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Predicting Software Build Failure Using Source Code Metrics

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ABSTRACT

In this paper, we describe the extraction of source code metrics from the Jazz repository and the application of data mining techniques to identify the most useful of those metrics for predicting the success or failure of an attempt to construct a working instance of the software product. We present results from a study using the J48 classification method used in conjunction with a number of attribute selection strategies applied to a set of source code metrics calculated from the code base at the beginning of a build cycle. The results indicate that only a relatively small number of the available software metrics that we considered have any significance for predicting the outcome of a build. These significant metrics are discussed and implication of the results discussed, particularly the relative difficulty of being able to predict failed build attempts. The results also indicate that there is some scope for predicting the outcomes of an attempt to construct a working instance of the software product by analysing the characteristics of the source code to be changed. This provides the opportunity for software project managers to estimate the risk exposure of the planned changes in the build prior to commencing the coding activities.

Keywords: *Data Mining, Jazz, Software Metrics, Software Repositories*

I. INTRODUCTION

Software development projects involve the use of a wide range of tools to produce a software artifact. Software repositories such as source control systems and bug tracking databases have become a focus for emergent research as being a source of information regarding the performance and management of software development projects. The mining of such repositories is becoming increasingly common with a view to gaining a deeper understanding of the development process and building better prediction and recommendation systems. The Jazz development environment has been recognized as offering both opportunities and challenges in this area [1]. Jazz integrates the software archive and bug database by linking bug reports and source code changes with each other through the concept of work items. Whilst this provides much potential in gaining valuable insights into the development process of software projects, such potential is yet to be fully realised.

In this paper we describe an extension of previous work [2] to continue to attempt the extraction of rich data from the Jazz dataset by utilizing source code metrics as a means of directly measuring the impact of code issues on build success. In particular, in this paper we attempt to make more useful predictions by changing the code base on which the prediction classifier is built. Previous work [2] utilised code that was submitted to the repository immediately prior to the build taking place where as in this work we utilise code that is extracted from the repository at the beginning of the build cycle. The ability to predict potential outcomes at the beginning of the build cycle provides the development team with a greater ability to manage the risk inherent in the build.

In the next section we provide a brief overview of related work. Section 3 discusses the nature of the Jazz data repository and metrics that we utilized to mine the repository. In section 4, we discuss our approach to mining the software repository in Jazz, while our results are presented in section 5. Finally, we conclude our paper with a discussion of the limitations of the current work and a plan for addressing these issues in future work.

II. BACKGROUND & RELATED WORK

According to Herzig & Zeller [1], Jazz offers not only huge opportunities for software repository mining but also a number of challenges. One of the opportunities is that Jazz provides a more detailed dataset in which all artifacts are linked to each other. To date, much of the work that utilizes Jazz as a repository has focused on the convenience provided by linking artifacts such as bug reports to specification items along with the team communication history. Researchers have focused on areas such as whether there is an association between team communication and build failure [3] or whether it is possible to identify relationships among requirements, people and software defects [4]. Other work [5] has focused purely on the collaborative nature of software development. To date, most of the work involving the Jazz dataset has focused on aspects other than analysis of the source code contained in the repository.

Research that focuses on the analysis of metrics derived from source code analysis to predict software defects has generally shown that there is no single code or churn metric capable of predicting failures [6, 7, 8], though evidence suggests that a combination can be used effectively [9]. In previous work [2] source code analysis has been conducted on the Jazz project data to perform an in-depth analysis of the repository to gain insight into the usefulness of software product metrics in predicting software build failure. Whilst some successes have been achieved in determining the relationship between build outcomes and source code [2] there is still a pressing need to provide additional clarity to what is a complex problem domain.

Buse and Zimmerman [10] suggest that whilst software projects can be rated by a range of metrics that describe the complexity, maintainability, readability, failure propensity and many other important aspects of software development process health, it still continues to be risky and unpredictable. In their paradigm of software analytics, Buse and Zimmerman suggest that metrics themselves need to be utilised to gain insights and as such it is necessary to distinguish questions of information which some tools already provide (e.g., how many bugs are in the bug database?) from questions of insight which provide managers with an understanding of a project's dynamics (e.g., will the project be delayed?). They continue by suggesting that the primary goal of software analytics is to help managers move beyond information and toward insight, though this requires knowledge of the domain coupled with the ability to identify patterns involving multiple indicators.

The Jazz data has the potential to provide sufficiently rich information to support these goals. In our work to date [2] we have analysed the software product metrics available through Jazz and shown that there is scope to classify a set of software changes by the source code metrics and predict the likely outcomes of the build immediately prior to compilation and testing. This prediction is based on calculation of metrics related to the source code that has been changed throughout the build cycle and has been finalised for inclusion. Our previous work [2] showed that some metrics derived from such code can be used to classify build outcome, however the usefulness of such a prediction is limited in terms of the timeliness of the information presented to the project team.

This current paper therefore presents an attempt to transform the timing of a prediction event from the time the code is committed to the repository immediately prior to the build to an earlier and more useful time. An early prediction event provides greater insight into the likely outcomes of a build and hence can be used in managing the risk inherent in project's dynamics and hence this research supports the goals of the software analytics paradigm. In this work we utilise the code extracted from the repository at the beginning of the build cycle which does not include any changes since the last build. In this paper we investigate whether a similar set of metrics are also significant in terms of predicting build outcomes early.

III. THE JAZZ DATASET

A. Overview of Jazz

IBM Jazz is a fully integrated software development tool that automatically captures software development processes and artifacts. The Jazz repository contains real-time evidence that allows researchers to gain insights into team collaboration and development activities within software engineering projects [11]. With Jazz it is possible to extract the interactions between contributors in a development project and examine the artifacts produced. This means that Jazz provides the capability to extract social network data and relate such data to the software project outcomes. Figure 1 illustrates that through the use of Jazz it is possible to visualize members, work items and project team areas.

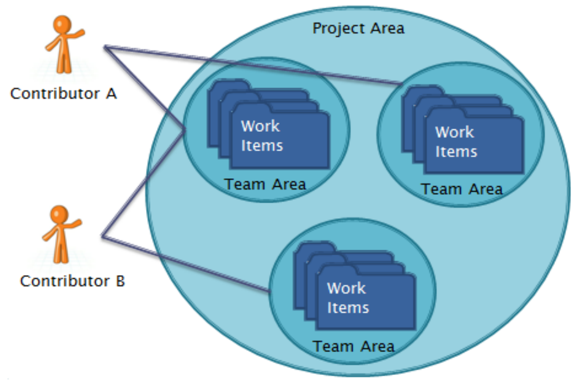

Figure 1: Jazz Repository: Contributors, Project Area, Team Areas and Work Items.

The Jazz repository artifacts include work items, build items, change sets, source code files, authors and comments. A work item is a description of a unit of work, which is categorized as a task, enhancement or defect. A build item is compiled software to form a working unit. A change set is a collection of code changes in a number of files. In Jazz a change set is created by one author only and relates to one work item. A single work item may contain many change sets. Source code files are included in change sets and over time can be related to multiple change sets. Authors are contributors to the Jazz project. Comments are recorded communication between contributors of a work item. Comments on work items are the primary method of information transfer among developers.

There are limitations for incorporating the Jazz repository into research. Firstly, the repository is highly complex and has huge storage requirements for tracking software artifacts. Another issue is that the repository contains holes and misleading elements which cannot be removed or identified easily. This is because the Jazz environment has been used within the development of itself; therefore many features provided by Jazz were not implemented at early stages of the project. We acknowledge the challenge in dealing with such inconsistency and are proposing an approach that delves further down the artifact chain than most previous work using Jazz. It is our premise that the early software releases were functional, so whilst the project "meta-data" may be missing details (such as developer comments) the source code should represent a stable system that can be analyzed to gain insight regarding the development project.

B. Software Metrics

Software metrics have been generated in order to

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deal with the sparseness of the data. Metric values can be derived from extracting development code from software repositories. Such metrics are commonly used within model-based project management methods. Software metrics are used to measure the complexity, quality and effort of a software development project [12]. The Jazz database contains over 200 relations, containing numerous cryptic fields that are not clearly documented. Thus data extraction via SQL queries runs the high risk of retrieving unreliable or incomplete data. Instead, we used the Jazz client/server APIs, an approach recommended in a study by Nguyen, Schröter, and Damian [11]. The Jazz API is much better document and provides a more reliable means of extracting data from the repository.

The Jazz repository consists of various types of software builds. Included in this study were continuous builds (regular user builds), nightly builds (incorporating changes from the local site) and integration builds (integrating components from remote sites). Source code files were extracted for each available build within the repository. Subsequently software metrics were generated by utilizing the IBM Rational Software Analyzer tool. As a result the following basic, object orientated and Halstead software metrics were derived from the source code files for each build. These are shown in Table 1 along with the classification of the metric, Basic (B), Object Oriented (OO) or Halstead (H).

Table 1: Available Metrics

ID	Metric	Type
1	Number of attributes	B
2	Average number of attributes per class	B
3	Average number of constructors per class	B
4	Average number of comments	B
5	Average lines of code per method	B
6	Average number of methods	B
7	Average number of parameters	B
8	Number of types per package	B
9	Comment/Code Ratio	B
10	Number of constructors	B
11	Number of import statements	B
12	Number of interfaces	B
13	Lines of code	B
14	Number of comments	B
15	Number of methods	B
16	Number of parameters	B
17	Number of lines	B
18	Abstractness	OO
19	Afferent coupling	OO
20	Efferent coupling	OO
21	Instability	OO
22	Normalized Distance	OO
23	Average block depth	OO
24	Weighted methods per class	OO
25	Maintainability index	OO
26	Cyclomatic complexity	OO
27	Lack of cohesion 1	OO
28	Lack of cohesion 2	OO
29	Lack of cohesion 3	OO
30	Number of operands	H
31	Number of operators	H
32	Number of unique operands	H
33	Number of unique operators	H
34	Number of delivered bugs	H
35	Difficulty level	H
36	Effort to implement	H
37	Time to implement	H
38	Program length	H
39	Program level	H
40	Program vocabulary size	H
41	Program volume	H
42	Depth of Inheritance	H

In addition to software (source code) metrics a range of metrics that are unique to the Jazz environment are available, however at present this research only includes whether the build attempt is successful or whether it fails. A failed build is in essence one where the end product does not pass all of the test cases or does not behave as expected.

IV. EXPERIMENTAL METHOD

This work revolves around the use of classification methods for the analysis of software metrics. For this purpose the Weka [13] machine learning workbench was used. There are various challenges that arise when adopting data mining approaches. Firstly, real life data is not always suitable for the mining process because there can often be noise within the data, missing data, or even misleading data that can have negative impacts on the mining and learning process [14]. This certainly the case with the data utilised in this research which relates to the development of the Jazz platform by IBM.

The primary cause of the noisy and inconsistent data is that the project data that is extracted from Jazz was gathered during the development of Jazz itself. As a consequence features that automatically capture project processes did not exist until later development stages of Jazz meaning that gaps would often appear at early stages of the project data set. This has presented us with a unique challenge in terms of cleaning and preparing the data from this software development project. Excluded from the data set were instances that had no work items associated with a build, build warning results and builds that had missing values within the derived software metrics.

Software metrics from continuous builds were used to construct the data set, however in doing so there were more instances of successful builds than failed builds. In order to balance the data set failed builds were injected from nightly and integration builds. This option was preferred over removing successful builds from the data set, thus decreasing the possibility of model over-fitting. In total, 129 builds were included, out of which there were 51 successful builds and 78 failed builds. This presents a situation where the number of features is fairly close to the number of instances available for analysis, which is not an ideal scenario from a data mining perspective. One possible solution was to increase the number of instances by including more builds but more

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data was not forthcoming from IBM at the time that the research was executed. Therefore we have opted to investigate various strategies for reducing the number of metrics used to classify the relatively small number of builds in the dataset.

A. Dataset Representations

In the Jazz dataset a given build consists of a number of different work items. Each work item contains a *changeset* that indicates the actual source code files that are modified during the implementation of the work item. Each build has a corresponding *before* and *after* state. Previous work [2] used the *after* state to extract source code that included all changes in the build. The *after* state was utilised in order to ensure that the source code snapshot represented the actual software artefact that either failed or succeeded. In this work, we utilise the *before* state in order to determine whether build failure can be predicted prior to any changes in the source code being made. In essence, this is an attempt to characterise source code that is about to be changed in terms of its likelihood to be modified successfully.

Source code metrics are calculated for each source code file in the changeset using the IBM Software Analyser tool. In previous work [2] we conducted a systematic study into different ways of characterising the changeset using a single metric value to represent all source code files in the changeset. This showed that the most reliable approach was to calculate the value for each metric for each source code file and then propagate the maximum determined value up to the build level. This approach is adopted in the current work.

B. Experiment Descriptions

The goal of our experimentation is to determine which software metrics give the best indicators of whether the build will be successful or will fail. Our experiments systematically filter the available metrics using a variety of methods to simplify the problem space and determine the best classification trees. This is necessary as previous work [2] has determined that the ratio of metrics (42) to build instances (129) creates a complex classification scenario.

The methods used to filter the metrics used are shown in Table 2. These methods include the use of feature selection approaches in Weka as well as more heuristic filtering. Each strategy is based on selecting a relatively small number of the available software metrics and comparing them to the baseline classification where no filtering of the metrics is done.

Strategies 2 and 3 utilise two different feature selection algorithms available in Weka. Previous work has shown that the use Infogain to produce a ranked list has produced good results. However, we still investigate the use of CfsSubset feature selection (combined with Best First search algorithm) as this approach takes into account combinations of metrics that are not considered when using the Infogain algorithm (used with the Ranker search algorithm).

Table 2: Metric Filtering Strategies

ID	Strategy
1	No filtering
2	Weka Feature Selection (CfsSubset)
3	Weka Feature Selection (Infogain)
4	Basic metrics
5	Object orientated metrics
6	Halstead metrics
7	Exclude "Average number of..." metrics
8	Weka Feature Selection (CfsSubset: After)
9	Weka Feature Selection (Infogain: After)
10	Frequency Selection (After)

Strategies 4-6 are based on the classification of metrics as given in Table 1. Strategy 7 is used to remove metrics that may have biased values due to the technique used to propagate a single metric value to the whole build. Strategies 8-10 utilise results from previous work [2] where a systematic study was conducted using Weka on the *after* state of each build.

Using these filtered metrics experiments are conducted to attempt to classify builds as either successful or failed using the metrics calculated from source code extracted from the *before* state. These experiments are conducted to attempt to determine whether the outcome of a build can be predicted from the characteristics of the source code prior to any changes being made.

V. RESULTS

For each of the experiments we first apply the metric filter strategy and then use the J48 classification algorithm to attempt to discover common patterns amongst the selected metrics. Given the relatively small size of the data set we utilized 10-fold cross validation in order to make the best use of the training data. We acknowledge the relative optimism of cross validation and will address this in future work when more data becomes available from the Jazz project.

A. Classification Results: Before State

For each of the strategies outlined in section 4.2, the selected metrics are shown in Table 3. The metric IDs correspond to the metrics in Table 1.

Of particular interest are the results of applying the feature selection algorithms from Weka, as both the selection strategies are based around finding significant impact arising in the data. This differs from the more heuristic based filtering approaches that are based on the classification of the metrics rather than arising from the data. A number of the available metrics are selected when applying both the Infogain and CfsSubst algorithms, possibly indicating that these are stronger indicators of build failure. These metrics include ones classified as size and complexity metrics.

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Table 3: Selected Metrics

ID	Selected Metrics
1	N/A
2	23, 5, 2, 9, 27, 25, 32, 39
3	17, 9, 27, 23, 25, 2, 40, 32, 22, 39, 33, 29, 16, 14, 5, 26, 8, 1
4	1 - 17
5	18 - 29
6	30 - 42
7	1, 8 - 42
8	2, 8, 9, 11, 14, 23, 27, 28, 33
9	9, 2, 23, 11, 33, 32, 14, 40, 28, 27, 1, 16, 8, 29, 42
10	1, 8, 9, 10, 11, 14, 16, 23, 27, 28, 30, 32, 33, 35, 37

Table 3 shows the accuracy of the classification for each dataset with the features selected using the each metric selection strategy. The overall accuracy is given in each case along with the number of correctly (and incorrectly) classified builds. The bracketed values refer to the number falsely predicted to be either failures (in the case of the "Failed Builds" column) or successes (in the case of the "Successful Builds") column.

Table 4: Classification Results

ID	Accuracy	# Failed Builds Correct (Incorrect)	# Successful Builds Correct (Incorrect)
1	67.4419 %	22 (29)	65 (13)
2	72.8682 %	25 (26)	69 (9)
3	68.9922 %	22 (29)	67 (11)
4	67.4419 %	16 (35)	71 (7)
5	75.9690 %	34 (17)	64 (14)
6	71.3178 %	25 (26)	67 (11)
7	67.4419 %	23 (28)	64 (14)
8	82.1705 %	36 (15)	70 (8)
9	79.845 %	38 (13)	65 (13)
10	84.4961 %	40 (11)	69 (9)

These classification results support the conclusions of our previous work [2] particularly that the prediction of failed builds is generally more challenging than the classification of successful builds, though some improvement has been made by using the data relating to the *before* state of the build. Of particular interest is that the highest overall accuracy and the best classification of failed builds come from using features selected from the *after* state.

The classifications of particular interest result from applying strategies 8, 9 and 10 as these offer predictions comparable or better than those identified in previous work [2]. Figure 2 shows the classification tree for strategy 8.

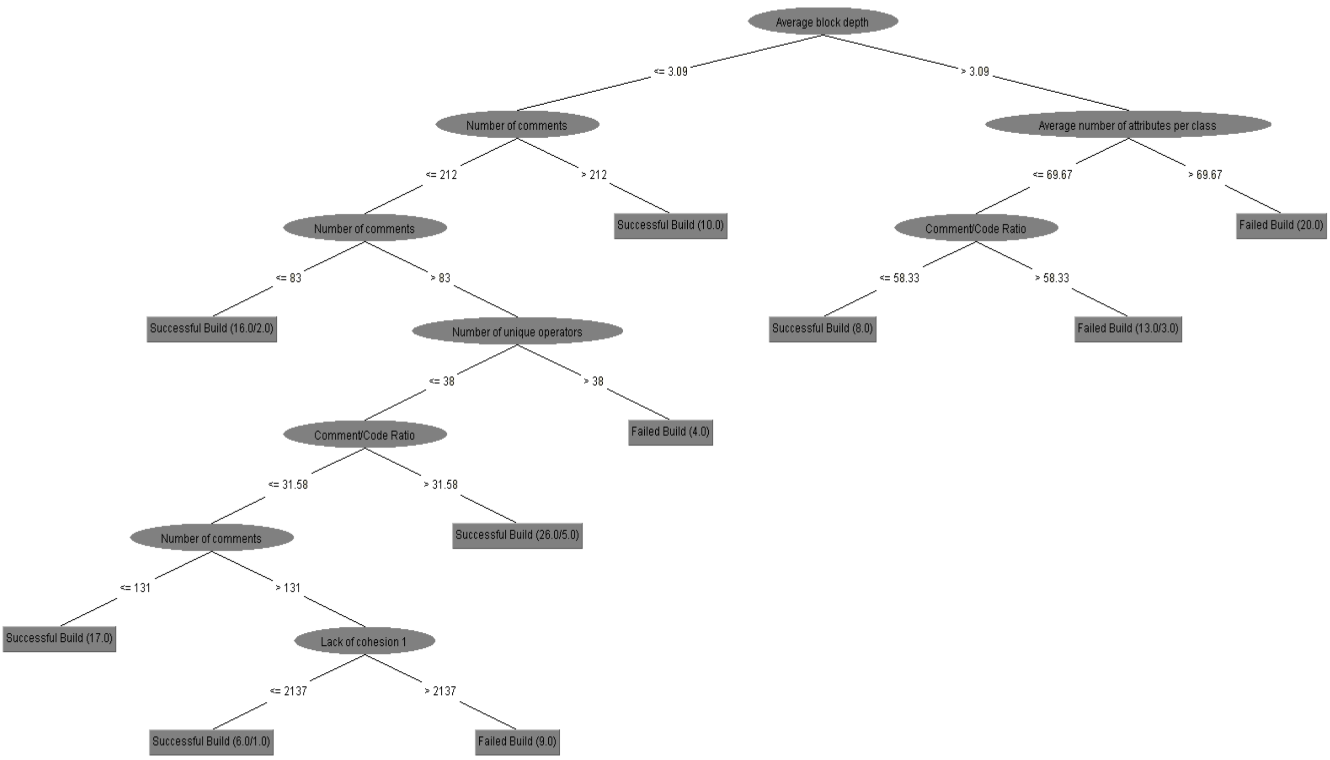

Figure 2: Classification Tree (Strategy 8)

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Inspection of the classification tree illustrates that there is some basis for relating code quality to the classification tree. For example, a low average block depth is preferred with some internet sources [15] indicating that a preferred threshold for Java source code should be less than 2.8. In the classification tree shown in Figure 2, an average block depth greater than 3.09 is predominately associated with failed build except for the number of attributes per class is small and the number of lines of code per comment is small. This is reasonable, given that relatively small classes that are implemented with good commenting may be more understandable and maintainable even if it has other less desirable characteristics.

The other branch of the tree also survives a simple sanity check, with many nodes displaying classifications that are intuitive. For example, when the number of comments is greater than 212 there is a correlation with successful builds.

However, there is some confusion in the classification tree arising from the number of comments metric where ranges of metric values give rise to differing outcomes, some of which are non-intuitive. This confusion was also present in previous work [2] using the *after* state of the source code. In Section VI of this paper and attempt is made to manually prune the classification trees to improve on clarity without reducing the accuracy of the classification.

Figure 3 shows the classification tree for strategy 9.

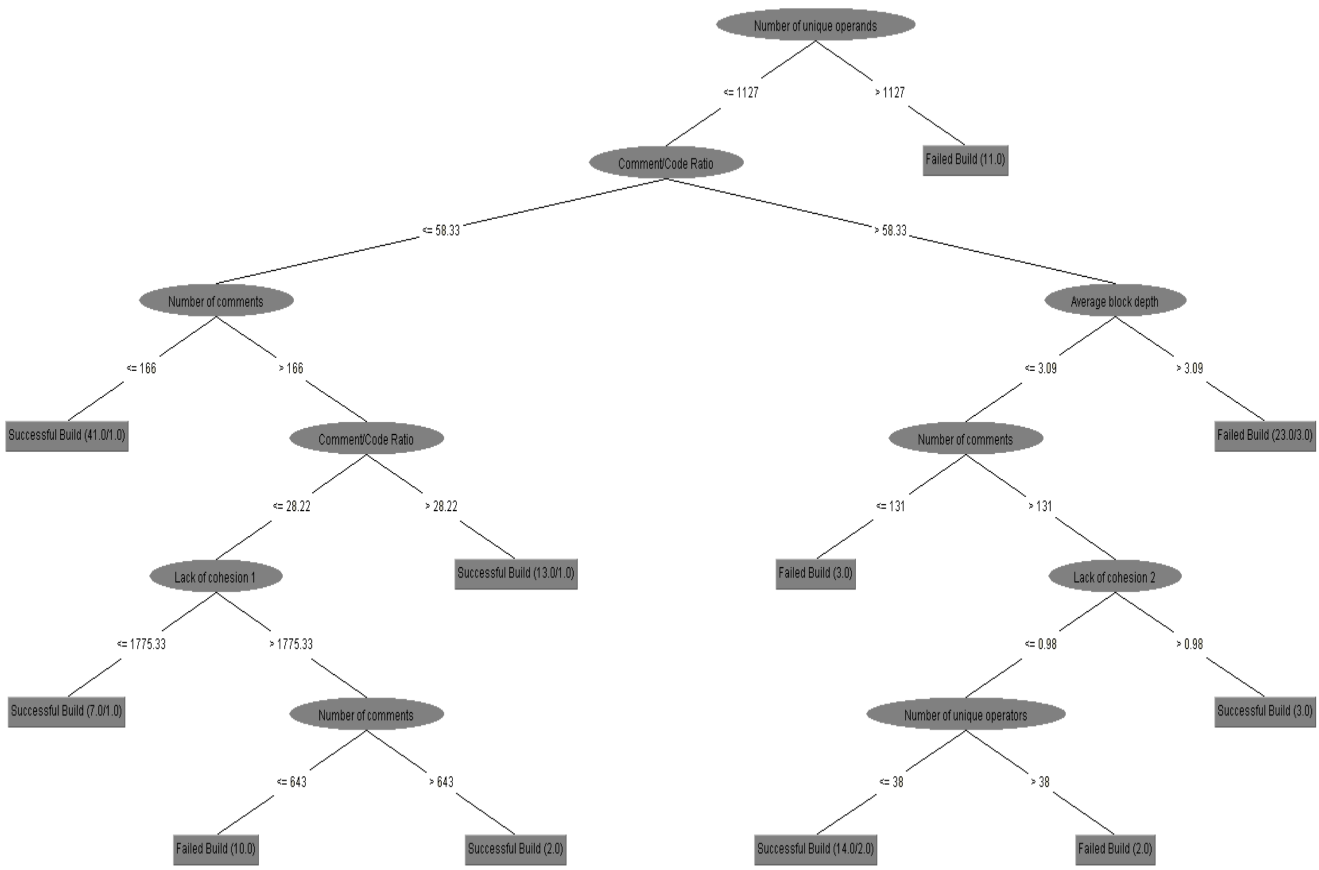

Figure 3: Classification Tree (Strategy 9)

As with the previous classification tree, inspection indicates that there are some common sense classifications being made, for example a high number of unique operands tends to be associated with failure which is intuitive as a large code base tends to be less understandable and maintainable than a smaller one. Whilst the hierarchy of the classification is different from that shown in Figure 2, the indicative values for the classification are the same. Whilst there is some confusion in the classification tree arising from the number of comments metric, the degree of confusion is less than for the classification show in Figure 2. In Section VI of this paper and attempt is made to manually prune the classification trees to improve on clarity without reducing the accuracy of the classification.

Figure 4 shows the classification tree for strategy 10.

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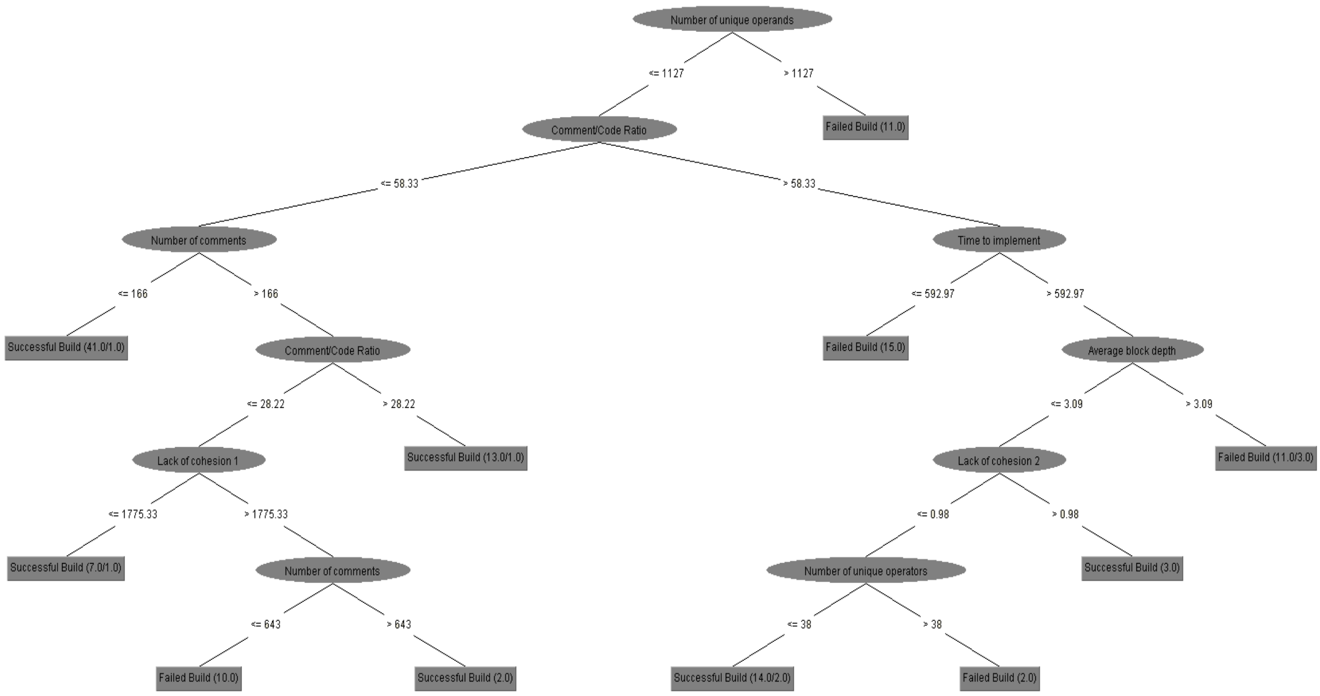

Figure 4: Classification Tree (Strategy 10)

This classification tree shows some similarity with those presented in Figure 2 and 3, both in terms of the structural elements and the metric values used for classifying success and failure. This classification has not the highest overall accuracy, but also the highest accuracy in terms of identifying failed builds. There is still some confusion in the classification tree related to the number of comments metric. In the next section, manual pruning strategies are investigated to improve the clarity of classification.

VI. MANUAL PRUNING & RE-CLASSIFICATION

All of the classification trees shown in Section V have some similarity, both in terms of the metrics used and the threshold values apparent in the classification. The results not only improve on previous work [2] but also show that it is possible to move the prediction event forward in time to be more useful.

The confusion apparent in the classification trees relates to the number of comments metric. All of the classification trees also include the metric comment/code ratio. Whilst these two metrics are not directly related, as the total size of code base is not present in the number of comments metric, they do measure the same characteristics of the source code. In this section an attempt at manually pruning the classification trees is undertaken by removing each metric in turn and seeing the impact on the classification. Table 5 presents the outcomes of this activity, where the ID has been appended with an "a" (removal of number of comments metric) and a "b" (removal of comment/code ratio metric).

Table 5: Manual Pruning Results

ID	Accuracy	# Failed Builds Correct (Incorrect)	# Successful Builds Correct (Incorrect)
8a	79.0698 %	34 (17)	68 (10)
8b	79.0698 %	29 (22)	73 (5)
9a	78.2946 %	38 (13)	63 (15)
9b	77.5194 %	35 (16)	65 (13)
10a	83.7209 %	40 (11)	68 (10)
10b	77.5194 %	36 (15)	64 (14)

All of the attempts to manually prune the tree by removing one of the two metrics has resulted either in a reduction in overall accuracy, a reduction in the ability to classify failures or both. However, as the goal was to improve clarity in the classification this should be expected and the only way to determine the outcomes is to inspect the classification trees.

Such inspection has shown that only 8a has resulted in classification tree with no confusion arising from metrics appearing multiple times in the same classification branch. This has come at the cost of a reduced ability to identify failed builds. Figure 5 shows the classification tree associated with this manual pruning. Figure 6 also shows the classification tree for 10a, for which there is no reduction in the ability to identify failures.

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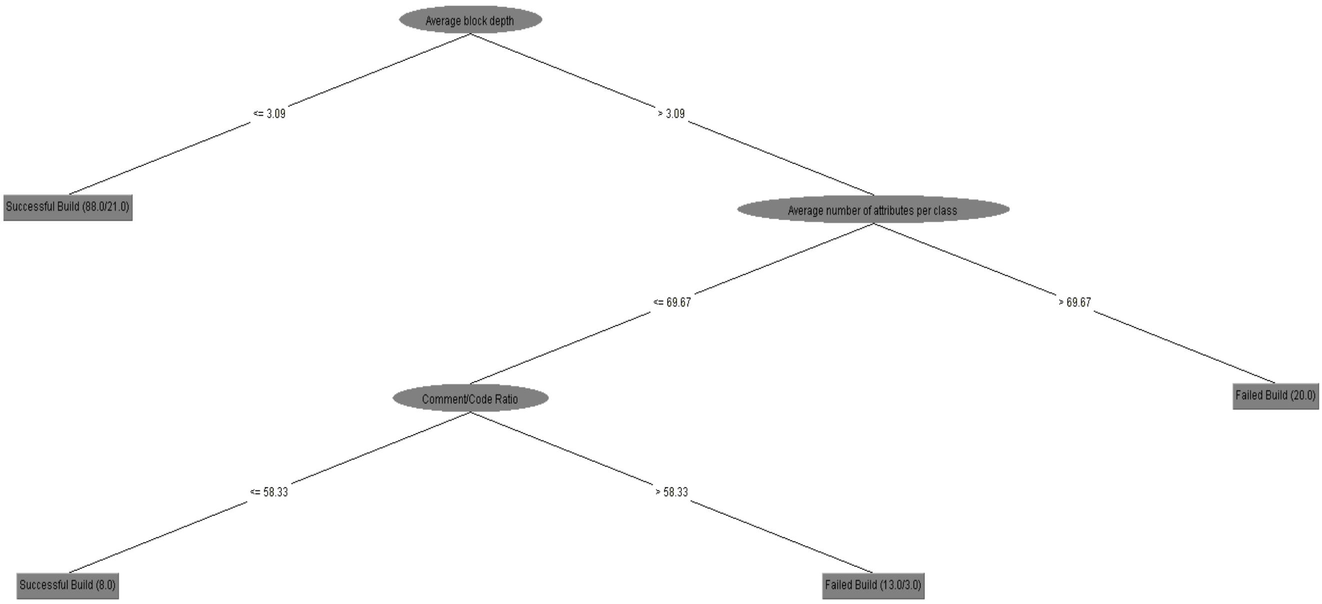

Figure 5: Classification Tree (Strategy 8a)

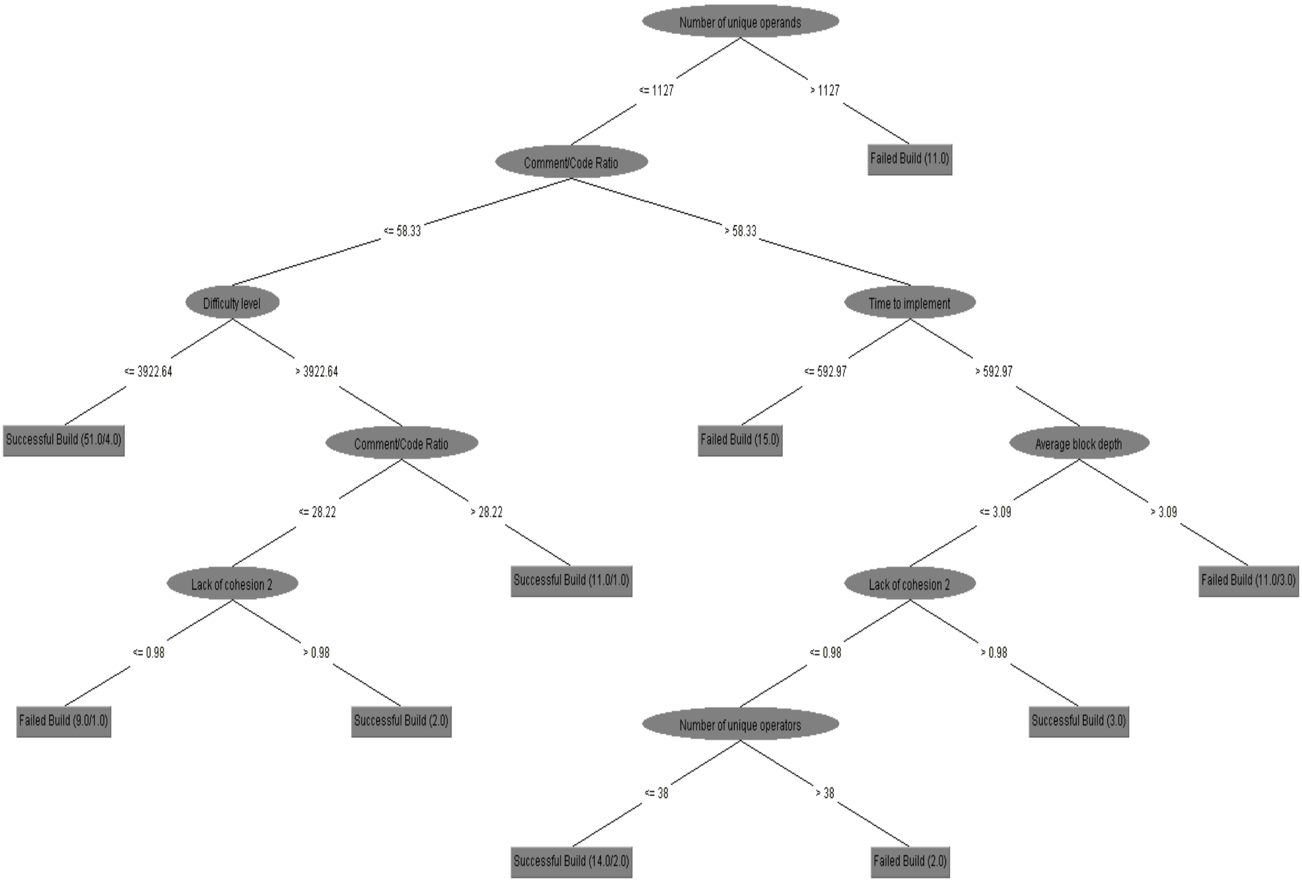

Figure 6: Classification Tree (Strategy 10a)

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Whilst the classification tree shown in Figure 5 is simple and clear, it is difficult to determine whether this clarity offsets the reduction in ability to identify failed builds. If nothing else, inspection of the tree can provide an indication of likely risk factors for developers and software project managers.

The classification tree shown in Figure 6 still has some confusion arising from the comment/code ratio metric. Again, it is difficult to determine whether maintaining the ability to identify failures offsets the confusion in the tree. Given the sparse nature of the Jazz dataset the best that may be achievable is an early indication of risk that may be imprecise, but still useful.

Whilst these research has attempted to be systematic, there is little basis for justifying the use of metrics determined from the *after* state of the software to predict build failure using the *before* state source code. Bearing this in mind, one further re-classification strategy has been attempted. Rather than manually prune the trees arising from classification, this approach examines the best strategies in Table 4 (strategies 8, 9 & 10) and looks for metrics that are common to all three strategies. The only possible justification for such an approach is that the classification trees shown in Figures 2, 3 & 4 bear some resemblance to each other, however the authors do acknowledge the weakness of this justification. Such an approach results in selecting the following metrics: 8, 9, 11, 14, 23, 27 & 28 (refer to Table 1 for metric names).

This approach results in the best overall classification accuracy (84.4961%), the best ability to identify failed builds (41 correct, 10 incorrect) and a classification tree with no inherent confusion. The output from Weka is included as an appendix to this paper. Please note the attribute IDs in the appendix do not correlate to those given in Table 1 as the experiments in the Weka environment used alphabetically ordered metrics). The classification tree is shown in Figure 7, at this stage for interest. Future work will be required to determine why such a non-justifiable approach has resulted in the most significant classification outcome and to verify the classification tree against an intuitive understanding of the metrics involved in the classification.

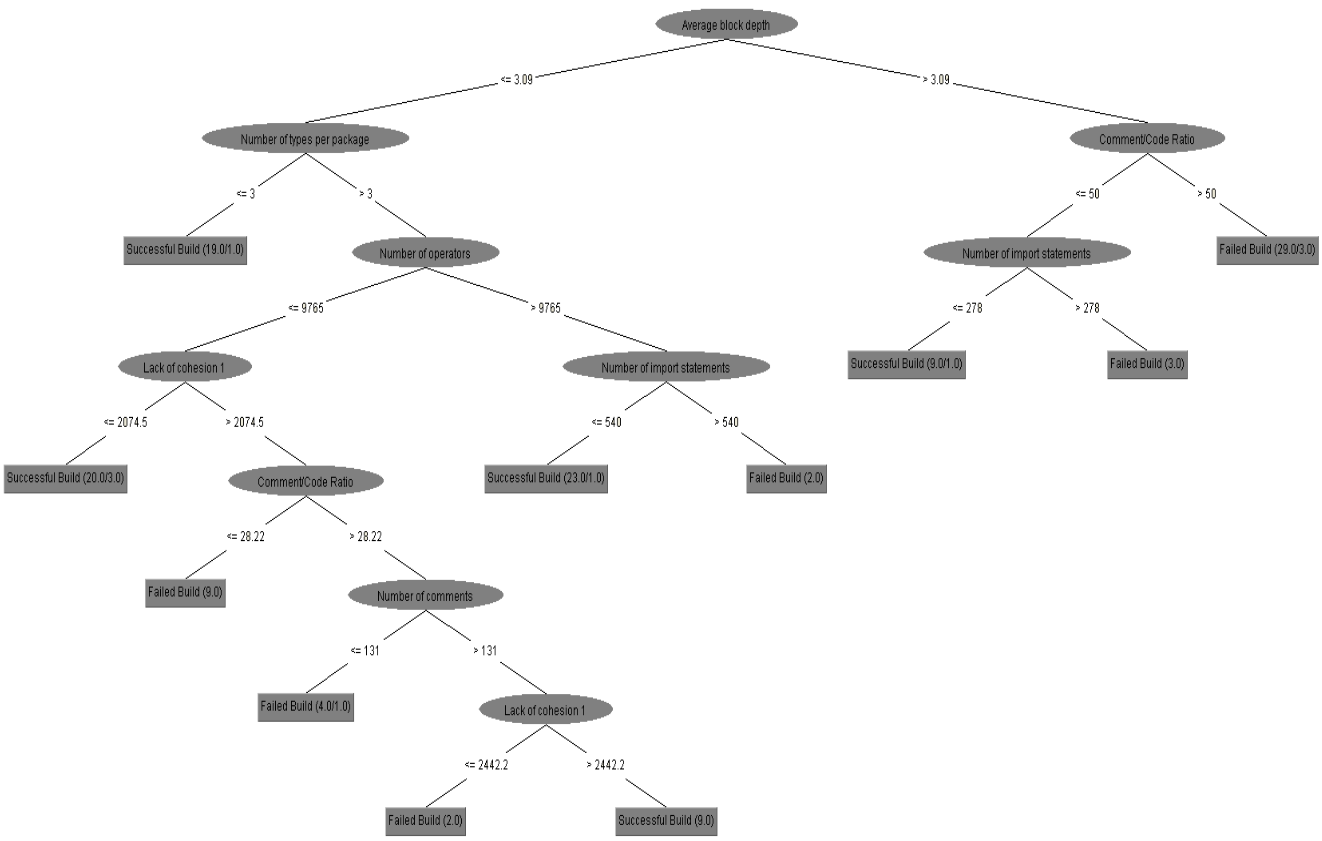

Figure 7: Final Classification Tree

VII. LIMITATIONS & FURTHER WORK

Most of the limitations in the current study are products of the relatively small sample size of build data from the Jazz project combined with the sparseness of the data itself. For example, the ratio of metrics (48) to builds (120) is such that it is difficult to truly identify significant metrics. Whilst various strategies for reducing the number of metrics used in the classification have been investigated, this does not address the fundamental problem that the dataset is very small.

Whilst a new release of the Jazz repository is pending, in the meantime the main thrust of our future work is to expand the build data to improve the degree of granularity and potentially remove some of the confusion in the classification trees. By doing so, we aim to also address the limitation of this work that arises from using a single metric value to characterise all source code files within the build. By incorporating all source code files and their corresponding metrics into the analysis, we intend to further investigate the use of the *before* and *after* states in the Jazz repository as a means to provide a dynamic risk dashboard to provide an early indication of potential failure of a build.

Therefore another key aspect for further study is to investigate why predicting failures is harder than predicting successes. In particular, we have again observed that predicting failure is more challenging than predicting success and that not predicting failure doesn't mean that success has been predicted. This is due to the fact that the build successes and failures overlap in feature space and "failure" signatures have a greater degree of fragmentation than their "success" counterparts. This is most apparent in the very different classification trees that have been discussed. Each shows a different set of software metrics that can be used to gain roughly the same overall prediction accuracy. As a result, one aspect of future work is to develop a deeper understanding of what source code characteristics are most related to build failure and develop a set of indicative metrics that can provide development teams with the opportunity to proactively manage risk exposure throughout a development project even if they cannot categorically predict build failure or success.

VIII. CONCLUSIONS

This paper presents the outcomes of an initial attempt to predict build success and/or failure for a software product by utilizing source code metrics. Prediction accuracies of up to 84% have been achieved through the use of the J48 classification algorithm combined with 10-fold cross validation. Some improvement has been made on previous work [2] in terms of better identifying characteristics of failed builds, however we acknowledge that the strategy of using metrics associated with the *after* state of the build to classify the *before* state source code may in some way be overfitting the data to the classification strategy. Further work is needed to fully validate this approach.

Despite this high overall accuracy, there is difficulty in predicting failure and at present many classification trees contain some uncertainty and confusion, but show promise in terms of informing software development activities in order to minimize the chance of failure.

Despite these difficulties, our results show that there is potential for predicting build success or failure on the basis of an analysis of source code that will be changed during a build, even when the degree of change is not known. Due to the relatively small data set, this potential has not yet been fully realised and further work is needed to do so. However, more clarity in the prediction is gained when the degree of change during a build is analysed. This provides the opportunity for development teams to incrementally examine their exposure to risk during the build cycle.

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APPENDIX

```
=== Run information ===

Scheme:weka.classifiers.trees.J48 -C 0.25 -M 2
Relation:Jazz_MAX_Before-weka.filters.unsupervised.attribute.Remove-R2-3,5-10,12-17,20-24,26-27,29-
32,34,36-43
Instances:129
Attributes:9
              BuildResult
              Average block depth
              Comment/Code Ratio
              Lack of cohesion 1
              Lack of cohesion 2
              Number of comments
              Number of import statements
              Number of operators
              Number of types per package
Test mode:10-fold cross-validation

=== Classifier model (full training set) ===

J48 pruned tree
------------------
```

```
Average block depth <= 3.09
|   Number of types per package <= 3: Successful Build (19.0/1.0)
|   Number of types per package > 3
|   |   Number of operators <= 9765
|   |   |   Lack of cohesion 1 <= 2074.5: Successful Build (20.0/3.0)
|   |   |   Lack of cohesion 1 > 2074.5
|   |   |   |   Comment/Code Ratio <= 28.22: Failed Build (9.0)
|   |   |   |   Comment/Code Ratio > 28.22
|   |   |   |   |   Number of comments <= 131: Failed Build (4.0/1.0)
|   |   |   |   |   Number of comments > 131
|   |   |   |   |   |   Lack of cohesion 1 <= 2442.2: Failed Build (2.0)
|   |   |   |   |   |   Lack of cohesion 1 > 2442.2: Successful Build (9.0)
|   |   Number of operators > 9765
|   |   |   Number of import statements <= 540: Successful Build (23.0/1.0)
|   |   |   Number of import statements > 540: Failed Build (2.0)
Average block depth > 3.09
|   Comment/Code Ratio <= 50
|   |   Number of import statements <= 278: Successful Build (9.0/1.0)
|   |   Number of import statements > 278: Failed Build (3.0)
|   Comment/Code Ratio > 50: Failed Build (29.0/3.0)

Number of Leaves  :     11

Size of the tree :      21


Time taken to build model: 0seconds

=== Stratified cross-validation ===
=== Summary ===

Correctly Classified Instances         109               84.4961 %
Incorrectly Classified Instances        20               15.5039 %
Kappa statistic                          0.6757
Mean absolute error                      0.217
Root mean squared error                  0.3755
Relative absolute error                 45.34   %
Root relative squared error             76.7743 %
Total Number of Instances              129

=== Detailed Accuracy By Class ===

               TP Rate   FP Rate   Precision   Recall  F-Measure   ROC Area  Class
                 0.804     0.128      0.804     0.804     0.804      0.837    Failed Build
                 0.872     0.196      0.872     0.872     0.872      0.837    Successful Build
Weighted Avg.    0.845     0.169      0.845     0.845     0.845      0.837

=== Confusion Matrix ===

  a  b   <-- classified as
 41 10 |  a = Failed Build
 10 68 |  b = Successful Build
```