THE RELATIONSHIP BETWEEN CODE BASED OBJECT ORIENTED SYSTEM DESIGN METRICS AND PRODUCT QUALITY

by

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Abstract

Code based measurements are frequently used by practitioners during software development. This study examines code based measurements for object oriented systems from the perspective of a software development manager. Based on past research a theoretical model relating code based Object Oriented system design metrics and product quality was developed. Hypotheses based on the model were tested using a data sample of 55 releases from 12 different Open Source projects. The study identified four key findings. First, code structure decides the strength of the relationship between metrics and defect count. Second, aggregation effect converts weak relationships at the class level into strong relationships at the package level. Third, when adequate testing is done there is a very good chance of finding correlation at the package level between metrics and defect count. Fourth, at the package level, number of lines of code is as good a measure as other object oriented metrics. Based on these key findings the study has recommended steps for using these metrics in practice.

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1 Research question

Software metrics form a very popular research area in the field of computer science and systems engineering (Briand and Wust 2002). Object oriented (referred to henceforth in the thesis as OO) code based metrics were defined around 1990. There are numerous versions of different OO metrics. Automated tools were developed to collect these metrics. Testing of OO metrics using empirical data is still a popular research topic in computer science and system engineering (Olague, Etzkorn, Gholston and Quattlebaum, 2007).

Research to date in the area of OO metrics provides a lot of insights for software developers. This research, however, does not provide adequate guidelines for software development managers and for testing processes. Many past researchers were restricted by limitations of the amount of the data they could gather. Open Source development has created new opportunities to address this issue. Open Source has provided the following:

- Large amount of source and compiled code from multiple versions of many different products
- Tools for extracting required code based metrics

In my thesis I have answered following question from the perspective of software development management:

What code-based measurements provide system quality indicators for object oriented systems?

1.1 Who cares, why and why me

Both academics and managers in the field of software development should be interested in the outcome of my thesis. The software development managers should be interested because:

- The focus of my thesis is managerial and not technical
- The research model in the thesis is based on the most common used metrics by practitioners and academics
- My research has tested metrics for iterative development which is most commonly used development methodology

Academic interest in my thesis derives from the fact that I re-examine past research in a new context (iterative development) with the limitations of past research overcome (Open Source data).

System engineering and computer science researchers are focused on new OO metrics and models. They are not interested in re-examining past research in the current context from a management perspective. For a management student, it is possible to develop a model and hypotheses based on the literature. Unlimited amount of data are supplied by Open Source projects. Open Source tools for extracting the required OO metrics from source and compile code are also available. The Open Source data that can be used for hypothesis testing comes from many sources and in different format. To extract data required for hypothesis testing, it is essential to build a data extraction system. Development of such system requires programming expertise. I have the required

programming expertise and built just such a system to extract data for hypothesis testing. This research is a combination of positive and constructive research approaches. A positive approach was used for developing the research model and hypotheses. A constructive approach was used for building the system for collecting data for hypothesis testing.

1.2 Contribution

My thesis makes four contributions:

- Based on the results of the hypothesis testing, I have proposed a revised model for OO metrics use. The traditional, recommended use of OO metrics is to measure them and then take action based on the measurements. My research has shown that it is essential to measure the strength of the relationship between code and defect count before using metrics. For any given project, the relationship may be very weak or even does not exist.
- Development of semi-automated Open Source data collection system that
 - Captured project information from SourceForge.net web site
 - Used Open Source tools to extract OO metrics from Open Source systems written in Java (compiled and source code)
 - Loaded OO metrics information in an SQL database and matched it against version control database extract information
 - Extracted data in the required format for hypothesis testing
- At the package level, due to aggregation effect, there is a very strong possibility of finding strong positive relationship between OO metrics and defect count.

- At the package level, the number of lines of code provide a measure equivalent to other OO metrics

1.3 Relevance

OO design metrics testing is very popular research topic. Academics have been doing research on OO metrics since 1990. Software development processes and tools are constantly evolving. It was possible to reexamine past research in the current context to find new interesting findings. The past OO research was examined in three different contexts.

First, system development process:

Iterative development process is the most popular development methodology. During iterative development, the software is in two modes simultaneously, maintenance (defect fix) and enhancement (new functionality addition). As identified in the literature review, the iterative nature of software development was not considered in most of the past research.

Second, language evolution:

The size of OO systems has continued to grow. In the early days of OO development, class was the unit of organization. It worked well for small systems. Most current OO systems have several hundred classes. These systems are organized in packages.

Third, data and tool availability:

Many past OO metrics studies were done using limited amount of data. Open Source have made available vary large amount of data. Many Open Source researchers have developed and published tools for metrics collection.

The research model in my thesis provides code-based measurements close to current code organization practice (package based code organization instead of class bases). With a pragmatic approach, my research has identified useful metrics from the metrics defined by past research. It also simplified metrics measurements by eliminating metrics that were measuring same OO system properties. Open Source has supplied automated tools for gathering metrics and large number of applications for data collection.

The literature review identified that code based metrics defined by Chidamber and Kemerer (1991) (referred to henceforth in the thesis as C&K) and Martin (2003) were most used among academic and practitioner communities. At the class level, three metrics defined by Chidamber and Kemerer (1991) have a positive relationship with number of defects in the class.

A theoretical model was created based on metrics defined by Chidamber and Kemerer (1991), Martin (2003) and measurement theory (Briand and Morasca 1996). Hypotheses were developed for both release (iterative incremental development) and accumulated defects (snap shot) of the software system. A sample of 55 releases from 12 different Open Source products implemented using the Java programming language (Appendix A) were collected for data analysis. A Java based system was developed by integrating Open Source tools. Hypothesis testing was done using original data collected for this research.

1.4 Thesis organization

The rest of the thesis is organized as follows:

- Section 2 is a literature review. Academic publications and current practices were reviewed to identify the current research status of using code based metrics for product quality.
- Section 3 describes the research model based on existing research and develops hypotheses based on the research model.
- Section 4 describes the data collection process. Although Open Source data are available, it was necessary to build a semi-automated system for collecting data in the format required for hypothesis testing.
- Section 5 describes the hypothesis testing. All the hypotheses were tested using data collected from Open Source software systems.
- Section 6 explains the relationship between metrics defined by Chidamber and Kemerer (1991) and Martin (2003).
- Section 7 describes conclusions and provides summary

2 Literature review

This section reviews the literature published by academics and practitioners on the following topics:

- Identification of successful OO metrics
- Past empirical research on OO metrics
- OO metrics measurement tools
- Data availability for empirical testing

Academic journals, material published on World Wide Web and books were reviewed. The focus of the review was the management of software development rather than state of art technical research without obvious managerial impact. Useful findings for software development managers were identified.

2.1 Importance of code based metrics

During software development many deliverables are produced. Some of the most important are: requirement specifications, architectural design , detailed design, source code, test cases and user documentation. Software systems constantly evolve. As user requirements change, it is necessary to make system changes. Many times due to a lack of resources and time, not all deliverables are updated. Source code is the exception. It is always updated. Without updating the source code, it is not possible to deliver modified functionality.

Static measurements based on source code provide primary data about software systems. Using backfiring technique developed by Jones (1995) source statements

could be converted to function points. Function points can be used for system sizing or predicting development effort. McCabe (1976) defined Cyclomatic complexity. It can be used to calculate code complexity. Both of these techniques may seem to be in the past but are currently very much in use. IFPUG (2008) is a non-profit organization committed to promoting and supporting function point analysis and other software measurement techniques. Tables developed using backfiring technique are part of a successful consulting business run by Jones (SPR, 2008). Cyclomatic complexity is integrated into tools sold by McCabe (2008).

Static code based metrics are also important because:

- Programming languages have well defined syntax. It is easy to define counting rules for metrics.
- Metrics for well-defined rules can be gathered automatically. This leads to efficient collection of metrics at low cost.
- It is easy to present gathered information in tabular or graphical form

Limitations of the static code based metrics include

- Do not take into account execution time behavior of the program, and
- Do not take into account the effect of overall software development process on the product quality.

2.2 Software metrics lifecycle

Numerous metrics have been defined for OO systems by academics and practitioners. Some of these metrics have received wide attention and have undergone extensive

empirical testing. Successful software metrics created by academics go through the following lifecycle stages: definition, empirical testing by other academic researchers, academic acceptance and practitioner acceptance.

2.2.1 Definition

The creator first publishes the initial definitions of the metrics. Its initial testing may follow the definition publication. Academics and practitioners have published many OO design measurements. The review paper by Briand and Wust (2002) has identified about ten different OO measurements reviewed by academic researchers. Briand and Wust (2002) maintained that the measurements defined by Chidamber and Kemerer (1991) were the most widely used in empirical studies. This observation was confirmed by El-Emam (2001) in his review paper about OO metrics.

2.2.2 Empirical testing by other academic researchers

Empirical testing by other academic researchers is an important milestone in the metrics lifecycle. Reaching this milestone indicates that academics other than the creator have accepted the metrics as having academic value. The C&K metrics have been tested more than any other metrics (Briand and Wust 2002). Recent publications that have tested C&K metrics include Subramayam and Krishan (2005), Zhou and Leung (2006) and Olague, Etzkorn, Gholston and Quattlebaum (2007).

2.2.3 Academic acceptance

At this stage, metrics become a de facto standard. Anyone doing metrics research in the associated domain has either to reference and/or test them. Academically accepted

metrics are used for different purposes than assessing code quality. For example, Gyimothy, Ferenc and Siket (2005) have used C&K metrics to validate a reverse engineering framework. The framework extracted individual code file updates and, using reported defects from defect database, calculated number of defects for individual classes in different releases of Mozilla software. The correlation study was carried out using C&K metrics values and class defect count.

2.2.4 Practitioner acceptance

When the academic world provides enough evidence about the usefulness of a metric, the commercial world steps in to create a business opportunity. Metrics can be collected through automated processes. Hence metrics tools typically gather many metrics for many different entities. The following are some of the commercial products that collect C&K metrics:

- Krakatau, Metrics Professional by Krakatau, Metrics Professional, (2008)
- SDMetrics by Wust (2008)
- Rational by IBM (2008)
- Project Analyzer by Aivosto (2008)

Open Source has added another dimension to automated metrics tool creation processes. Capable individual developers have developed tools to capture different software metrics and have made them available (both as source code and as executable program) for others to use. CKJM by Spinellis (2008) and BCML by Yamashita (2008) are the Open Source tools that collect C&K metrics for the Java programming

language. Tools such as these have created opportunity for skilled programmers to gather source code metrics without buying commercial tools.

2.2.5 Popular metrics created by practitioners

The metrics created by practitioners do not follow the first three steps of the metric life cycle described above. Martin (2003) developed package level design principles for Java programming language. He has used these principles in his successful consulting business and has also written a very popular book (Martin 2003). Some of these principles can be measured using source code. These measurements are very popular among practitioners. The metrics defined by Martin are interesting for the following reasons:

- The metrics created by Martin did not follow earlier three stages followed by C&K metrics. They are not referenced academically. This fact was confirmed by searching the Carleton digital library.
- No publications about empirical testing of Martin's metrics were found in a search of the Carleton digital library.
- Jdepend (Clarkware Consulting 2008), the tool used to capture Martin's metrics, has over 300,000 references on www.google.com.

Thus, these are two popular sets of code based OO metrics, one defined by academics and the other defined by a practitioner: C&K (1991) and Martin's package metrics (2003). In the context of OO systems, the purpose of these two metrics is quite different. The following section describes these metrics in detail.

2.3 Metrics for classes

C&K metrics are the most popular class-based metrics. The metrics suite has six metrics. These metrics were based on theoretical concepts in measurement and OO design methodology. This section describes these metrics briefly.

2.3.1 Weighted Methods per Class (WMC)

In OO systems, a class has one or more methods. WMC for a class is the sum of complexity of all methods of the class. According to C&K (1991) WMC measures the class complexity. If all methods in the class were of unit complexity then WMC for a class would be total number of methods in the class.

2.3.2 Depth of Inheritance Tree (DIT) and Number Of Children (NOC)

In OO systems, an inheritance hierarchy relates classes to each another. It is possible to draw inheritance hierarchy in the form of inverted tree as follows:

Figure 1: Sample tree for measuring metrics

Each class in the above tree (except the root class) is influenced by the classes above it, on the way to root class through the inheritance of methods and variables. Each class (except the leaf node classes) influences the classes derived from it. For example, in above diagram, class F is influenced by classes A, C and D and class F influences classes G, H and I. The DIT metric measures the “influenced by” effect. The DIT for a class is defined as the maximum length from the class node to the root of the tree. The NOC metric measures the “influencing others” effect. The NOC for a class is the number of immediate subclasses derived from the class. High DIT value indicates that many classes are influencing the class. High NOC value indicates that the class is influencing many classes.

2.3.3 Coupling Between Objects Classes (CBO)

Objects are instances of classes. In OO systems, objects belonging to different classes collaborate and/or interact with one another to perform required work. The collaboration/interaction happens when one object uses an instance variable or method from other class. The CBO measures the number of classes with which the given class interacts.

2.3.4 Response For a Class (RFC)

The RFC for a class is the set of methods that can be executed potentially in response to the message received by any object in the class. The RFC measure includes only first level calls to methods from other classes. As RFC measures the outside method calls in

addition to method calls from the class itself, its measurement includes coupling measurement.

2.3.5 Lack of Cohesion in Methods (LCOM)

A typical class consists of a number of variables and methods. Each method can use one or more variables in the class. Two methods in a class are similar if they use at least one common variable. Two methods in a class are not similar if they do not use or operate on single common variable.

LCOM for a class = Count of not similar method pairs – Count of similar method pairs

A high LCOM value for a class indicates that the class is a collection of unrelated methods.

2.4 Complexity measures for class methods

For WMC metrics, C&K did not define the complexity measure for individual methods in a class. Many empirical tests of C&K metrics have used either McCabe's cyclomatic complexity (McCabe 1976) or uniform complexity of one for each method as measure for class complexity. Cyclomatic complexity is the most widely used method for measuring the structural complexity of modules for procedural languages. It has been around since 1976. It measures the number of linearly independent paths through the module. The formula for calculation cyclomatic complexity is:

$$\text{Cyclomatic complexity} = \text{Number of edges} - \text{Number of nodes} + 1$$

Consider the following pseudo code example:

```
Integer result, marks
Input marks
If marks > 40 Then (Node)
    Result = Pass (Edge)
Else
    Result = Fail (Edge)
End if
```

The above code has one node and two edges. This results in cyclomatic complexity of two.

2.5 Metrics for packages

2.5.1 Metrics by Martin

The C&K metrics suite is defined for classes. For OO oriented system, class is the basic building block. It is very common to have real life OO systems with hundreds of classes. As a result, class is not very suitable unit for the organization of large OO systems. Large OO applications are organized using packages. Package is Java terminology.

Martin (2003) described six design principles for package design. The first three deal with partitioning classes into packages. The last three deal with interrelationships between packages. Martin provided only general guidelines for partitioning classes into packages. He did not provide any direct measurements for these principles. Martin described three principles for interrelationships between packages and provided direct measurements for each principle:

1) The Acyclic-Dependency Principle (ADP)

Dependencies between packages must not form cycles. The number of cycles in which a package is involved provides a direct measurement for the ADP principle.

2) Stable-Dependencies Principle (SDP)

Martin relates stability to the amount of work required to change a package. A package is difficult to change when many packages depend upon it. For example packages B, C and D are dependent upon package A. This requires package A to be a stable package. Any change to package A must take into account the effect of changes on packages B, C and D. A package on which no other package depends is an independent package and can be changed without much effort. Such a package can be unstable. When package A depend upon package B, package B should be more stable than package A. Martin has measured package stability using coupling between packages as follows:

- (Ca) Afferent Coupling: The number of classes outside the package that depend upon classes inside the package (incoming dependencies)
- (Ce) Efferent Coupling: The number of classes outside the package on which classes inside the package depend upon (outgoing dependencies)
- Instability : $I = Ce / (Ca + Ce)$

According to SDP, the instability metrics of a package should be smaller than the instability metrics of the package that depends on it.

3) The Stable-Abstractness Principle (SAP)

A stable package should be abstract so that it can be extended. An unstable package should be concrete so that it can be easily changed. For this principle it is necessary to

measure stability and abstractness. Martin measured stability using Instability (I) as described above. He has provided measurement for abstractness of package as follows.

- N_a = Number of classes in the package
- N_c = Number of abstract classes in the package
- Abstractness: $A = N_a / (N_a + N_c)$. The range for A is [0, 1], 0= No abstract class, 1=Completely Abstract

The main sequence line (Martin 2003) connects two extreme categories of packages, maximally stable and abstract with maximally instable and concrete. This line provides the ideal balance of stability and abstractness for a package. Each package should be as close to main sequence line as possible. The perpendicular distance of a package from metrics could be measured as follows:

$$\text{Distance: } D = \text{Mod}(A + I - 1) / \text{Sqrt}(2). \text{ The range of } D \text{ is } [0, 0.707]$$

2.5.2 Extension of Chidamber and Kemerer metrics for packages

Vernazza, Granatella, Succi and Benedicenti (2001) extended C&K metrics to packages using Briand and Morasca's (1996) mathematical framework. They only provided mathematical proof for the package metrics. They did not develop any hypothesis based on the metrics.

2.6 Empirical testing of the C&K metrics suite

The OO design measures proposed by C&K (1991) have received the most attention from software engineering researchers and have been used in many empirical studies. Briand and Wust (2002) surveyed the work done by software engineering researchers

on quality models in OO systems, covering about ten years. Their survey looked at 33 correlational studies. Out of 33 studies, 16 tested the relationship between the C&K metrics and defect count. Instead of reviewing many individual papers about C&K metrics empirical testing, the survey paper published by Briand and Wust (2002) was used as the major source on C&K metrics studies. For additional information, some individual papers on C&K metrics empirical testing were reviewed. Briand and Wust (2002) identified that a significant positive relationship exists between size and coupling measures, and number of defects in the class. The WMC, RFC and CBO are C&K size and coupling related measures. For other C&K measures (DIT, NOC and LCOM) the survey paper could not find a similar relationship.

2.6.1 Data size used in the study

The following table provides information about the size of OO systems reviewed in Briand and Wust (2002) as measured by number of classes in the system.

Table 1: Sample system sizes from past empirical studies

Number of classes	< 50	51 to 100	101 to 150	151 to 200	501 to 550	601 to 650	Information not available
No of occurrences	4	6	8	1	1	1	12

It can be seen that 19 studies out of 33 were done using object oriented systems having fewer than 200 classes. It is very common to have real life systems with many more than 200 classes. The following information is based on the two Open Source projects from the sample collected for thesis data analysis. The projects have more classes than

many data samples used in the past empirical studies. For a complete data description of the data used in the thesis, please refer to “Appendix A: Data gathered for analysis”.

Table 2: Open Source, sample system size

Project name	Version Number	Number of classes
Java Group	10	553
Jasper Report	35	743

2.6.2 Type of defects measured

During development of software and its release to end users, defects can be found in the following phases: unit test, integration test, system test, acceptance test, and field implementation. Total system defects equals the sum of the defects identified in all phases. The number of defects found at each phase depends on the quality and quantity of testing done in previous stages. For example, if unit, integration and system tests are carried out properly, then fewer defects are likely to be found during acceptance testing. The following table provides information about the type of defects studied in the research reviewed by Briand and Wust (2002).

Table 3: Defect types studied empirically Briand and Wust (2002)

Defect measured from	No of occurrences
Acceptance test	2
Field	10
System test and field	1

These data indicate that different researchers have measured defects from different phases of software development. Defects from different phases were successfully used to demonstrate positive relationships between defects and C&K metrics. Each

individual phase defects are subset of total system defects. This indicates a very strong relationship between C&K metrics and defect count.

2.6.3 C&K metrics suite study period

Briand and Wust's survey paper was published in 2002. The earliest work on C&K metrics referred to in the survey paper was carried out in 1993. Some of the most recent OO metrics research work done using C&K metrics includes Olague, Etzkorn, Gholston and Quattlebaum (2007), Zhou and Leung (2006), Gyimothy, Ferenc and Siket (2005). Both the survey paper and these other research publications indicate that the C&K metrics suite in its original form is still quite popular for measuring OO design quality.

2.6.4 C&K metrics and other research

As identified in the survey paper, many empirical studies have shown that WMC, RFC and CBO for a class have a positive relationship with number of defects in the class. For the remaining C&K metrics, the results were mixed, positive or no relationships. Hence WMC, RFC and CBO metrics provide more useful class quality indication than NOC, DIT and LCOM. The C&K (1991) metrics were designed to measure different features of the OO systems as follows:

Table 4: System properties measured by C&K metrics

Metrics	Measured property
WMC	Class complexity
RFC	Attributes of objects in the class
CBO	Coupling between objects
DIT	Scope of properties: Number of ancestor classes affecting class under measurement
NOC	Scope of properties: Number of subclasses that inherit methods of parent class
LCOM	Similarity of methods

Briand and Morasca (1996) applied a mathematical framework to software system measurements. They identified system properties measured by C&K metrics and McCabe's (1976) cyclomatic complexity metrics. Along with the property being measured, the type of measurement were also identified.

Table 5: Metrics, System properties, Type of measurement

Class Metrics	System property being measured	Type of measurement
WMC	Size	Ratio
DIT	Length	Ratio
NOC	Size	Ratio
CBO	Coupling	Ratio
RFC	Size and Coupling	Ratio
LCOM	Not defined	Not defined
Cyclomatic complexity	Size	Ratio

2.7 How C&K metrics are used in practice

Mayer (1998) provided general classification of software metrics along with usage guideline. A concrete application of C&K metrics was implemented by the Software Assurance Technology Centre (SATC) division of NASA. SATC has been gathering

OO metrics over seven years. They have published following recommended thresholds for the Java programming language.

Table 6: NASA threshold values

Metrics	Threshold value
Number of methods (NOM)	40
WMC	100
RFC	100
RFC / NOM	10
CBO	5
DIT	5

The STAC has provided its own interpretation for different C&K metrics. The WMC value provides indication of total complexity of the class. It provides a predictor for the time and effort required to develop and maintain a class. A high RFC value implies increased complexity and decreased understandability. High RFC value classes complicate testing and debugging. Making changes to high RFC value classes is difficult due to the potential ripple effect. STAC has created new metrics based on RFC metrics. They compute RFC / NOM, which helps them identify classes that need extensive testing. High CBO value classes may be difficult to understand, reuse or maintain. Changes to high CBO value classes can cause ripple effects. The DIT value indicates the amount of reuse. OO systems with a majority of classes having DIT less than 2 indicate very little reuse. A DIT value of 2 or 3 indicate high degree of reuse. Classes with DIT value greater than 5 indicate overuse of inheritance resulting in very complex classes.

The SATC document does not state clearly the action that should be taken when their upper threshold for the metrics is crossed. There are two possibilities. First, refactor

the code to bring the metrics value below the threshold. Second, understand the effect of crossing the threshold and adjust the process accordingly.

Benlarb, El Emam, Goel and Rai (2000) have shown that there is no threshold effect for WMC, DIT, CBO and RFC C&K metrics. The relationship between metrics and fault proneness is continuous. This observation is against the practice of metrics threshold implemented at STAC. This is an indication of contrasting research done in the OO metrics area. I could not find any empirical testing of hypotheses based on the STAC thresholds.

Tool vendor “Aivosto” (Project Analyzer, 2008) has provided guidelines for using C&K metrics. These guidelines are quite similar to those provided by SATC.

2.8 OO metrics measurement tools

For OO metrics research, it is necessary to have automated tools for gathering metrics such as size (number of lines), C&K metrics, McCabe cyclomatic complexity metrics and package metrics by Martin.

Many past researchers were restricted in the research due to a lack of tool availability. The commercially available tools were very expensive. Open Source has solved the problem of tool availability. The metrics defined by Martin are for the Java language. The C&K metrics can be applied to any object oriented programming language. The McCabe cyclomatic complexity metrics can be applied to any procedural and OO language. Each programming language has its own well-defined syntax. To collect

C&K and McCabe cyclomatic complexity metrics for different programming languages, different tools are required. Since Martin's metrics were defined for the Java programming language, it is necessary to collect other metrics for Java. The following table identifies Open Source tools that were used for collecting different metrics required for OO metrics study.

Table 7: Open Source tools for metrics measurement

Tool	Reference	Computed Metrics
NCSS	Lee (2008)	Line count
NCSS	Lee (2008)	McCabe cyclomatic complexity
CKJM	Spinellis (2008)	C&K
Jdepend	Clarkware Consulting (2008)	Martin's metrics

2.9 Data availability

SourceForge is the largest collection of Open Source projects. It has over 100,000 projects, including over 22,000 projects implemented using Java.

For any published project, a lot of information is available to users of the web site.

Published information includes:

- General project information such as operating system, license type, implementation language
- Source code, compiled code (if published), executable (if published)
- Support request, defect information (at release level)
- Developer information

From the SourceForge web site it was possible to identify projects with the characteristics required for the research. This eliminated most of the data availability problems faced by past researchers.

2.10 Literature review insights

The literature review identified four insights. First, C&K metrics are most popular OO metrics but they provide only partial OO design measurements and provide too many measurements for the project managers. Second, the incremental nature of software development is not considered by empirical testing of C&K metrics. Third, different researchers have tested the relationship between OO design quality and C&K metrics successfully using different type of defects (All type / system / field). Fourth, C&K metrics measurements are related to only size and coupling.

3 Research model and hypothesis development

This section develops a theoretical research model based on past research that incorporates several hypotheses relating code based OO system design metrics and product quality.

3.1 OO system measurement model

C&K metrics provide OO design level measurements based on classes. Empirical testing had shown that WMC, CBO and RFC for a class have a positive relationship with the number of defects in the class. A project manager can assess the quality of a system using WMC, CBO and RFC metrics values for the classes in the system. On the other hand, project managers find class measurements difficult to use for three reasons. First, most of the real life systems have many hundreds of classes. This results in too many class level measurements. Second, the OO system code is organized using packages or modules. Third, after the release of the software for system testing, reported defects are tracked at the release level. It is almost impossible to identify the classes modified for each specific defect. The defects reported by end users are also tracked at release level.

All C&K measurements are based on the OO system model as a collection of interrelated classes. Current OO systems are organized into collection of interrelated packages. Each package contains collection of interrelated classes. Individual classes interact with other classes in the same or any other package in the OO system. Using class based measurements only does not take into account interrelated package based

structure. For current OO systems three measurements are required: first, class based measurements; second, package based measurements; and third, measurements based on package relationships.

C&K metrics provide class based measurements. Martin's measurements provide package relationship measurements. To obtain package measurements, it was necessary to use the research done by Briand and Morasca (1996). They defined property based measures for C&K metrics. These measurements identified the system property being measured by each metrics and also identified measurement type. The following table is based on their research.

Table 8: Metrics, System properties, Type of measurement

Class Metrics	System property being measured	Type of measurement
WMC	Size	Ratio
CBO	Coupling	Ratio
RFC	Size and Coupling	Ratio

WMC, CBO and RFC are ratio measurements. Ratio measurements allow the addition operation for components of a system. Class is the smallest building block of the OO system. Related classes are grouped together into packages. WMC, CBO and RFC metrics can be defined for packages as follows:

$WMC(\text{Package}) = \text{Sum of WMC for all classes in the package}$

$CBO(\text{Package}) = \text{Sum of CBO for all classes in the package}$

$RFC(\text{Package}) = \text{Sum of RFC for all classes in the package}$

These definitions for packages are similar to those defined by Vernazza, Granatella, Succi and Benedicenti (2001).

The division of classes into packages is not arbitrary. Martin (2003) has provided six design principles for dividing classes into packages. These principles are not about content of individual classes but are about dividing classes into packages. Out of six, three provide direct measurement:

- Acyclic-Dependency Principle (ADP)
- Stable-Dependencies Principle (SDP)
- Stable Abstractions Principle (SAP)

Package level C&K metrics provide measurements for the contents of the package and Martin's metrics provide measurement for dividing classes among packages. These two sets of metrics together provide a more complete set of measurement for an OO system.

Figure 2: Research model

3.2 Hypothesis development

This section develops hypotheses based on the research model. To ensure that the hypotheses were most likely to be true, care was taken so that each hypothesis was supported by strong theory, empirical test results or practical use. Many hypotheses were based on practical situations that had not yet been empirically tested.

3.3 Identification of best quality indicator

Most software products are developed iteratively. At any time the software is in both development and maintenance state. As part of development, new functionality is added to the system. During maintenance, defects from previous release are fixed. Typically each release has some defect fixes from earlier release (maintenance) and new functionality is added (enhancement).

As indicated in the Figure 3, it is possible to measure system/package/class defects in two different ways, accumulated and release. Accumulated defects are associated with a snapshot of the system. For a specific release accumulated defects are counted as all defects from the start. In Figure 3, accumulated defects for release four (R4) is the total of all defects reported until the release of release five (R5). Release defects are associated with an individual software release. For a specific release, defects are count as newly reported defects. In Figure 3, release defects for release four (R4) is the number of defects reported between release four (R4) and five (R5).

Figure 3: Defects measurements for release

Many empirical studies have shown positive relationships between the C&K metrics, WMC, RFC, CBO, and the number of defects in a class. For the C&K metrics, the number of defects is all defects identified for the class. During iterative development, a system is constantly evolving. The code associated with any given class keeps changing. As pointed out in earlier, for a release it was possible to measure class defects in following two possible ways:

- Accumulated defects
- Defects specific to release

Accumulated defects come close to all defects reported for a class. It is not exactly the same as all defects in the class since the code associated with the class can change from release to release due to either defect fixes or the addition of new functionality.

The following table summarizes different OO system properties measured by metrics.

Table 9: Metrics, System property

Metrics	Measured system property
WMC: Number of functions	Size
WMC: Cyclomatic complexity	Size
RFC	Size and coupling
CBO	Coupling
Size	Size

Note that only the CBO metric is not associated with system size. WMC and RFC are related to size. Since WMC and RFC are size related measures, it seemed useful to see the relationship between size and defect count.

Many researchers have tested the relationship between WMC, RFC, CBO and defect count. Using my data these hypotheses were also successfully tested. The successful testing of well established hypotheses using my data went some way to validating my data.

A package is collection of related classes. WMC, RFC, CBO and size are usually defined at the class level and are ratio type measures for which addition operation is permitted. These package measures can be obtained by adding measures associated with individual classes in the package.

3.3.1 Hypotheses for accumulated defects

Figure four shows the hypotheses developed for accumulated defects at the class and the package level.

Figure 4: Hypotheses for accumulated defects

The WMC metrics is being measured by two different methods, counting number of functions and using cyclomatic formula. In each set of hypotheses there are two hypotheses for WMC, one each for each measurement method. To make the hypotheses definitions simple, following symbols were used:

- WMCF – WMC calculated using number of functions in the class / package
- WMCC – WMC calculated using cyclomatic complexity at class / package level

These symbols are used all hypotheses, at class and package level.

The following hypotheses were defined at the class level. All hypotheses were defined for a specific software release:

H1: WMCF for a class is positively related to the accumulated defects in the class

H2: WMCC for a class is positively related to the accumulated defects in the class

H3: RFC for a class is positively related to the accumulated defects in the class

H4: CBO for a class is positively related to the accumulated defects in the class

H5: Size for a class is positively related to the accumulated defects in the class

The following hypotheses were defined at the package level:

H6: WMCF for a package is positively related to the accumulated defects in the package

H7: WMCC for a package is positively related to the accumulated defects in the package

H8: RFC for a package is positively related to the accumulated defects in the package

H9: CBO for a package is positively related to the accumulated defects in the package

H10: Size for a package is positively related to the accumulated defects in the package

The hypotheses associated with the packages is my research contribution. I have not found any study that has tested package relationships. Testing the above hypotheses at both class and package levels should help to identify best quality indicators at the class and package level.

3.3.2 Hypotheses for release defects

For iterative development, release specific defects are more important than accumulated defects for project managers. They provide quality measurement for the release. It is not possible to draw any conclusion about release quality based on accumulated defects because accumulated defects are based on all past releases. For any release either some defects reported in the earlier release have been fixed or new functionality has been added or both. Each defects found in the release should be due to one or more of the following:

- Code added for new functionality

- Defects induced by fixing earlier reported defects
- Pre-release existing defects which have not yet been found

For each release not all classes in the system are likely to be modified. Many more classes are likely to be modified for a larger release than for small release. When only few classes the OO system are modified, it is difficult to predict the relationship between C&K measures and release defects. Figure 5 shows the hypotheses developed for release defects at class and package level.

Figure 5: Hypothesis for release defects

The following hypotheses were defined at the class level. All hypotheses were defined for a specific software release:

H11: WMCF for a class is positively related to the release defects in the class

H12: WMCC for a class is positively related to the release defects in the class

H13: RFC for a class is positively related to the release defects in the class

H14: CBO for a class is positively related to the release defects in the class

H15: Size for a class is positively related to the release defects in the class

The following hypotheses were defined at the package level. All hypotheses were defined for a specific software release:

H16: WMCF for a package is positively related to the release defects in the package

H17: WMCC for a package is positively related to the release defects in the package

H18: RFC for a package is positively related to the release defects in the package

H19: CBO for a package is positively related to the release defects in the package

H20: Size for a package is positively related to the release defects in the package

3.3.3 Hypotheses for testing the effect of Martin's metrics

This section defines the hypotheses for each of the three measurable principles defined by Martin (2003).

3.3.3.1 The Acyclic-Dependency Principle (ADP)

The dependency cycles can exist among classes as follows.

- Direct dependency: Class A depends upon class B and class B depends upon class A.
- Indirect dependency: Class A depends upon class B. Class B depends upon class C. Class C depends upon class A.

Consider the situation when related classes are grouped together into packages. If all the classes involved in the dependency cycle are located in the same package then dependency cycle exists only among classes and not packages. Whenever classes involved in the dependency cycles are separated into different packages, cyclic

dependency among packages is created. A package structure without any dependency cycles is manageable. With each dependency cycle packages become dependent on each other. Packages that are dependent upon each other need to be build and tested together.

Consider a system with ten packages (P1, P2,P10) without any cyclic dependencies. Whenever new code is added or existing code is modified for any of the packages P1 to P10, it is necessary to test only the modified package. It is not necessary to test any other package. Now consider the same system but with cyclic dependencies among P2, P4 and P5. Whenever new code is added or existing code is modified for any of the packages P2, P4 or P5, it is necessary to test all three packages together. More efforts is required to add or modify code to packages involved in dependency cycles than packages not involved in any dependency cycle. More new defects are also likely to be introduced as a side effect when adding new functionality or code fixes for system with cyclic dependencies. The introduced defects might be in any package in the cycle. From OO design perspective, class dependency cycles are acceptable but package dependency cycles are not accepted. In an ideal package structure there will be no cyclic dependencies.

H21: The number of package dependency cycles is positively related to number of defects in the package

3.3.3.2 Stable-Dependencies Principle (SDP)

In order to add more functionality to a system, the design of the system must be continuously changed. A change in design requires changes in code resulting in associated package changes. A package upon which no other package depends is easier to change than a package upon which many packages depend. When package A depends upon package B, it is easier to change package B than package A. Changing package A has no effect on package B. But whenever package B is changed, one has to consider the impact of change on dependent package A. When package A depends upon package B, package B should be more stable than package A. To measure package dependency Martin(2003) defined two types of coupling between packages.

Afferent coupling (C_a) is defined as the number of classes outside the package that depend upon classes within the package (incoming dependencies). Efferent coupling (C_e) is defined as the number of classes inside the package that depend upon classes outside the package (outgoing dependencies). Based on these two measurements Martin (2003) defined instability (I) as follows:

$$I = C_e / (C_a + C_e)$$

This instability metric provides measure of a package stability according to class dependencies among packages. When I is zero, the package is maximally stable. It does not depend upon any package but other packages depend upon it. Any change to this package may produce ripple effect through the packages that depend upon it. When I is one, no other package depend upon it but it depend upon other packages. Modification to such package has no effect on any other package. For ideal package dependency, a

dependent package should have a higher I metric (less stable) than the package upon which it depends (more stable). This is the Stability Dependency Principle (SDP) defined by Martin (2003).

In ideal OO system structure, the SDP principle should be followed. It is possible to measure number of times SDP is broken for each package in the OO system. This leads to following hypothesis to test the effectiveness of SDP:

H22: The number of times the SDP is broken for a package is positively related to number of defects in the package

3.3.3.3 Stable Abstractness Principle (SAP)

Martin (2003) stated this design principle as, “The abstractness of package should be in proportion to its stability”. It sets up relationship between stability and abstractness. The abstractness (A) of a package is:

$$A = \text{Number of abstract classes in the package} / \text{Number of classes in the package}$$

A class with at least one pure interface is an abstract class. The range for abstractness metrics is from zero to one. Zero means that the package has no abstract classes (completely concrete package) and one means that the package has only abstract classes (completely abstract package).

Martin (2003) combined stability and abstractness for two best cases. The maximally stable package should be abstract so that it could be extended and the packages that are

maximally unstable should be concrete. These two extreme cases provide two end points for a line drawn on the abstractness verses instability graph (Figure 6). This line is called main sequence. Packages that fall on the main sequence line have a balance of stability and abstractness.

In practical applications, few packages fall on the main sequence line. Although it is desirable that they be as close to the line as possible. To measure the deviation from ideal, Martin (2003) defined Distance (D) as:

$$D = |A + I - 1| / \text{SQRT}(2)$$

Ideal design should have sum of D metrics for all packages close to zero. The following hypothesis was designed to test effectiveness of Martin's D metrics.

H23: The D metrics for a package is positively related to number of defects in the package.

Figure 6: Abstractness and Instability

3.4 Relationships between metrics

Different OO metrics measure the size and coupling properties of a system. Because of the relationship between size and coupling as described in earlier section, these metrics (WMC: Number of functions, WMC: Cyclomatic complexity, RFC, CBO, and Size) should be correlated at the class and the package levels. Establishing the strength of such correlation can assist a manager in selecting and using these metrics. If these metrics are highly correlated, then any one of them might be used as a single quality indicator for the system.

3.5 Summary

This chapter developed a research model based on empirical research. Based on the research model, hypotheses were developed at both the class and the package levels.

4 Data collection for hypothesis testing

4.1 Language selection

The basic research model is not tied to any specific implementation language. The model can be applied to projects implemented in any object-oriented language. As pointed out in an earlier section, to obtain data for hypothesis testing, it was necessary to use projects implemented in a specific implementation language because each programming language requires a different tool set for extracting the same OO metrics. Open Source tools are available for the Java programming language, which is one of the most popular programming languages. Hence projects implemented only in Java were selected for gathering hypothesis testing data.

4.2 Population

The research model is applicable only to projects developed using OO programming languages but it is not dependent upon any specific programming language. The tools for extracting metrics from source code are language dependent. Java is one of the most popular programming languages and tools are available for source code metrics extraction. For the research projects implemented using only Java programming language were considered. Most of the standalone systems fall under this category. Typically client serve systems are written using multiple programming languages. Such projects were not considered during data collection. Hence the hypothesis testing outcome could be applied to standalone systems developed using only Java programming language. The population for the thesis model is any standalone project implemented using only Java programming language.

4.3 Sample selection

For hypothesis testing the information such as project release information, source code, compiled source code and source code was required for each individual project. Projects implemented in Java for which this information could be obtained were eligible candidates. Such information can be obtained easily for Open Source projects. The web site <http://sourceforge.net> is the largest collection of Open Source projects. It has over 100,000 projects, including over 22,000 projects implemented using Java. It was possible to obtain the project release information, source code and complied source code for the individual projects from the web site. The web site <http://sourceforge.net> is also the largest collection of Open Source projects users. The defects reported by users are tracked at the release level. The defect information does not include information about class file modification done for fixing defects, however so the defect information available on the web site could not be used to calculate the defect counts for individual classes.

4.4 Proxy for the defect count for the class

Defect count information was not available at the class level; hence it was necessary to use a proxy for defect count at class level. For Open Source projects, different types of information were available on different sites. Howison (2006) has identified these academic Open Source data sources: Notre Dame's Sourceforge Dumps, FLOSSmole, CVSanalY.

FLOSSmole provides all the information from the web pages of the <http://sourceforge.net> web site, but does not provide any details about either source or executable code. FLOSSmole does not provide all of the required information for my hypothesis testing. Notre Dame's Sourceforge Dumps have all the information from the <http://sourceforge.net> web site, but this information is not available publicly. Researchers have to sign a contract to receive data. After sign up data is supplied on a case per case basis. Hence, although useful, this source was not very convenient. The CVSanalY data source created by Gregorio (2006) provided a relational database dump of version management system used by projects implemented on <http://sourceforge.net> web site. From this database it was possible to obtain file update information at the class level. It was then possible to use file update information as a proxy for defect count at the class level.

4.5 Limitation of the file count proxy measurement

Open Source projects are in both maintenance and enhancement state at the same time. Maintenance includes fixing defects from previous release. Enhancement includes adding new features. A change made to a file can be done either for a defect fix or for adding a new feature.

It was necessary to separate file updates done for defect fixes from those done for adding new functionality. To understand the file change characteristics, I spoke to three different developers from my company who were working on different IT systems. All three had over ten years of experience in software development and maintenance. These

IT systems were being extended for new functionality and defects were being fixed from previous releases. The following are the common conclusions drawn from my interviews with these developers:

- With reasonable amount of testing before releasing software to a test team, defect fixes do not require a lot of code changes.
- Most defects code fixes changes are associated with one or more missed condition.
- Lot of code change for a defect indicates adding new functionality.
- Typical defect fix modification includes following:
 - Only few source code lines added
 - Only few source code lines modified
 - Very rarely source code lines were deleted

Above information was used to classify each file update in the data set as either a defect fix or a new functionality change. The CVSanalY data source by Gregorio(2006) provided number of lines added and number of lines deleted information for each file update. It did not provide a separate count for number of modified lines. The number of modified lines was added to both line addition and line deletion count. Following is an example:

For a defect fix source code file was modified so that 10 new lines were added, 4 lines were deleted and 5 lines were modified. The version control system stored 15 lines as added and 9 lines as deleted.

Using file update information, it was necessary to separate each file update either as defect or new functionality change. To separate defects from the new functionality the following approach was used:

- New functionality : (Number of lines added – Number of lines deleted) > 10
- Defect fix : (Number of lines added – Number of lines deleted) <= 10

This proxy measurement has two limitations. First, due to unavailability of modified line count, the defects are approximately calculated. Second, for a defect fix multiple files may get updated. With this method each file update is counted as separate defect. For example when 4 separate files were modified to fix one defects, this proxy method would count each file modification as separate defect. This resulted in higher defect count than actual. Despite these limitations, this is most practical proxy alternative available for measuring defects at individual class level. Gyimothy, Ferenc and Siket (2005) have used file update information as defect count without separating into defect fix or new functionality. Table 10 summarizes the source for all pieces of information required for hypothesis testing.

Table 10: Source of information

Information	Source
Project related information such as project name, id etc.	Available at: http://sourceforge.net
Project release information such as detailed information about files in each release	Available at: http://sourceforge.net
Source code and Compiled source code	Available at: http://sourceforge.net
Proxy for defect: Individual file update information	Extract from database available at: http://libresoft.urjc.es/Data/CVSAAnalY_SF

Based on this information, the source code based metrics (number of lines of code) was collected using Java source code and Java class or JAR file was used for collecting C&K and package based Martin's metrics.

4.6 Project eligibility criteria

In order to include a project in the study, the project had to satisfy all of the following criteria:

- The project must be implemented using Java only. Projects that used Java along with other programming languages were not considered because only the Java related software part would have been measured. For projects implemented using Java and other programming languages, only Java measurement would not cover the entire project. To avoid partial project measures, such projects were discarded.
- The project must have at least one release with release defects.
- The software release should include both source code and compiled version.
- The software release must have both source code and compiled code (either class or JAR files). Some projects released source code and executable file. The executable file could be used to execute the application on the Windows platform, but the compiled file was required for collecting C&K and Martin's metrics. For projects that do not supply either class or JRE files, it would be necessary to compile code. The source code compilation could be done but is time consuming and requires detailed understanding of the project. Hence projects without class or JAR files were not considered.

- The project must have file update information available in the CVSanalY data source published by Gregorio (2006). Some projects were missing from the database and some had only partial information. Such projects were discarded.

The Java programming language was selected due to following reasons:

- Open Source tools were available for collecting metrics for Java programming language
- Java is most modern and popular object oriented programming language
- Hundreds of standalone projects implemented using only Java programming languages were available on <http://sourceforge.net> web site
- The C&K metrics could be applied to any object oriented language but Martin's metrics are defined for Java programming language

4.7 Project selection process

The following steps were used for selecting projects:

- On the site, <http://sourceforge.net>, projects using Java were listed in the descending order of activity.
- The list was scanned from the top and projects were selected that satisfied the project selection criteria.

4.8 Data collection system

Figure 7 provides the details about the data collection system at the block diagram level.

Figure 7: Data collection system

The following steps were executed to extract data for a project from the SourceForge web site:

- 1) Obtained project summary and release information from web pages on the SourceForge web site
- 2) Downloaded manually source and JRE files from the SourceForge web site. This task was time consuming as many files needed to be downloaded for many projects.

- 3) From project summary and release information, database tables related to project information were populated.
- 4) Java source files were scanned using the tool, JavaNCSS, and information about all classes was extracted. Additionally line count and cyclomatic complexity was also obtained.
- 5) JAR files were scanned using the tool, CKJM, to obtain C&K metrics.
- 6) JAR files were scanned using the tool, JDepend, to obtain Martin's metrics.
- 7) Each class was searched in the CVS extract database to find accumulated and release defects.
- 8) All of the above information was merged and loaded into database tables.
- 9) These steps were repeated for each release of the project.
- 10) Extract program extracted class and package level data from database for statistical analysis.

4.9 Challenges in the data gathering process

The Open Source data for hypothesis testing was available from different sources in different formats. Individual release information was available from project web pages. Source and compiled code was available in different compressed formats for different platforms (Unix/Windows). The file update information for individual source files was available in compressed files that could be loaded into the mySQL database. It was not possible to process data manually. A semi-automated system was developed to gather, process and extract data in the required format from these sources.

For many projects, some information was missing. Either source code or compiled code was not fully published, or the file update information was not available in the version control database extract. Due to missing information it was necessary to search many projects before projects with all required information could be found. The suitability of a project was known only after complete information was downloaded and processed through the data collection system. This task was very time consuming and was feasible because of automated processes.

The release information from project web pages was screen scrapped using a test automation tool. The source and compiled code was downloaded manually because each project had a different directory structure. Hence it was not possible to automate the download process.

4.10 Data analysis

Briand and Wust (2002) had identified Pearson r and Spearman Rho as statistical tests. Academic researchers have executed these tests on all the classes in the project. I performed these tests for classes from the same release of a project and for packages from the same release of the project.

Performing statistical testing in the above manner had two advantages. First, fewer and simpler tests were required. Second, data needed to be collected for fewer projects. But it also had two major disadvantages. First, cross-sectional statistical analysis was carried out using related sample points since classes and packages in the OO system are

interrelated. Second, hypothesis testing was done using fewer projects. To get around these limitations, an attempt was made to collect data from as many different projects as possible.

5 Hypothesis testing and result discussion

The hypothesis testing of C&K metrics was done at both the class and package levels using accumulated and release defects. The Martin's metrics were tested using release defects. Table 11 provides the section numbers for different type of hypothesis testing.

Table 11: Hypothesis testing section summary

Metrics	Defect type	Section
Class	Accumulated	5.1
Package	Accumulated	5.2
Class	Release	5.3
Package	Release	5.4
Martin	Release	5.5

Appendix A provides details about the data collected for statistical analysis. Data from 55 different releases of 12 different projects were collected for analysis. This sample size is many times larger than most empirical studies referred in Briand and Wust (2000). Table 12 provides appendix references for statistical analysis for accumulated and release type of defects at the class and package levels.

Table 12: Appendix information

Measure	Defect type	Condition	Appendix
Class	Accumulated	All classes	B
	Accumulated	Only classes with defect	C
	Release	All classes	F
	Release	Only classes with defect	H
Package	Accumulated	All packages	D
	Accumulated	Only packages with defect	E
	Release	All packages	G
	Release	Only packages with defect	I

Following table provides the coefficient value ranges that was used in identifying relationship strength. It was used for interpreting positive and negative Pearson's

correlations. These are only crude estimates for interpreting strengths of correlations (Reference: <http://faculty.quinnipiac.edu/libarts/polsci/Statistics.html>). There were five ranges on either side, positive and negative. These ranges provided easy comparison between different releases.

Table 13: Coefficient ranges for relationship strength

Coefficient value	Relationship strength
+.70 or higher	Very strong positive
+.40 to +.69	Strong positive
+.30 to +.39	Moderate positive
+.20 to +.29	Weak positive
+.01 to +.19	No or negligible
-.01 to -.19	No or negligible
-.20 to -.29	Weak negative
-.30 to -.39	Moderate negative
-.40 to -.69	Strong negative
-.70 or higher	Very strong negative

5.1 Hypothesis testing: classes with accumulated defects

This section provides the results of hypothesis testing performed at class level using accumulated defects. This type of testing was performed by many past researchers (Briand and Wust 2000). Appendix B provides Pearson correlation coefficients between different class metrics and accumulated defect count. Four projects have releases without any correlation between C&K metrics and accumulated defects for the release at the class level: DrJava, Jguard, HtmlParser and HsqlDB. For all other projects the C&K metrics were positively related to accumulated defects. Hence it seemed useful to analyze each of the above four projects individually to find out why they did not support C&K metrics.

5.1.1 Project analysis: DrJava

Figure 8: Scatter plot for OO project DrJava

Figure 8 is a scatter plot for release number 34 of DrJava. It identifies outlier values.

Other releases of the DrJava project had similar shaped plots. There were a few very small classes with high defect counts. To eliminate outliers, the following case selection criteria was used:

Project_id = 5 and wmc > 0 and accumulated_defects < 100

After removing outlier values the following correlation results were obtained:

Table 14: DrJava - Corelational analysis

Rel	N	WMC	N	Cyclo.	N	RFC	N	CBO	N	NCSS
		p-value		p-value		p-value		p-value		p-value
11	206	.542(**)	206	.228(**)	206	.635(**)	206	.657(**)	206	.595(**)
		.000		.001		.000		.000		.000
34	149	.443(**)	149	.290(**)	149	.556(**)	149	.421(**)	149	.634(**)
		.000		.000		.000		.000		.000
35	149	.356(**)	149	.306(**)	149	.372(**)	149	.302(**)	149	.446(**)
		.000		.000		.000		.000		.000
36	149	.361(**)	149	.316(**)	149	.372(**)	149	.304(**)	149	.449(**)
		.000		.000		.000		.000		.000
38	139	.345(**)	139	.322(**)	139	.350(**)	139	.308(**)	139	.431(**)
		.000		.000		.000		.000		.000
40	128	.423(**)	128	.354(**)	128	.426(**)	128	.319(**)	128	.443(**)
		.000		.000		.000		.000		.000

Table 13 shows that, after removing outlier values, positive correlations exists between C&K metrics and accumulated defects for the release at the class level.

5.1.2 Project analysis: Jguard

Table 14 provides details about correlations between C&K metrics and accumulated defects for the release at the class level for the Jguard project.

Table 15: Jguard - Corelational analysis

Rel	N	WMC	N	Cyclo.	N	RFC	N	CBO	N	NCSS
		p-value		p-value		p-value		p-value		p-value
6	76	.471(**)	76	.290(*)	76	.570(**)	76	.679(**)	76	.522(**)
		.000		.011		.000		.000		.000
7	63	.467(**)	67	.281(*)	63	.535(**)	63	.693(**)	67	.466(**)
		.000		.021		.000		.000		.000
8	47	.385(**)	47	.552(**)	47	.651(**)	47	.657(**)	47	.530(**)
		.008		.000		.000		.000		.000
9	43	.279	46	.282	43	.369(*)	43	.254	46	.435(**)
		.070		.057		.015		.100		.003
10	35	.116	38	-.214	35	-.037	35	-.048	38	-.154
		.508		.198		.831		.783		.357

From the table it can be seen that the relationship between C&K metrics and accumulated defects did not exist for release 9 and 10. Table 15 has additional information about defect count and deployment days for the Jguard project.

Table 16: Jguard project - deployment information

Name	Proj. Id	Rel. Id	Release date	No of deployment days	Total Release Defects	Acc. Defects
Jguard	7	6	2005-10-31	54	14	611
		7	2005-09-07	67	205	587
		8	2005-07-02	81	185	329
		9	2005-06-26	81	15	132
		10	2005-04-06	--	94	108

Release 10 was the first release for which data were collected. Hence numbers of development days were not available for it. The accumulated defect counts for releases 10 and 9 are not enough for positive relationship between metrics and accumulated defect count. Once accumulated defect count crosses a threshold, positive relationship is established between metrics and accumulated defect count. Compared to release seven and eight release six, nine and ten had fewer release defects reported. For release six low release defect count is irrelevant because of high enough accumulated defect count.

5.1.3 Project plot: HtmlParser

The scattering in Figure 9 shows that the project HtmlParser had two distinct groups divided about WMC metrics value 25. The lower group had classes without many defects. It also had large classes with few defects. The lower group was eliminated using following filter:

`(proj_id = 10) and ( wmc > 0 ) and (accumulated_defects > 25 )`

Figure 9: Scatter plot - HtmlParser project

Table 16 was created after removing lower group. It can be seen that there is positive correlation between defects and C&K measures.

Table 17: HtmlParser - Correlation analysis

Rel	N	WMC	N	Cyclo.	N	RFC	N	CBO	N	NCSS
2	56	.458(**)	56	.329(*)	56	.525(**)	56	.666(**)	56	.306(*)
		.000		.013		.000		.000		.022
3	60	.477(**)	60	.435(**)	60	.563(**)	60	.609(**)	60	.411(**)
		.000		.001		.000		.000		.001
4	60	.393(**)	60	.343(**)	60	.462(**)	60	.560(**)	60	.328(*)
		.002		.007		.000		.000		.011

5.1.4 Project analysis: HsqlDB

The two scatter plots in figure 10 provides details for two different releases from HsqlDB project. From these graphs, it can be seen that classes with smaller WMC were

being modified. In such a situation it was not possible to have positive correlation between WMC and accumulated defects for the class.

Figure 10: Scatter plot - Project HsqlDB

5.1.5 Result summary: classes with accumulated defects

The following summary table was created using modified data for DrJava and HtmlParser projects as described in the previous sections:

Table 18: Correlation strength - Accumulated defects at class level

	Very strong positive	Strong positive	Moderate positive	Weak positive	Negligible	None	Total
WMC	0	27	9	12	3	4	55
Cyclomatic complexity	0	20	9	12	10	4	55
RFC	5	26	17	3	0	4	55
CBO	3	25	8	15	0	4	55
NCSS	1	26	8	10	7	3	55

It is important to note that all correlations between C&K metrics and defect count at class level were on positive side.

Table 19: Correlation summary - Accumulated defects at class level

	Significant correlation	%	No significant correlation	%	Total releases
WMC	48	87	7	13	55
Cyclomatic complexity	41	75	14	25	55
RFC	51	93	4	7	55
CBO	51	93	4	7	55
NCSS	45	82	10	18	55

The following were the class based hypotheses for accumulated defects.

- WMC for a class is positively related to the accumulated defects in the class
- WMCC for a class is positively related to the accumulated defects in the class
- RFC for a class is positively related to the accumulated defects in the class
- CBO for a class is positively related to the accumulated defects in the class
- Size for a class is positively related to the accumulated defects in the class

Table 18 had provided strong support for each of the hypotheses for C&K metrics. The positive results for these hypotheses previously tested in the literature was important

because it offers some support for the relevance and accuracy of my data collection, and for the use of my data for further hypothesis testing.

Table 18 also provides strong support for a positive relationship between class size (NCSS) and accumulated defect count. Out of all metrics, the RFC and CBO had highest percentage of significant correlations. Table 19 provides overall correlation descriptions for each project. These descriptions were identified by counting different significant relationship strengths for each project.

Table 20: Correlation strength trend - Accumulated defects at class level

Project	No of release	General correlation trend for RFC
JasperReports	5	Strong positive
FindBugs	16	Moderate positive
DrJava	6	None
GFD	3	Very strong positive
Jguard	5	Strong positive
JavaGroups	7	Strong positive
Itext	2	Moderate positive
HtmlParser	3	None
Azureus	1	Very strong positive
Jung	1	Strong positive
HsqlDB	2	None
Spring	4	Strong positive

Following table has provided the summary of above table for RFC measure.

Table 21: RFC metrics, correlation strength trend summary - Accumulated defects at the class level

Very strong positive	Strong positive	Moderate positive	Weak positive	Negligible	None
2	5	2	0	0	3

For each individual project, the best C&K measure had different strength such as very strong, strong, moderate etc. Projects that did not support C&K metrics and accumulated defects relationship identified following important observations:

- Presence of outlier values had effect on the relationship. Once these values were eliminated the C&K metrics and accumulated defects relationship becomes positive.
- Not all defects may be identified. In such case there was no relationship between the C&K metrics and accumulated defects.
- Some times smaller classes could have most defects.

The OO system code structure decides the strength of the relationship between C&K measure and defect count at the class level.

5.2 Hypothesis testing: packages with accumulated defects

This section provides the results of hypothesis testing performed at the package level using accumulated defects. Package level testing is one of the major contributions of the thesis. Appendix D provides Pearson correlation coefficients between different package measures and accumulated defect count. The following summary table was created using data from Appendix D:

Table 22: Correlation strength - Accumulated defects at package level

	Very strong positive	Strong positive	Moderate positive	Weak positive	Negligible	None	Total
WMC	48	2	0	0	0	5	55
Cyclomatic complexity	45	5	0	0	0	5	55
RFC	45	4	0	0	0	6	55
CBO	49	1	0	0	0	5	55
NCSS	44	6	0	0	0	5	55

It is important to note that all correlations between C&K metrics and defect count at the package level were on the positive side.

Table 23: Correlation summary - Accumulated defects at package level

	Significant correlation	%	No significant correlation	%	Total releases
WMC	50	91	5	9	55
Cyclomatic complexity	50	91	5	9	55
RFC	49	89	6	11	55
CBO	50	91	5	9	55
NCSS	50	91	5	9	55

Note: For DrJava project there were 5 releases without any correlation with any of measures. Omitting DrJava project, there was correlation almost (except RFC) every time at the package level.

The following were the package based hypotheses for accumulated defects.

- WMC for a package is positively related to the accumulated defects in the package
- WMCC for a package is positively related to the accumulated defects in the package

- RFC for a package is positively related to the accumulated defects in the package
- CBO for a package is positively related to the accumulated defects in the package
- Size for a package is positively related to the accumulated defects in the package

Table 22 provides strong support for all of the hypotheses for C&K metrics and size.

The following table provides comparison for different measures at class and package level.

Table 24: Correlation comparison - Class and package, accumulated defects

	Very strong positive	Strong positive	Moderate positive	Weak positive	Negligible	None	Total
WMC – Class	0	27	9	12	3	4	55
Package	48	2	0	0	0	5	55
Cyclo. – Class	0	20	9	12	10	4	55
Package	45	5	0	0	0	5	55
RFC – Class	5	26	17	3	0	4	55
Package	45	4	0	0	0	6	55
CBO - Class	3	25	8	15	0	4	55
Package	49	1	0	0	0	5	55
NCSS - Class	1	26	8	10	7	3	55
Package	44	6	0	0	0	5	55

Weak and moderate positive relationships at the class level become strong or very strong at the package level. This is due to an aggregation effect. Due to aggregation all C&K and package size (NCSS) metrics have very strong positive relationship with accumulated defect count at the package level. For the purpose of illustration, consider some typical cases (one measure for each type) identified in Table 24 from class and package correlations. The Table 24 shows that for the same data the class level correlations are weak or moderate but package level correlations are very strong.

Figures 11 to 15 are the scatter plots for the cases identified in Table 24. The aggregation effect can be seen clearly in each of scatter plots (Figure 11 to 15).

Table 25: Aggregation effect - accumulated defects

	Project	Release	Class Coefficient / p-value	Package Coefficient / p-value
WMC	JasperReport	7	.455	.930
			.000	.000
Cyclomatic complexity	Findbugs	20	.229	.914
			.000	.000
RFC	GFD	16	.766	.910
			.000	.000
CBO	Itext	10	.204	.922
			.000	.000
NCSS	Azureus	5	.645	.788
			.000	.000

Figure 11: Scatter plots - Aggregation effect, accumulated defects (WMC)

Figure 12: Scatter plots - Aggregation effect, accumulated defects (Cycomatic Complexity)

Figure 13: Scatter plots - Aggregation effect, accumulated defects (RFC)

Figure 14: Scatter plots - Aggregation effect, accumulated defects (CBO)

Figure 15: Scatter plots - Aggregation effect, accumulated defects (NCSS)

5.3 Hypothesis testing: classes with release defects

This section provides the results of hypothesis testing performed at the class level using release defects. Many past researchers were restricted by a limited availability of data. Gyimothy, Ferenc and Siket (2005) has analyzed multiple releases of a single product. Class level testing using release defects is one of the major contributions of the thesis. Appendix F (all classes) and H (only classes with release defects) provides Pearson correlation coefficients between different class measures and individual release defect count. The following two summary tables were based on the information from appendix F. All the classes were considered for correlation analysis.

Table 26: Correlation strength - Release defects at class level (all classes)

	Very strong positive	Strong positive	Moderate positive	Weak positive	Negligible	None	Total
WMC	0	11	9	7	8	20	55
Cyclomatic complexity	0	11	8	8	5	23	55
RFC	0	18	9	10	6	12	55
CBO	0	14	11	10	2	18	55
NCSS	1	13	8	6	10	17	55

It is important to note that all correlations between C&K metrics and defect count at the class level were on the positive side.

Table 27: Correlation summary - Release defects at class level (all classes)

	Significant correlation	%	No significant correlation	%	Total releases
WMC	27	49	28	51	55
Cyclomatic complexity	27	49	28	51	55
RFC	37	67	18	33	55
CBO	35	64	20	36	55
NCSS	28	51	27	49	55

Following two summary tables were based on the information from appendix H. Only classes with release defects were considered for correlation analysis.

Table 28: Correlation strength - Only classes with release defects at class level

	Very strong positive	Strong positive	Moderate positive	Weak positive	Negligible	None	Total
WMC	0	10	7	4	0	34	55
Cyclomatic complexity	2	8	9	1	1	34	55
RFC	3	13	5	3	0	31	55
CBO	0	13	7	3	1	31	55
NCSS	2	12	7	3	3	28	55

It is important to note that all correlations between C&K metrics and defect count at the class level were on the positive side.

Table 29: Correlation summary - Only classes with release defects at class level

	Significant correlation	%	No significant correlation	%	Total releases
WMC	21	38	34	62	55
Cyclomatic complexity	20	36	35	64	55
RFC	24	44	31	56	55
CBO	23	42	32	58	55
NCSS	24	44	31	56	55

Classes without any release defects were outliers. Once they were removed, the chance of finding correlation reduced considerably. For example, for RFC the chance reduced from 67% to 44%. Hence in the further analysis, only classes with defects were considered.

Following were the class based hypotheses for release defects.

- WMCF for a class is positively related to the release defects in the class
- WMCC for a class is positively related to the release defects in the class
- RFC for the a is positively related to the release defects in the class
- CBO for the a is positively related to the release defects in the class
- Size for the a is positively related to the release defects in the class

From the above summary tables it could be seen that the support for all hypotheses was moderate. RFC provides best correlation. For only classes with defects there was about 44% chance of finding significant correlation for RFC metrics. To obtain further

insights, it was necessary to analyze the effect of number of defects on the correlation. In the following table, releases were divided into two categories, few defects and reasonable number of defects. The releases with few defects had less than 10% of highest release defects for that project. Projects with single release were included as is.

Table 30: Correlation analysis, few and many defects

Measure	Few defects			Many defects		
	Significant correlation	No significant correlation	% of finding correlation	Significant correlation	No significant correlation	% of finding correlation
WMC	0	19	0	21	15	58
Cyclomatic complexity	2	17	11	18	18	50
RFC	1	18	6	23	13	64
CBO	2	17	11	21	15	58
NCSS	2	17	11	22	14	61

When very few defects were found in the class, the chances of finding correlation was very low. But for releases with high defects, chances of finding correlation was reasonable. The RFC provided best correlation with 64% times correlation being present.

5.4 Hypothesis testing: packages with release defects

This section provides the results of hypothesis testing performed at package level using release defects. Package level testing using release defects is one of the major contributions of the thesis. Appendix G(all packages) and I(only packages with release defects) provides Pearson correlation coefficients between different package measures and individual release defect count. Following two summary tables were based on the

information from appendix G. All the packages were considered for correlation analysis.

Table 31: Correlation strength - Release defects at package level

	Very strong positive	Strong positive	Moderate positive	Weak positive	Negligible	None	Total
WMC	22	15	0	0	0	18	55
Cyclomatic complexity	26	18	1	0	0	10	55
RFC	28	13	0	0	0	14	55
CBO	27	13	0	0	0	15	55
NCSS	29	14	0	0	0	12	55

It is important to note that all correlations between C&K metrics and defect count at package level were on positive side.

Table 32: Correlation summary - Release defects at package level

	Significant correlation	%	No significant correlation	%	Total releases
WMC	37	67	18	33	55
Cyclomatic complexity	45	82	10	18	55
RFC	41	75	14	25	55
CBO	40	73	15	27	55
NCSS	43	78	12	22	55

Following two summary tables were based on the information from appendix I. Only packages with release defects were considered for correlation analysis.

Table 33: Correlation strength - Only classes with release defects at package level

	Very strong positive	Strong positive	Moderate positive	Weak positive	Negligible	None	Total
WMC	19	7	1	0	0	28	55
Cyclomatic complexity	23	3	2	0	0	27	55
RFC	21	5	1	0	0	28	55
CBO	24	5	0	0	0	26	55
NCSS	18	8	1	1	0	27	55

It is important to note that all correlations between C&K metrics and defect count at package level were on positive side.

Table 34: Correlation summary - Only classes with release defects at package level

	Release with correlation	%	Release without correlation	%	Total releases
WMC	27	49	28	51	55
Cyclomatic complexity	28	51	27	49	55
RFC	27	49	28	51	55
CBO	29	53	26	47	55
NCSS	28	51	27	49	55

Packages without any release defects were outliers. Once they were removed, the chance of finding correlation reduced considerably. For example, for RFC the chance reduce from 75% to 49%. Hence in the further analysis, only classes with defects were considered.

Following were the package based hypotheses for release defects.

- WMCF for a package is positively related to the release defects in the package
- WMCC for a package is positively related to the release defects in the package
- RFC for a package is positively related to the release defects in the package

- CBO for a package is positively related to the release defects in the package
- Size for a package is positively related to the release defects in the package

For all only packages with defect, the correlation between metrics and release defect was about 50%. This provided only moderate support for the above hypotheses. For further analysis it was necessary to analyze effect of package release defects on the correlation..

From earlier class based results, it was clear that it was hard to find correlation when very few defects were detected in the release. Also, for package-based correlations if system has very few packages then very few data points were available for statistical analysis. For such cases correlation could not be found.

For further analysis, the packages were divided into two groups as follows.

- Packages with few defects (<10% of maximum defects for release of the same project) or small sample size (not many packages in the release) < 10
- Packages with reasonable defects and not small sample size ($N \geq 10$)

Table 35: Detailed analysis - Release defects at package level

Measure	Few defects or small sample size	Many defects and not small sample		
		Significant correlation	No significant correlation	% of finding correlation
WMC	29	20	6	77
Cyclomatic complexity	25	23	7	77
RFC	29	20	6	77
CBO	29	18	8	69
NCSS	25	23	7	77

From above table it could be seen that for releases with many defects and not small sample size correlation was present about 77% time. WMC, Cyclomatic complexity, RFC and NCSS provided best measures. This provided strong support for above package based hypotheses for release defects.

5.5 Hypothesis testing: Martin's metrics

These are three hypotheses derived from Martin's design principles.

H21: The number of package dependency cycles is positively related to number of defects in the package

H22: The number of times the SDP is broken for a package is positively related to number of defects in the package

H23: The D metrics for a package is positively related to number of defects in the package

Pearson's correlation tests at the package level provided no support for any of the these hypotheses. For further analysis, weaker versions of the hypotheses were tested.

5.5.1 Dependency cycles

Following weaker hypothesis was constructed for dependency cycles:

H0: Packages with cycles have the same or lower defect rate than packages without cycles.

Ha: Packages with cycles have a higher defect rate than packages without cycles.

To test above hypotheses, the packages in each release were divided into two groups, one with cycles and another without. Defect density (number of defects per 1000 lines

of code) was calculated for both groups using release defects. Releases without any cycles were not considered. The detailed data is available in Appendix J.

The hypothesis was tested using regular t test (one tailed distribution, unequal variance). The test resulted in p-value of 0.17. As the p-value was greater than significance level value (0.05), the null hypothesis could not be rejected.

5.5.2 SDP principle

Following weaker hypothesis was constructed for SDP principle:

H0: Packages with SDP principle broken at least once have the same or lower defect rate than packages where SDP principle is not broken.

Ha: Packages with SDP principle broken at least once have a higher defect rate than packages where SDP principle is not broken.

To test above hypotheses, the packages in each release were divided into two groups, one where the SDP principle was not broken and other where it was broken one or more times. Defect density (number of defects per 1000 lines of code) was calculated for both groups using release defects. The detailed data is available in Appendix J.

The hypothesis was tested using regular t test (one tailed distribution, unequal variance). The test resulted in p-value of 0.25. As the p-value was greater than significance level value (0.05), the null hypothesis could not be rejected.

5.5.3 D Metrics

Following weaker hypothesis was constructed for D metrics:

H0: Packages that are away from main sequence line have the same or lower defect rate than packages that are close to main sequence line.

Ha: Packages that are away from main sequence line have a higher defect rate than packages that are close to main sequence line.

To test the above hypotheses, the packages in each release were divided into two groups, the first group had D metrics value less than 0.5 (closer to main sequence) while the second group had D metrics value greater than or equal to 0.5 (away from main sequence).. Defect density (number of defects per 1000 lines of code) was calculated for both groups using release defects. The detailed data is available in Appendix J.

The hypothesis was tested using regular t test (one tailed distribution, unequal variance). The test resulted in p-value of 0.45. As the p-value was greater than significance level value (0.05), the null hypothesis could not be rejected.

5.6 Summary of results

5.6.1 Accumulated defects and class metrics

The hypothesis testing has provided strong support for the positive relationship between C&K metrics, NCSS and number of accumulated defects in the class. The RFC and CBO C&K metrics provided best measures. For both of them the relationship was found 93% time (51 releases out of 55).

In addition following four measure findings were identified:

- OO system code structure decides the strength of the relationship between C&K metrics, NCSS and defect count. For each individual project, the best C&K measure could be of different strength such as very strong, strong, moderate etc.
- It is possible to classify any project into one of the following categories:
 - A relationship exists between C&K metrics and accumulated defects
 - A relationship exists between C&K metrics and accumulated defects, after removing outlier classes
 - A relationship does not exist between C&K metrics and accumulated defects
- Although C&K metrics are universally accepted, project managers could make better use of these metrics after analyzing their projects for correlation.
- To measure C&K measures, special tools were required, but no special tool was required to measure NCSS.

There are situations where the relationship between class measure and defect count is not likely to be supported. Two such examples are:

- For a class with a large number of variables, a developer may write get and set functions for each individual variable (OO recommended approach). In such a situation the WMC for the class would be quite large, but all these functions are quite small and simple, and unlikely to have many defects. This creates a situation where classes with large WMC has very few defects.
- When code from another application is reused, the system is likely to have fewer defects in the reused code, since the reused code should be adequately tested

during earlier development. If reused code has larger classes than newly developed classes then a situation is created where more defects are found in classes with lower C&K metrics value.

5.6.2 Accumulated defects and package metrics

The hypothesis testing has provided very strong support for the positive relationship between C&K, NCSS and number of accumulated defects in a package. For all measures the relationship existed in about 90% of the cases. The package based hypothesis testing for accumulated defects had identified following measure findings:

- Due to an aggregation effect, all C&K and package size (NCSS) metrics at the package level have a very strong positive relationship with accumulated defect count. Even weak or moderate relationships at the class level convert to very strong relationships at the package level.

These results are not very useful for iterative software development processes. The relationship between release defects and different measures is more useful for iterative software development process, however.

5.6.3 Release defects and class metrics

The hypothesis testing provides moderate support for the positive relationship between C&K, NCSS and number of release defects in a class. The hypothesis testing for release defects had identified following measure findings:

- For a release with a reasonable number of defects, the chance of correlation between C&K measures, NCSS and defect count is moderate (about 60%).

The sources of release defects are defect fix in earlier release, new functionality added and defect not founded in earlier release.

As more functionality is added to a release, more classes are likely to be modified. The larger the release, more classes are likely to be modified. Additionally the new functionality to be added determines the classes that are going to be updated. In every release, it is highly unlikely that large classes are always updated. To add new functionality only small classes are sometimes updated. In such cases it is highly unlikely to find correlation between class measures and defect count. The hypothesis testing results provide evidence for this. Only 60% of the cases in my data had positive correlations between metrics and release defects at the class level.

5.6.4 Release defects and package metrics

The hypothesis testing provides strong support for the positive relationship between C&K measures, NCSS and number of accumulated defects at the package level. The hypothesis testing for release defects had identified following measure findings:

- For a release with reasonable number of defects and reasonable sample size the chances of finding correlation between C&K measure, NCSS and defect count was quite high (about 80% cases). Additionally the strength of relationship was likely to be strong or very strong.

6 Relationship between C&K and Martin's metrics

6.1 About C&K and Martin's metrics

The hypothesis testing has shown that WMC, RFC and CBO C&K metrics were positively related to defect count at the class level. The C&K metrics measures were based on methods within a class. The original measurements were defined at the class level. These metrics were also extended to the package level

Table 36: C&K metrics and description

Metrics	Measurement based on	Description
WMC	Method	Size related measure
RFC	Method	Size and coupling related measure
CBO	Method	Coupling related measure

Martin defined two levels of metrics, basic and derived. Design principle metrics were based on basic metrics. Martin's basic metrics are:

- Number of concrete classes (CC)
- Number of abstract classes (CA)
- Afferent Coupling (Ca)
 - The number of classes outside this package that depend upon classes within the package (incoming)
- Efferent Coupling (Ce)
 - The number of classes inside package that depends upon classes outside this package (outgoing)

Based on these basic metrics Martin derived the following metrics:

- Abstractness (A) = $CA / (CC + CA)$
- Instability (I) = $Ce / (Ce + Ca)$
- Distance from the main sequence (D)

$D = \text{Mod}(A + I - 1) / \text{Sqrt}(2)$, The D has range 0 to 0.707

Martin also defined one more measure not dependent on any of above measures:

- Package Dependency Cycles (CYL)

Martin used CYL, D and I to define three measurable design principles.

6.2 Relationship between C&K and Martin's metrics

Each class in a package is either concrete or abstract. Adding CC and CA metrics together provide total number of classes in the package. CC and CA added together provide size related measures at package level, calculated using individual classes in the package. Hence fourth this measure is referred as M-Size. M-Size measure was similar to the C&K measure, WMC. The only difference being that WMC is calculated using individual methods in a class. Both Ce and Ca provided coupling related measurements calculated at the class level. Ce is similar to the C&K measure, CBO. The only difference is that CBO is measured using methods in a class. Martin's CYLS metrics have no equivalent C&K measure.

WMC metrics defined by C&K is equivalent to Martin's M-Size metrics. RFC metrics defined by C&K is equivalent to Martin's Ce metrics.

6.3 Verification of relationship between M-Size and WMC

To verify the relationship between M-Size and WMC, Pearson correlations were used. In Table 39 only releases with reasonable number of defects and not small sample size were considered. Release with reasonable defects have number of defects more than 10% of highest defect release from same project. Release with fewer than 10 packages were considered as small sample size.

Table 37: Relationship between M-Size and WMC

Project	Few defects or small sample	Many defects and not small sample						Total
		Very strong positive	Strong positive	Moderate positive	Weak positive	Negligible	None	
JasperReports	2	3						5
FindBugs	14	2						16
DrJava	4	1	1					6
GFD	1	2						3
Jguard	3	2						5
JavaGroups	2	5						7
Itext	1	1						2
HtmlParser	1	2						3
Azureus	0	1						1
Jung	1							1
HsqlDB	0	2						2
Spring	0	4	1					4
Total	29	25	1					55

Out of 55 releases, 25 releases had more than 10 packages and reasonable defects. For each of these release with reasonable defects and not small sample size, a very strong positive correlation existed in almost every case. There was very strong correlation between M-Size and WMC.

6.4 Verification of relationship between Ce and CBO

To verify the relationship between Ce and CBO, Pearson correlations were used. In Table 40 only releases with reasonable number of defects and not small sample size were considered. Release with reasonable defects have number of defects more than 10% of highest defect release from same project. Release with fewer than 10 packages were considered as small sample size.

Table 37: Relationship between Ce and CBO

Project	Few defects or small sample	Many defects and not small sample						Total
		Very strong positive	Strong positive	Moderate positive	Weak positive	Negligible	None	
JasperReports	2	3						5
FindBugs	14		1				1	16
DrJava	4						2	6
GFD	1	2						3
Jguard	3	2						5
JavaGroups	2	5						7
Itext	1						1	2
HtmlParser	1	2						3
Azureus	0	1						1
Jung	1	2						1
HsqlDB	0	2	2					2
Spring	0							4
Total	29	19	3				4	55

Out of 55 releases, 25 releases had more than 10 packages and reasonable defects. For each release with reasonable defects and sample size more than 10, strong positive correlation exists in 85% cases. There was very strong positive correlation between Ce and CBO.

6.5 Identification of better indicator

Given that Martin's metrics and the C&K metrics are very similar it seems useful to find out which set provides better correlations with release defect counts. Table 41 aggregates the results of Pearson correlation tests between these measures and release defect counts.

Table 38: Comparison summary: Martin and C&K

Measure	Few defects or small sample size	Many defects and not small sample		
		Correlation	No Correlation	% Of finding correlation
WMC	29	20	6	77
M0-Size	29	16	10	62
CBO	29	18	8	69
Ce	29	16	10	62

From above table it can be seen that correlation was found in 77% cases for WMC and 62% for M-Size. The correlation was found in 69% cases for CBO and 62% for Ce. WMC and CBO seems to be better indicators than M-Size and Ce.

7 Conclusions and summary

7.1 Thesis research findings

The thesis research has identified useful finding at both the class and package levels for OO systems.

Two class level findings were identified. First, code structure determines the strength of relationship between C&K metrics and defect counts. Here are the two examples:

- For class with large number of variables, the developer may write get and set function for each individual variable (OO recommended approach). In such situations the WMC for classes is quite large. But all these functions are quite small and simple. Hence they are unlikely to have many defects. This creates a situation where classes with large WMC have very few defects.
- When code from another application is reused, the system is likely to have fewer defects in the reused code because the reused code should well tested. If reused code has larger classes than the newly developed classes then a situation is created where more defects are likely to be found in classes with smaller C&K metrics.

Second, if a relationship between C&K metrics and defect count exists for a release then it is preserved in most subsequent releases when sufficient numbers of defects are identified during release testing. That is, the relationship seldom disappears in subsequent releases.

The package level findings are as follows:

- An aggregation effect converts weak to moderate relationships at the class level between C&K metrics and defect count into strong or very strong relationships at the package level.
- For projects with a relationship between C&K metrics and defect count at the class level, the chances of finding correlation at package level are very good (about 90%).
- At the package level, NCSS (Non Commented Source Statements) metrics provide equivalent results to the C&K metrics WMC, RFC and CBO.

The following sections discuss managerially relevant consequences of these findings.

7.2 C&K measures at the class level

Empirical testing (Briand and Wust, 2002) has shown that the three C&K metrics, WMC, RFC and CBO, have a positive relationship with the number of defects in a class. The higher the metrics value, the more defects the class is likely to have. Aivosto (2008) and SATC (2002) have provided guidelines for interpreting and using these metrics. The steps recommend by them are as follows:

- For an OO system, measure the C&K metrics at the class level.
- Based on the measurements obtained, predict trouble spots using threshold levels.
- Take one or both of the following corrective action for trouble spots:
 - Code refactoring
 - Allocating extra resources

The thesis research has identified that OO system code structure determines the strength of the relationship between C&K metrics and defect count. For each individual project release, the relationship between the C&K measures and defects can have different strengths from none to very strong. Typically whenever a relationship exists, it is exhibited in most of the releases of the project. OO systems with weak to no relationship between C&K metrics and defect count are likely to identify incorrect trouble spots. Hence before using C&K metrics to predict trouble spots, it is necessary to know the relationship strength between C&K metrics and defect.

The steps recommended by Aivosto (2008) and SATC (2002) are not particularly useful for an iterative software development methodology due to the following:

- In iterative development, large classes may not always get modified in every release.
- Not all classes are modified in every release. Only those classes in which new functionality is added or defects fixed get modified in a specific release.
- The number of classes that get modified depends upon the size of the release. For small release only few classes may get modified.

Taking corrective action based on C&K metrics for a release in which mostly smaller classes are modified or no relationship exists between C&K metrics and defect count is likely to produce counterproductive result. Based on this thesis research, the relationship strength between C&K metrics and defect count should be measured before using C&K metrics for predicting trouble spots. The C&K metrics should be used for

prediction of trouble spots only if the relationship strength between C&K metrics and defect count is at least moderate.

To measure relationship strength, it is necessary to find all classes that are fixed for each defect. For projects based on a test driven development methodology, no code is written without first writing a test. For such projects, the information about which classes are being fixed is available for each defect. For most software development projects that do not follow a test driven methodology, however it is not easy to measure relationship strength between metrics and defect count at the class level because defects are maintained only at the release level and any association between defect fix and corresponding class fix is not available.

For projects that maintain defect information at the release level, it is necessary to use proxy measures for defect count. The thesis research has shown that it is possible to use file update count as a proxy for defect count. It is usually possible to obtain the file update count information from the source code configuration management system.

7.3 C&K measures at the package level

Any reasonable sized software release usually takes a few weeks of testing during which the test team tests multiple versions of the release. Usually, a new release contains new features and some defect fixes from previous releases. At the end of the release testing, the test manager has to decide if the software is good enough to be released for customer testing. Some of the techniques used in making this decision

include: gut instinct, defect arrival rate and test coverage and comparing defect count with defect counts from similar systems

The decision is mostly based on qualitative information. The thesis results have shown that an aggregation effect converts weak or moderate relationship between C&K metrics and defect count at class level into strong or very strong relationship at package level. Also when reasonable amount of testing is done the chances of finding correlation are very good (about 90%). At the end of the testing phase the relationship could be tested at the package level. The relationship is expected to be strongly positive. If the relationship is weak or absent then it would be necessary to find out the reason.

Consider a possible example use of C&K measures in software testing. A software system in being enhanced with new features and some previously reported defects are also being fixed. For the software code it was established that the moderate relationship exists at class level between C&K metrics and defect count. The release description is as follows:

- OO system has 20 packages
- New release content
 - 10 new change requests
 - 20 previously reported defects fixed
- Test development
 - 150 tests for 10 change requests

- Test execution cycle duration - four weeks

During the testing cycle four versions are released to the test team. At the end of the testing cycle the test lead has to decide if the release is good enough for user acceptance testing. At the end of the testing cycle the relationship strength between defects count (reported during four weeks of testing period) and C&K metrics at the package level were measured. The strength measures were moderate. Since a moderate relationship exists at class level, a strong relationship is expected at the package level due to aggregation. This result leads to further analysis of defects. The analysis identifies that three large packages that were modified for the new release had very few defects identified. To find the reason for fewer defects, the tests associated with the functionality implemented by those packages were analyzed. Review of the tests identifies that, due to lack of clarity of two change requests, the tester missed some functionality during test development. This resulted in fewer tests being written for some functionality in those three packages. Corrective action is taken to develop missing tests. The difference between expected and actual relationship strength at package level enabled the test lead to identify the problem. Ideally this issue should have been identified at the test case review time but in many instances, the review is not properly done due to a lack of time or resources. Additionally on many projects there is very little interaction between development and test teams.

Note that this suggestion for using C&K metrics at the package level for evaluating testing effectiveness is not yet field-tested. The ideas still have merit because they are based on sound research and should allow manager to make more educated decisions.

The thesis research has shown that at the package level NCSS metrics provide equivalent results to the C&K metrics WMC, RFC and CBO. This result has important practical implication. To measure C&K metrics a special tool is required but NCSS can be computed from the source code control system.

7.4 Further research

The following are possible directions for further research:

Focused data collection for better analysis: From a development manager's perspective, the OO metrics for release defects are more useful than those for accumulated defects. Hypothesis testing for release defects require projects with multiple releases. In the data used in this thesis, there were two projects with a single release. Better insights could be obtained using data based on many projects each having multiple releases.

Verification of package level relationship in actual project environment: Set up an experiment in a real project and verify that package level metrics can be used for assessing effectiveness of software testing in incremental software development.

Automated tool for relationship strength measurement: The setup for measuring the relationship strength between OO measures and defect count at the class level needs resources and time. Explore the possibility of developing software that would analyze multiple versions of an OO system and try to estimate relationship strength for different OO measures.

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Appendix A: Data gathered for analysis

This appendix provides information about data collected for statistical analysis.

1) Individual project release selection

A release from project was selected if it had at least one release defect. Fifty five releases of twelve projects were selected for data analysis. Following table provides the details for each selected release for further analysis.

Name	Project Id.	Release Id.	Release date	No of dev days	Release Defects	Acc. Defects
JasperReports	2	7	2005-10-11	9	51	6812
		8	2005-10-12	35	435	6497
		9	2005-09-07	12	704	6064
		10	2005-08-26	37	127	5376
		11	2005-07-20	--	336	5210
FindBugs	3	18	2005-09-04	2	2	1715
		19	2005-09-02	79	3	1714
		20	2005-06-15	4	302	1880
		21	2005-06-11	39	3	1626
		22	2005-05-03	18	154	1610
		23	2005-04-15	114	68	1515
		24	2004-12-22	75	129	1406
		25	2004-10-08	59	123	1320
		26	2004-04-10	4	187	1199
		27	2004-08-06	38	17	1018
		28	2004-06-29	5	61	941
		29	2004-06-24	1	9	884
		30	2004-06-23	28	18	876
		31	2004-05-26	13	34	853
		32	2004-05-13	53	20	826
		33	2004-03-21	--	25	766
DrJava	5	11	2005-08-13	944	19	3672
		34	2003-01-12	47	2325	3852
		35	2002-11-26	8	9	1526
		36	2002-11-18	107	6	1517
		38	2002-08-03	46.	156	1519
		40	2002-06-18	--	276	1608

GFD	6	16	2005-10-09	5	107	952
		17	2005-10-04	47	6	845
		19	2005-08-18	--	51	814
Jguard	7	6	2005-10-31	54	14	611
		7	2005-09-07	67	205	587
		8	2005-07-02	81	185	329
		9	2005-06-26	81	15	132
		10	2005-04-06	--	94	108
JavaGroups	8	14	2005-10-27	56	29	3411
		15	2005-09-01	128	99	3389
		17	2005-04-26	230	770	3184
		18	2004-09-08	35	703	2468
		19	2004-08-04	40	56	1762
		20	2004-06-25	116	478	1705
		21	2004-03-01	--	511	1239
Ittext	9	10	2005-10-20	28	87	9344
		11	2005-09-22	--	35	9246
HtmlParser	10	2	2005-06-14	323	13	5082
		3	2004-07-26	66	178	5246
		4	2004-05-21	--	177	5068
Azureus	11	5	2005-06-27	--	604	11455
Jung	21	5	2005-10-19	--	17	3274
HsqlDB	22	2	2005-02-07	46	296	680
		3	2004-12-23	--	263	642
Spring	23	4	2005-11-14	53	703	11353
		5	2005-09-22	27	308	10631
		6	2005-08-26	31	502	10307
		7	2005-07-26	--	147	9792

Note:

1) Number of development days was not available for the first release. There was no earlier release than first release hence it was not possible to calculate number of days for the first release.

2) Highest release number is the earliest release.

3) For each release N following relationship does not hold true.

Accumulated defects = Release(N-1) accumulated defects + Release(N) release defects

Because there could be different classes in the different releases of the same project.

New classes may get added and some old classes may get dropped.

2) Size of the sample used for data testing

Following table provides details about average number of classes for each project.

No	Project	No of release	Average classes per release
1	JasperReports	5	601
2	FindBugs	16	360
3	DrJava	6	221
4	GFD	3	276
5	Jguard	5	54
6	JavaGroups	7	312
7	Itext	2	434
8	HtmlParser	3	213
9	Azureus	1	1959
10	Jung	1	534
11	HsqlDB	2	272
12	Spring	4	1703

The data was collected for 55 different releases from 12 different projects. This sample size is many times larger than most empirical studies (Briand and Wust 2000).

Following table provides details about defects associated with each individual release.

Name	Proj. Id	Rel. Id	Compiled classes	Source classes	Release Defects	Acc. Defects
JasperReports	2	7	636	707	51	6812
		8	518	583	435	6497
		9	510	576	704	6064
		10	510	576	127	5376
		11	566	566	336	5210
FindBugs	3	18	241	485	2	1715
		19	241	485	3	1714
		20	249	486	302	1880
		21	248	485	3	1626
		22	226	435	154	1610
		23	227	428	68	1515

		24	196	366	129	1406
		25	182	353	123	1320
		26	176	336	187	1199
		27	176	335	17	1018
		28	150	278	61	941
		29	150	277	9	884
		30	150	277	18	876
		31	149	260	34	853
		32	144	254	20	826
		33	133	220	25	766
DrJava	5	11	211	304	19	3672
		34	152	214	2325	3852
		35	151	213	9	1526
		36	151	213	6	1517
		38	140	201	156	1519
		40	130	183	276	1608
GFD	6	16	258	280	107	952
		17	258	280	6	845
		19	250	270	51	814
Jguard	7	6	76	76	14	611
		7	63	67	205	587
		8	47	47	185	329
		9	43	46	15	132
		10	35	38	94	108
JavaGroups	8	14	519	519	29	3411
		15	525	525	99	3389
		17	461	461	770	3184
		18	484	484	703	2468
		19	472	472	56	1762
		20	469	469	478	1705
		21	484	484	511	1239
Itext	9	10	439	439	87	9344
		11	430	430	35	9246
HtmlParser	10	2	148	234	13	5082
		3	117	203	178	5246
		4	117	203	177	5068
Azureus	11	5	1159	1159	604	11455
Jung	21	5	454	534	17	3274
HsqlDB	22	2	214	272	296	680
		3	214	272	263	642
Spring	23	4	1137	1729	703	11353
		5	1124	1710	308	10631
		6	1114	1694	502	10307

		7	1106	1682	147	9792
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Note:

For many projects there were more source classes than compiled classes. The additional source classes were potentially due to following:

- Classes that were not required in the current release were not available in compiled form
- Classes were required in the release but complied code not supplied. These classes were available in source format.

Missing compiled classes were not further analyzed.

Appendix B: Class correlation (all classes, accumulated defects)

Class based hypothesis testing for accumulated defects (All classes)

Following tables summarizes Pearson Correlation for different class based measurements.

JasperReports (2)

Rel	N	WMC	N	Cyclo.	N	RFC	N	CBO	N	NCSS
		p-value		p-value		p-value		p-value		p-value
7	636	.455(**)	707	.397(**)	636	.579(**)	636	.436(**)	707	.504(**)
		.000		.000		.000		.000		.000
8	518	.568(**)	583	.479(**)	518	.595(**)	518	.458(**)	583	.523(**)
		.000		.000		.000		.000		.000
9	510	.559(**)	576	.463(**)	510	.577(**)	510	.440(**)	576	.505(**)
		.000		.000		.000		.000		.000
10	510	.540(**)	576	.480(**)	510	.577(**)	510	.437(**)	576	.509(**)
		.000		.000		.000		.000		.000
11	566	.542(**)	566	.499(**)	566	.508(**)	566	.355(**)	566	.499(**)
		.000		.000		.000		.000		.000

FindBugs (3)

Rel	N	WMC	N	Cyclo.	N	RFC	N	CBO	N	NCSS
		p-value		p-value		p-value		p-value		p-value
18	241	.193(**)	485	.150(**)	241	.351(**)	241	.319(**)	485	.145(**)
		.003		.001		.000		.000		.001
19	241	.194(**)	485	.151(**)	241	.353(**)	241	.322(**)	485	.146(**)
		.002		.001		.000		.000		.001
20	249	.251(**)	486	.229(**)	249	.427(**)	249	.369(**)	486	.208(**)
		.000		.000		.000		.000		.000
21	248	.241(**)	485	.195(**)	248	.374(**)	248	.288(**)	485	.188(**)
		.000		.000		.000		.000		.000
22	226	.254(**)	435	.226(**)	226	.395(**)	226	.296(**)	435	.199(**)
		.000		.000		.000		.000		.000
23	227	.218(**)	428	.202(**)	227	.361(**)	227	.277(**)	428	.187(**)
		.001		.000		.000		.000		.000
24	196	.169(*)	366	.223(**)	196	.315(**)	196	.277(**)	366	.153(**)
		.018		.000		.000		.000		.003
25	182	.203(**)	353	.258(**)	182	.326(**)	182	.239(**)	353	.169(**)
		.006		.000		.000		.001		.001
26	176	.231(**)	336	.183(**)	176	.339(**)	176	.237(**)	336	.281(**)
		.002		.001		.000		.002		.000
27	176	.241(**)	335	.199(**)	176	.306(**)	176	.223(**)	335	.270(**)
		.001		.000		.000		.003		.000
28	150	.247(**)	278	.190(**)	150	.299(**)	150	.224(**)	278	.264(**)

		.002		.001		.000		.006		.000
29	150	.253(**)	277	.183(**)	150	.271(**)	150	.271(**)	277	.249(**)
		.002		.002		.001		.001		.000
30	150	.265(**)	277	.184(**)	150	.279(**)	150	.205(*)	277	.251(**)
		.001		.002		.001		.012		.000
31	149	.271(**)	260	.191(**)	149	.304(**)	149	.209(*)	260	.328(**)
		.001		.002		.000		.010		.000
32	144	.262(**)	254	.202(**)	144	.307(**)	144	.209(*)	254	.315(**)
		.002		.001		.000		.012		.000
33	133	.313(**)	220	.167(*)	133	.348(**)	133	.238(**)	220	.329(**)
		.000		.013		.000		.006		.000

DrJava (5)

Rel	N	WMC	N	Cyclo.	N	RFC	N	CBO	N	NCSS
		p-value		p-value		p-value		p-value		p-value
11	211	.079	304	.030	211	.070	211	.041	304	.056
		.255		.603		.310		.555		.327
34	152	.068	214	.030	152	.058	152	.020	214	.046
		.405		.659		.475		.805		.502
35	151	.062	213	.051	151	.041	151	.015	213	.046
		.452		.459		.619		.856		.504
36	151	.062	213	.053	151	.040	151	.015	213	.046
		.448		.445		.624		.015		.501
38	140	.057	201	.052	140	.032	140	.014	201	.038
		.503		.465		.705		.869		.592
40	130	.278(**)	183	.066	130	.296(**)	130	.220(*)	183	.230(**)
		.001		.372		.001		.012		.002

GFD(6)

Rel	N	WMC	N	Cyclo.	N	RFC	N	CBO	N	NCSS
		p-value		p-value		p-value		p-value		p-value
16	258	.398(**)	280	.450(**)	258	.766(**)	258	.760(**)	280	.702(**)
		.000		.000		.000		.000		.000
17	258	.418(**)	280	.473(**)	258	.753(**)	258	.735(**)	280	.697(**)
		.000		.000		.000		.000		.000
19	250	.400(**)	270	.473(**)	250	.745(**)	250	.729(**)	270	.692(**)
		.000		.000		.000		.000		.000

Jguard (7)

Rel	N	WMC	N	Cyclo.	N	RFC	N	CBO	N	NCSS
		p-value		p-value		p-value		p-value		p-value
6	76	.471(**)	76	.290(*)	76	.570(**)	76	.679(**)	76	.522(**)
		.000		.011		.000		.000		.000
7	63	.467(**)	67	.281(*)	63	.535(**)	63	.693(**)	67	.466(**)
		.000		.021		.000		.000		.000

8	47	.385(**)	47	.552(**)	47	.651(**)	47	.657(**)	47	.530(**)
		.008		.000		.000		.000		.000
9	43	.279	46	.282	43	.369(*)	43	.254	46	.435(**)
		.070		.057		.015		.100		.003
10	35	.116	38	-.214	35	-.037	35	-.048	38	-.154
		.508		.198		.831		.783		.357

JavaGroups (8)

Rel	N	WMC	N	Cyclo.	N	RFC	N	CBO	N	NCSS
		p-value		p-value		p-value		p-value		p-value
14	519	.584(**)	519	.648(**)	519	0.654	519	.490(**)	519	.643(**)
		.000		.000		.000		.000		.000
15	525	.586(**)	525	.627(**)	525	.658(**)	525	.476(**)	525	.646(**)
		.000		.000		.000		.000		.000
17	461	.616(**)	461	.557(**)	461	.700(**)	461	.545(**)	461	.699(**)
		.000		.000		.000		.000		.000
18	484	.583(**)	484	.544(**)	484	.670(**)	484	.561(**)	484	.646(**)
		.000		.000		.000		.000		.000
19	472	.559(**)	472	.546(**)	472	.663(**)	472	.596(**)	472	.633(**)
		.000		.000		.000		.000		.000
20	469	.545(**)	469	.365(**)	469	.494(**)	469	.595(**)	469	.626(**)
		.000		.000		.000		.000		.000
21	484	.466(**)	484	.522(**)	484	.594(**)	484	.578(**)	484	.582(**)
		.000		.000		.000		.000		.000

Itext (9)

Rel	N	WMC	N	Cyclo.	N	RFC	N	CBO	N	NCSS
		p-value		p-value		p-value		p-value		p-value
10	439	.386(**)	439	.287(**)	439	.351(**)	439	.204(**)	439	.256(**)
		.000		.000		.000		.000		.000
11	430	.374(**)	430	.264(**)	430	.340(**)	430	.200(**)	430	.241(**)
		.000		.000		.000		.000		.000

HtmlParser (10)

Rel	N	WMC	N	Cyclo.	N	RFC	N	CBO	N	NCSS
		p-value		p-value		p-value		p-value		p-value
2	148	-.018	234	.018	148	-.064	148	.186(*)	234	.029
		.825		.788		.438		.024		.656
3	117	.087	203	.128	117	.039	117	.245(**)	203	.083
		.351		.069		.675		.008		.237
4	117	.056	203	.098	117	.004	117	.226(*)	203	.055
		.547		.163		.968		.014		.434

Azureus (11)

Rel	N	WMC	N	Cyclo.	N	RFC	8.1.1	CBO	N	NCSS
		p-value		p-value		p-value		p-value		p-value
5	1959	.624(**)	1959	.215(**)	1959	.688(**)	1959	.598(**)	1959	.645(**)
		.000		.000		.000		.000		.000

Jung (21)

Rel	N	WMC	N	Cyclo.	N	RFC	N	CBO	N	NCSS
		p-value		p-value		p-value		p-value		p-value
5	454	.483(**)	534	.358(**)	454	.591(**)	454	.538(**)	534	.529(**)
		.000		.000		.000		.000		.000

HsqlDB (22)

Rel	N	WMC	N	Cyclo.	N	RFC	N	CBO	N	NCSS
		p-value		p-value		p-value		p-value		p-value
2	214	.016	272	.014	214	.086	214	.217(**)	272	.040
		.818		.824		.208		.001		.511
3	214	.004	272	-.004	214	.069	214	.199(**)	272	.017
		.948		.948		.314		.004		.777

Spring (23)

Rel	N	WMC	N	Cyclo.	N	RFC	N	CBO	N	NCSS
		p-value		p-value		p-value		p-value		p-value
4	1137	.541(**)	1729	.537(**)	1137	.669(**)	1137	.614(**)	1729	.306(**)
		.000		.000		.000		.000		.000
5	1124	.532(**)	1710	.521(**)	1124	.664(**)	1124	.622(**)	1124	.308(**)
		.000		.000		.000		.000		.000
6	1114	.517(**)	1694	.515(**)	1114	.649(**)	1114	.608(**)	1694	.301(**)
		.000		.000		.000		.000		.000
7	1106	.492(**)	1682	.491(**)	1106	.625(**)	1106	.594(**)	1682	.301(**)
		.000		.000		.000		.000		.000

In the following tables, the correlation significance was ignored. Only correlation value was considered. Considering both would have made different release comparison very complicated.

Following table summarizes strengths of different C&K metrics at class level.

WMCF (Release n)

Project	Very strong positive	Strong positive	Moderate positive	Weak positive	Negligible	None	Total
JasperReports		5					5
FindBugs			1	12	3		16
DrJava		3	3				6
GFD		2	1				3
Jguard		2	1			2	5
JavaGroups		7					7
Itext			2				2
HtmlParser		2	1				3
Azureus		1					1
Jung		1					1
HsqlDB						2	2
Spring		4					4
Total	0	27	9	12	3	4	55

WMCC (Release n)

Project	Very strong positive	Strong positive	Moderate positive	Weak positive	Negligible	None	Total
JasperReports		4	1				5
FindBugs				6	10		16
DrJava			4	2			6
GFD		3					3
Jguard		1		2		2	5
JavaGroups		6	1				7
Itext				2			2
HtmlParser		1	2				3
Azureus		1					1
Jung			1				1
HsqlDB						2	2
Spring		4					4
Total	0	20	9	12	10	4	55

RFC (Release n)

Project	Very strong positive	Strong positive	Moderate positive	Weak positive	Negligible	None	Total
JasperReports		5					5
FindBugs		1	12	3			16
DrJava		3	3				6
GFD	3						3
Jguard		3				2	5
JavaGroups	1	6					7
Itext			2				2
HtmlParser		3					3
Azureus	1						1
Jung		1					1
HsqlDB						2	2
Spring		4					4
Total	5	26	17	3	0	4	55

CBO (Release n)

Project	Very strong positive	Strong positive	Moderate positive	Weak positive	Negligible	None	Total
JasperReports		4	1				5
FindBugs			3	13			16
DrJava		2	4				6
GFD	3						3
Jguard		3				2	5
JavaGroups		7					7
Itext				2			2
HtmlParser		3					3
Azureus		1					1
Jung		1					1
HsqlDB						2	2
Spring		4					4
Total	3	25	8	15	0	4	55

Size (Release n)

Project	Very strong positive	Strong positive	Moderate positive	Weak positive	Negligible	None	Total
JasperReports		5					5
FindBugs			3	6	7		16
DrJava		6					6
GFD	1	2					3
Jguard		4				1	5
JavaGroups		7					7
Itext				2			2
HtmlParser			1	2			3
Azureus		1					1
Jung		1					1
HsqlDB						2	2
Spring			4				4
Total	1	26	8	10	7	3	55

Appendix C: Class correlation (only classes with accumulated defects)

JasperReports (2)

Rel	N	WMC	N	Cyclo.	N	RFC	N	CBO	N	NCSS
		p-value		p-value		p-value		p-value		p-value
7	592	.453(**)	659	.397(**)	592	.397(**)	592	.580(**)	659	.436(**)
		.000		.000		.000		.000		.000
8	475	.571(**)	536	.482(**)	475	.602(**)	475	.461(**)	536	.523(**)
		.000		.000		.000		.000		.000
9	468	.562(**)	530	.466(**)	468	.583(**)	468	.441(**)	530	.505(**)
		.000		.000		.000		.000		.000
10	468	.543(**)	530	.484(**)	468	.585(**)	468	.440(**)	530	.510(**)
		.000		.000		.000		.000		.000
11	519	.544(**)	519	.505(**)	519	.509(**)	519	.350(**)	519	.501(**)
		.000		.000		.000		.000		.000

FindBugs (3)

Rel	N	WMC	N	Cyclo.	N	RFC	N	CBO	N	NCSS
		p-value		p-value		p-value		p-value		p-value
18	241	.193(**)	467	.140(**)	241	.351(**)	241	.319(**)	467	.138(**)
		.003		.002		.000		.000		.003
19	241	.194(**)	467	.141(**)	241	.353(**)	241	.322(**)	467	.139(**)
		.002		.002		.000		.000		.003
20	249	.251(**)	468	.218(**)	249	.427(**)	249	.369(**)	468	.201(**)
		.000		.000		.000		.000		.000
21	248	.241(**)	467	.184(**)	248	.374(**)	248	.288(**)	467	.181(**)
		.000		.000		.000		.000		.000
22	226	.254(**)	408	.218(**)	226	.395(**)	226	.296(**)	408	.199(**)
		.000		.000		.000		.000		.000
23	225	.214(**)	398	.191(**)	225	.357(**)	225	.272(**)	398	.185(**)
		.001		.000		.000		.000		.000
24	196	.169(*)	347	.219(**)	196	.315(**)	196	.277(**)	347	.156(**)
		.018		.000		.000		.000		.004
25	182	.203(**)	336	.254(**)	182	.326(**)	182	.239(**)	336	.171(**)
		.006		.000		.000		.001		.002
26	176	.231(**)	304	.214(**)	176	.339(**)	176	.237(**)	304	.386(**)
		.002		.000		.000		.002		.000
27	175	.237(**)	302	.229(**)	175	.302(**)	175	.219(**)	302	.368(**)
		.002		.000		.000		.004		.000
28	150	.247(**)	255	.223(**)	150	.299(**)	150	.224(**)	255	.353(**)
		.002		.000		.000		.006		.000
29	150	.253(**)	254	.216(**)	150	.271(**)	150	.198(*)	254	.336(**)
		.002		.001		.001		.015		.000
30	150	.265(**)	254	.218(**)	150	.279(**)	150	.205(*)	254	.340(**)
		.001		.000		.001		.012		.000
31	149	.271(**)	237	.208(**)	149	.304(**)	149	.209(*)	237	.363(**)
		.001		.001		.000		.010		.000
32	144	.262(**)	231	.218(**)	144	.307(**)	144	.209(*)	231	.345(**)
		.002		.001		.000		.012		.000

33	133	.313(**)	199	.181(*)	133	.348(**)	133	.238(**)	199	.359(**)
		.000		.010		.000		.006		.000

DrJava (5)

Rel	N	WMC	N	Cyclo.	N	RFC	N	CBO	N	NCSS
		p-value		p-value		p-value		p-value		p-value
11	202	.075	295	.027	202	.066	202	.037	295	.054
		.292		.650		.349		.601		.360
34	147	.066	209	.029	147	.056	147	.019	209	.044
		.425		.681		.503		.823		.531
35	141	.062	203	.049	141	.040	141	.010	203	.043
		.468		.491		.637		.906		.538
36	141	.061	203	.049	141	.039	141	.009	203	.043
		.469		.486		.647		.912		.538
38	131	.055	192	.048	131	.030	131	.008	192	.035
		.532		.508		.732		.929		.628
40	123	.275(**)	176	.065	123	.293(**)	123	.215(*)	176	.227(**)
		.002		.388		.001		.017		.002

GFD(6)

Rel	N	WMC	N	Cyclo.	N	RFC	N	CBO	N	NCSS
		p-value		p-value		p-value		p-value		p-value
16	258	.398(**)	278	.450(**)	258	.766(**)	258	.760(**)	278	.704(**)
		.000		.000		.000		.000		.000
17	258	.418(**)	278	.474(**)	258	.753(**)	258	.735(**)	278	.699(**)
		.000		.000		.000		.000		.000
19	250	.400(**)	268	.474(**)	250	.745(**)	250	.729(**)	268	.694(**)
		.000		.000		.000		.000		.000

Jguard (7)

Rel	N	WMC	N	Cyclo.	N	RFC	N	CBO	N	NCSS
		p-value		p-value		p-value		p-value		p-value
6	76	.471(**)	76	.290(*)	76	.570(**)	76	.679(**)	76	.522(**)
		.000		.011		.000		.000		.000
7	63	.467(**)	67	.281(*)	63	.535(**)	63	.693(**)	67	.466(**)
		.000		.021		.000		.000		.000
8	47	.385(**)	47	.552(**)	47	.651(**)	47	.657(**)	47	.530(**)
		.008		.000		.000		.000		.000
9	43	.279	45	.269	43	.369(*)	43	.254	45	.438(**)
		.070		.074		.015		.100		.003
10	35	.116	37	-.220	35	-.037	35	-.048	37	-.149
		.508		.191		.831		.783		.380

JavaGroups (8)

Rel	N	WMC	N	Cyclo.	N	RFC	N	CBO	N	NCSS
		p-value		p-value		p-value		p-value		p-value
14	491	.577(**)	491	.645(**)	491	.645(**)	491	.474(**)	491	.635(**)
		.000		.000		.000		.000		.000
15	498	.580(**)	498	.624(**)	498	.650(**)	498	.460(**)	498	.638(**)
		.000		.000		.000		.000		.000
17	417	.606(**)	417	.552(**)	417	.552(**)	417	.540(**)	417	.691(**)
		.000		.000		.000		.000		.000
18	419	.578(**)	419	.552(**)	419	.658(**)	419	.549(**)	419	.648(**)
		.000		.000		.000		.000		.000
19	412	.556(**)	412	.557(**)	412	.652(**)	412	.594(**)	412	.638(**)
		.000		.000		.000		.000		.000
20	410	.541(**)	410	.549(**)	410	.651(**)	410	.595(**)	410	.634(**)
		.000		.000		.000		.000		.000
21	410	.479(**)	410	.524(**)	410	.581(**)	410	.564(**)	410	.584(**)
		.000		.000		.000		.000		.000

Itext (9)

Rel	N	WMC	N	Cyclo.	N	RFC	N	CBO	N	NCSS
		p-value		p-value		p-value		p-value		p-value
10	439	.386(**)	439	.287(**)	439	.351(**)	439	.204(**)	439	.256(**)
		.000		.000		.000		.000		.000
11	430	.374(**)	430	.264(**)	430	.340(**)	430	.200(**)	430	.241(**)
		.000		.000		.000		.000		.000

HtmlParser (10)

Rel	N	WMC	N	Cyclo.	N	RFC	N	CBO	N	NCSS
		p-value		p-value		p-value		p-value		p-value
2	147	-.023	233	.016	147	-.068	147	.181(*)	233	.027
		.786		.812		.411		.028		.682
3	110	.175	194	.187(**)	110	.075	110	.247(**)	194	.113
		.067		.009		.433		.009		.117
4	110	.136	194	.153(*)	110	.035	110	.226(*)	194	.082
		.155		.033		.713		.018		.258

Azureus (11)

Rel	N	WMC	N	Cyclo.	N	RFC	N	CBO	N	NCSS
		p-value		p-value		p-value		p-value		p-value
5	1895	.632(**)	1895	.239(**)	1895	.706(**)	1895	.609(**)	1895	.676(**)
		.000		.000		.000		.000		.000

Jung (21)

Rel	N	WMC	N	Cyclo.	N	RFC	N	CBO	N	NCSS
		p-value		p-value		p-value		p-value		p-value
5	454	.483(**)	534	.358(**)	454	.591(**)	454	.538(**)	534	.529(**)
		.000		.000		.000		.000		.000

HsqlDB (22)

Rel	N	WMC	N	Cyclo.	N	RFC	N	CBO	N	NCSS
		p-value		p-value		p-value		p-value		p-value
2	214	.016	265	.009	214	.086	214	.217(**)	265	.035
		.818		.885		.208		.001		.573
3	214	.004	265	-.009	214	.069	214	.199(**)	265	.012
		.948		.890		.314		.004		.846

Spring (23)

Rel	N	WMC	N	Cyclo.	N	RFC	N	CBO	N	NCSS
		p-value		p-value		p-value		p-value		p-value
4	1137	.541(**)	1729	.537(**)	1137	.669(**)	1137	.614(**)	1729	.306(**)
		.000		.000		.000		.000		.000
5	1124	.532(**)	1709	.521(**)	1124	.664(**)	1124	.622(**)	1709	.308(**)
		.000		.000		.000		.000		.000
6	1114	.517(**)	1693	.515(**)	1114	.649(**)	1114	.608(**)	1693	.301(**)
		.000		.000		.000		.000		.000
7	1105	.492(**)	1680	.491(**)	1105	.625(**)	1105	.595(**)	1680	.301(**)
		.000		.000		.000		.000		.000

In the following tables, the correlation significance was ignored. Only correlation value was considered. Considering both would have made different release comparison very complicated.

WMCF (Release n)

Project	Very strong positive	Strong positive	Moderate positive	Weak positive	Negligible	None	Total
JasperReports		5					5
FindBugs			1	12	3		16
DrJava				1		5	6
GFD		2	1				3
Jguard		2	1			2	5
JavaGroups		7					7
Itext			2				2
HtmlParser						3	3
Azureus		1					1
Jung		1					1
HsqlDB						2	2
Spring		4					4
Total	0	22	5	13	3	12	55

WMCC (Release n)

Project	Very strong positive	Strong positive	Moderate positive	Weak positive	Negligible	None	Total
JasperReports		4	1				5
FindBugs				11	5		16
DrJava						6	6
GFD		3					3
Jguard		1		2		2	5
JavaGroups		7					7
Itext				2			2
HtmlParser					2	1	3
Azureus				1			1
Jung			1				1
HsqlDB						2	2
Spring		4					4
Total	0	19	2	16	7	11	55

RFC (Release n)

Project	Very strong positive	Strong positive	Moderate positive	Weak positive	Negligible	None	Total
JasperReports		4	1				5
FindBugs		1	12	3			16
DrJava			1			5	6
GFD	3						3
Jguard		3	1			1	5
JavaGroups		7					7
Itext			2				2
HtmlParser						3	3
Azureus	1						1
Jung		1					1
HsqlDB						2	2
Spring		4					4
Total	4	20	17	3	0	11	55

CBO (Release n)

Project	Very strong positive	Strong positive	Moderate positive	Weak positive	Negligible	None	Total
JasperReports		4	1				5
FindBugs			3	12	1		16
DrJava				1		5	6
GFD	3						3
Jguard		3				2	5
JavaGroups		7					7
Itext				2			2
HtmlParser				2	1		3
Azureus		1					1
Jung		1					1
HsqlDB				1	1		2
Spring		4					4
Total	3	20	4	18	3	7	55

Size (Release n)

Project	Very strong positive	Strong positive	Moderate positive	Weak positive	Negligible	None	Total
JasperReports		5					5
FindBugs			8	1	7		16
DrJava				1		5	6
GFD	1	2					3
Jguard		4				1	5
JavaGroups		7					7
Itext				2			2
HtmlParser						3	3
Azureus		1					1
Jung		1					1
HsqlDB						2	2
Spring			4				4
Total	1	20	12	4	7	11	55

Appendix D: Package correlation (all packages, accumulated defects)

Following tables have summarized Pearson Correlation at package level measurements.

JasperReports (2)

Rel	N	WMC	N	Cyclo.	N	RFC	N	CBO	N	NCSS
		p-value		p-value		p-value		p-value		p-value
7	27	.930(**)	35	.918(**)	27	.926(**)	27	.895(**)	35	.851(**)
		.000		.000		.000		.000		.000
8	21	.917(**)	28	.896(**)	21	.876(**)	21	.870(**)	28	.755(**)
		.000		.000		.000		.000		.000
9	20	.921(**)	27	.896(**)	20	.873(**)	20	.866(**)	27	.749(**)
		.000		.000		.000		.000		.000
10	20	.925(**)	27	.893(**)	20	.881(**)	20	.864(**)	27	.760(**)
		.000		.000		.000		.000		.000
11	27	.918(**)	27	.889(**)	27	.827(**)	27	.788(**)	27	.783(**)
		.000		.000		.000		.000		.000

FindBugs (3)

Rel	N	WMC	N	Cyclo.	N	RFC	N	CBO	N	NCSS
		p-value		p-value		p-value		p-value		p-value
18	21	.951(**)	32	.902(**)	21	.985(**)	21	0.943	32	.943(**)
		.000		.000		.000		.000		.000
19	21	.951(**)	32	.902(**)	21	.985(**)	21	.944(**)	32	.859(**)
		.000		.000		.000		.000		.000
20	21	.945(**)	30	.914(**)	21	.978(**)	21	.920(**)	30	.868(**)
		.000		.000		.000		.000		.000
21	21	.959(**)	30	.925(**)	21	.963(**)	21	.882(**)	21	.881(**)
		.000		.000		.000		.000		.000
22	16	.950(**)	21	.920(**)	16	.953(**)	16	.845(**)	21	.876(**)
		.000		.000		.000		.000		.000
23	16	.936(**)	20	.929(**)	16	.968(**)	16	.871(**)	20	.897(**)
		.000		.000		.000		.000		.000
24	11	.853(**)	14	.902(**)	11	.977(**)	11	.888(**)	14	.853(**)
		.001		.000		.000		.000		.000
25	10	.860(**)	23	.920(**)	10	.963(**)	10	.859(**)	23	.872(**)
		.001		.000		.000		.001		.000
26	9	.878(**)	22	.858(**)	9	.955(**)	9	.825(**)	22	.931(**)
		.002		.000		.000		.006		.000
27	9	.878(**)	22	.868(**)	9	.939(**)	9	.818(**)	22	.933(**)
		.002		.000		.000		.007		.000
28	8	.900(**)	21	.878(**)	8	.968(**)	8	.851(**)	21	.956(**)
		.002		.000		.000		.007		.000
29	8	.918(**)	21	.875(**)	8	.951(**)	8	.820(*)	21	.948(**)
		.001		.000		.000		.013		.000
30	8	.920(**)	21	.876(**)	8	.948(**)	8	.815(*)	21	.948(**)

		.001		.000		.000		.014		.000
31	8	.929(**)	21	.833(**)	8	.961(**)	8	.812(*)	21	.962(**)
		.001		.000		.000		.014		.000
32	8	.914(**)	21	.817(**)	8	.944(**)	8	.776(*)	21	.946(**)
		.001		.000		.000		.024		.000
33	8	.903(**)	18	.812(**)	8	.921(**)	8	.761(*)	18	.946(**)
		.002		.000		.001		.028		.000

DrJava (5)

Rel	N	WMC	N	Cyclo.	N	RFC	N	CBO	N	NCSS
		p-value		p-value		p-value		p-value		p-value
11	23	.263	25	.308	23	.346	23	.413	25	.365
		.226		.134		.106		.050		.073
34	19	.223	19	.260	19	.269	19	.258	19	.287
		.359		.283		.266		.287		.234
35	19	.322	19	.427	19	.332	19	.365	19	.425
		.179		.068		.164		.124		.070
36	19	.327	19	.433	19	.335	19	.370	19	.429
		.172		.064		.160		.119		.067
38	19	.310	19	.423	19	.328	19	.402	19	.416
		.197		.071		.171		.088		.077
40	18	.580(*)	18	.485(*)	18	.587(*)	18	.630(**)	18	.640(**)
		.012		.041		.011		.005		.004

GFD(6)

Rel	N	WMC	N	Cyclo.	N	RFC	N	CBO	N	NCSS
		p-value		p-value		p-value		p-value		p-value
16	32	.715(**)	35	.717(**)	32	.910(**)	32	.913(**)	35	.899(**)
		.000		.000		.000		.000		.000
17	32	.764(**)	35	.750(**)	32	.910(**)	32	.894(**)	35	.894(**)
		.000		.000		.000		.000		.000
19	30	.749(**)	34	.737(**)	30	.902(**)	30	.890(**)	34	.881(**)
		.000		.000		.000		.000		.000

Jguard (7)

Rel	N	WMC	N	Cyclo.	N	RFC	N	CBO	N	NCSS
		p-value		p-value		p-value		p-value		p-value
6	15	.837(**)	15	.827(**)	15	.834(**)	15	.894(**)	15	.817(**)
		.000		.000		.000		.000		.000
7	13	.777(**)	13	.728(**)	13	.686(**)	13	.779(**)	13	.693(**)
		.002		.005		.010		.002		.009
8	11	.729(*)	11	.902(**)	11	.871(**)	11	.871(**)	11	.841(**)

		.011		.000		.000		.000		.001
9	10	.874(**)	11	.875(**)	10	.950(**)	10	.924(**)	11	.825(**)
		.001		.000		.000		.000		.002
10	9	.798(**)	10	.757(*)	9	.861(**)	9	.730(*)	10	.688(*)
		.010		.011		.003		.026		.028

JavaGroups (8)

Rel	N	WMC	N	Cyclo.	N	RFC	N	CBO	N	NCSS
		p-value		p-value		p-value		p-value		p-value
14	24	.974(**)	24	.978(**)	24	.972(**)	24	.927(**)	24	.982(**)
		.000		.000		.000		.000		.000
15	26	.975(**)	26	.979(**)	26	.974(**)	26	.927(**)	26	.983(**)
		.000		.000		.000		.000		.000
17	23	.979(**)	23	.978(**)	23	.980(**)	23	.941(**)	23	.987(**)
		.000		.000		.000		.000		.000
18	24	.982(**)	24	.972(**)	24	.984(**)	24	.958(**)	24	.989(**)
		.000		.000		.000		.000		.000
19	24	.972(**)	24	.921(**)	24	.989(**)	24	.981(**)	24	.982(**)
		.000		.000		.000		.000		.000
20	24	.969(**)	24	.914(**)	24	.989(**)	24	.981(**)	24	.982(**)
		.000		.000		.000		.000		.000
21	25	.971(**)	25	.937(**)	25	.989(**)	25	.978(**)	25	.989(**)
		.000		.000		.000		.000		.000

Itext (9)

Rel	N	WMC	N	Cyclo.	N	RFC	N	CBO	N	NCSS
		p-value		p-value		p-value		p-value		p-value
10	27	.975(**)	27	.950(**)	27	.951(**)	27	.922(**)	27	.934(**)
		.000		.000		.000		.000		.000
11	26	.975(**)	26	.949(**)	26	.951(**)	26	.923(**)	26	.933(**)
		.000		.000		.000		.000		.000

HtmlParser (10)

Rel	N	WMC	N	Cyclo.	N	RFC	N	CBO	N	NCSS
		p-value		p-value		p-value		p-value		p-value
2	18	.606(**)	18	.458(*)	18	.439	18	.759(**)	18	.522(**)
		.008		.011		.068		.000		.003
3	13	.728(**)	13	.628(**)	13	.593(*)	13	.893(**)	13	.580(**)
		.005		.001		.033		.000		.002
4	13	.722(**)	13	.617(**)	13	.588(*)	13	.892(**)	13	.575(**)
		.005		.001		.035		.000		.002

Azureus (11)

Rel	N	WMC	N	Cyclo.	N	RFC	N	CBO	N	NCSS
-----	---	-----	---	--------	---	-----	---	-----	---	------

		p-value		p-value		p-value		p-value		p-value
5	335	0.734	335	0.503	335	0.810	335	0.752	335	0.788
		.000		.000		.000		.000		.000

Jung (21)

Rel	N	WMC	N	Cyclo.	N	RFC	N	CBO	N	NCSS
		p-value		p-value		p-value		p-value		p-value
5	40	.900(**)	61	.873(**)	40	.916(**)	40	.812(**)	61	.896(**)
		.000		.000		.000		.000		.000

HsqlDB (22)

Rel	N	WMC	N	Cyclo.	N	RFC	N	CBO	N	NCSS
		p-value		p-value		p-value		p-value		p-value
2	12	.946(**)	14	.982(**)	12	.960(**)	12	.996(**)	14	.957(**)
		.000		.000		.000		.000		.000
3	12	.945(**)	12	.983(**)	12	.961(**)	12	.996(**)	12	.958(**)
		.000		.000		.000		.000		.000

Spring (23)

Rel	N	WMC	N	Cyclo.	N	RFC	N	CBO	N	NCSS
		p-value		p-value		p-value		p-value		p-value
4	136	.741(**)	163	.828(**)	136	.797(**)	136	.752(**)	163	.763(**)
		.000		.000		.000		.000		.000
5	136	.728(**)	173	.818(**)	136	.784(**)	136	.754(**)	163	.767(**)
		.000		.000		.000		.000		.000
6	136	.720(**)	163	.818(**)	136	.779(**)	136	.748(**)	163	.762(**)
		.000		.000		.000		.000		.000
7	135	.701(**)	162	.804(**)	135	.759(**)	135	.736(**)	162	.751(**)
		.000		.000		.000		.000		.000

Note:

** Correlation is significant at the 0.01 level (2-tailed).

* Correlation is significant at the 0.05 level (2-tailed).

In the following tables, the correlation significance was ignored. Only correlation value was considered. Considering both would have made different release comparison very complicated.

WMCF (Release n)

Project	Very strong positive	Strong positive	Moderate positive	Weak positive	Negligible	None	Total
JasperReports	5						5
FindBugs	16						16
DrJava		1				5	6
GFD	3						3
Jguard	5						5
JavaGroups	7						7
Itext	2						2
HtmlParser	2	1					3
Azureus	1						1
Jung	1						1
HsqlDB	2						2
Spring	4						4
Total	48	2	0	0	0	5	55

WMCC (Release n)

Project	Very strong positive	Strong positive	Moderate positive	Weak positive	Negligible	None	Total
JasperReports	5						5
FindBugs	16						16
DrJava		1				5	6
GFD	3						3
Jguard	5						5
JavaGroups	7						7
Itext	2						2
HtmlParser		3					3
Azureus		1					1
Jung	1						1
HsqlDB	2						2
Spring	4						4
Total	45	5	0	0	0	5	55

RFC (Release n)

Project	Very strong positive	Strong positive	Moderate positive	Weak positive	Negligible	None	Total
JasperReports	5						5
FindBugs	16						16
DrJava		1				5	6
GFD	3						3
Jguard	4	1					5
JavaGroups	7						7
Itext	2						2
HtmlParser		2				1	3
Azureus	1						1
Jung	1						1
HsqlDB	2						2
Spring	4						4
Total	45	4	0	0	0	6	55

CBO (Release n)

Project	Very strong positive	Strong positive	Moderate positive	Weak positive	Negligible	None	Total
JasperReports	5						5
FindBugs	16						16
DrJava		1				5	6
GFD	3						3
Jguard	5						5
JavaGroups	7						7
Itext	2						2
HtmlParser	3						3
Azureus	1						1
Jung	1						1
HsqlDB	2						2
Spring	4						4
Total	49	1	0	0	0	5	55

Size (Release n)

Project	Very strong positive	Strong positive	Moderate positive	Weak positive	Negligible	None	Total
JasperReports	5						5
FindBugs	16						16
DrJava		1				5	6
GFD	3						3
Jguard	3	2					5
JavaGroups	7						7
Itext	2						2
HtmlParser		3					3
Azureus	1						1
Jung	1						1
HsqlDB	2						2
Spring	4						4
Total	44	6	0	0	0	5	55

Appendix E: Package correlation (only packages with accumulated defects)

Following tables have summarized Pearson Correlation at package level measurements.

JasperReports (2)

Rel	N	WMC	N	Cyclo.	N	RFC	N	CBO	N	NCSS
		p-value		p-value		p-value		p-value		p-value
7	27	.744(**)	34	.810(**)	27	.886(**)	27	.875(**)	34	.863(**)
		.000		.000		.000		.000		.000
8	21	.834(**)	27	.872(**)	21	.863(**)	21	.847(**)	27	.789(**)
		.000		.000		.000		.000		.000
9	20	.833(**)	26	.792(**)	20	.766(**)	20	.813(**)	26	.641(**)
		.000		.000		.000		.000		.000
10	20	.919(**)	26	.907(**)	20	.898(**)	20	.873(**)	26	.768(**)
		.000		.000		.000		.000		.000
11	26	.900(**)	26	.929(**)	26	.886(**)	26	.886(**)	26	.835(**)
		.000		.000		.000		.000		.000

FindBugs (3)

Rel	N	WMC	N	Cyclo.	N	RFC	N	CBO	N	NCSS
		p-value		p-value		p-value		p-value		p-value
18	21	.951(**)	32	.902(**)	21	.985(**)	21	.943(**)	32	.858(**)
		.000		.000		.000		.000		.000
19	21	.951(**)	32	.902(**)	21	.985(**)	21	.944(**)	32	.859(**)
		.000		.000		.000		.000		.000
20	21	.945(**)	30	.914(**)	21	.978(**)	21	.920(**)	30	.868(**)
		.000		.000		.000		.000		.000
21	21	.959(**)	30	.925(**)	21	.963(**)	21	.882(**)	30	.881(**)
		.000		.000		.000		.000		.000
22	16	.950(**)	21	.920(**)	16	.953(**)	16	.845(**)	21	.876(**)
		.000		.000		.000		.000		.000
23	16	.936(**)	20	.929(**)	16	.968(**)	16	.871(**)	20	.897(**)
		.000		.000		.000		.000		.000
24	11	.853(**)	14	.902(**)	11	.977(**)	11	.888(**)	14	.853(**)
		.001		.000		.000		.000		.000
25	10	.860(**)	23	.920(**)	10	.963(**)	10	.859(**)	23	.872(**)
		.001		.000		.000		.000		.000
26	9	.878(**)	12	.803(**)	9	.955(**)	9	.825(**)	12	.911(**)
		.002		.002		.000		.006		.000
27	9	.878(**)	12	.818(**)	9	.939(**)	9	.818(**)	12	.913(**)
		.002		.001		.000		.007		.000
28	8	.900(**)	11	.836(**)	8	.968(**)	8	.851(**)	11	.952(**)
		.002		.001		.000		.007		.000
29	8	.918(**)	11	.831(**)	8	.951(**)	8	.820(*)	11	.941(**)
		.001		.002		.000		.013		.000
30	8	.920(**)	11	.833(**)	8	.948(**)	8	.815(*)	11	.940(**)

		.001		.001		.000		.014		.000
31	8	.929(**)	11	.782(**)	8	.961(**)	8	.812(*)	11	.951(**)
		.001		.004		.000		.014		.000
32	8	.914(**)	11	.756(**)	8	.944(**)	8	.776(*)	11	.925(**)
		.001		.007		.000		.024		.000
33	8	.903(**)	9	.717(*)	8	.921(**)	8	.761(*)	9	.917(**)
		.002		.030		.001		.028		.001

DrJava (5)

Rel	N	WMC p-value	N	Cyclo. p-value	N	RFC p-value	N	CBO p-value	N	NCSS p-value
11	23	.263	25	.308	23	.346	23	.413	25	.365
		.226		.134		.106		.050		.073
34	18	.188	18	.226	18	.239	18	.231	18	.257
		.455		.368		.340		.357		.303
35	18	.294	18	.403	18	.307	18	.343	18	.403
		.237		.097		.216		.163		.097
36	18	.299	18	.410	18	.310	18	.348	18	.408
		.229		.091		.211		.157		.093
38	18	.282	18	.400	18	.301	18	.382	18	.393
		.258		.100		.225		.118		.106
40	17	.565(*)	17	.462	17	.574(*)	17	.619(**)	17	.628(**)
		.018		.062		.016		.008		.007

GFD(6)

Rel	N	WMC p-value	N	Cyclo. p-value	N	RFC p-value	N	CBO p-value	N	NCSS p-value
16	32	.715(**)	34	.714(**)	32	.910(**)	32	.913(**)	34	.899(**)
		.000		.000		.000		.000		.000
17	32	.764(**)	34	.748(**)	32	.910(**)	32	.894(**)	34	.894(**)
		.000		.000		.000		.000		.000
19	30	.749(**)	33	.734(**)	30	.902(**)	30	.890(**)	33	.881(**)
		.000		.000		.000		.000		.000

Jguard (7)

Rel	N	WMC p-value	N	Cyclo. p-value	N	RFC p-value	N	CBO p-value	N	NCSS p-value
6	15	.837(**)	15	.827(**)	15	.834(**)	15	.894(**)	15	.817(**)
		.000		.000		.000		.000		.000
7	13	.777(**)	13	.728(**)	13	.686(**)	13	.779(**)	13	.693(**)
		.002		.005		.010		.002		.009
8	11	.729(*)	11	.902(**)	11	.871(**)	11	.871(**)	11	.841(**)

		.011		.000		.000		.000		.001
9	10	.874(**)	10	.875(**)	10	.950(**)	10	.924(**)	10	.900(**)
		.001		.001		.000		.000		.000
10	9	.798(**)	10	.757(*)	9	.861(**)	9	.730(*)	10	.688(*)
		.010		.011		.003		.026		.028

JavaGroups (8)

Rel	N	WMC	N	Cyclo.	N	RFC	N	CBO	N	NCSS
		p-value		p-value		p-value		p-value		p-value
14	24	.974(**)	24	.978(**)	24	.972(**)	24	.927(**)	24	.982(**)
		.000		.000		.000		.000		.000
15	26	.975(**)	26	.979(**)	26	.974(**)	26	.927(**)	26	.983(**)
		.000		.000		.000		.000		.000
17	21	.979(**)	21	.978(**)	21	.980(**)	21	.942(**)	21	.988(**)
		.000		.000		.000		.000		.000
18	21	.983(**)	21	.973(**)	21	.984(**)	21	.961(**)	21	.991(**)
		.000		.000		.000		.000		.000
19	21	.973(**)	21	.920(**)	21	.990(**)	21	.984(**)	21	.984(**)
		.000		.000		.000		.000		.000
20	21	.969(**)	21	.913(**)	21	.990(**)	21	.984(**)	21	.983(**)
		.000		.000		.000		.000		.000
21	21	.974(**)	21	.937(**)	21	.991(**)	21	.982(**)	21	.992(**)
		.000		.000		.000		.000		.000

Itex (9)

Rel	N	WMC	N	Cyclo.	N	RFC	N	CBO	N	NCSS
		p-value		p-value		p-value		p-value		p-value
10	27	.975(**)	27	.950(**)	27	.951(**)	27	.922(**)	27	.934(**)
		.000		.000		.000		.000		.000
11	26	.975(**)	26	.949(**)	26	.951(**)	26	.923(**)	26	.933(**)
		.000		.000		.000		.000		.000

HtmlParser (10)

Rel	N	WMC	N	Cyclo.	N	RFC	N	CBO	N	NCSS
		p-value		p-value		p-value		p-value		p-value
2	18	.606(**)	30	.458(*)	18	.439	18	.759(**)	30	.522(**)
		.008		.011		.068		.000		.003
3	12	.779(**)	24	.677(**)	12	.614(*)	12	.891(**)	24	.593(**)
		.003		.000		.034		.000		.002
4	12	.770(**)	24	.664(**)	12	.608(*)	12	.890(**)	24	.587(**)
		.003		.000		.036		.000		.003

Azureus (11)

Rel	N	WMC	N	Cyclo.	N	RFC	N	CBO	N	NCSS
		p-value		p-value		p-value		p-value		p-value
5	321	.742(**)	321	.525(**)	321	.822(**)	321	.757(**)	321	.806(**)
		.000		.000		.000		.000		.000

Jung (21)

Rel	N	WMC	N	Cyclo.	N	RFC	N	CBO	N	NCSS
		p-value		p-value		p-value		p-value		p-value
5	40	.900(**)	61	.873(**)	40	.916(**)	40	.812(**)	61	.896(**)
		.000		.000		.000		.000		.000

HsqlDB (22)

Rel	N	WMC	N	Cyclo.	N	RFC	N	CBO	N	NCSS
		p-value		p-value		p-value		p-value		p-value
2	12	.946(**)	14	.982(**)	12	.960(**)	12	.996(**)	14	.957(**)
		.000		.000		.000		.000		.000
3	12	.945(**)	14	.983(**)	12	.961(**)	12	.996(**)	14	.958(**)
		.000		.000		.000		.000		.000

Spring (23)

Rel	N	WMC	N	Cyclo.	N	RFC	N	CBO	N	NCSS
		p-value		p-value		p-value		p-value		p-value
4	136	.741(**)	163	.828(**)	136	.797(**)	136	.752(**)	163	.763(**)
		.000		.000		.000		.000		.000
5	136	.728(**)	163	.818(**)	136	.784(**)	136	.754(**)	163	.767(**)
		.000		.000		.000		.000		.000
6	136	.720(**)	163	.818(**)	136	.779(**)	136	.748(**)	163	.762(**)
		.000		.000		.000		.000		.000
7	135	.701(**)	162	.804(**)	135	.759(**)	135	.736(**)	162	.751(**)
		.000		.000		.000		.000		.000

Note:

** Correlation is significant at the 0.01 level (2-tailed).

* Correlation is significant at the 0.05 level (2-tailed).

In the following tables, the correlation significance was ignored. Only correlation value was considered. Considering both would have made different release comparison very complicated.

WMCF (Release n)

Project	Very strong positive	Strong positive	Moderate positive	Weak positive	Negligible	None	Total
JasperReports	5						5
FindBugs	16						16
DrJava		1				5	6
GFD	3						3
Jguard	5						5
JavaGroups	7						7
Itext	2						2
HtmlParser	2	1					3
Azureus	1						1
Jung	1						1
HsqlDB	2						2
Spring	4						4
Total	48	2	0	0	0	5	55

WMCC (Release n)

Project	Very strong positive	Strong positive	Moderate positive	Weak positive	Negligible	None	Total
JasperReports	5						5
FindBugs	16						16
DrJava						6	6
GFD	3						3
Jguard	5						5
JavaGroups	7						7
Itext	2						2
HtmlParser		3					3
Azureus		1					1
Jung	1						1
HsqlDB	2						2
Spring	4						4
Total	45	4	0	0	0	6	55

RFC (Release n)

Project	Very strong positive	Strong positive	Moderate positive	Weak positive	Negligible	None	Total
JasperReports	5						5
FindBugs	16						16
DrJava		1				5	6
GFD	3						3
Jguard	5						5
JavaGroups	7						7
Itext	2						2
HtmlParser		2				1	3
Azureus	1						1
Jung	1						1
HsqlDB	2						2
Spring	4						4
Total	46	3	0	0	0	6	55

CBO (Release n)

Project	Very strong positive	Strong positive	Moderate positive	Weak positive	Negligible	None	Total
JasperReports	5						5
FindBugs	16						16
DrJava		1				5	6
GFD	3						3
Jguard	5						5
JavaGroups	7						7
Itext	2						2
HtmlParser	3						3
Azureus	1						1
Jung	1						1
HsqlDB	2						2
Spring	4						4
Total	49	1	0	0	0	5	55

Size (Release n)

Project	Very strong positive	Strong positive	Moderate positive	Weak positive	Negligible	None	Total
JasperReports	4	1					5
FindBugs	16						16
DrJava		1				5	6
GFD	3						3
Jguard	3	2					5
JavaGroups	7						7
Itext	2						2
HtmlParser		3					3
Azureus	1						1
Jung	1						1
HsqlDB	2						2
Spring	4						4
Total	43	7	0	0	0	5	55

Appendix F: Class correlation (all classes, release defects)

In the following analysis all classes (with release and without release defects) in the release were considered.

JasperReports(2)

Rel	Days	Def. count	N	WMC	N	Cyclo.	N	RFC	N	CBO	N	NCSS
				p-value		p-value		p-value		p-value		p-value
7	9	51	636	.217(**)	707	.201(**)	636	.399(**)	636	.385(**)	707	.347(**)
				.000		.000		.000		.000		.000
8	35	435	518	.464(**)	583	.515(**)	518	.614(**)	518	.492(**)	583	.558(**)
				.000		.000		.000		.000		.000
9	12	704	510	.501(**)	576	.339(**)	510	.438(**)	510	.349(**)	576	.378(**)
				.000		.000		.000		.000		.000
10	37	127	510	.485(**)	576	.501(**)	510	.487(**)	510	.454(**)	576	.454(**)
				.000		.000		.000		.000		.000
11	NA	336	566	.465(**)	566	.607(**)	566	.601(**)	566	.408(**)	566	.634(**)
				.000		.000		.000		.000		.000

FindBugs (3)

Rel	Days	Def. count	N	WMC	N	Cyclo.	N	RFC	N	CBO	N	NCSS
				p-value		p-value		p-value		p-value		p-value
18	2	2	241	-.012	485	-.006	241	.008	241	-.062	485	.000
				.852		.897		.900		.339		.992
19	79	3	241	.122	485	.028	241	.182(**)	241	.008	485	.110(*)
				.060		.542		.005		.903		.016
20	4	302	249	.170(**)	486	.217(**)	249	.459(**)	249	.563(**)	486	.168(**)
				.007		.000		.000		.000		.000
21	39	3	248	.022	485	.009	248	.030	248	-.025	485	.012
				.728		.839		.639		.692		.793
22	18	154	226	.216(**)	435	.043	226	.210(**)	226	.111	435	.084
				.001		.374		.002		.096		.079
23	114	68	227	.021	428	-.015	227	.161(*)	227	.076	428	.022
				.753		.763		.015		.255		.656
24	75	129	196	.147(*)	366	.152(**)	196	.363(**)	196	.248(**)	366	.134(*)
				.040		.004		.000		.000		.011
25	59	123	182	-.011	353	.124(*)	182	.187(*)	182	.208(**)	353	.154(**)
				.879		.020		.011		.005		.005
26	4	187	176	.036	336	.020	176	.286(**)	176	.152(*)	336	.197(**)
				.633		.713		.000		.043		.000
27	38	17	176	.030	335	-.005	176	.103	176	-.013	335	.078
				.694		.931		.173		.862		.154
28	5	61	150	.057	278	.100	150	.254(**)	150	.217(**)	278	.179(**)
				.488		.095		.002		.008		.003
29	1	9	150	-.024	277	.065	150	.045	150	.016	277	.079
				.772		.284		.582		.849		.192
30	28	18	150	-.010	277	-.004	150	.061	150	.042	277	-.010
				.901		.944		.457		.607		.867
31	13	34	149	.136	260	.077	149	.200(*)	149	.312(**)	260	.215(**)

				.098		.219		.014		.000		.000
32	53	20	144	.015	254	.055	144	.078	144	.022	254	.110
				.863		.380		.354		.795		.079
33	NA	25	133	.001	220	.010	133	.051	133	.031	220	.060
				.990		.883		.558		.721		.377

DrJava (5)

Rel	Days	Def. count	N	WMC	N	Cyclo.	N	RFC	N	CBO	N	NCSS
				p-value		p-value		p-value		p-value		p-value
11	944	19	211	.200(**)	304	.081	211	.203(**)	211	.130	304	.077
				.004		.158		.003		.060		.179
34	47	2325	152	.071	214	.015	152	.069	152	.023	214	.045
				.387		.831		.398		.781		.515
35	8	9	151	.054	213	-.031	151	.163(*)	151	.076	213	.028
				.507		.650		.046		.354		.685
36	107	6	151	-.032	213	-.039	151	-.059	151	-.063	213	.053
				.692		.570		.473		.440		.445
38	47	156	140	.092	201	.014	140	.102	140	.048	201	.044
				.279		.847		.232		.573		.536
40	NA	276	130	.309(**)	183	.014	130	.355(**)	130	.264(**)	183	.236(**)
				.000		.852		.000		.002		.001

GFD(6)

Rel	Days	Def. count	N	WMC	N	Cyclo.	N	RFC	N	CBO	N	NCSS
				p-value		p-value		p-value		p-value		p-value
16	5	107	258	.238(**)	280	.252(**)	258	.639(**)	258	.695(**)	280	.543(**)
				.000		.000		.000		.000		.000
17	47	6	258	.261(**)	280	.130(*)	258	.193(**)	258	.017	280	.079
				.000		.029		.002		.786		.187
19	NA	51	250	.154(*)	270	.200(**)	250	.423(**)	250	.397(**)	270	.365(**)
				.015		.001		.000		.000		.000

Jguard (7)

Rel	Days	Def. count	N	WMC	N	Cyclo.	N	RFC	N	CBO	N	NCSS
				p-value		p-value		p-value		p-value		p-value
6	54	14	76	.198	76	.072	76	.109	76	.047	76	.019
				.086		.536		.349		.684		.870
7	67	205	63	.441(**)	67	.150	63	.375(**)	63	.540(**)	67	.270(*)
				.000		.225		.002		.000		.027
8	81	185	47	.399(**)	47	.562(**)	47	.643(**)	47	.615(**)	47	.486(**)
				.005		.000		.000		.000		.001
9	81	15	43	.208	46	.596(**)	43	.571(**)	43	.399(**)	46	.743(**)
				.181		.000		.000		.008		.000
10	NA	94	35	.116	38	-.156	35	-.037	35	-.048	38	-.134
				.508		.349		.831		.783		.421

JavaGroups (8)

Rel	Days	Def. count	N	WMC	N	Cyclo.	N	RFC	N	CBO	N	NCSS
				p-value		p-value		p-value		p-value		p-value
14	56	29	519	.159(**)	519	.124(**)	519	.149(**)	519	.209(**)	519	.128(**)
				.000		.005		.001		.000		.004
15	128	99	525	.363(**)	525	.339(**)	525	.365(**)	525	.233(**)	525	.367(**)
				.000		.000		.000		.000		.000
17	230	770	461	.482(**)	461	.446(**)	461	.568(**)	461	.376(**)	461	.560(**)
				.000		.000		.000		.000		.000
18	35	703	484	.526(**)	484	.463(**)	484	.575(**)	484	.421(**)	484	.561(**)
				.000		.000		.000		.000		.000
19	40	56	472	.357(**)	472	.327(**)	472	.340(**)	472	.298(**)	472	.349(**)
				.000		.000		.000		.000		.000
20	116	478	469	.377(**)	469	.365(**)	469	.494(**)	469	.409(**)	469	.457(**)
				.000		.000		.000		.000		.000
21	NA	511	484	.426(**)	484	.524(**)	484	.546(**)	484	.557(**)	484	.550(**)
				.000		.000		.000		.000		.000

Itext (9)

Rel	Days	Def. count	N	WMC	N	Cyclo.	N	RFC	N	CBO	N	NCSS
				p-value		p-value		p-value		p-value		p-value
10	28	87	439	.418(**)	439	.468(**)	439	.553(**)	439	.388(**)	439	.490(**)
				.000		.000		.000		.000		.000
11	NA	35	430	.239(**)	430	.267(**)	430	.334(**)	430	.250(**)	430	.279(**)
				.000		.000		.000		.000		.000

HtmlParser (10)

Rel	Days	Def. count	N	WMC	N	Cyclo.	N	RFC	N	CBO	N	NCSS
				p-value		p-value		p-value		p-value		p-value
2	323	13	148	.348(**)	234	.364(**)	148	.239(**)	148	.186(*)	234	.218(**)
				.000		.000		.003		.023		.001
3	66	178	117	.398(**)	203	.431(**)	117	.456(**)	117	.323(**)	203	.409(**)
				.000		.000		.000		.000		.000
4	NA	177	117	.192(*)	203	.323(**)	117	.210(*)	117	.603(**)	203	.366(**)
				.038		.000		.023		.000		.000

Azureus (11)

Rel	Days	Def. count	N	WMC	N	Cyclo.	N	RFC	N	CBO	N	NCSS
				p-value		p-value		p-value		p-value		p-value
5	NA	604	1159	.551(**)	1159	.241(**)	1159	.538(**)	1159	.460(**)	1159	.516(**)
				.000		.000		.000		.000		.000

Jung (21)

Rel	Days	Def. count	N	WMC	N	Cyclo.	N	RFC	N	CBO	N	NCSS
				p-value		p-value		p-value		p-value		p-value
5	NA	17	454	.102(*)	534	.039	454	.200(**)	454	.223(**)	534	.302(**)
				.030		.375		.000		.000		.000

HsqlDB (22)

Rel	Days	Def. count	N	WMC	N	Cyclo.	N	RFC	N	CBO	N	NCSS
				p-value		p-value		p-value		p-value		p-value
2	46	296	214	.255(**)	272	.379(**)	214	.381(**)	214	.469(**)	272	.492(**)
				.000		.000		.000		.000		.000
3	NA	263	214	.197(**)	272	.279(**)	214	.293(**)	214	.348(**)	272	.337(**)
				.004		.000		.000		.000		.000

Spring (23)

Rel	Days	Def. count	N	WMC	N	Cyclo.	N	RFC	N	CBO	N	NCSS
				p-value		p-value		p-value		p-value		p-value
4	53	703	1137	.354(**)	1729	.393(**)	1137	.440(**)	1137	.346(**)	1729	.206(**)
				.000		.000		.000		.000		.000
5	27	308	1124	.337(**)	1710	.247(**)	1124	.376(**)	1124	.366(**)	1710	.180(**)
				.000		.000		.000		.000		.000
6	31	502	1114	.453(**)	1694	.400(**)	1114	.499(**)	1114	.407(**)	1694	.118(**)
				.000		.000		.000		.000		.000
7	NA	147	1106	.185(**)	1682	.182(**)	1106	.233(**)	1106	.228(**)	1682	.108(**)
				.000		.000		.000		.000		.000

WMCF (Release n)

Project	Very strong positive	Strong positive	Moderate positive	Weak positive	Negligible	None	Total
JasperReports		4		1			5
FindBugs				1	2	13	16
DrJava			1	1		4	6
GFD				2	1		3
Jguard		1	1			3	5
JavaGroups		3	3		1		7
Itext		1		1			2
HtmlParser			2		1		3
Azureus		1					1
Jung					1		1
HsqlDB				1	1		2
Spring		1	2		1		4
Total	0	11	9	7	8	20	55

WMCC (Release n)

Project	Very strong positive	Strong positive	Moderate positive	Weak positive	Negligible	None	Total
JasperReports		3	1	1			5
FindBugs				1	2	13	16
DrJava						6	6
GFD				2	1		3
Jguard		2				3	5
JavaGroups		3	3		1		7
Itext		1		1			2
HtmlParser		1	2				3
Azureus				1			1
Jung						1	1
HsqlDB			1	1			2
Spring		1	1	1	1		4
Total	0	11	8	8	5	23	55

RFC (Release n)

Project	Very strong positive	Strong positive	Moderate positive	Weak positive	Negligible	None	Total
JasperReports		4	1				5
FindBugs		1	1	4	3	7	16
DrJava			1	1	1	3	6
GFD		2			1		3
Jguard		2	1			2	5
JavaGroups		4	2		1		7
Itext		1	1				2
HtmlParser		1		2			3
Azureus		1					1
Jung				1			1
HsqlDB			1	1			2
Spring		2	1	1			4
Total	0	18	9	10	6	12	55

CBO (Release n)

Project	Very strong positive	Strong positive	Moderate positive	Weak positive	Negligible	None	Total
JasperReports		3	2				5
FindBugs		1	1	3	1	10	16
DrJava				1		5	6
GFD		1	1			1	3
Jguard		2	1			2	5
JavaGroups		3	1	3			7
Itext			1	1			2
HtmlParser		1	1		1		3
Azureus		1					1
Jung				1			1
HsqlDB		1	1				2
Spring		1	2	1			4
Total	0	14	11	10	2	18	55

Size (Release n)

Project	Very strong positive	Strong positive	Moderate positive	Weak positive	Negligible	None	Total
JasperReports		3	2				5
FindBugs				1	6	9	16
DrJava				1		5	6
GFD		1	1			1	3
Jguard	1	1		1		2	5
JavaGroups		4	2		1		7
Itext		1		1			2
HtmlParser		1	1	1			3
Azureus		1					1
Jung			1				1
HsqlDB		1	1				2
Spring				1	3		4
Total	1	13	8	6	10	17	55

Appendix G: Package correlation (all packages, release defects)

Package based hypothesis testing for release defects (all packages)

Following tables have summarized Pearson Correlation at package level measurements.

All packages, with and without defects were considered.

JasperReports (2)

Rel	Days	Def. count	N	WMC	N	Cyclo.	N	RFC	N	CBO	N	NCSS
				p-value		p-value		p-value		p-value		p-value
7	9	51	27	.744(**)	35	.812(**)	27	.886(**)	27	.875(**)	35	.864(**)
				.000		.000		.000		.000		.000
8	35	435	21	.834(**)	28	.874(**)	21	.863(**)	21	.847(**)	28	.792(**)
				.000		.000		.000		.000		.000
9	12	704	20	.833(**)	27	.795(**)	20	.766(**)	20	.813(**)	27	.647(**)
				.000		.000		.000		.000		.000
10	37	127	20	.919(**)	27	.908(**)	20	.898(**)	20	.873(**)	27	.771(**)
				.000		.000		.000		.000		.000
11	NA	336	27	.901(**)	27	.930(**)	27	.888(**)	27	.888(**)	27	.923(**)
				.000		.000		.000		.000		.000

FindBugs (3)

Rel	Days	Def. count	N	WMC	N	Cyclo.	N	RFC	N	CBO	N	NCSS
				p-value		p-value		p-value		p-value		p-value
18	2	2	21	.602(**)	32	.645(**)	21	.453(*)	21	.244	32	.683(**)
				.004		.000		.039		.287		.000
19	79	3	21	.585(**)	32	.271	21	.468(*)	21	.214	32	.269
				.005		.134		.032		.351		.136
20	4	302	21	.811(**)	30	.897(**)	21	.950(**)	21	.980(**)	30	.880(**)
				.000		.000		.000		.000		.000
21	39	3	21	.610(**)	30	.502(**)	21	.663(**)	21	.617(**)	30	.450(*)
				.003		.005		.001		.003		.013
22	18	154	16	.809(**)	21	.826(**)	16	.583(*)	16	.364	21	.760(**)
				.000		.000		.018		.165		.000
23	114	68	16	.865(**)	20	.876(**)	16	.869(**)	16	.659(**)	20	.918(**)
				.000		.000		.000		.005		.000
24	75	129	11	.457	14	.696(**)	11	.809(**)	11	.892(**)	14	.740(**)
				.157		.006		.003		.000		.002
25	59	123	10	.285	23	.685(**)	10	.700(*)	10	.861(**)	23	.781(**)
				.424		.000		.024		.001		.000
26	4	187	9	.830(**)	22	.758(**)	9	.988(**)	9	.821(**)	22	.868(**)
				.006		.000		.000		.007		.000
27	38	17	9	.266	22	.633(**)	9	.643	9	.513	22	.764(**)
				.488		.002		.062		.158		.000
28	5	61	8	.388	21	.700(**)	8	.731(*)	8	.800(*)	21	.793(**)
				.343		.000		.040		.017		.000
29	1	9	8	.319	21	.489(*)	8	.686	8	.791(*)	21	.657(**)

				.441		.024		.061		.019		.001
30	28	18	8	.566	21	.524(*)	8	.833(*)	8	.828(*)	21	.506(*)
				.143		.015		.010		.011		.019
31	13	34	8	.138	21	.321	8	.428	8	.736(*)	21	.526(*)
				.744		.155		.290		.037		.014
32	53	20	8	.486	21	.564(**)	8	.735(*)	8	.776(*)	21	.773(**)
				.222		.008		.038		.024		.000
33	NA	25	8	.726(*)	18	.909(**)	8	.745(*)	8	.435	18	.881(**)
				.041		.000		.034		.281		.000

DrJava (5)

Rel	Days	Def. count	N	WMC p-value	N	Cyclo. p-value	N	RFC p-value	N	CBO p-value	N	NCSS p-value
11	944	19	23	.072	25	-.081	23	.046	23	.012	25	-.025
				.743		.701		.836		.958		.907
34	47	2325	19	.144	19	.131	19	.214	19	.169	19	.178
				.555		.593		.380		.490		.467
35	8	9	19	-.047	19	-.139	19	.062	19	-.067	19	-.080
				.849		.572		.801		.785		.746
36	107	6	19	-.082	19	-.095	19	-.055	19	-.114	19	-.014
				.739		.698		.823		.642		.954
38	46	156	19	.193	19	-.043	19	.306	19	.180	19	.097
				.429		.860		.203		.462		.694
40	NA	276	18	.466	18	.054	18	.536(*)	18	.473(*)	18	.376
				.051		.831		.022		.047		.124

GFD(6)

Rel	Days	Def. count	N	WMC p-value	N	Cyclo. p-value	N	RFC p-value	N	CBO p-value	N	NCSS p-value
16	5	107	32	.441(*)	35	.498(**)	32	.816(**)	32	.898(**)	35	.819(**)
				.012		.002		.000		.000		.000
17	47	6	32	.446(*)	35	.311	32	.284	32	.082	35	.246
				.011		.069		.116		.654		.155
19	NA	51	30	.420(*)	34	.445(**)	30	.725(**)	30	.758(**)	34	.714(**)
				.021		.008		.000		.000		.000

Jguard (7)

Rel	Days	Def. count	N	WMC p-value	N	Cyclo. p-value	N	RFC p-value	N	CBO p-value	N	NCSS p-value
6	54	14	15	.494	15	.515(*)	15	.480	15	.459	15	.468
				.061		.049		.070		.086		.078
7	67	205	13	.589(*)	13	.440	13	.338	13	.437	13	.309
				.034		.133		.259		.135		.304
8	81	185	11	.560	11	.795(**)	11	.675(*)	11	.639(*)	11	.915(**)

				.073		.003		.023		.025		.000
9	81	15	10	.557	11	.755(**)	10	.718(*)	10	.729(*)	11	.798(**)
				.094		.007		.019		.017		.003
10	NA	94	9	.798(**)	10	.761(*)	9	.861(**)	9	.730(*)	10	.615
				.010		.011		.003		.026		.059

JavaGroups (8)

Rel	Days	Def. count	N	WMC	N	Cyclo.	N	RFC	N	CBO	N	NCSS
				p-value		p-value		p-value		p-value		p-value
14	56	29	24	.892(**)	24	.857(**)	24	.851(**)	24	.836(**)	24	.844(**)
				.000		.000		.000		.000		.000
15	128	99	26	.712(**)	26	.781(**)	26	.700(**)	26	.646(**)	26	.733(**)
				.000		.000		.000		.000		.000
17	230	770	23	.951(**)	23	.955(**)	23	.965(**)	23	.921(**)	23	.967(**)
				.000		.000		.000		.000		.000
18	35	703	24	.910(**)	24	.978(**)	24	.890(**)	24	.829(**)	24	.919(**)
				.000		.000		.000		.000		.000
19	40	56	24	.761(**)	24	.797(**)	24	.681(**)	24	.690(**)	24	.710(**)
				.000		.000		.000		.000		.000
20	116	478	24	.930(**)	24	.858(**)	24	.966(**)	24	.961(**)	24	.948(**)
				.000		.000		.000		.000		.000
21	NA	511	25	.934(**)	25	.967(**)	25	.956(**)	25	.928(**)	25	.973(**)
				.000		.000		.000		.000		.000

Itext (9)

Rel	Days	Def. count	N	WMC	N	Cyclo.	N	RFC	N	CBO	N	NCSS
				p-value		p-value		p-value		p-value		p-value
10	28	87	27	.914(**)	27	.918(**)	27	.941(**)	27	.930(**)	27	.927(**)
				.000		.000		.000		.000		.000
11	NA	35	26	.673(**)	26	.642(**)	26	.684(**)	26	.640(**)	26	.673(**)
				.000		.000		.000		.000		.000

HtmlParser (10)

Rel	Days	Def. count	N	WMC	N	Cyclo.	N	RFC	N	CBO	N	NCSS
				p-value		p-value		p-value		p-value		p-value
2	323	13	18	.535(*)	30	.617(**)	18	.228	18	.273	30	.238
				.022		.000		.364		.273		.205
3	66	178	13	.566(*)	26	.705(**)	13	.475	13	.549	26	.517(**)
				.044		.000		.101		.052		.007
4	NA	177	13	.503	26	.533(**)	13	.340	13	.917(**)	26	.574(**)
				.080		.005		.256		.000		.002

Azureus (11)

Rel	Days	Def. count	N	WMC	N	Cyclo.	N	RFC	N	CBO	N	NCSS
				p-value		p-value		p-value		p-value		p-value

5	NA	604	335	.551(**)	335	.375(**)	335	.574(**)	335	.527(**)	335	.597(**)
				.000		.000		.000		.000		.000

Jung (21)

Rel	Days	Def. count	N	WMC	N	Cyclo.	N	RFC	N	CBO	N	NCSS
				p-value		p-value		p-value		p-value		p-value
5	NA	17	40	.544(**)	61	.485(**)	40	.623(**)	40	.608(**)	61	.646(**)
				.000		.000		.000		.000		.000

HsqlDB (22)

Rel	Days	Def. count	N	WMC	N	Cyclo.	N	RFC	N	CBO	N	NCSS
				p-value		p-value		p-value		p-value		p-value
2	46	296	12	.965(**)	14	.964(**)	12	.984(**)	12	.946(**)	14	.980(**)
				.000		.000		.000		.000		.000
3	NA	263	12	.940(**)	14	.927(**)	12	.966(**)	12	.907(**)	14	.958(**)
				.000		.000		.000		.000		.000

Spring (23)

Rel	Days	Def. count	N	WMC	N	Cyclo.	N	RFC	N	CBO	N	NCSS
				p-value		p-value		p-value		p-value		p-value
4	53	703	136	.594(**)	163	.686(**)	136	.657(**)	136	.510(**)	163	.614(**)
				.000		.000		.000		.000		.000
5	27	308	136	.542(**)	163	.493(**)	136	.550(**)	136	.546(**)	163	.515(**)
				.000		.000		.000		.000		.000
6	31	502	136	.780(**)	163	.775(**)	136	.808(**)	136	.690(**)	163	.707(**)
				.000		.000		.000		.000		.000
7	NA	147	135	.468(**)	162	.505(**)	135	.503(**)	135	.426(**)	162	.472(**)
				.000		.000		.000		.000		.000

Note:

** Correlation is significant at the 0.01 level (2-tailed).

* Correlation is significant at the 0.05 level (2-tailed).

In the following tables, the correlation significance was ignored. Only correlation value was considered. Considering both would have made different release comparison very complicated.

WMCF (Release n)

Project	Very strong positive	Strong positive	Moderate positive	Weak positive	Negligible	None	Total
JasperReports	5						5
FindBugs	5	3				8	16
DrJava						6	6
GFD		3					3
Jguard	1	1				3	5
JavaGroups	7						7
Itext	1	1					2
HtmlParser		2				1	3
Azureus		1					1
Jung		1					1
HsqlDB	2						2
Spring	1	3					4
Total	22	15	0	0	0	18	55

WMCC (Release n)

Project	Very strong positive	Strong positive	Moderate positive	Weak positive	Negligible	None	Total
JasperReports	5						5
FindBugs	6	8				2	16
DrJava						6	6
GFD		2				1	3
Jguard	3	1				1	5
JavaGroups	7						7
Itext	1	1					2
HtmlParser	1	2					3
Azureus			1				1
Jung		1					1
HsqlDB	2						2
Spring	1	3					4
Total	26	18	1	0	0	10	55

RFC (Release n)

Project	Very strong positive	Strong positive	Moderate positive	Weak positive	Negligible	None	Total
JasperReports	5						5
FindBugs	9	4				3	16
DrJava		1				5	6
GFD	2					1	3
Jguard	2	1				2	5
JavaGroups	6	1					7
Itext	1	1					2
HtmlParser						3	3
Azureus		1					1
Jung		1					1
HsqlDB	2						2
Spring	1	3					4
Total	28	13	0	0	0	14	55

CBO (Release n)

Project	Very strong positive	Strong positive	Moderate positive	Weak positive	Negligible	None	Total
JasperReports	5						5
FindBugs	9	2				5	16
DrJava		1				5	6
GFD	2					1	3
Jguard	2	1				2	5
JavaGroups	5	2					7
Itext	1	1					2
HtmlParser	1					2	3
Azureus		1					1
Jung		1					1
HsqlDB	2						2
Spring		4					4
Total	27	13	0	0	0	15	55

Size (Release n)

Project	Very strong positive	Strong positive	Moderate positive	Weak positive	Negligible	None	Total
JasperReports	4	1					5
FindBugs	10	5				1	16
DrJava						6	6
GFD	2					1	3
Jguard	2					3	5
JavaGroups	7						7
Itext	1	1					2
HtmlParser		2				1	3
Azureus		1					1
Jung		1					1
HsqlDB	2						2
Spring	1	3					4
Total	29	14	0	0	0	12	55

Appendix H: Class correlation (only classes with release defects)

In the following analysis only classes with at least one release defects were considered.

JasperReports (2)

Rel	Days	Def. count	N	WMC p-value	N	Cyclo. p-value	N	RFC p-value	N	CBO p-value	N	NCSS p-value
7	9	51	35	.308	38	.376(*)	35	.555(**)	35	.472(**)	38	.532(**)
				.072		.020		.001		.004		.001
8	35	435	261	.481(**)	277	.589(**)	261	.726(**)	261	.502(**)	277	.665(**)
				.000		.000		.000		.000		.000
9	12	704	250	.470(**)	263	.283(**)	250	.427(**)	250	.267(**)	263	.362(**)
				.000		.000		.000		.000		.000
10	37	127	85	.223(*)	92	.330(**)	85	.289(**)	85	.201	92	.251(*)
				.040		.001		.007		.066		.016
11	NA	336	239	.493(**)	239	.754(**)	239	.723(**)	239	.562(**)	239	.768(**)
				.000		.000		.000		.000		.000

FindBugs (3)

Rel	Days	Def. count	N	WMC p-value	N	Cyclo. p-value	N	RFC p-value	N	CBO p-value	N	NCSS p-value
18	2	2	1	-----	2	-----	1	-----	1	-----	2	-----
19	79	3	3	-----	3	-----	3	-----	3	-----	3	-----
20	4	302	120	.125	120	.008	120	.324(**)	120	.410(**)	120	.165(*)
				.173		.926		.000		.000		.042
21	39	3	3	-----	3	-----	3	-----	3	-----	3	-----
22	18	154	88	.396(**)	109	.123	88	.503(**)	88	.345(**)	109	.306(**)
				.000		.202		.000		.001		.001
23	114	68	36	-.006	46	-.019	36	.106	36	.054	46	-.045
				.972		.899		.538		.756		.765
24	75	129	56	.149	72	.077	56	.180	56	-.103	72	.100
				.273		.521		.183		.448		.402
25	59	123	43	.053	81	.091	43	.106	43	-.022	81	.316(**)
				.736		.418		.498		.889		.004
26	4	187	139	.153	148	-.023	139	.309(**)	139	.095	148	.245(**)
				.072		.777		.000		.264		.003
27	38	17	8	-.533	13	-.118	8	-.507	8	-.422	13	-.177
				.174		.700		.200		.298		.563
28	5	61	33	-.145	41	.106	33	.038	33	.049	41	.037
				.421		.509		.833		.785		.818
29	1	9	5	-.441	6	-.468	5	-.433		-.808	6	-.309
				.457		.350		.467		.098		.551
30	28	18	4	-----	18	-----	4	-----	4	-----	18	-----
31	13	34	26	-.111	28	.065	26	-.078	26	-.187	28	-.018
				.588		.742		.704		.360		.926
32	53	20	11	-.171	13	-.138	11	-.165	11	-.345	13	-.090
				.615		.652		.628		.298		.769

33	NA	25	10	-.465	14	.000	10	-.521	10	-.531	14	-.236
				.176		.999		.123		.114		.417

DrJava (5)

Rel	Days	Def. count	N	WMC	N	Cyclo.	N	RFC	N	CBO	N	NCSS
				p-value		p-value		p-value		p-value		p-value
11	944	19	14	-.187	16	-.098	14	-.184	14	-.211	16	-.163
				.521		.717		.530		.469		.547
34	47	2325	147	.069	209	.013	147	.013	147	.066	209	.021
				.406		.853		.853		.424		.799
35	8	9	7	-.572	7	-.451	7	-.601	7	-.446	7	-.568
				.179		.310		.154		.315		.183
36	107	6	2	----	3	-.596	2	----	2	----	3	-.857
						.593						.344
38	47	156	46	-.021	65	-.052	46	-.032	46	-.048	65	-.035
				.890		.682		.831		.752		.779
40	NA	276	46	.332(*)	57	-.014	46	.338(*)	46	.276	57	.290(*)
				.024		.918		.021		.063		.029

GFD(6)

Rel	Days	Def. count	N	WMC	N	Cyclo.	N	RFC	N	CBO	N	NCSS
				p-value		p-value		p-value		p-value		p-value
16	5	107	60	.423(**)	60	.432(**)	60	.723(**)	60	.658(**)	60	.646(**)
				.001		.001		.000		.000		.000
17	47	6	1	----	6	----	1	----	1	----	6	----
19	NA	51	27	.232	27	-.041	27	.264	27	.277	27	.193
				.243		.838		.184		.162		.335

Jguard (7)

Rel	Days	Def. count	N	WMC	N	Cyclo.	N	RFC	N	CBO	N	NCSS
				p-value		p-value		p-value		p-value		p-value
6	54	14	12	-.320	12	-.134	12	.000	12	-.372	12	-.048
				.311		.678		1.000		.233		.882
7	67	205	43	.355(*)	44	-.060	43	.244	43	.434(**)	44	.148
				.020		.696		.115		.004		.338
8	81	185	38	.343(*)	38	.529(**)	38	.613(**)	38	.576(**)	38	.458(**)
				.035		.001		.000		.000		.004
9	81	15	7	.119	7	.779(*)	7	.540	7	.255	7	.790(*)
				.799		.039		.211		.582		.035
10	NA	94	35	.116	37	-.164	35	-.037	35	-.048	37	-.128
				.508		.331		.831		.783		.449

JavaGroups (8)

Rel	Days	Def. count	N	WMC	N	Cyclo.	N	RFC	N	CBO	N	NCSS
				p-value		p-value		p-value		p-value		p-value
14	56	29	25	-.069	25	-.064	25	-.177	25	-.351	25	-.131
				.744		.761		.397		.085		.531
15	128	99	56	.380(**)	56	.342(**)	56	.439(**)	56	.351(**)	56	.364(**)
				.004		.010		.001		.008		.006
17	230	770	287	.439(**)	287	.391(**)	287	.511(**)	287	.337(**)	287	.512(**)
				.000		.000		.000		.000		.000
18	35	703	264	.438(**)	264	.368(**)	264	.497(**)	264	.347(**)	264	.484(**)
				.000		.000		.000		.000		.000
19	40	56	34	.143	34	.110	34	.225	34	.346(*)	34	.302
				.418		.535		.201		.045		.083
20	116	478	248	.092	248	.087	248	.112	248	.150(*)	248	.141(*)
				.147		.170		.078		.018		.026
21	NA	511	295	.300(**)	295	.424(**)	295	.400(**)	295	.399(**)	295	.428(**)
				.000		.000		.000		.000		.000

Itext (9)

Rel	Days	Def. count	N	WMC	N	Cyclo.	N	RFC	N	CBO	N	NCSS
				p-value		p-value		p-value		p-value		p-value
10	28	87	72	.341(**)	72	.479(**)	72	.495(**)	72	.480(**)	72	.513(**)
				.003		.000		.000		.000		.000
11	NA	35	31	.300	31	.459(**)	31	.321	31	.313	31	.390(*)
				.101		.009		.078		.086		.030

HtmlParser (10)

Rel	Days	Def. count	N	WMC	N	Cyclo.	N	RFC	N	CBO	N	NCSS
				p-value		p-value		p-value		p-value		p-value
2	323	13	10	.341	10	.045	10	.442	10	.496	10	.081
				.335		.901		.201		.145		.824
3	66	178	70	.480(**)	103	.440(**)	70	.420(**)	70	.266(*)	103	.341(**)
				.000		.000		.000		.026		.000
4	NA	177	53	.181	98	.383(**)	53	.279(*)	53	.629(**)	98	.375(**)
				.195		.000		.043		.000		.000

Azureus (11)

Rel	Days	Def. count	N	WMC	N	Cyclo.	N	RFC	N	CBO	N	NCSS
				p-value		p-value		p-value		p-value		p-value
5	NA	604	325	.573(**)	325	.142(*)	325	.545(**)	325	.470(**)	325	.526(**)
				.000		.011		.000		.000		.000

Jung (21)

Rel	Days	Def. count	N	WMC	N	Cyclo.	N	RFC	N	CBO	N	NCSS
				p-value		p-value		p-value		p-value		p-value
5	NA	17	13	-.204	13	-.105	13	-.055	13	.171	13	.217
				.505		.734		.858		.577		.476

HsqlDB (22)

Rel	Days	Def. count	N	WMC	N	Cyclo.	N	RFC	N	CBO	N	NCSS
				p-value		p-value		p-value		p-value		p-value
2	46	296	214	.255(**)	265	.376(**)	214	.381(**)	214	.469(**)	265	.491(**)
				.000		.000		.000		.000		.000
3	NA	263	200	.220(**)	251	.331(**)	200	.391(**)	200	.532(**)	251	.440(**)
				.002		.000		.000		.000		.000

Spring (23)

Rel	Days	Def. count	N	WMC	N	Cyclo.	N	RFC	N	CBO	N	NCSS
				p-value		p-value		p-value		p-value		p-value
4	53	703	356	.415(**)	446	.522(**)	356	.519(**)	356	.380(**)	446	.196(**)
				.000		.000		.000		.000		.000
5	27	308	192	.260(**)	235	.071	192	.277(**)	192	.290(**)	235	.094
				.000		.276		.000		.000		.151
6	31	502	347	.504(**)	364	.382(**)	347	.552(**)	347	.465(**)	364	.515(**)
				.000		.000		.000		.000		.000
7	NA	147	111	.043	131	.106	111	.108	111	.093	131	.113
				.656		.229		.260		.330		.199

WMCF (Release n)

Project	Very strong positive	Strong positive	Moderate positive	Weak positive	Negligible	None	Total
JasperReports		3		1		1	5
FindBugs			1			15	16
DrJava			1			5	6
GFD		1				2	3
Jguard			2			3	5
JavaGroups		2	2			3	7
Itext			1			1	2
HtmlParser		1				2	3
Azureus		1					1
Jung						1	1
HsqlDB				2			2
Spring		2		1		1	4
Total	0	10	7	4	0	34	55

WMCC (Release n)

Project	Very strong positive	Strong positive	Moderate positive	Weak positive	Negligible	None	Total
JasperReports	1	1	2	1			5
FindBugs						16	16
DrJava						6	6
GFD		1				2	3
Jguard	1	1				3	5
JavaGroups		1	3			3	7
Itext		2					2
HtmlParser		1	1			1	3
Azureus					1		1
Jung						1	1
HsqlDB			2				2
Spring		1	1			2	4
Total	2	8	9	1	1	34	55

RFC (Release n)

Project	Very strong positive	Strong positive	Moderate positive	Weak positive	Negligible	None	Total
JasperReports	2	2		1			5
FindBugs		1	2			13	16
DrJava			1			5	6
GFD	1					2	3
Jguard		1				4	5
JavaGroups		4				3	7
Itext		1				1	2
HtmlParser		1		1		1	3
Azureus		1					1
Jung						1	1
HsqlDB			2				2
Spring		2		1		1	4
Total	3	13	5	3	0	31	55

CBO (Release n)

Project	Very strong positive	Strong positive	Moderate positive	Weak positive	Negligible	None	Total
JasperReports		3		1		1	5
FindBugs		1	1			14	16
DrJava						6	6
GFD		1				2	3
Jguard		2				3	5
JavaGroups			5		1	1	7
Itext		1				1	2
HtmlParser		1		1		1	3
Azureus		1					1
Jung						1	1
HsqlDB		2					2
Spring		1	1	1		1	4
Total	0	13	7	3	1	31	55

Size (Release n)

Project	Very strong positive	Strong positive	Moderate positive	Weak positive	Negligible	None	Total
JasperReports	1	2	1	1			5
FindBugs			2	1	1	12	16
DrJava				1		5	6
GFD		1				2	3
Jguard	1	1				3	5
JavaGroups		3	1		1	2	7
Itext		1	1				2
HtmlParser			2			1	3
Azureus		1					1
Jung						1	1
HsqlDB		2					2
Spring		1			1	2	4
Total	2	12	7	3	3	28	55

Appendix I: Package correlation (only packages with release defects)

Package based hypothesis testing for release defects (Only packages with release defects). In the following analysis only packages with at least one release defects were considered.

JasperReports (2)

Rel	Days	Def. count	N	WMC	N	Cyclo.	N	RFC	N	CBO	N	NCSS
				p-value		p-value		p-value		p-value		p-value
7	9	51	12	.669(*)	13	.774(**)	12	.873(**)	12	.877(**)	13	.825(**)
				.017		.002		.000		.000		.001
8	35	435	15	.827(**)	18	.851(**)	15	.843(**)	15	.851(**)	18	.732(**)
				.000		.000		.000		.000		.001
9	12	704	14	.816(**)	18	.758(**)	14	.716(**)	14	.802(**)	18	.567(*)
				.000		.000		.004		.001		.014
10	37	127	8	.880(**)	10	.820(**)	8	.773(*)	8	.850(**)	10	.481
				.004		.004		.024		.008		.160
11	NA	336	16	.882(**)	16	.910(**)	16	.848(**)	16	.867(**)	16	.777(**)
				.000		.000		.000		.000		.000

FindBugs (3)

Rel	Days	Def. count	N	WMC	N	Cyclo.	N	RFC	N	CBO	N	NCSS
				p-value		p-value		p-value		p-value		p-value
18	2	2	1	-----	2	-----	1	-----	1	-----	2	-----
19	79	3	2	-----	2	-----	2	-----	2	-----	2	-----
20	4	302	11	.805(**)	16	.889(**)	11	.956(**)	11	.977(**)	16	.864(**)
				.003		.000		.000		.000		.000
21	39	3	3	-----	3	-----	3	-----	3	-----	3	-----
22	18	154	10	.783(**)	11	.761(**)	10	.466	10	.227	11	.659(*)
				.007		.007		.174		.528		.028
23	114	68	8	.866(**)	9	.821(**)	8	.838(**)	8	.628	9	.884(**)
				.005		.007		.009		.096		.002
24	75	129	6	.293	7	.564	6	.790	6	.939(**)	7	.635
				.573		.187		.061		.006		.126
25	59	123	7	.237	18	.696(**)	7	.678	7	.854(*)	18	.790(**)
				.608		.001		.094		.014		.000
26	4	187	9	.830(**)	10	.599	9	.988(**)	9	.821(**)	10	.782(**)
				.006		.067		.000		.007		.008
27	38	17	4	-.762	5	-.307	4	-.173	4	.172	5	-.137
				.238		.615		.827		.828		.826
28	5	61	4	-.040	5	.248	4	.477	4	.909	5	.407
				.960		.687		.523		.091		.496
29	1	9	2	----	3	----	2	----	2	----	3	----
30	28	18	3	-.992	4	-.053	3	-.566	3	.921	4	-.669

				.079		.947		.617		.255		.331
31	13	34	3	-.202	4	.486	3	.285	3	.888	4	.463
				.870		.514		.816		.304		.537
32	53	20	4	.201	5	-.002	4	.578	4	.971(*)	5	.457
				.799		.998		.422		.029		.439
33	NA	25	4	.788	5	.931(*)	4	.693	4	.372	5	.898(*)
				.212		.022		.307		.628		.039

DrJava (5)

Rel	Days	Def. count	N	WMC p-value	N	Cyclo. p-value	N	RFC p-value	N	CBO p-value	N	NCSS p-value
11	944	19	7	-.677	7	-.659	7	-.511	7	-.493	7	-.604
				.095		.108		.242		.261		.151
34	47	2325	18	.105	18	.090	18	.181	18	.138	18	.143
				.677		.723		.473		.585		.571
35	8	9	5	-.169	5	-.070	5	-.187	5	-.200	5	-.155
				.786		.911		.763		.747		.803
36	107	6	2	----	2	----	2	----	2	----	2	----
38	46	156	14	.083	14	-.205	14	.226	14	.008	14	-.052
				.778		.483		.437		.978		.861
40	NA	276	13	.402	13	-.085	13	.491	13	.398	13	.293
				.174		.783		.088		.178		.331

GFD(6)

Rel	Days	Def. count	N	WMC p-value	N	Cyclo. p-value	N	RFC p-value	N	CBO p-value	N	NCSS p-value
16	5	107	17	.369	17	.469	17	.813(**)	17	.896(**)	17	.823(**)
				.145		.058		.000		.000		.000
17	47	6	3	.995	4	.501	3	.997	3	1.000(*)	4	.623
				.065		.499		.051		.014		.377
19	NA	51	14	.365	14	.378	14	.682(**)	14	.712(**)	14	.662(**)
				.199		.183		.007		.004		.010

Jguard (7)

Rel	Days	Def. count	N	WMC p-value	N	Cyclo. p-value	N	RFC p-value	N	CBO p-value	N	NCSS p-value
6	54	14	8	.421	8	.376	8	.223	8	.086	8	.246
				.299		.359		.595		.839		.556
7	67	205	13	.589(*)	13	.440	13	.338	13	.437	13	.309
				.034		.133		.259		.135		.304
8	81	185	11	.560	11	.795(**)	11	.675(*)	11	.639(*)	11	.666(*)
				.073		.003		.023		.034		.025
9	81	15	5	.934(*)	5	.990(**)	5	.986(**)	5	.985(**)	5	.989(**)
				.020		.001		.002		.002		.001
10	NA	94	9	.798(**)	10	.761(*)	9	.861(**)	9	.730(*)	10	.615

				.010		.011		.003		.026		.059
--	--	--	--	------	--	------	--	------	--	------	--	------

JavaGroups (8)

Rel	Days	Def. count	N	WMC	N	Cyclo.	N	RFC	N	CBO	N	NCSS
				p-value		p-value		p-value		p-value		p-value
14	56	29	8	.815(*)	8	.810(*)	8	.757(*)	8	.729(*)	8	.742(*)
				.014		.015		.030		.040		.035
15	128	99	13	.620(*)	13	.720(**)	13	.626(*)	13	.547	13	.665(*)
				.024		.005		.022		.053		.013
17	230	770	21	.950(**)	21	.954(**)	21	.964(**)	21	.921(**)	21	.966(**)
				.000		.000		.000		.000		.000
18	35	703	17	.898(**)	17	.977(**)	17	.875(**)	17	.810(**)	17	.909(**)
				.000		.000		.000		.000		.000
19	40	56	9	.529	9	.598	9	.427	9	.477	9	.471
				.143		.089		.252		.194		.200
20	116	478	20	.927(**)	20	.850(**)	20	.965(**)	20	.962(**)	20	.947(**)
				.000		.000		.000		.000		.000
21	NA	511	19	.930(**)	19	.967(**)	19	.953(**)	19	.925(**)	19	.972(**)
				.000		.000		.000		.000		.000

Itext (9)

Rel	Days	Def. count	N	WMC	N	Cyclo.	N	RFC	N	CBO	N	NCSS
				p-value		p-value		p-value		p-value		p-value
10	28	87	11	.917(**)	11	.917(**)	11	.947(**)	11	.950(**)	11	.928(**)
				.000		.000		.000		.000		.000
11	NA	35	5	.499	5	.494	5	.549	5	.565	5	.496
				.392		.398		.338		.320		.395

HtmlParser (10)

Rel	Days	Def. count	N	WMC	N	Cyclo.	N	RFC	N	CBO	N	NCSS
				p-value		p-value		p-value		p-value		p-value
2	323	13	6	.039	6	.369	6	-.187	6	-.328	6	.203
				.941		.471		.723		.525		.699
3	66	178	11	.613(*)	19	.714(**)	11	.437	11	.451	19	.396
				.045		.001		.179		.163		.094
4	NA	177	10	.463	18	.431	10	.245	10	.957(**)	18	.456
				.178		.074		.495		.000		.057

Azureus (11)

Rel	Days	Def. count	N	WMC	N	Cyclo.	N	RFC	N	CBO	N	NCSS
				p-value		p-value		p-value		p-value		p-value
5	NA	604	132	.630(**)	132	.481(**)	132	.623(**)	132	.577(**)	132	.650(**)
				.000		.000		.000		.000		.000

Jung (21)

Rel	Days	Def. count	N	WMC	N	Cyclo.	N	RFC	N	CBO	N	NCSS
				p-value		p-value		p-value		p-value		p-value
5	NA	17	6	.064	6	-.062	6	.137	6	.172	6	.129
				.904		.908		.796		.744		.808

HsqlDB (22)

Rel	Days	Def. count	N	WMC	N	Cyclo.	N	RFC	N	CBO	N	NCSS
				p-value		p-value		p-value		p-value		p-value
2	46	296	12	.965(**)	14	.964(**)	12	.984(**)	12	.946(**)	14	.980(**)
				.000		.000		.000		.000		.000
3	NA	263	12	.940(**)	14	.927(**)	12	.966(**)	12	.958(**)	14	.881(**)
				.000		.000		.000		.000		.000

Spring (23)

Rel	Days	Def. count	N	WMC	N	Cyclo.	N	RFC	N	CBO	N	NCSS
				p-value		p-value		p-value		p-value		p-value
4	53	703	97	.587(**)	104	.670(**)	97	.638(**)	97	.493(**)	104	.561(**)
				.000		.000		.000		.000		.000
5	27	308	71	.435(**)	74	.322(**)	71	.405(**)	71	.408(**)	74	.372(**)
				.000		.005		.000		.000		.001
6	31	502	95	.781(**)	96	.755(**)	95	.802(**)	95	.671(**)	96	.656(**)
				.000		.000		.000		.000		.000
7	NA	147	59	.306(*)	62	.307(*)	59	.315(*)	59	.233	62	.261(*)
				.018		.015		.015		.076		.040

Note:

** Correlation is significant at the 0.01 level (2-tailed).

* Correlation is significant at the 0.05 level (2-tailed).

In the following tables, the correlation significance was ignored. Only correlation value was considered. Considering both would have made different release comparison very complicated.

WMCF (Release n)

Project	Very strong positive	Strong positive	Moderate positive	Weak positive	Negligible	None	Total
JasperReports	4	1					5
FindBugs	4					12	16
DrJava						6	6
GFD						3	3
Jguard	2	1				2	5
JavaGroups	5	1				1	7
Itext	1					1	2
HtmlParser		1				2	3
Azureus		1					1
Jung						1	1
HsqlDB	2						2
Spring	1	2	1				4
Total	19	7	1	0	0	28	55

WMCC (Release n)

Project	Very strong positive	Strong positive	Moderate positive	Weak positive	Negligible	None	Total
JasperReports	5						5
FindBugs	4	1				11	16
DrJava						6	6
GFD						3	3
Jguard	3					2	5
JavaGroups	6					1	7
Itext	1					1	2
HtmlParser	1					2	3
Azureus		1					1
Jung						1	1
HsqlDB	2						2
Spring	1	1	2				4
Total	23	3	2	0	0	27	55

RFC (Release n)

Project	Very strong positive	Strong positive	Moderate positive	Weak positive	Negligible	None	Total
JasperReports	5						5
FindBugs	3					13	16
DrJava						6	6
GFD	2					1	3
Jguard	2	1				2	5
JavaGroups	5	1				1	7
Itext	1					1	2
HtmlParser						3	3
Azureus		1					1
Jung						1	1
HsqlDB	2						2
Spring	1	2	1				4
Total	21	5	1	0	0	28	55

CBO (Release n)

Project	Very strong positive	Strong positive	Moderate positive	Weak positive	Negligible	None	Total
JasperReports	5						5
FindBugs	5					11	16
DrJava						6	6
GFD	3						3
Jguard	2	1				2	5
JavaGroups	5					2	7
Itext	1					1	2
HtmlParser	1					2	3
Azureus		1					1
Jung						1	1
HsqlDB	2						2
Spring		3				1	4
Total	24	5	0	0	0	26	55

Size (Release n)

Project	Very strong positive	Strong positive	Moderate positive	Weak positive	Negligible	None	Total
JasperReports	3	1				1	5
FindBugs	5	1				10	16
DrJava						6	6
GFD	1	1				1	3
Jguard	1	1				3	5
JavaGroups	5	1				1	7
Itext	1					1	2
HtmlParser						3	3
Azureus		1					1
Jung						1	1
HsqlDB	2						2
Spring		2	1	1			4
Total	18	8	1	1	0	27	55

Appendix J: Martin's metrics – defect density

1: Package dependency cycles

Project	Release	N	Acc Def	Rel Def	Total cycle count	Total lines	%	Acc Def Density	Release Def Density
2	7	1	3	0	0	246	1	12.19512	0
		26	6615	50	141	42628	99	155.1797	1.172938
	8	1	3	0	0	246	1	12.19512	0
		20	6302	413	94	30768	99	204.8232	13.42304
	9	1	3	0	0	246	1	12.19512	0
		19	5876	682	88	30305	99	193.8954	22.50454
	10	1	3	0	0	246	1	12.19512	0
		19	5194	117	88	30189	99	172.0494	3.875584
3	11	1	3	0	0	246	1	12.19512	0
		19	5042	310	90	28697	99	175.6978	10.80252
	18	3	15	0	0	214	3	70.09346	0
		18	1375	1	80	7776	97	176.8261	0.128601
	19	3	22	0	0	214	3	102.8037	0
		18	1374	3	80	7777	97	176.6748	0.385753
	20	3	31	4	0	360	4	86.11111	11.11111
		18	1538	231	75	8635	96	178.1123	26.75159
	21	3	27	0	0	360	4	75	0
		18	1307	3	75	8609	96	151.8179	0.348473
	22	3	27	0	0	360	4	75	0
		14	1338	122	60	8818	96	151.7351	13.83534
	23	3	27	0	0	360	4	75	0
		14	1241	47	59	8838	96	140.4164	5.317945
	24	3	27	1	0	360	5	75	2.777778
		8	1152	104	32	7574	95	152.0993	13.73119
	25	3	42	2	0	593	8	70.82631	3.372681
		7	1045	60	27	7083	92	147.5364	8.470987
	26	3	40	4	0	587	8	68.1431	6.81431
		6	978	174	23	6708	92	145.7961	25.93918
	27	3	36	0	0	578	8	62.28374	0
		6	804	12	23	6700	92	120	1.791045
	28	5	360	8	0	2755	46	130.6715	2.903811
		3	428	42	14	3220	54	132.9193	13.04348
	29	5	352	0	0	2751	46	127.9535	0
		3	386	8	14	3220	54	119.8758	2.484472
	30	5	352	1	0	2751	46	127.9535	0.363504
		3	378	3	14	3208	54	117.8304	0.935162

	31	5	251	1	0	2691	46	93.27388	0.371609
		3	374	30	14	3066	54	121.983	9.784736
	32	5	357	4	0	3033	51	117.7052	1.318826
		3	342	14	14	2881	49	118.7088	4.859424
	33	5	345	10	0	2673	51	129.0685	3.741115
5		3	324	10	14	2558	49	126.6615	3.909304
	11	10	813	2	0	4618	31	176.0502	0.433088
		15	2859	17	64	10193	69	280.4866	1.667811
	34	8	833	505	0	4247	32	196.1385	118.9075
		11	3019	1820	43	8970	68	336.5663	202.8986
	35	8	328	2	0	4246	32	77.24918	0.471032
		11	1198	7	43	8950	68	133.8547	0.782123
	36	8	326	0	0	4246	32	76.77814	0
		11	1191	6	43	8924	68	133.4603	0.672344
	38	8	326	4	0	4217	34	77.30614	0.948542
		11	1193	152	43	8251	66	144.5885	18.42201
	40	8	306	15	0	3867	29	79.13111	3.878976
		10	1302	261	43	9268	71	140.4834	28.16142
6	16	11	133	4	0	2391	15	55.62526	1.67294
		21	810	103	115	14098	85	57.45496	7.306001
	17	11	129	2	0	2391	15	53.95232	0.83647
		21	707	2	115	14032	85	50.38483	0.142531
	19	16	272	9	0	6716	43	40.5003	1.340083
		14	527	42	78	8868	57	59.42715	4.73613
7	6	6	133	5	0	1446	25	91.97787	3.457815
		8	439	8	42	4266	75	102.9067	1.875293
	7	6	125	41	0	1198	24	104.3406	34.22371
		6	424	161	28	3698	76	114.6566	43.53705
	8	4	62	33	0	596	17	104.0268	55.36913
		6	232	138	28	2896	83	80.1105	47.65193
	9	4	29	3	0	573	17	50.61082	5.235602
		6	93	12	28	2765	83	33.63472	4.339964
	10	3	23	23	0	378	15	60.84656	60.84656
		6	68	68	28	2180	85	31.19266	31.19266
8	14	--	--	--	--	--	--	--	--
		24	3411	29	99	60102	100	56.75352	0.482513
	15	--	--	--	--	--	--	--	--
		26	3389	99	107	59659	100	56.80618	1.659431
	17	1	30	12	0	489	1	61.34969	24.53988
		22	3154	758	89	54937	99	57.41122	13.79762
	18	1	18	2	0	481	1	37.42204	4.158004
		23	2450	701	93	55670	99	44.00934	12.59206
	19	1	16	1	0	480	1	33.33333	2.083333

		23	1746	55	93	53952	99	32.3621	1.019425
	20	1	15	2	0	480	1	31.25	4.166667
		23	1690	476	93	53772	99	31.429	8.852191
	21	2	13	2	0	1180	2	11.01695	1.694915
		23	1226	509	93	53091	98	23.09243	9.587312
9	10	3	57	0	0	1981	3	28.77335	0
		24	9287	87	107	60561	97	153.3495	1.436568
	11	3	57	0	0	1981	3	28.77335	0
		23	9189	35	104	59938	97	153.3084	0.583937
10	2	2	37	0	0	320	2	115.625	0
		16	2821	13	63	13715	98	205.6872	0.947867
	3	2	33	0	0	219	3	150.6849	0
		12	2943	130	47	8517	97	345.5442	15.26359
	4	2	33	0	0	219	3	150.6849	0
		12	2813	93	47	8513	97	330.4358	10.92447
11	5	48	482	21	0	11509	9	41.88027	1.824659
		287	10973	583	1681	112369	91	97.65149	5.188264
21	5	1	5	0	0	15	0	333.3333	0
		39	2886	17	192	24129	100	119.6071	0.704546
22	2	1	1	1	0	32	0	31.25	31.25
		10	635	251	53	39466	100	16.0898	6.359905
	3	1	1	1	0	32	0	31.25	31.25
		10	597	218	53	39404	100	15.15075	5.532433
23	4	136	10958	687	0	101322	--	108.1503	6.780364
		--	--	--	--	--	--	--	--
	5	136	10252	299	0	98883	--	103.6781	3.023776
		--	--	--	--	--	--	--	--
	6	136	9937	501	0	97557	--	101.8584	5.135459
		--	--	--	--	--	--	--	--
	7	135	9423	144	0	96458	--	97.69019	1.492878
		--	--	--	--	--	--	--	--

2: Stable-Dependencies Principle

Project	Release	N	Acc Def	Rel Def	SDP broken count	Total lines	%	Acc Def Density	Rel Def Density
2	7	15	1607	12	0	11870	28	135.3833	1.010952
		12	5011	38	30	31004	72	161.6243	1.225648
	8	13	1558	122	0	10433	34	149.3338	11.69366
		8	4747	291	19	20581	66	230.6496	14.13925
	9	12	1428	176	0	10146	33	140.7451	17.34674
		8	4451	506	19	20405	67	218.1328	24.79784
	10	12	1252	15	0	10143	33	123.4349	1.478852
		8	3945	102	19	20292	67	194.4116	5.026611
	11	12	1206	84	0	9096	31	132.5858	9.234828
		8	3839	226	18	19847	69	193.4297	11.38711
3	18	12	794	0	0	4707	59	168.6849	0
		9	603	1	14	3283	41	183.6735	0.304599
	19	12	794	1	0	4707	59	168.6849	0.21245
		9	602	2	14	3284	41	183.313	0.609013
	20	12	921	171	0	5723	64	160.9296	29.87943
		9	648	64	14	3272	36	198.044	19.5599
	21	12	750	1	0	5723	64	131.0501	0.174734
		9	584	2	14	3246	36	179.9137	0.616143
	22	11	603	48	0	5315	58	113.4525	9.031044
		6	762	74	9	3863	42	197.256	19.1561
	23	13	688	19	0	5639	61	122.0074	3.369392
		4	580	28	7	3559	39	162.9671	7.867378
	24	9	628	76	0	4748	60	132.2662	16.00674
		2	551	29	2	3186	40	172.9441	9.102323
	25	9	859	59	0	6076	79	141.3759	9.710336
		1	228	3	1	1600	21	142.5	1.875
	26	8	793	143	0	5704	78	139.0252	25.07013
		1	225	35	1	1582	22	142.225	22.12389
	27	8	650	11	0	5696	78	114.1152	1.93118
		1	190	1	1	1582	22	120.1011	0.632111
	28	8	788	50	0	5975	--	131.8828	8.368201
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	29	8	738	8	0	5971	--	123.5974	1.339809
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	30	8	730	4	0	5959	--	122.5038	0.671254
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	31	8	725	31	0	5757	--	125.9336	5.384749
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	32	8	699	18	0	5914	--	118.1941	3.043625
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	33	8	699	20	0	5231	--	133.6265	3.823361
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5	11	16	1352	9	0	7386	50	183.049	1.218522
		9	2320	10	21	7425	50	312.4579	1.346801
	34	14	1906	1142	0	8169	62	233.3211	139.7968
		5	1946	1183	14	5048	38	385.4992	234.3502
	35	14	866	3	0	9629	73	89.93665	0.311559
		5	660	6	14	3567	27	185.0294	1.682086
	36	14	863	0	0	9604	73	89.85839	0
		5	654	6	14	3566	27	183.3988	1.682557
	38	15	898	76	0	9554	77	93.99205	7.954783
		4	621	80	13	2914	23	213.1091	27.45367
	40	15	1032	151	0	10755	82	95.95537	14.03998
		3	576	125	9	2380	18	242.0168	52.52101
6	16	24	612	74	0	12395	75	49.37475	5.970149
		8	331	33	9	4094	25	80.85002	8.060576
	17	24	538	4	0	12403	76	43.3766	0.322503
		13	298	0	9	4020	24	74.12935	0
	19	24	536	30	0	12560	81	42.67516	2.388535
		13	263	21	6	3024	19	86.9709	6.944444
7	6	13	569	12	0	5656	99	100.6011	2.121641
		1	3	1	1	56	1	53.57143	17.85714
	7	12	549	202	0	4896	--	112.1324	41.25817
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	8	9	253	145	0	3089	88	81.90353	46.94076
		1	41	26	1	403	12	101.737	64.51613
	9	8	101	12	0	2700	81	37.40741	4.444444
		6	21	3	2	638	19	32.91536	4.702194
	10	8	90	90	0	2425	95	37.1134	37.1134
		1	1	1	1	133	5	7.518797	7.518797
8	14	18	1203	11	0	23119	38	52.03512	0.475799
		6	2208	18	13	36983	62	59.70311	0.48671
	15	20	1202	38	0	23233	39	51.73675	1.635605
		6	2187	61	13	36426	61	60.03953	1.674628
	17	18	1361	310	0	26947	49	50.50655	11.50406
		5	1823	460	12	28479	51	64.01208	16.15225
	18	19	1134	234	0	29007	52	39.09401	8.067018
		5	1334	469	11	27144	48	49.1453	17.27822
	19	20	1020	33	0	32186	59	31.6908	1.02529
		4	742	23	11	22246	41	33.35431	1.033894
	20	20	987	268	0	32097	59	30.75054	8.34969

		4	718	210	11	22155	41	32.40803	9.478673
	21	21	729	274	0	32605	60	22.35853	8.403619
		4	510	237	11	21666	40	23.53919	10.9388
9	10	20	1137	36	0	18154	29	62.63083	1.983034
		7	8207	51	23	44388	71	184.8923	1.148959
	11	18	1076	15	0	17349	28	62.02087	0.864603
		8	8170	20	23	44570	72	183.3072	0.448732
10	2	11	660	0	0	7303	52	90.37382	0
		7	2198	13	20	6732	48	326.5003	1.931075
	3	9	964	56	0	3830	44	251.6971	14.62141
		5	2012	74	14	4906	56	410.1101	15.08357
	4	9	908	39	0	3824	44	237.4477	10.19874
		5	1938	54	14	4908	56	394.8655	11.00244
11	5	225	5561	290	0	76646	62	72.55434	3.783629
		110	5894	314	204	47232	38	124.7883	6.648035
21	5	27	1379	4	0	13760	57	100.218	0.290698
		13	1512	13	28	10384	43	145.6086	1.251926
22	2	7	103	93	0	14084	36	7.313263	6.603238
		4	533	159	6	25414	64	20.97269	6.256394
	3	7	97	87	0	14075	36	6.891652	6.181172
		4	501	132	6	25361	64	19.75474	5.204842
23	4	119	8118	549	0	80860	80	100.3957	6.789513
		17	2840	138	25	20462	20	138.7939	6.744209
	5	119	7550	250	0	78731	80	95.89615	3.175369
		17	2702	49	25	20152	20	134.081	2.43152
	6	119	7282	361	0	77469	80	93.99889	4.659928
		17	2655	140	25	20088	20	132.1685	6.969335
	7	118	6910	113	0	76722	80	90.06543	1.47285
		17	2513	31	25	19736	20	127.3308	1.570734

3: D Metrics

Project	Release	N	Acc Def	Rel Def	D metrics	Total lines	%	Acc Def Density	Rel Def Density
2	7	24	5811	43	$D < 0.5$	36074	84	161.0855	1.191994
		3	807	7	$D \geq 0.5$	6800	16	118.6765	1.029412
	8	18	5536	360	$D < 0.5$	25318	82	218.6587	14.21913
		3	767	53	$D \geq 0.5$	5696	18	134.6559	9.304775
	9	17	5167	639	$D < 0.5$	24932	82	207.2437	25.62971
		3	712	43	$D \geq 0.5$	5619	18	126.7129	7.652607
	10	17	4528	107	$D < 0.5$	24911	82	181.7671	4.295291
		3	669	10	$D \geq 0.5$	5524	18	121.1079	1.810282
	11	17	4386	284	$D < 0.5$	23571	81	186.0761	12.0487
		3	659	26	$D \geq 0.5$	5372	19	122.6731	4.839911
3	18	17	1388	1	$D < 0.5$	7912	99	175.4297	0.12639
		4	9	0	$D \geq 0.5$	78	1	115.3846	0
	19	17	1387	3	$D < 0.5$	7913	99	175.2812	0.379123
		4	9	0	$D \geq 0.5$	78	1	115.3846	0
	20	14	1512	231	$D < 0.5$	8504	95	177.7987	27.16369
		7	57	4	$D \geq 0.5$	491	5	116.0896	8.14664
	21	14	1281	2	$D < 0.5$	8478	95	151.097	0.235905
		7	53	1	$D \geq 0.5$	491	5	107.943	2.03666
	22	12	1354	121	$D < 0.5$	9064	99	149.3822	13.34951
		5	11	1	$D \geq 0.5$	114	1	96.49123	8.77193
	23	11	1023	38	$D < 0.5$	7404	80	138.1686	5.132361
		6	245	9	$D \geq 0.5$	1794	20	136.5663	5.016722
	24	8	938	99	$D < 0.5$	6208	78	151.0954	15.94716
		3	241	6	$D \geq 0.5$	1726	22	139.6292	3.476246
	25	7	836	57	$D < 0.5$	5781	75	144.6117	9.859886
		3	251	5	$D \geq 0.5$	1895	25	132.4538	2.638522
	26	6	772	141	$D < 0.5$	5424	74	142.3304	25.99558
		3	246	37	$D \geq 0.5$	1862	26	132.116	19.87111
	27	6	631	11	$D < 0.5$	5416	74	116.5066	2.031019
		3	209	1	$D \geq 0.5$	1862	26	112.2449	0.537057
	28	5	572	42	$D < 0.5$	4087	68	139.956	10.27649
		3	216	8	$D \geq 0.5$	1888	32	114.4068	4.237288
	29	5	530	8	$D < 0.5$	4087	68	129.6795	1.957426
		3	208	0	$D \geq 0.5$	1884	32	110.4034	0
	30	5	522	3	$D < 0.5$	4075	68	128.0982	0.736196
		3	208	1	$D \geq 0.5$	1884	32	110.4034	0.530786
	31	5	518	31	$D < 0.5$	3889	68	133.1962	7.971201
		3	207	0	$D \geq 0.5$	1868	32	110.8137	0
	32	5	492	14	$D < 0.5$	4062	69	121.1226	3.446578

5		3	207	4	$D \geq 0.5$	1862	31	111.1708	2.148228
	33	5	474	10	$D < 0.5$	3717	71	127.5222	2.690342
		3	195	0	$D \geq 0.5$	1514	29	128.7979	0
	11	18	2915	17	$D < 0.5$	10508	71	277.4077	1.617815
		7	757	2	$D \geq 0.5$	4303	29	175.9238	0.464792
	34	13	3395	1972	$D < 0.5$	11965	91	283.7443	164.814
		6	457	353	$D \geq 0.5$	1252	9	365.016	281.9489
	35	13	1422	7	$D < 0.5$	11945	91	119.0456	0.586019
		6	104	2	$D \geq 0.5$	1251	9	83.13349	1.598721
	36	13	1415	6	$D < 0.5$	11919	91	118.718	0.503398
		6	102	0	$D \geq 0.5$	1251	9	81.53477	0
	38	13	1417	154	$D < 0.5$	11228	90	126.2024	13.71571
		6	102	2	$D \geq 0.5$	1240	10	82.25806	1.612903
	40	12	1524	262	$D < 0.5$	12247	93	124.4386	21.39299
6		6	84	14	$D \geq 0.5$	888	7	94.59459	15.76577
	16	20	631	93	$D < 0.5$	10368	63	60.86034	8.969907
		12	312	14	$D \geq 0.5$	6121	37	50.97206	2.287208
	17	20	538	0	$D < 0.5$	10302	63	52.22287	0
		12	298	4	$D \geq 0.5$	6121	37	48.68486	0.653488
	19	20	541	41	$D < 0.5$	10480	67	51.62214	3.912214
7		10	258	10	$D \geq 0.5$	5104	33	50.54859	1.959248
	6	7	436	7	$D < 0.5$	4210	74	103.5629	1.662708
		3	136	6	$D \geq 0.5$	1502	27	90.54594	3.994674
	7	6	424	161	$D < 0.5$	3698	76	114.6566	43.53705
		6	125	41	$D \geq 0.5$	1198	24	104.3406	34.22371
	8	6	232	138	$D < 0.5$	2896	83	80.1105	47.65193
		4	62	33	$D \geq 0.5$	596	17	104.0268	55.36913
	9	6	93	12	$D < 0.5$	2765	83	33.63472	4.339964
		4	29	3	$D \geq 0.5$	573	17	50.61082	5.235602
	10	5	67	67	$D < 0.5$	2047	80	32.73083	32.73083
8		4	24	24	$D \geq 0.5$	511	20	46.96673	46.96673
	14	19	2876	24	$D < 0.5$	50970	85	56.42535	0.470865
		5	535	5	$D \geq 0.5$	9132	15	58.58519	0.547525
	15	20	2666	85	$D < 0.5$	49110	82	54.2863	1.730808
		6	723	14	$D \geq 0.5$	10549	18	68.5373	1.32714
	17	19	2545	617	$D < 0.5$	45793	83	55.57618	13.47368
		4	639	153	$D \geq 0.5$	9633	17	66.33448	15.8829
	18	20	1986	541	$D < 0.5$	46838	83	42.40147	11.55045
		4	482	162	$D \geq 0.5$	9313	17	51.75561	17.39504
	19	20	1442	42	$D < 0.5$	45132	83	31.95072	0.930604
		4	320	14	$D \geq 0.5$	9300	17	34.4086	1.505376
	20	20	1400	390	$D < 0.5$	45045	83	31.08003	8.658009
		4	305	88	$D \geq 0.5$	9207	17	33.12697	9.557945

9	21	21	1081	449	$D < 0.5$	46374	85	23.31048	9.682149
		4	158	62	$D \geq 0.5$	7897	15	20.0076	7.851083
	10	18	1736	30	$D < 0.5$	15395	25	112.7639	1.948685
		9	7608	57	$D \geq 0.5$	47147	75	161.3676	1.208985
	11	17	1696	14	$D < 0.5$	14933	24	113.574	0.937521
10		9	7550	21	$D \geq 0.5$	46986	76	160.6862	0.446942
	2	13	1316	6	$D < 0.5$	9870	70	133.3333	0.607903
		5	1542	7	$D \geq 0.5$	4165	30	370.2281	1.680672
	3	9	1731	62	$D < 0.5$	5134	59	337.164	12.07635
		5	1245	68	$D \geq 0.5$	3602	41	345.6413	18.8784
	4	9	1669	58	$D < 0.5$	5128	59	325.468	11.31045
11		5	1177	35	$D \geq 0.5$	3604	41	326.5816	9.711432
	5	296	9871	534	$D < 0.5$	102790	83	96.03074	5.195058
		39	1584	70	$D \geq 0.5$	21088	17	75.11381	3.319423
	21	5	2745	17	$D < 0.5$	23254	96	118.0442	0.731057
		6	146	0	$D \geq 0.5$	890	4	164.0449	0
22	2	6	589	207	$D < 0.5$	35994	94	16.36384	5.750958
		5	47	45	$D \geq 0.5$	2488	6	18.89068	18.08682
	3	6	552	175	$D < 0.5$	35932	94	15.36235	4.870311
		5	46	44	$D \geq 0.5$	2488	6	18.48875	17.68489
23	4	109	9270	539	$D < 0.5$	86613	85	107.0278	6.223084
		27	1688	148	$D \geq 0.5$	14709	15	114.7597	10.06187
	5	109	8714	265	$D < 0.5$	84388	85	103.2611	3.140257
		27	1538	34	$D \geq 0.5$	14495	15	106.1056	2.345636
	6	108	8419	432	$D < 0.5$	83166	85	101.2313	5.19443
		28	1518	69	$D \geq 0.5$	14391	15	105.4826	4.794663
	7	106	7937	120	$D < 0.5$	81978	85	96.81866	1.463807
		29	1486	24	$D \geq 0.5$	14480	15	102.6243	1.657459

Appendix K: Martin's metrics, package correlation (only packages with release defects)

Package based hypothesis testing for release defects (Only packages with release defects). In the following analysis only packages with at least one release defects were considered.

JasperReports (2)

Rel	Days	Def. count	N	CC+CA & WMC	N	Defect & CC+CA	N	CBO & Ce	N	Defect & Ce
				p-value		p-value		p-value		p-value
7	9	51	12	.870(**)		.788(**)		.925(**)		.808(**)
				.000		.002		.000		.001
8	35	435	15	.895(**)		.798(**)		.903(**)		.794(**)
				.000		.000		.000		.000
9	12	704	14	.888(**)		.646(*)		.901(**)		.668(**)
				.000		.013		.000		.009
10	37	127	8	.858(**)		-----		.899(**)		.856(**)
				.006				.002		.007
11	NA	336	14	.903(**)		.843(**)		.900(**)		.764(**)
				.000		.000		.000		.001

FindBugs (3)

Rel	Days	Def. count	N	CC+CA & WMC	N	Defect & CC+CA	N	CBO & Ce	N	Defect & Ce
				p-value		p-value		p-value		p-value
18	2	2	1	-----	1	-----	1	-----	1	-----
19	79	3	2	1.000(**)	2	1.000(**)	2	1.000(**)	2	1.000(**)
				.		.		.		.
20	4	302	11	.832(**)	11	-----	11	.654(*)	11	.729(*)
				.002				.029		.011
21	39	3	3	1.000(**)	3	-----	3	-----	3	-----
				.007						
22	18	154	10	.864(**)	10	-----	10	-----	10	-----
				.001						
23	114	68	8	.844(**)	8	.818(*)	8	-----	8	.922(**)
				.008		.013				.001
24	75	129	6	-----	6	-----	6	-----	6	-----
25	59	123	7	.826(*)	7	-----	7	-----	7	-----
				.022						
26	4	187	9	.773(*)	9	.792(*)	9	-----	9	.897(**)
				.015		.011				.001
27	38	17	4	-----	4	-.987(*)	4	-----	4	-----
						.013				
28	5	61	4	-----	4	-----	4	-----	4	-----

29	1	9	2	1.000(**)	2	-1.000(**)	2	-1.000(**)	2	-1.000(**)
				.		.		.		.
30	28	18	3	----	3	----	3	----	3	----
31	13	34	3	----	3	----	3	----	3	----
32	53	20	4	-----	4	-----	4	-----	4	-----
33	NA	25	4	-----	4	.998(**)	4	-----	4	-----
						.002				

DrJava (5)

Rel	Days	Def. count	N	CC+CA & WMC	N	Defect & CC+CA	N	CBO & Ce	N	Defect & Ce
				p-value		p-value		p-value		p-value
11	944	19	7	.772(*)	7	----	7	----	7	----
				.042						
34	47	2325	18	.623(**)	18	----	18	----	18	----
				.006						
35	8	9	5	.980(**)	5	----	5	----	5	----
				.003						
36	107	6	2	1.000(**)	2	-1.000(**)	2	1.000(**)	2	-1.000(**)
				.		.		.		.
38	46	156	14	.575(*)	14	----	14	----	14	----
				.032						
40	NA	276	13	.837(**)	13	----	13	----	13	----
				.000						

GFD(6)

Rel	Days	Def. count	N	CC+CA & WMC	N	Defect & CC+CA	N	CBO & Ce	N	Defect & Ce
				p-value		p-value		p-value		p-value
16	5	107	17	.894(**)	17	.523(*)	17	.863(**)	17	.838(**)
				.000		.031		.000		.000
17	47	6	3	.999(*)	3	.998(*)	3	1.000(*)	3	1.000(**)
				.027		.039		.014		.000
19	NA	51	14	.963(**)	14	----	14	.749(**)	14	.702(**)
				.000				.002		.005

Jguard (7)

Rel	Days	Def. count	N	CC+CA & WMC	N	Defect & CC+CA	N	CBO & Ce	N	Defect & Ce
				p-value		p-value		p-value		p-value
6	54	14	7	.934(**)	7	----	7	.766(*)	7	----
				.002				.045		

7	67	205	12	.941(**)	12	----	12	.769(**)	12	----
				.000				.003		
8	81	185	10	.871(**)	10	----	10	.718(*)	10	----
				.001				.019		
9	81	15	5	.979(**)	5	.976(**)	5	----	5	----
				.004						
10	NA	94	9	.864(**)	9	.767(*)	9	.679(*)	9	----
				.003				.044		

JavaGroups (8)

Rel	Days	Def. count	N	CC+CA & WMC	N	Defect & CC+CA	N	CBO & Ce	N	Defect & Ce
				p-value		p-value		p-value		p-value
14	56	29	8	.932(**)	8	----	8	.957(**)	8	----
				.001				.000		
15	128	99	13	.956(**)	13	----	13	.930(**)	13	----
				.000				.000		
17	230	770	21	.968(**)	21	.905(**)	21	.877(**)	21	.772(**)
				.000				.000		.000
18	35	703	17	.937(**)	17	.713(**)	17	.867(**)	17	.648(**)
				.000				.000		.005
19	40	56	9	.916(**)	9	----	9	.821(**)	9	----
				.001				.007		
20	116	478	20	.941(**)	20	.965(**)	20	.843(**)	20	.807(**)
				.000				.000		.000
21	NA	511	19	.945(**)	19	.859(**)	19	.843(**)	19	.690(**)
				.000				.000		.001

Itext (9)

Rel	Days	Def. count	N	CC+CA & WMC	N	Defect & CC+CA	N	CBO & Ce	N	Defect & Ce
				p-value		p-value		p-value		p-value
10	28	87	11	.889(**)	11	.811(**)	11	----	11	----
				.000						
11	NA	35	5	.991(**)	5	----	5	----	5	.916(*)
				.001						.029

HtmlParser (10)

Rel	Days	Def. count	N	CC+CA & WMC	N	Defect & CC+CA	N	CBO & Ce	N	Defect & Ce
				p-value		p-value		p-value		p-value
2	323	13	6	----	6	----	6	----	6	----
3	66	178	11	.779(**)	11	----	11	.805(**)	11	----

				.005				.003		
4	NA	177	10	.795(**)	10	.679(*)	10	.866(**)	10	.791(**)
				.006		.031		.001		.006

Azureus (11)

Rel	Days	Def. count	N	CC+CA & WMC	N	Defect & CC+CA	N	CBO & Ce	N	Defect & Ce
				p-value		p-value		p-value		p-value
5	NA	604	132	.730(**)	132	.522(**)	132	.730(**)	132	.421(**)
				.000		.000		.000		.000

Jung (21)

Rel	Days	Def. count	N	CC+CA & WMC	N	Defect & CC+CA	N	CBO & Ce	N	Defect & Ce
				p-value		p-value		p-value		p-value
5	NA	17	6	----	6	----	6	.908(*)	6	----
								.012		

HsqlDB (22)

Rel	Days	Def. count	N	CC+CA & WMC	N	Defect & CC+CA	N	CBO & Ce	N	Defect & Ce
				p-value		p-value		p-value		p-value
2	46	296	11	.890(**)	11	.972(**)	11	.866(**)	11	.791(**)
				.000		.000		.001		.004
3	NA	263	11	.890(**)	11	.991(**)	11	.866(**)	11	.754(**)
								.001		.007

Spring (23)

Rel	Days	Def. count	N	CC+CA & WMC	N	Defect & CC+CA	N	CBO & Ce	N	Defect & Ce
				p-value		p-value		p-value		p-value
4	53	703	97	.861(**)	97	.570(**)	97	.701(**)	97	----
				.000		.000		.000		
5	27	308	71	.875(**)	71	.469(**)	71	.700(**)	71	----
				.000		.000		.000		
6	31	502	95	.852(**)		.668(**)		.698(**)		.344(**)
				.000		.000		.000		.001
7	NA	147	59	.893(**)		----		.689(**)		----
				.000				.000		

Note:

** Correlation is significant at the 0.01 level (2-tailed).

* Correlation is significant at the 0.05 level (2-tailed).

In the following tables, the correlation significance was ignored. Only correlation value was considered. Considering both would have made different release comparison very complicated.

Appendix L: Acronyms

C&K : Chidamber and Kemerer (1991)
OO : Object oriented