

Enron's Spreadsheets and Related Emails: A Dataset and Analysis

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Abstract—Spreadsheets are used extensively in business processes around the world and as such, are a topic of research interest. Over the past few years, many spreadsheet studies have been performed on the EUSES spreadsheet corpus. While this corpus has served the spreadsheet community well, the spreadsheets it contains are mainly gathered with search engines and might therefore not represent spreadsheets used in companies. This paper presents an analysis of a new dataset, extracted from the Enron email archive, containing over 15,000 spreadsheets used within the Enron Corporation. In addition to the spreadsheets, we also present an analysis of the associated emails, where we look into spreadsheet-specific email behavior.

Our analysis shows that 1) 24% of Enron spreadsheets with at least one formula contain an Excel error, 2) there is little diversity in the functions used in spreadsheets: 76% of spreadsheets in the presented corpus use the same 15 functions and, 3) the spreadsheets are substantially more *smelly* than the EUSES corpus, especially in terms of long calculation chains. Regarding the emails, we observe that spreadsheets 1) are a frequent topic of email conversation with 10% of emails either referring to or sending spreadsheets and 2) the emails are frequently discussing errors in and updates to spreadsheets.

I. INTRODUCTION

Spreadsheets are an important type of software. Scaffidi and colleagues estimate that there are more than 55 million end user programmers in the US alone [1].

In many ways, developing a spreadsheet is similar to writing code. Both entail analyzing data, manipulating operations on that data and understanding dependencies between different parts of the program. One of the main differences is that in software engineering, several methods and techniques have been developed that support developers in managing complexity and understanding existing artifacts. Although recent efforts to transfer software engineering methods to spreadsheets have had some success (e.g., [2]), there is still a lot to be gained, as spreadsheet errors remain common.

For example, Reinhart and Rogoff reported on their analysis of data in Excel in a working paper that concluded that countries with high economic debt-to-GDP ratios have slow economic growth [3]. Politicians have used this result to implement debt-reducing measures across Europe, in an attempt to increase economic growth [4]. However, when the spreadsheet was shared with scientists doing a replication study, it was revealed that the original spreadsheet contained a selection

error; when the error was corrected, the paper's main finding about debt and growth were reversed [5].

As a consequence of the importance of spreadsheets, significant existing research has studied spreadsheets in a variety of contexts. For example, at ICSE 2007 Abraham and Erwig evaluated GoalDebug, a spreadsheet debugger [6]; at ICSE 2012 we presented a method for detecting and visualizing spreadsheet smells [7]; and at ICSE 2014 Dou and colleagues presented AmCheck, a tool that finds and repairs ambiguous computations [8].

A significant amount of prior work on spreadsheets does formative or evaluative studies using the EUSES corpus; a set of 4,498 spreadsheets published in 2005. Abraham and Erwig use the EUSES corpus to motivate their approach [6]; We ourselves use EUSES to set thresholds for our code smells [7]; and Dou and colleagues use EUSES to determine how often ambiguous computation occurs [8].

One of the reasons that EUSES is so commonly used is that it is the best there is: there is no open other corpus of similar size. Some researchers have tried to get access to spreadsheets from industry, but companies are reluctant to share them. Firstly, the contents of the spreadsheets might hold confidential information, such as pricing models, which companies want to keep out of the hands of competitors or customers. Secondly, organizations are afraid detailed studies of their spreadsheets might reveal errors that yields bad press or even lawsuits.

In this paper, we introduce a new spreadsheet corpus obtained from industry for researchers to explore. This dataset was extracted from the Enron email archive [9], which is a large set of email messages that were made public during the legal investigation concerning the Enron corporation. It differs from the EUSES corpus in a number of ways:

- Although EUSES is the largest spreadsheet corpus today, it is relatively small by modern software repository standards; EUSES has about 4.5 thousand spreadsheets, while Sourceforge lists 350 thousand software projects¹ and OpenHub lists about 666 thousand software projects².
- Most EUSES spreadsheets were obtained through the public world-wide-web. What is missing is a substantial

¹<http://sourceforge.net/blog/sourceforge-myths/>

²<https://www.openhub.net/explore/projects>

set of private spreadsheets, that is, spreadsheets that were not intended to be made available to the public.

- The EUSES corpus is not publicly available. To use it, “you must be a researcher in the field of software engineering, end-user programming, human-computer interaction, or usability”³, and even then, you must explicitly ask for a copy by email.

The contributions of this paper are as following:

- An industrial dataset of over 15,000 spreadsheets
- An analysis of these spreadsheets, including the use of named ranges, built-in and user defined functions
- A dataset of over 65,000 emails either having a spreadsheet as an attachment or talking about spreadsheets
- An analysis of these emails, including an analysis of discussed errors and updates

II. THE DATASET

A. Obtaining the emails

First, we requested the most recent version of the Enron email dataset, via this website⁴. We got access to v1.3, last updated 29 July, 2013. This version contains 130 folders, one per employee, each containing one or more Personal Storage Table (.pst) files. Pst files are “an open proprietary file format used to store copies of messages, calendar events[...]”[10] The Enron dataset contains 190 such pst files, totaling 53 gigabytes in size. The pst files together contains 752,605 eml files, representing an email or note.

B. Extracting the spreadsheets

A single pst file can be opened with, for example, Outlook, which can then list all emails with attachments to be subsequently copied. However, performing this operation manually for 190 files is quite labor intensive. Hence, we used Systool’s Outlook Attachment Extractor⁵ to obtain the spreadsheets from the pst files. The Enron set contains 265,586 attachment files (32.3 gigabytes), of which 51,572 are Excel files. Among those files are 16,189 unique spreadsheets, based on MD5 file hashes.

C. Spreadsheet analysis

We processed all spreadsheets with the Spreadsheet Scantool, developed at Delft University of Technology. This tool runs on the previously developed Breviz core [2], made for spreadsheet visualization and smell detection. Scantool gathers metrics on spreadsheets, worksheets, formulas, errors and user-defined functions.

III. BASIC CHARACTERISTICS OF THE SPREADSHEETS

Table I shows an overview of the characteristics of the spreadsheets of Enron, compared to EUSES. Out of the 16,189 unique files, 15,770 spreadsheets could be analyzed. The remaining 419 were password protected, corrupt, or otherwise

unreadable. In total, our set of analyzable spreadsheets contains of 15,770 files. Their average file size is 113.4 kilobytes, while the biggest file is 41 megabytes.

A. Worksheets

In total the 15,770 spreadsheets contain 79,983 worksheets, which is an average of 5.1 worksheets per spreadsheet. EUSES has an average of 3.7 worksheets per spreadsheet. Figure 1 shows the distribution of worksheets over the spreadsheets. The x-axis lists the number of worksheets, while the y-axis shows the number of spreadsheets that contain that number of worksheets. As we can see from this figure, many spreadsheets have one or three worksheets, which is due to the fact that three is the default number of worksheets Excel puts into any newly created spreadsheet. However, it is not uncommon to have more worksheets: there are 1,652 spreadsheets in the corpus with 10 or more worksheets. The spreadsheet with the most worksheets has 175 worksheets.

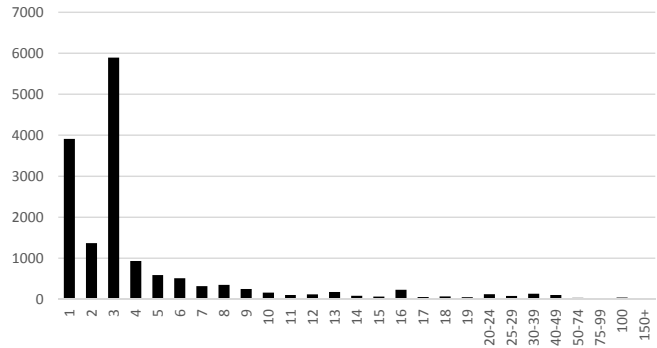


Fig. 1. Distribution of the number of worksheets over the spreadsheet files.

B. Formulas

The 15,770 spreadsheets together have 97,636,511 non-empty cells of which 20,277,835 are formulas. This is an average of 6,191 cells and 1,286 formulas per spreadsheet.

Not all spreadsheets in the Enron set contain formulas: there are 9,120 spreadsheets containing formulas, which is about half of all spreadsheets in the set. Together the spreadsheets with formulas contain 20,277,835 formulas and 913,472 unique formulas. Unique formulas are defined in terms of having an equal relative R1C1 notation⁶; non-unique formulas include those that the user has dragged down or right to repeat a calculation. The average spreadsheet *with formulas* contains 2,223 formulas of which 100 are unique. In the EUSES set, spreadsheets have an average of 372 formulas and 33 unique formulas, which is substantially lower.

³<http://eusesconsortium.org/resources.php>

⁴<http://info.nuix.com/Enron.html>

⁵<http://www.systoolsgroup.com/outlook-attachment-extractor.html>

⁶<https://support.office.com/en-US/article/overview-of-formulas-d258ec72-149a-42ac-8eae-b50a667eb491>

TABLE I
AN OVERVIEW THE SPREADSHEETS IN THE ENRON AND EUSES SET

	EUSES	Enron
Number of spreadsheets analyzed	4,447	15,770
Number of spreadsheets with formulas	1,961	9,120
Number of worksheets	16,853	79,983
Maximum number of worksheets	106	175
Number of non-empty cells	8,209,095	97,636,511
Average number of non-empty cells per spreadsheet	1,846	6,191
Number of formulas	730,186	20,277,835
Average of formulas per spreadsheet with formulas	372	2,223
Number of unique formulas	65,143	913,472
Number of unique formulas per spreadsheet with formulas	33	100

TABLE II
AN OVERVIEW OF EXCEL ERRORS

Error Type	Explanation
#DIV/0!	Trying to divide by 0
#N/A!	A formula or a function inside a formula cannot find the referenced data
#NAME?	Text in the formula is not recognized
#NULL!	A space was used in formulas that reference multiple ranges; a comma separates range references
#NUM!	A formula has invalid numeric data for the type of operation
#REF!	A reference is invalid
#VALUE!	The wrong type of operand or function argument is used

TABLE III
SPREADSHEETS CONTAINING EXCEL ERRORS IN THE ENRON SET

Error type	Spreadsheets	Formulas	Unique Ones
#DIV/0!	580	76,656	4,779
#N/A	635	948,194	6,842
#NAME?	297	33,9365	29,422
#NUM!	52	4,087	178
#REF!	931	18,3014	6824
#VALUE!	423	11,1024	1751
Total	2,205	1,662,340	49,796

C. Excel errors

It is impossible to determine what cells in the set are erroneous, because we cannot possibly know what was the intention of the formula. This rules out finding semantic errors. Also, syntactical errors in the formulas are not possible, as Excel does not allow a user to input a syntactically incorrect formula. However, There is potential for some automated analysis, by looking at Excel errors (#DIV/0 or #REF). In a sense, we can compare these errors to *run-time errors* in software. The inputted formulas are syntactically correct, but faulty input (like #DIV/0 or #NUM) or missing references

(#REF) result in unwanted behavior when the formula is executed. Table III list all built-in Excel errors⁷.

To get insight into the robustness of the Enron spreadsheets, we analyze the number of formulas that result in an Excel error. In total, we have found 2,205 spreadsheets that contained as least one Excel error, which amounts to 24% of all spreadsheets with formulas (14% of all spreadsheets). They together contain 1,662,340 erroneous formulas (49,796 unique ones), which is 585.5 (17.5 unique ones) on average. There were 755 files with over a hundred errors, with the maximum number of errors in one file being 83,273. Table III lists the number of spreadsheets, formulas and unique formulas in the Enron set that suffer from the given Excel errors.

Errors and their dependents. For the erroneous cells, we have analyzed their dependents, meaning those cells that use the erroneous cell as an input. The more cells depend on the erroneous cell, the more impact this error will have on the spreadsheet as a whole and the more ‘dangerous’ we could consider the formula. Of the 49,796 unique formulas, there are 29,324 with one or more dependents. This is 59% of all unique error formulas, which indicates that spreadsheet errors can have an impact on many other cells in the spreadsheet. On average, erroneous cells have 9.6 other formulas depending on them.

D. Use of Built-In Functions

In addition to basic metrics and Excel errors, we also investigated what functions are used within the formulas. In total, there are 9,012 spreadsheets containing formulas with functions. 108 spreadsheets contain only “referring” formulas, like =A1 and hence do not use built-in functions. Figure 2 shows the number of used functions for all spreadsheets, where we can see that spreadsheets in the set use a remarkably low number of functions per spreadsheet. The spreadsheet with the most distinct functions, only uses 34 different ones.

⁷<http://www.dummies.com/how-to/content/excel-formulas-and-functions-for-dummies-cheat-she.html>

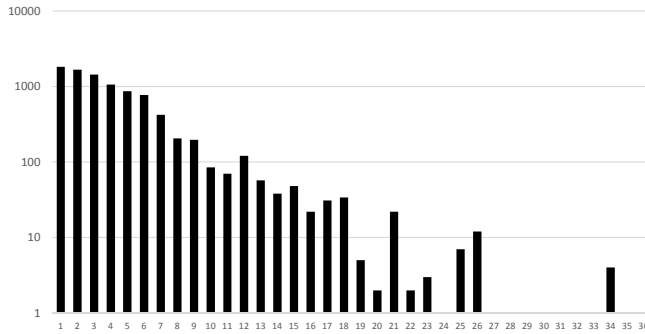


Fig. 2. Distribution of the number of distinct built-in functions over spreadsheet files on a logarithmic scale.

TABLE IV
NUMBER OF SPREADSHEETS AND PERCENTAGES OUT OF 9,012
SPREADSHEETS USING FUNCTIONS

Distinct built-in functions	# Spreadsheets	Percentage
≤1	1,822	2.20%
≤2	3,489	38.7%
≤3	4,922	54.6%
≤4	5,983	66.4%
≤5	6,850	76.0%
≤10	8,534	94.7%
≤15	8,868	98.4%
≤20	8,962	99.4%
≤25	8,996	99.8%
≤30	9,008	100.0%
≤35	9,012	100.0%

Table IV shows the same data. There it is easier to observe that more than half (4,922 spreadsheets = 54.6%) of the spreadsheets with functions, use just three or fewer ones. 8,534 spreadsheets (94.7%) use fewer than 10 built-in functions. This shows that the complexity of spreadsheets does not necessarily stem from the use of different built-in functions that Excel provides. In fact, over the entire corpus with 913,472 different formulas only 134 of are ever used, out of the 329 functions that Excel provides⁸.

There is also little variety in which of the 134 functions are used. Table V shows the 15 most used functions in the corpus, that appear in 8,916 = 99.4% of all spreadsheets that contain at least one function.

Even more lack of diversity is shown by the Table VI. This table shows the number of spreadsheets and the corresponding percentage that contain *only* the listed function, cumulatively. As an example: 5,733 spreadsheets (63.6%) contain only the top 9 functions: SUM, +, -, /, *, IF, NOW, AVERAGE and VLOOKUP. As can be seen from Table VI, 75.6% of all spreadsheets *only* use the top 15 functions. This means that most spreadsheets are constructed from a small and similar set

⁸<http://office.microsoft.com/en-001/excel-help/excel-specifications-and-limits-HP005199291.aspx>

TABLE V
LIST OF MOST USED FUNCTIONS, THE NUMBER OF SPREADSHEETS IN WHICH THEY OCCUR AND CORRESPONDING PERCENTAGES

Rank	Functions	# Spreadsheets	Percentage
1	SUM	6493	72.0%
2	+	5571	61.8%
3	-	4866	54.0%
4	*	3527	39.1%
5	/	3112	34.5%
6	IF	1827	20.3%
7	NOW	1501	16.7%
8	AVERAGE	879	9.8%
9	VLOOKUP	763	8.5%
10	ROUND	606	6.7%
11	TODAY	537	6.0%
12	SUBTOTAL	385	4.3%
13	MONTH	325	3.6%
14	CELL	321	3.6%
15	YEAR	287	3.2%
	Any above	8961	99.4%

of functions.

TABLE VI
THE MOST USED FUNCTIONS, THE NUMBER OF SPREADSHEETS IN WHICH ONLY THEY OCCUR AND CORRESPONDING PERCENTAGES, LISTED CUMULATIVELY

Rank	Functions	# Spreadsheets	Percentage
1	SUM	578	6.4%
2	+	1259	14.0%
3	-	2262	25.1%
4	/	2625	29.1%
5	*	3959	43.9%
6	IF	4260	47.3%
7	NOW	5322	59.1%
8	AVERAGE	5664	62.8%
9	VLOOKUP	5733	63.6%
10	ROUND	5990	66.5%
11	TODAY	6182	68.6%
12	SUBTOTAL	6480	71.9%
13	MONTH	6520	72.3%
14	CELL	6774	75.2%
15	YEAR	6812	75.6%

E. Use of User-Defined Functions

We also analyzed the use of user-defined functions, functions created with the use of Visual Basic for Applications code. These are not that common; only 47 of the spreadsheets use them. If they are used, most often (41 out of 47 files) only one is used, and in 36 of the cases, the user-defined function is only used in one unique formula. From this we can conclude that spreadsheet users at Enron mainly rely on built-in Excel functions for their calculations. Interestingly enough, there are

TABLE VII
NUMBER AND PERCENTAGE OF SPREADSHEETS IN THE ENRON CORPUS THAT SUFFER FROM AT LEAST ONE OF THE SPREADSHEET SMELLS FOR THREE THRESHOLDS.

Smell	Number of files > 70%	> 80%	> 90%	Percentage > 70%	> 80%	> 90%
Multiple References	3,308	2,680	1,955	36.3%	29.4%	21.5%
Multiple Operations	2,709	2,375	1,258	29.8%	26.1%	13.8%
Duplicated Formulas	441	383	352	4.8%	4.2%	3.9%
Long Calculation Chain	2,030	1,404	1,000	22.3%	15.4%	11.0%
Conditional Complexity	5,05	420	379	5.5%	4.6%	4.2%
Embedded Constant	2,541	1,652	1,213	27.9%	18.1%	13.3%
Any of the above smells	4,504	3,667	2,772	49.5%	40.3%	30.5%

Smell	> 70%	> 80%	> 90%
Multiple References	23.8%	18.4%	6.3%
Multiple Operations	21.6%	17.1%	6.3%
Duplicated Formulas	10.8%	7.1%	3.7%
Long Calculation Chain	9.0%	7.9%	3.3%
Conditional Complexity	4.4%	3.0%	1.1%
Any of the above smells	42.7%	31.4%	19.7%

Fig. 3. Percentage of spreadsheets in the EUSES corpus that suffer from at least one of the five spreadsheet smells in EUSES corpus, for the three thresholds (taken from [11]).

a number of files that use a self-defined ‘Concat’ function that basically replicates the built-in concatenate function.

F. Use of Named Ranges

Named ranges in spreadsheets have been a research topic for a while, with some researchers arguing that it is better not to use them [12, 13, 14]. In practice it seems they are not used frequently; only 721 of the spreadsheets use them, which amounts to 8.0% of all spreadsheets with functions. In total, these 721 files contain 4,719 named ranges, which is an average of 6.5 ranges per spreadsheet. Most commonly (in 181 spreadsheets = 25% of range using spreadsheets) files contain only 1 named range. Over half of the spreadsheets (384 = 53%) contain fewer than five named ranges.

If we look into the number of cells that a named range refers to, we spot a remarkable pattern. The vast majority of them (3,160 = 67.%) consist of one cell only. This seems to indicate that rather than naming actual ranges in spreadsheets, Excel users have a need to define and use ‘variables’.

IV. REPLICATION OF PREVIOUS SPREADSHEET WORK

In addition to analyzing basic characteristics of the spreadsheets, we also compare how the current set relates to previous analyses we have done on EUSES, in terms of *spreadsheet smells*: weak spots in a spreadsheet’s design and test behaviors of spreadsheet builders.

A. Smells

In previous work we have analyzed so-called *smells* in spreadsheet formulas [7, 15, 11], and subsequently, other researchers have added to our catalog of smells [16]. For this

analysis, we detect all smells described in [15] and also add a smell from [16].

Briefly summarizing our previous work: we have set thresholds for the smells based on the EUSES, such that 30% of the formulas were marked smelly at the lowest level, 20% at a moderate and 10% at a high level. As you can see in Figure 3, this resulted in 42.7% of the spreadsheets to be smelly. For a more extensive background of the spreadsheet smells and the metrics that calculate them, we refer to [11].

We have repeated this analysis for the spreadsheets of Enron, and found they are smelly to a much higher degree than the EUSES spreadsheets. Table VII shows the number of files and the percentage that have cells with metric values above the thresholds.

In these results, two things stand out. Firstly, the percentage of files with duplication is lower. Duplication means a part of a formula is repeated within another formula, for example, the formula SUM(A1:A5)+B7 has the duplication smell if there is another formula in the worksheet that contains one of its subformulas, like SUM(A1:A5)+B12.

What further catches the eye is the fact that many files (22%) suffer from the ‘Long Calculation Chain’ smell. This means formulas depend on a long string of other formulas as input. We know from previous work that this makes spreadsheets hard to comprehend: “...it is difficult to get a global sense of the structure of the spreadsheet, which requires tracing the dependencies among the cells. Many users in our study described awkward pencil and paper procedures for tracing cell dependencies in debugging spreadsheets.”[17]

We looked into this issue a bit more and found one formula with a calculation chain of no less than 1205 cells, with 2,401 indirect dependents. Figure 4 shows part of the spreadsheet in which this formula occurs. As you can see, the user had to trace 250 columns to find out the formula depends on a higher row too, after which these have to be inspected, and this pattern repeats several times. However, not all dependents are exactly the same, in some places of the chain, different operations are used. Hence, fully understanding this formula’s meaning means tracing along all those other cells, scattered over the spreadsheet. Obviously, not all ‘smelly’ cells inhibited such a long calculation chain.

In total there are 41,367 *unique formulas* that have a calculation chain of five or longer, and are hence marked as

C. Emails describing problems with spreadsheets

Furthermore, we have looked at what other words those emails contain. We especially have an interest in emails that discuss problems with spreadsheets. Hence we also analyzed the occurrence of words related to errors within the 68,979 spreadsheet related emails. We searched the emails for the following words: error, mistake, problem, discrepancy, anomaly, anomalies, incorrect, bug, fault and failure.

These words were quite common in the Enron set. Of all 68,979 emails that discuss spreadsheets, 4,140 contain words related to errors, which is 6.0% of all spreadsheet-related emails and 0.6% of all emails. From the emails, although we get the impression that problems with spreadsheets are common, it does not look like a phenomenon that needs further immediate attention. For example:

“For yet another day we seem to be having problems including all the schedules in our EPE schedule sheet.”

“The minimum runtime is the one that is garnering the most attention, but there is another parameter that would appear to be modeled incorrectly.”

“This was the original problem around the pipe option spreadsheets which we discovered yesterday and the reason why the numbers did not match between the old and new processes.”

“The EOL deal will error out in Spreadsheet - Natural Gas, therefore you won’t see it erroring out under Sitara.”

There are some cases in which spreadsheets were explicitly reviewed: *“Dear Louise and Faith, I had a review of the spreadsheet and noticed an error in allocation of value for the Central Maine Power deal .”*

Sometimes, people discuss the testing of spreadsheets: *“The analytical approach is implemented in a spreadsheet and fully tested already so there will be no problems with the algorithm itself.”*

D. Emails describing modification of spreadsheets

Finally, we know that different versions of spreadsheets being emailed around pose a threat to spreadsheet correctness. Hence, we also looked for emails containing the following: new version, update, change, revision, revising, revised. Out of the total of 68,979 email concerning spreadsheets, 14,084 (20.4%) contain these change related words (2.0% of all emails). A few examples extracted from the emails:

“Please, find attached an excel spreadsheet that was reviewed and updated by the environmental team”

“Five of the thirteen teams which have EOTT facilities have been inspected and appropriate changes made to the database and spreadsheet.”

“I have attached the most recent update of the tank spreadsheet for you to pass on to the teams”

These quotes indicate how common it is to pass emails around, and even have other send them further. This point to the lack of a version control system, and the reliance on people to email spreadsheets around.

E. Emails as documentation

While inspecting the emails related to spreadsheets, we found that the emails were often used to describe the functionality of the attached spreadsheets. A few examples:

*“The value applicable for next year will be calculated as follows: PFC ratio for next year 3D (Applicable percentage * NOx Budget for next year)/ Banked allowances 3D (10% * 100)/ 25 3D 0.4 This implies that 40% of 25 will be available at face value but the balance 60% of 25 will be available at 50% (variable in the Inputs sheet) of the face value!”*

“Doug, I have looked through the preliminary 2002 Corporate Allocations spreadsheet and summarized for European Government Affairs as follows : (All in thousands) Plan 2001 Actual YTD 2001 Plan 2002 Government Affairs Environment 70 41 86 Environmental Policy & Compliance 76 44 27 Managing Director Government Affairs 0 0 200 Total 146 85 313”

Sometimes, even documentation is provided about spreadsheets not even attached to the messages: *“This directory also hosts the traders models, position managers, one off spreadsheets and custom databases.”*

VII. DISCUSSION

In prior sections, we have described an industrial set of spreadsheets and emails extracted from the Enron archive. Arguably, because the data set was obtained by subpoena rather than voluntarily, it is an accurate depiction of a slice of the information industry. In this section, we discuss a variety of issues that affect the applicability and suitability of the proposed approach.

A. Cleaned dataset

The Enron dataset has been cleaned before it was made available. During this cleaning process, potentially sensitive, personal information was removed from it, including credit card numbers, personal contact details, resumes, Social Security or other national identity numbers, dates of birth and information of a highly personal nature such as medical or legal matters. In total, over 10,000 emails were removed from the set for these reasons [20]. As we do not know the details of the cleaning operations performed, we do not know the exact effects of this.

B. Age of the data

The emails in the set were sent between 2000 and 2001, which is over a decade ago. However, we believe many of our findings, like frequent emailing, complex formulas with little built-in functions and few named ranges, still hold for today’s spreadsheets. Since spreadsheets have a long life-span [21],

many of the spreadsheets in use today will originate from years ago.

C. Error analysis

When analyzing the Excel errors, one can of course wonder which of these errors are ‘real errors’, the type endangering the correct functionality of the spreadsheet. Some of the built-in errors could be the result of missing values. This holds for #DIV/0! and #N/A. The other errors however indicate wrong use of built-in functions, missing names or missing references. Therefore, we believe they are not anticipated by the spreadsheet’s creator and thus point at some type of vulnerability.

VIII. RELATED WORK

While EUSES is the largest prior spreadsheet corpus of which we are aware, there are a few other, smaller corpora. Two prominent corpora are the Galumpke and Wall corpora, containing 82 and 150 spreadsheets respectively, both derived from classroom experiments [22]. Powell and colleagues survey other corpora used in field audits, each audit examining between 1 and 30 spreadsheets [23]. To our knowledge, none of these corpora are publicly available. These existing corpora underscore the need for larger, publicly available spreadsheet corpora.

Efforts related to our research in analyzing smells in the the spreadsheets include efforts focused on the automatic identification of code smells by means of metrics. Marinescu [24] for instance, uses metrics to identify *suspect* classes, those classes that might have design flaws. Lanza and Marinescu [25] explain this methodology in more detail. Alves and colleagues [26] focus on a strategy to obtain thresholds for metrics from a benchmark. Olbrich and colleagues further investigate the changes in smells over time, and discusses their impact [27].

Furthermore, there are papers on spreadsheet metrics, which also measure properties of spreadsheets. In 2004, Bregar published a paper presenting a list of spreadsheet metrics based on software metrics [28]. He however does not provide any justification of the metrics, nor did he present an evaluation. Hodnigg and Mittermeir [29] propose several spreadsheet metrics of which some are similar to Bregar’s. Their metrics are divided into three categories: general metrics, such as the number of formulas and the number of distinct formulas; formula complexity metrics, such as the number of references per formula, and the length of the longest calculation chain; and finally metrics related to user defined functions and external sources. Hole and colleagues [30] also propose an interesting approach to analyze spreadsheets in terms of basic spreadsheet metrics, such as the number of functions used, the presence of charts and the complexity of program code constructs to predict the level of expertise of the spreadsheet creator.

Other work related to ours includes papers that describe desirable properties of spreadsheets. Raffensberger [31], for instance, advises merging references that occur only once.

He furthermore states that unnecessary complex formulas with many operations and parenthesis should be avoided. Rajalingham and colleagues [32] also propose guidelines to improve spreadsheet quality, which they base on principles of software engineering. Secondly, there are papers that address common errors in spreadsheets, like [33, 34], together with their causes. Powell and colleagues for instance [35] name conditional formulas among the top three of commonly occurring spreadsheet error categories. Furthermore there is related work on finding anomalies on spreadsheets, for instance the work on the UCheck tool [36, 37, 38]. UCheck determines the type of cells, and locates possible anomalies based on the type system.

We ourselves have worked on spreadsheet smells in previous work [7, 15, 11]. In those papers we have explored both spreadsheet smells at the low level of formulas as in a spreadsheets structure. Those papers followed our earlier work, in which we visualized spreadsheets by means of class diagrams [39] and dataflow diagrams [21]. Recently, other work on spreadsheet smells has been published [16] that aims to find smells in values, such as typographical errors and values that do not follow the normal distribution.

IX. CONCLUSION

The goal of this paper is to give researchers and others access to industrial spreadsheets and related emails to obtain a deeper understanding of the problems and challenges surrounding spreadsheets. To that end, this paper presents a dataset of over 15,000 spreadsheets and 65,000 emails related to those spreadsheets. We have performed a preliminary analysis of all the spreadsheets and emails ourselves and we believe that this paper is a valuable first step to obtain more insight into the actual use of spreadsheets within companies, with the following contributions:

- An industrial dataset of over 15,000 spreadsheets.
- An analysis of these spreadsheets, including the use of named ranges, built-in and user defined functions.
- A dataset of over 65,000 emails either having a spreadsheet as an attachment or talking about spreadsheets.
- An analysis of these emails, including an analysis of discussed errors and updates.

From these analyses, we conclude that:

- 24% of Enron spreadsheets with formulas contain an Excel error.
- There is remarkably little diversity in the functions used in spreadsheets: we observe that there is a core set of 15 spreadsheet functions which is used in 76% of spreadsheets.
- The spreadsheets in this set are more *smelly* than the EUSES corpus, especially in terms of long calculation chains.
- Spreadsheet use within companies is common, with 100 spreadsheets emailed around *per day*!
- Spreadsheets are commonly shared via email, with about 10% of emails concerning spreadsheets, either in topic or as an attachment.

X. FUTURE WORK

This paper gives rise to many directions for future work. First of all, we believe this paper lays ground for more detailed analyses of the both the Enron spreadsheets and the related emails. We encourage this by sharing all data¹¹, enabling others to both replicate our analyses and perform new ones. A few analyses we think would be especially interesting are, for instance, sentiment analysis on the spreadsheet emails. In addition to more analyses on the Enron set, this paper has underlined the need for several other directions of work:

A. Version control for emails

When analyzing the emails we observed again that emailing spreadsheets is still the default way of sharing them. While the Enron set is a bit dated, our experience in industry confirms that this is still very common, despite the frequent use of SharePoint within companies that does do a basic form of version control. Hence, this paper underlines the need for more spreadsheet specific version control systems. While there is currently a UK based company¹² that tries to address this, we believe there are still many open challenges to be answered by research.

B. Mining emails for documentation

When analyzing the emails in more detail, we found that often emails contain description of spreadsheets. One interesting angle could be a plugin in Excel that connects with an email client like Outlook and fetches emails corresponding to the spreadsheet the user is currently working with to help understanding it.

Furthermore, we will take a more detailed look into the email, connecting the described errors to actual cells within the spreadsheets, in order to facilitate more studies into the root cause of industrial spreadsheet errors.

C. Support for using variables

As described previously, the typical way in which named ranges are used—i.e. referring to only one cell—indicates the need for variables in spreadsheets, separated from cells. We have observed before that spreadsheet users can feel the need to observe certain values, in one of our previous studies, a subject stated: “it is easy to always have the value in sight when working on the spreadsheet, because then I can see the values I am calculating with” [7]. The results of this paper again give credibility to the hypothesis that to a certain extent, the grid structure of the spreadsheet could be too restrictive. Hence, it would be interesting to explore models in which the grid is mixed with variables or even other programming concepts.

¹¹www.felienne.com/enron

¹²<https://spreadgit.com/>

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