed in the last pattern, we discussed a few moments ago, pattern 8, that there was lots of changes. If we go to the second pattern, this would give us [like] a reversed result and since you confirmed what we said in pattern 8, I guess that this pattern is not calculating the values correctly.

Abdullah: [DISCUSSING WITH SINAN] Actually it is at some point. The three is not working. So maybe we can compare these values with the values we confirmed already? we will do this later ourselves. So they are actually confirming this thing. This one's not working. Pattern 3 is some somewhat working or sometimes it works and sometimes it's not maybe we have so much changes on leaves. It is giving us an indication. Because here we have like none that much of changes but because we're considering the total number of changes on inner-nodes and and leaves but here we're focusing only on leaves. So maybe this pattern is saying that more leaves got affected with changes, you know, and these are the inner nodes. So more changes were applied on leaves but less changes were applied on inner nodes and this is logical right?

Abdullah: is it that most of the changes are applied on leaves level?

Interviewee: Yes.

Abdullah: That's actually logical. So the pattern is describing something at some point. Let's pick something to be sure or to check. Yeah, if we go back to ..

Interviewee: But, actually when you. What you have between this [Group Model 70] and the [Group Model 236] is that you can reuse items, so you reuse requirements between them. So if you have an update in one of them then, You might use it in another, so and then maybe you encapsulate it. So if you have a component in [Group Model 70] and you want to use exactly the same component in [Group Model 236] you had another level in the structure where we encapsulate this component and add some restrictions on it, so you have the same Leaf not Leaf in that case, but the same component in [Group Model 70] and the [Group Model 236] and then by the encapsulation you're reusing the same thing that means that you have the stuff around another model, that means that you don't come down to the leave level of that component, you don't change in the leaf. you're adding some. Some other Leaf beside it or you add some information on top of it.

Abdullah: Well, this is a special case that might answer the question basically pattern 2 and pattern 3 are similar the pattern 2 is applied on leaves. While pattern 3 is applied on inner nodes. OK. So if we take this ..

Interviewee: now you're in that old model.

Abdullah: it's an old one, But this is [like] has a very special case that I want to be sure of if possible .. through the changes in 7a1, 7a2, and 7a3 we can see that leaves got more changes in 7a1 and 7a3 but nodes, inner-nodes, had more changes in 7a2 if we were able to confirm this I would consider those patterns valid. So is there any way we can like maybe open these models and see if changes were actually applied on the leaves in those two and on inner-nodes in the second one. That would be great.

Interviewee: This is an interesting exercises.

Abdullah: This would be the last one, we don't want to take more time. [GIVING HANDLE ID OF THE MODEL], So it should be [Group Model 19] Version 7a1. Were you able to find the version?

Interviewee: Yeah, I have it.

Abdullah: OK, so. We need to compare the three versions together.

Interviewee: Yes. I have no idea why. Why this should change?

Abdullah: Is it hard to find that the changes were applied mostly on leaves or inner nodes?

Interviewee: I can say that it was changed in the inner nodes probably, but I cannot say about the leaves. this is a gigantic model. So ..

Abdullah: I mean, I will probably say that a2 had more changes on the inner nodes compared to a1 but in a3 we have more changes on leaves compared to a2. Do you think this is logical or possible?

Interviewee: Everything is possible.

Abdullah: If it's too hard we can skip it. It's okay..

Interviewee: Now I have the 7a1 and 7a2 in a comparison. What should I see?

Abdullah: 7a1 and 7a2, well, basically in 7a2 there was more changes applied on inner nodes. compared to 7a1.

Interviewee: in 7a2 you have a lot of changes in inner nodes, in a2

Abdullah: compared to a1.

Interviewee: and then I need to compare a1 with the previous but then you said that you have in a2 ..

Abdullah: in a2, Yeah, more changes on inner nodes but in a3 more changes on leaves. if this is old, we can go back to [Group Model 70] version 39 and...

Interviewee: let's .. I wanted to look at a2 and compare it with a3 .. a3 should have more changes in leaves compared to a2. So the changes should be on many leaves.

Abdullah: Yes, in a3..

Interviewee: the changes are so spread out. So it's impossible to see a pattern!

Abdullah: Yeah, last question would be on [Group Model 70] between 39 and 40 which we discussed a lot .. Here as well, we can see that in 39 there was so many changes on leaves. compared to 40. While in 40 there was so many changes on inner nodes compared to 39. This is the point when you said they introduced so many changes. Do you think that the change ..

Interviewee: Sorry, could you take it again? in version 40 you had ..

Abdullah: I will start always with 40 and compare it to 39. Yeah, okay in 40 there was less changes on leaves but more changes on inner nodes compared to 39. Does that sound logical or?

Interviewee: Yeah. a bit tricky this one as well because if you look at the leaves you you're kind of agnostic when it comes to what a leave is? you go down to the leaf regardless of what it is. so that means that if you have a list of leaves will never change, so you have a list of leaves never change. So if you're going to make a change to make another combination of this non-change-able leaves, so if you take a letter. You'll never change your letter but the inner node, the word we can create, we can change the word from spelled correctly / spelled erroneously without changing any leaves. So this is kind of the same here if you look at this model you have kind of leaves that were never changed. that means that they should maybe should not be considered as leaves when you looking at the model. That is kind of categorisation or what to say, so I think that when you're doing this kind of metrics to be able to. validate it you should probably have some knowledge about the leaves as well. say if this information carrier where people work. Or is it a leave that nobody wants. so it's a little bit tricky then because when you're looking at .. one part of me, should say that when you go in from the old variability model to the new you get less changes in the leaves.

Abdullah: OK, but it depends on what we consider leave here.

Interviewee: Yeah and on but I would say that the intentional of that model change is that you get fewer changes in the model a few changes in the leaf, what I considered as a leaf, but you don't stop at that level you'd measure everything below what I have as a leaf. So I think that the need to have some way of categorising the model, the meta-elements in the model, So that you can say something in that that means that if you're going back or your colleagues take the next step going in and trying to categorise the meta-model and then get the numbers of update due to the fact that the leaf is not what you consider as a leaf. just having one letter into the model that you say, it's an inner node is actually a leaf and then try to find out what is the border between the inner nodes and leaves

Abdullah: We would like to thank you so much. It was really the answers we're hoping to and this eventually will help us finish this Masters.

Interviewee: Yeah, and you actually have identified a few things that I could say that this was the transition from [Group Model 70], [Group Model 236], you meeting the version 1 in version 39 .. so you have identified ..

Abdullah: although we're not aware of what's going on in the models, but the numbers were identifying something. Yeah, and that's why we had an interview today and it was really helpful for you to give us all this information.

Interviewee: Yeah it is very interesting to look at the models this way.

Abdullah: Yeah, exactly. Yeah, so thank you so much for your time and sorry for taking longer than an hour.

Second Interview

Sinan: OK. Are you willing to participate in this interview?

Interviewee: Yes!

Sinan: Could you sign the consent of interview participation! However, we have two copies and we will keep one copy.

Interviewee: OK.

Sinan: I will explain through time. But what we want to focus on is a list of 8 situations or patterns that present efforts needed for changes and refer them with some group models. As we compared each version with the previous version from the groups or with the base version of each group model.

Interviewee: OK.

Sinan: The first pattern is that the weight of the references of each version of the models combined with the total number of items in that version of the model, might give an indication of the maintenance effort applied.

Interviewee: Could you explain the pattern more?

Sinan: We expect that the number of changes will increase when having more references to the items of a model as changing an item that is referenced by many models will require more effort to keep things correct and reliable.

Interviewee: Yes, it makes sense. The model becomes harder to make changes on if it has many references so with any change on some item we should consider the effect on other models.

Sinan: In pattern 2 we actually thought to consider the leaves characteristics, so the percentage of leaves out of all nodes we have and also the percentage of changes applied on leaves we might get an indication of the maintenance efforts. So basically if you have a 100 nodes and you have 50% of them as leaves and then you applied like 20 changes on leaves So 20% or 20 changes on the 50 nodes of leaves then basically we're trying to calculate something here, but it's related to the percentage of leaves we have in a model and the percentage of changes applied on leaves.

Interviewee: Yes ,which makes sense. Regarding my experience using leaves is really an effective way to represent the difficulty of dealing with models. It is easier to modify or evolve a model when it contains more leaves. And we try to apply this rule trying to reach the flat shape model "more leaves" as possible.

Sinan: Then what about the pattern 3, which is using the same formula but with inner nodes.

Interviewee: What do you mean in inner nodes?

Sinan: The nodes that are not leaves or parents "first item on the model".

Interviewee: OK, it makes sense too. But I think you should consider the depth of the inner node in the pattern formula.

Sinan: We will add this to be noticed in future work.

Interviewee: (After reading both patterns description) I think you need to express clearly for the second pattern, it is not so clear for me from reading from the first time and now specially when it is compared with your explanation.

Sinan: Thanks for the note we will consider this in our report. Now could you firstly read our description of pattern 4 so might not be affected or motivated by our opinion after describing it.

Interviewee: Yes, of course. After reading. Yes it is logical and I think it doesn't need you to explain. But for more confirmation you said that the ratio of changed nodes either leaves or inner nodes to the total number of nodes could be an indication for some maintenance issues if it increased sharply.

Sinan: Yes exactly.

Sinan: OK, then I completely agree.

Sinan: What about pattern 5.

Interviewee: Let me read it first.

Sinan: OK.

Interviewee: What do you mean in “their coverage”?

Sinan: It expresses the percentage of leaves that affected the total leaves count.

Interviewee: OK, it could be. However I don’t feel that it is consistent, anyway I think it is sort of applicable.

Sinan: And what about pattern 6 which is using the same formula for the inner nodes?

Interviewee: I feel the same as pattern 5. I am not convinced, let me see some examples.

Sinan: In the excel sheet let’s talk about model group 19, the model.

Interviewee: let me check it for a second. It might express maintainability issues like between version 9 and version 10 as some refactoring conducted. However both patterns 5 and 6 are not consistent but I think they are partially compatible with changes among versions.

Sinan: OK.

Interviewee: However I won’t be able to depend on them.

Interviewee: OK.. we will report this consideration. If you don’t have more comments could we move to pattern 7 as the time almost ends?

Sinan: Yes. Let me read it first… OK it is perfect. I really believe it is clear and expresses the efforts. However I feel that each metric used in the pattern expresses some kind of maintenance issue. Why do you use the combination of them?

Interviewee: Ah. OK… as we said before the pattern represents a status of changes that require maintenance efforts from historical data. Regarding statistics conducted on our study we concluded that a formula with those 3 metrics can present a defined situation.

Interviewee: OK... I am convinced in this pattern as I somehow worked before in older research with those parameters especially in depth and item count.

Sinan: So now. What about the last pattern?

Interviewee: Let me read it… this a good parameter to be considered in our work and it so interesting but I cannot give you an answer about it. I think this needs more study.

Interviewee: Thanks for time we finished.Is there any comment or consideration you like to add.

Sinan: No, only regarding the patterns 5 and 6 I do still feel they are not consistent.

Interviewee: Thanks.

Sinan: You're welcome.