Spreadsheet Error Categorization and Audit Documentation

Background

Studies suggest that spreadsheet development and usage is error-prone and spreadsheet errors are "common and non-trivial" (Panko 2000). Overviews published by Kruck (2006) and Panko (1998), show that the numbers of operational and laboratory spreadsheets with errors range between 7% and 82%, with an average of 40% of professional spreadsheets containing errors. KPMG, an international auditing company, (cited in Rajalingham et al. 2000), found over five errors in 95% of the financial models they reviewed.

To be able to discuss and understand spreadsheet error, a taxonomy or categorisation scheme is needed (Rajalingham et al. 2000). Furthermore, the taxonomy, allied with a systematic audit approach is needed in order to identify errors and their types in spreadsheets.

The purpose of this technical document is to support a study carried out by the authors which investigates spreadsheet error types and prevalence in a healthcare context, a domain which has been subject to few spreadsheet-error research studies. Two contributions of this research were (a) a spreadsheet error categorization scheme consolidated both from literature and error types found in healthcare spreadsheets and (b) a systematic audit approach based on interviews and spreadsheet inspection. These two results are documented in the following sections.
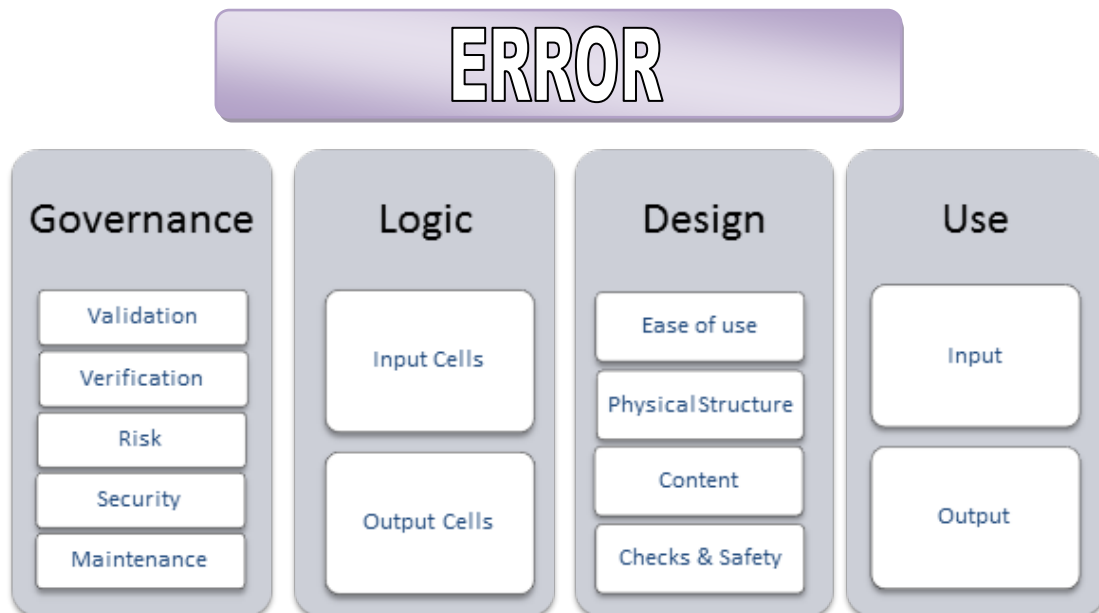
Spreadsheet Error Categorization Scheme

The definition of spreadsheet error used in this research study includes incorrect inputs, incorrect outputs, and anything which could be termed a design flaw or spreadsheet issue. For example, the following are included as errors: chaotic design; numbers embedded into formula (hard-coding); complex long formulae; and lack of documentation with respect to purpose / HOWTO etc. It is conventional in the spreadsheet error academic community to

define errors in this way (Powell et al. 2009a, Teo and Lee-Partridge 2001, Panko 2000). Many of these 'errors' may not cause an immediate incorrect output or impact on decisions made, but are classed as errors as they do not adhere to best practice and increase the risk of an incorrect spreadsheet output. The associated work on categories and taxonomies facilitates greater understanding of spreadsheet error and is "fundamental" to developing a "criterion for determining whether something is correct or an error" (Panko and Aurigemma 2010).

The errors and flaws are categorised according to the following categorisation scheme. The description and how to check for each error or flaws follows in each of the tables, arranged by method of assessing for the errors (i.e. through interview or by spreadsheet inspection) and then per the categorisation scheme.

The final categorization scheme (as well as the final version of the audit approach) was refined through several iterations of auditing in-vivo spreadsheets, after starting with a list of errors from literature. Each newly detected error that could not be adequately mapped to an existing type of error lead to a modification of the categorization scheme, e.g. to a

Figure 1: Healthcare Spreadsheet Categorisation Scheme: First and Second Levels

new type of error or a splitting of an existing error type. The framework for the error types

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is largely temporal and is presented in figure 1. The actual error types and the audit methods employed are now presented.

Spreadsheet Audit Approach

The Audit Approach used to identify spreadsheet errors consists of four distinct elements - the Interview, the Test Case, the Spreadsheet Inspection Audit, and the Feedback Interview. The first three contribute to the identification of errors whereas the Feedback Interview validates the errors found with the user / developer. This approach was modelled on the audit protocol developed by Powell et al. (2009) but instead of the subjects being surveyed, in this research study they were interviewed and they also completed a test case.

As the different error types were identified from the literature and other sources, it became obvious that some of the error types could be found only through discussion with the developers and users of the spreadsheets. Interview questions were therefore formulated that could be posed to the developer to determine whether the error was present or not in the spreadsheet being audited, or to inform further audit steps. The questions include 22 error testing questions that, if being answered adversely, indicate an error.

Other error types can be detected by inspecting the spreadsheet because certain directly observable characteristics or properties indicate an occurrence of an error of a certain type. Questions and audit criteria were therefore stated that can systematically lead the research/auditor through the spreadsheet inspection. This inspection can furthermore be informed by watching the spreadsheet user complete a test case, include the user entering a complete set of data and explaining their logic, decisions, rationale, assumptions, actions and considerations. By this, the researcher gets a better understanding of the spreadsheet's workings, can note potential errors were and validate or dismiss them during the spreadsheet inspection audit.

The following tables contain the developed interview questions (Table 1) and the questions and criteria developed for the spreadsheet inspection step (Table 2).

Each of the errors has been assigned a unique code. Firstly a letter, either 'E' or 'F' has been assigned. 'E' stands for 'error / quantitative error' and 'F' stands for 'Flaw / qualitative error'. Next follows a number which has been chronologicly assigned to each of the errors to give a unique identifier for every error discussed in the paper.

Table 1. Interview Questions – 22 error testing questions (shaded)

Category	Sub category	Question / audit criteria	Rationale
Governance	Validation (Raffensburger 2008)	Did you create the spreadsheet?	To establish responsibility
		Are you the owner of the spreadsheet? (O'Beirne 2005)	To establish responsibility
		Why did you create the spreadsheet?	To establish purpose
		What is the business problem that it is addressing?	To establish purpose
		• F2 - Is the spreadsheet used for: one decision; repeated decisions; continual updating; for expansion later? • F2 - Was the spreadsheet designed so it could be easily changed / updated? • F2 - Did spreadsheet design start off 'As Is' or has it evolved?	Establishing whether the spreadsheet is the appropriate tool
		How many users?	
		How did you know what was wanted / needed? (O'Beirne 2005, Bewig 2005)	To establish whether user requirements were sought
		• F1 - Does it meet user requirements? (O'Beirne 2005, Bewig 2005, Caulkins et al. 2006, Maditinos et al. 2012)) • F1 - Was there acceptance testing against requirements with different user groups? (O'Beirne 2005) • F1 - Was usability evaluation documented? (O'Beirne 2005)	To establish whether assessment against user requirements took place
		F3 - Was the spreadsheet approved / signed off by someone with authority? (Simkin 2004, O'Beirne 2005, Bewig 2005)	Mechanism to assure spreadsheet development is valid
	Verification	• F10 - Skill level of developer – 1 to 5 (Chan and Storey 1996) • F10 - Type of training (Arnott 2012, Caulkins et al. 2006, Ferguson 2011, Panko 2008) – informal / formal / self taught (Chan and Storey 1996) • F12 - Number of spreadsheets created by developer previously	To determine spreadsheet experience of developer. Self-graded spreadsheet skill level on 1-5 rating scale
		• F11 - Skill level of main user – 1 to 5 (Chan and Storey 1996) • F11 - Type of training (Arnott 2012, Caulkins et al. 2006, Ferguson 2011, Panko 2008) – informal / formal / self taught (Chan and Storey 1996)	Self-graded spreadsheet skill level on 1-5 rating scale
		• F5 - Was the spreadsheet reviewed by a qualified colleague? (Caulkins et al. 2006, Arnott 2011, O'Beirne 2005, Bewig 2005, Ferguson 2011, Raffensburger 2008)	Mechanism to check spreadsheet is correct

Governance	Verification	• F5 - Was there a group of people involved in reviewing the spreadsheet (Campbell 2010, Bewig 2005, Panko 2008)	
		• F9 - Are you aware of protocols and policies on spreadsheet development and use? (Burdick 2008) • F9 - Did you comply with them?	To determine good development practice
		• F8 - Were calculations specifically validated (O'Beirne 2005, Raffensburger 2008) • F8 - Were calculations 'reality checked' (Raffensburger 2008)	Check on formulae and functions
		F6 - Is there someone responsible for maintaining the spreadsheet (O'Beirne 2005)	To determine responsibility
		F7 - Was the spreadsheet sensitivity tested at development? (O'Beirne 2005, Simkin 2004, Spreadsheet Standards Review Board 2014)	To check on accuracy of calculations and logic
	Risk (Arnott 2012, Ferguson 2011)	Impact of errors / decisions (Caulkins et al. 2006, Ferguson 2011, Panko 2000) negligible (1), minor(2), moderate(3), major(4), extreme(5) (HSE Quality and Safety Directorate 2011)	To determine risk rating for spreadsheet
		What part does it play in decisions and documentation of business (O'Beirne 2005)	To determine impact of inaccurate outputs
		Probability / likelihood of errors (Arnott 2012, Caulkins et al. 2006, Ferguson 2011) rare(1), unlikely(2), possible(3), likely(4), almost certain(5) (HSE Quality and Safety Directorate 2011)	To determine risk rating for spreadsheet
		What is the highest level in the organisation that will use the information from the spreadsheet (Panko 2000, Chan and Storey 1996): National HSE / Professional body; CEO; CCD; Directorate; Heads of Service; Line Manager; Personal use.	To determine impact of inaccurate outputs
		F13 - Is quality control effort matched to level of risk? (Caulkins et al. 2006)	Review of existing quality control effort and determine likelihood of error
		F14 - Is the spreadsheet kept up to date? (Rajalingham et al. 2000)	To determine likelihood of error
		Is the turnover of staff using spreadsheet high? (O'Beirne 2005)	To determine likelihood of error
		Is there a diversity of skill level? (O'Beirne 2005)	To determine likelihood of error
		What is the frequency of use? (Caulkins et al. 2006)	To determine likelihood of error
		Are there any links to external files / databases (O'Beirne 2005, Bewig 2005)	To determine likelihood of error
		Is there data populated by programme code e.g. Live data feed (O'Beirne 2005)	To determine likelihood of error
	Security (Arnott 2012)	• F15 - Does the spreadsheet contain any sensitive/confidential information? (Campbell 2010)	To determine security protocols that are in place and compliance with them

Governance	Security	• F15 - Is there access control (Ferguson 2011) • F15 - Is the database password protected? (Arnott 2012, O'Beirne 2005, Ferguson 2011) • F15 - Passwords are changed regularly (O'Beirne 2005) F15 - Passwords meets HSE regulations	
		F16 - Protected sections / cells (Powell et al. 2008a, Arnott 2012, Bewig 2005, Croll and Butler 2006, Ferguson 2011, Panko 2008)	To determine level of protection to output cells
		• F17 - Back-up the spreadsheet (Arnott 2012, O'Beirne 2005, Ferguson 2011) • F17 - Access to previous back-up versions? (O'Beirne 2005) • F17 - Back-ups are secure (O'Beirne 2005) • F17 - Regularity of back-ups (Ferguson 2011) • F17 - Back-ups verified (O'Beirne 2005)	To determine back-up strategy
	Maintenance	• F18 - The underlying logic and basis for business assumptions are documented (Caulkins et al. 2006, Arnott 2012, O'Beirne 2005) • F18 - Limitations are documented (O'Beirne 2005) • F18 - Documented clearly what the spreadsheet does not do?	To determine whether spreadsheet information has been documented for future reference and for other users' understanding
		• F19 - Is there any documented information on development, use and a HOWTO section? (Arnott 2012, O'Beirne 2005, Campbell 2010, Croll and Butler 2006, Ferguson 2011, Kruck 2006, Panko 2008) • F19 - Is there documentation in a separate file (user training manual / SOP)? (O'Beirne 2005) • F19 - Is it documented where separately documented information is kept? (O'Beirne 2005) • F19 - Is the documented information kept up to date? (O'Beirne 2005)	To determine whether spreadsheet information has been documented for future reference and for other users' understanding
		• F20 - Is there detail on contents documented? (Arnott 2012, Kruck 2006) • F20 - Is intentionally omitted data documented (O'Beirne 2005) • F20 - Are non-obvious characteristics documented? (O'Beirne 2005) • F20 - Are the sources of input data documented? (O'Beirne 2005, Arnott 2012) • F20 - Are key formulae / assumptions documented? (Caulkins et al. 2006, Ferguson 2011) • F20 - Are scope and timeframe limits documented? (Powell et al. 2009a, O'Beirne 2005)	To determine whether spreadsheet information has been documented for future reference and for other users' understanding

Governance	Maintenance	F30 - Is there a change control protocol in place? (Arnott 2012, O'Beirne 2005, Caulkins et al. 2006, Ferguson 2011)	To determine good development practice
		• F31 - Do you keep a version history? (O'Beirne 2005, Caulkins et al. 2006, Ferguson 2011) • F31 - Is there an alternate version which is sent to 3rd parties? If so, can this be traced? (e.g. De-identified) (O'Beirne 2005)	To determine good version control so that correct version is being used
		• F34 - Do you have a test plan? (Arnott 2012, O'Beirne 2005, Ayalew et al. 2000, Ferguson 2011, Kruck 2006, Panko 2008) • F34 - Do you keep test records? (O'Beirne 2005, Ferguson 2011) • F34 - Is the spreadsheet tested after each change? (O'Beirne 2005, Ferguson 2011)	To determine good development practice

Category	Sub category	Question / audit criteria	Rationale
Logic	Input Cells	Is there any selective exclusion of data (Bell 2013)	To determine error in logic
		Are there any hidden columns, rows, worksheets or data? (Ferguson 2011, Powell et al. 2008a, O'Beirne 2005)	To determine error in logic or alert to areas requiring further investigation

Category	Sub category	Question / audit criteria	Rationale
Physical Design	Physical Structure	F49 - Does the design follow a specific structure / adherence to best practice standard (Arnott 2012, O'Beirne 2005, Rajalingham et al. 2000, Caulkins et al. 2006)	To determine whether best practice was followed in design
		Is the spreadsheet printed?	To give information needed for audit

Table 2. Spreadsheet Inspection Questions/Criteria

	Category	Sub category	Audit criteria (Error Type)		Rationale / check method
1	Governance	Validation (Raffensburger 2008)	F4 - The developer has adequate domain knowledge to create the right spreadsheet (Powell et al. 2009b, Rajalingham et al. 2000, Maditinos et al. 2012)		Adequacy of knowledge of spreadsheet subject domain **Check:** assessment based on spreadsheet inspection augmented by interview answers, test case commentary
2		Verification	F12 - The developer has adequate spreadsheet / device knowledge to create the spreadsheet accurately (Powell et al. 2009b)		Adequacy of knowledge of spreadsheet development and use **Check:** assessment based on spreadsheet inspection augmented by interview answers, test case commentary
3		Maintenance	Documentation	F21 - Approval of the spreadsheet is documented (Simkin 2004)	Name and role of individual approving spreadsheet documented within the spreadsheet to ensure accountability and traceability **Check:** visual inspection of documentation worksheets
4				F22 - Cell comments or text labels are used (O'Beirne 2005, Spreadsheet Standards Review Board 2014)	In-worksheet comments and labels used to annotate assumptions and outputs. Cell comments alerted by a red triangle. Text labels always visible. **Check:** visual inspection.
5				F23 - Spreadsheet details are recorded in File Properties (O'Beirne 2005, Bewig 2005, Powell et al. 2009a)	Capturing and recording properties for accountability and traceability. **Check:** right click on document name prior to opening and select 'Properties'. Amend properties by selecting 'Prepare' on Office button, then 'Properties'.
6				F24 - Detail on spreadsheet development and content is documented in a separate worksheet? (Powell et al. 2009a, O'Beirne 2005)	Documentation available to ensure full understanding of purpose, design and outputs of spreadsheet by all users. **Check:** visual inspection.
7				F25 - User instructions are documented in a separate worksheet? (O'Beirne 2005)	Documentation available to ensure full understanding of how to use / how to input into spreadsheet by all users. **Check:** visual inspection.
8				F35 - A table of contents is available in a separate worksheet (Spreadsheet Standards Review Board 2014)	Table of contents with hyperlinks to enable easy navigation of spreadsheet and knowledge of full contents. **Check:** visual inspection.

	Category	Sub category		Audit criteria (Error Type)	Rationale / check method
9	Governance	Maintenance	Version history	F32 - The version history has been documented within the spreadsheet? (O'Beirne 2005, Caulkins et al. 2006, Ferguson 2011)	A log of changes showing different releases should be kept to ensure the correct version is being used and so that previous versions can be referred to if needed **Check:** visual inspection of documentation worksheets
10				F33 - The release version in use is clearly documented (O'Beirne 2005, Ferguson 2011)	The release version being used should be easily identifiable so the user can be assured they are using the right version. **Check:** visual inspection of spreadsheet and worksheet names, files properties and documentation worksheets
11			A convention for naming has been used (O'Beirne 2005)Kruck, 2006 #4}	F27 - The spreadsheet has been given a meaningful name (Spreadsheet Standards Review Board 2014)	Purpose for and content of spreadsheet is clear from given names - ease of use and reduces risk of mix up between spreadsheets **Check:** visual inspection.
12				F28 - Each worksheet has been given a meaningful name (O'Beirne 2005)	Purpose for and content of worksheets are clear from given names - ease of use and reduces risk of mix up between worksheets. **Check:** visual inspection.
13				F29 - Spaces have not been left in the spreadsheet or worksheet names (O'Beirne 2005)	Spaces in names can lead to broken linkages between worksheets. If a name contains a space, the name must be surrounded by single quotation marks to ensure it is valid - this can be forgotten so result in error. **Check:** visual inspection
14			F26 - Time sensitive data is dated (O'Beirne 2005, Raffensburger 2008)		Any data that will cease to be current / accurate over time should be dated. **Check:** visual inspection.

	Category	Sub category	Audit criteria (Error Type)	Rationale / check method
1	Logic	Input Cells – error occurring in the logic of	E1 - There are no planned omissions to input data (Panko 2008, Powell et al. 2009b, Rajalingham et al. 2000, Campbell 2010, Powell et al. 2008a, Powell et al. 2009a, Maditinos et al. 2012)	**Check:** review of information sourced from interview, test case and inspection of logic of inputs, data flow and outputs of spreadsheet

	Category	Sub category		Audit criteria (Error Type)		Rationale / check method
2	Logic	what is entered in the input cells		E2 - All relevant input values are used (Powell et al. 2008a)		Alert to formulae reference errors, omitted data and incorrect ranges. **Check** - select 'Trace Precedents' in 'Formula Auditing' in 'Formulas' menu for each discrete type of formula. Visual check to find input values that have not been used.
3		Output Cells – errors occurring in the logic of the output cells	Formulae	E3 - formulae / functions are chosen to give required outputs (Powell et al. 2009a, Croll and Butler 2006, Raffensburger 2008, Maditinos et al. 2012, Panko 2008)		Inspect all unique formulae / functions to identify error in logic of output. **Check** - enter '0' or '1' into input cells and check output is accurate
4			Formulae	F36 - Data flow is clear and logical (O'Beirne 2005, Bewig 2005, Powell et al. 2008a, Goswami et al. 2008)		Could demonstrate error / unclear logic. **Check** - select 'Trace Precedents' in 'Formula Auditing' in 'Formulas' menu for each unique formula / function cell.
5			Charts and tables	F38 - Correct chart types are used (O'Beirne 2005, Bewig 2005)		Chart type chosen are correct for data displayed i.e. Column, line, pie, area **Check**: visual inspection and comparison to logic of spreadsheet
6				F37 - Scale of axes is appropriate (O'Beirne 2005)		Scale is appropriate for information. **Check:** visual inspection.
7				F39 - Chart layout allows all data to be displayed (O'Beirne 2005)		Comparison of values visible on chart against source data. **Check:** visual inspection and chart source data
8				F40 - are labelled correctly		Chart titles correctly explain data displayed in chart. **Check:** visual inspection compared to logic and chart source data
9				F41 - Pivot tables are used for managing large quantities of data (O'Beirne 2005, Powell et al. 2008a, Ferguson 2011)		Best practice to use pivot table if data base is large and data requires sorting and summarising. **Check:** visual inspection and review of spreadsheet properties.

	Category	Sub category	Audit criteria (Error Type)	Rationale / check method
1	Physical Design	Ease of use (Powell et al. 2008a)	F42 - Fonts, colours, borders and styles are used consistently (O'Beirne 2005, Campbell 2010, Spreadsheet Standards Review Board 2014, Ferguson 2011, Raffensburger 2008)	Risk that inconsistencies may lead to confusion and errors. **Check:** visual inspection.

2	Physical Design	Ease of Use		F43 - The spreadsheet is tidy (O'Beirne 2005)	Assessment of whether the spreadsheet appears 'tidy' / clear and easy to follow - reduces risks of errors. **Check:** visual inspection.
3				F44 - Empty worksheets are removed (O'Beirne 2005, Raffensburger 2008)	Unused worksheet cluttering the spreadsheet. Risk of worksheet selection errors. **Check:** visual inspection.
4				F45 - Conventional western order for reading is followed (O'Beirne 2005, Bewig 2005)	Conventional western order used for clarity and to reduce risk of error. **Check:** visual inspection.
5				F46 - Lists are ordered logically and consistently (O'Beirne 2005)	Reduces risk of error caused by assuming lists are same. **Check:** visual inspection.
6				F47 - Automatic calculation switched off for very large spreadsheets (O'Beirne 2005)	Default changed to manual calculation setting as calculation after each entry in a large spreadsheet will slow functionality. **Check:** 'Calculation Options' of 'Calculation' tab in 'Formula' menu.
7				F48 - Navigation features are used e.g. help, freeze panes, hyperlinks, automation (O'Beirne 2005, Spreadsheet Standards Review Board 2014)	Improves ease in navigating around the spreadsheet, so reduces selection errors. **Check:** visual inspection.
8		Physical Structure	Formatting	F50 - It is possible to view worksheet / section on one screen (O'Beirne 2005, Campbell 2010, Raffensburger 2008, Kruck 2006)	Ease of use and reduces risk of missing data when scrolling. Suggestion by Raffensburger that the worksheet, in Point 10 font, should be all visible on the screen (Raffensburger 2008) **Check:** visual inspection.
9				F51 - Input data regions / blocks of data are separated and bound by empty cells (O'Beirne 2005)	Boundary of empty cells helps prevent hardwiring in calculation cells **Check:** visual inspection.
10				F52 - Outputs / calculations are contained in one area (O'Beirne 2005, Raffensburger 2008)	Reduces risk of hardwiring errors and facilitates ease review of outputs. **Check:** visual inspection.
11				F53 - Reports are contained in a separate section (Bewig 2005, Spreadsheet Standards Review Board 2014, Ferguson 2011)	Reduces risk of hardwiring errors and facilitates ease review of outputs. **Check:** visual inspection.
12				F54 - Numbers are right justified (O'Beirne 2005, Raffensburger 2008)	Visual alert to numbers in text formatted cells **Check:** visual inspection and review of format settings

13	Physical Design	Physical Structure	Formatting	F55 - Text is left justified (O'Beirne 2005)	Visual alert to text in numbers formatted cells **Check:** visual inspection and review of format settings
14				F56 - Default / format settings are appropriate	Changes to pre-set default setting could result in unexpected errors. **Check:** review default settings in 'Excel Options' in 'Office Button'
15				F57 - Cell contents are not obscured by overlaid objects e.g. Charts (O'Beirne 2005)	Risk of interpretation error if only partial data viewed. **Check:** visual inspection.
16				F58 - Data is not truncated at the cell boundary (Ferguson 2011, O'Beirne 2005)	Risk of interpretation error if only partial data viewed. **Check:** visual inspection.
17			Printing	F59 - Print areas correspond to what needs to be printed (O'Beirne 2005, Campbell 2010, Spreadsheet Standards Review Board 2014)	Risk of interpretation error if only partial data viewed. **Check:** visual inspection and review if 'Wrap text' is selected in 'Alignment' tab of 'Format Cells'.
18				F60 - Colour is not used if spreadsheet is printed (Bewig 2005)	Risk of loss of detail if colour used and printing in black and white **Check:** visual inspection and review of 'Print Properties'
19		Content	Formula	E4 - Brackets in formulae are correct and paired (O'Beirne 2005, Caulkins et al. 2006)	Incorrect bracket ordering can result in incorrect cell output. **Check:** select 'show formula' and review each formula type.
20				E5 - Absolute range is used in the formula when necessary ($) (O'Beirne 2005, Ayalew et al. 2000, Bewig 2005)	Not using an absolute range in the formula will result in a shift in the specified range when the formula range is extended using the drag option. This may result in an error in the output. **Check:** using R1C1 reference style, review all formulae for consistency.
21				E6 - Formulae referring to the correct cells (O'Beirne 2005, Bewig 2005, Powell et al. 2008a, Goswami et al. 2008, Ayalew et al. 2000, Panko 2008, Powell et al. 2009a, Raffensburger 2008)	Causes output error in individual cell. **Check:** using R1C1 reference style, review all formulae for consistency.

22	Physical Design	Content	Formula	E7 - Grand totals do not include sub totals (O'Beirne 2005)	If subtotals and totals in same column, risk that grand total will incorporate subtotals therefore giving incorrect output **Check:** review of precedents for each formula using 'Trace Precedents' in 'Formula Auditing' tab.
23				E8 - Rounding function is not used when totalling (O'Beirne 2005)	Rounding function applied to output cells that are totalled can result in incorrect bottom-line answer. **Check**: review function in Formula bar for output cells.
24				E9 - Range area design covers all input cells required (e.g. For autosum) (O'Beirne 2005, Bewig 2005, Ayalew et al. 2000, Ferguson 2011)	Incorrect range may result in incorrect output. **Check:** select R1C1 reference style and review all formulae for consistency.
25				F61 - Precedence arc is short and narrow (Bewig 2005, Raffensburger 2008)	Risk of error due to complexity. **Check:** select 'Tract Precedents' in Formula Auditing' tab and follow arc. Suggestion that > 7 variables / operators would be too complex - based on Miller Magic Number 7 $\pm$ 2.
26				E10 - Formulae are consistent (O'Beirne 2005, Spreadsheet Standards Review Board 2014, Ferguson 2011, Bewig 2005)	can result in error in output **Check:** select R1C1 reference style, 'Show Formulas' then enter '0' or '1' into input cells and check outputs
27			E8 - Rounding to specific number of decimal points is consistent		Inconsistency could result in incorrect results. **Check:** visual inspection.
28			F63 - There are no duplication errors (Teo and Lee-Partridge 2001, O'Beirne 2005, Rajalingham et al. 2000, Powell et al. 2008a)		Two cells containing same variable – error may occur if one is changed and other not. **Check:** visual inspection
29			F64 - There are no jamming errors by design (e.g. First name and surname in the same cell) (Teo and Lee-Partridge 2001, Spreadsheet Standards Review Board 2014)		Two variables in one cell. This increased complexity gives potential for error and limits flexibility of use of cell contents. **Check:** visual inspection
30			F62 - External links and imported data are traceable (O'Beirne 2005, Powell et al. 2008a, Spreadsheet Standards Review Board 2014)		Enables checking of integrity of data. **Check:** visual inspection for information.
31		Checks and safety	F65 - Calculation methods and function arguments are explicit (O'Beirne 2005, Bewig 2005)		Misunderstanding of detail of calculation can result in error. **Check:** visual inspection of formula cells

32	Physical Design	Checks and safety	F66 - Formulae are not long or complex (O'Beirne 2005, Bluttman and Aitken 2007, Bewig 2005, Powell et al. 2008a, Croll and Butler 2006, Ferguson 2011, Raffensburger 2008, Kruck 2006)	Risk of error due to complexity. **Check:** select 'Tract Precedents' in Formula Auditing' tab and follow arc. Suggestion that > 7 variables / operators would be too complex - based on Miller Magic Number 7 + 2.
33			F67 - Only one unique formulae per row or column (Bewig 2005)	Keeping different types of formula separate reduces risk of error. **Check:** select 'Show Formulas' and visually inspect location.
34			F69 - Units of measure are clear (O'Beirne 2005, Bewig 2005, Spreadsheet Standards Review Board 2014, Raffensburger 2008, Croll and Butler 2006)	Units of measure are explicitly stated in range names, headers or elsewhere to prevent misinterpretation. **Check:** visual inspection
35			F68 - Cross check calculations are used (O'Beirne 2005)	Where possible, cross check calculation are used to check outputs are correct **Check:** visual inspection of formula cells
36			F70 - Spreadsheet is formatted so that months names are used not numeric dates (O'Beirne 2005)	Using numeric month description introduces risk of misunderstanding due international differences in dating styles. **Check:** visual inspection and review of cell format settings
37			F73 - Range names are used (O'Beirne 2005, Bewig 2005, Powell et al. 2008a, Spreadsheet Standards Review Board 2014, Ferguson 2011)	Range names are used to prevent errors possible when using cell addresses. **Check:** visual inspection and select 'Name a Range' from mouse right click menu.
38			F71 - Conditional formatting is used where appropriate (O'Beirne 2005, Campbell 2010, Bewig 2005, Powell et al. 2008a, Spreadsheet Standards Review Board 2014, Croll and Butler 2006, Ferguson 2011, Raffensburger 2008, Kruck 2006)	Use to alert to risk of error in cell entry. **Check:** select 'Conditional Formatting' from 'Styles' tab on 'Home' menu and then 'manage rules' tab and review settings for different cell types.
39			F72 - Data validation is used where appropriate (O'Beirne 2005, Campbell 2010, Bewig 2005, Powell et al. 2008a, Spreadsheet Standards Review Board 2014, Croll and Butler 2006, Ferguson 2011, Raffensburger 2008, Kruck 2006)	Used to standardise input to reduce errors where possible. **Check:** select 'Data Validation' from 'Styles' tab on 'Home' menu and review settings for different cell types.
40			F74 - Templates are saved in a separate worksheet (O'Beirne 2005, Bewig 2005)	Saving template to separate worksheet for copying reduces risk of carrying errors to subsequent worksheets. **Check:** visual inspection

	Category	Sub category	Audit criteria (Error Type)	Rationale / check method
1	Use	Input – error occurring in what is entered in the input cells	E12 - There are no typographical errors (O'Beirne 2005, Panko 2008, Croll and Butler 2006, Maditinos et al. 2012)	Risk of error in output. **Check**: visual inspection and 'Spelling' check on 'Review' menu.
2			F75 - Cell merging is limited and appropriate (O'Beirne 2005)	Cell merging limits functionality of spreadsheet e.g. Ability to sort / format sections. **Check:** visual inspection
3			E13 - There are no copy / paste errors (O'Beirne 2005, Powell et al. 2009b, Bewig 2005, Powell et al. 2008a)	For example errors when cell contents dragged into other cells e.g. Increasing number / date. **Check:** visual inspection and using R1C1 reference style to show errors in formulae. Steer from interview and test case.
4			E14 - There are no insertion / deletion errors (O'Beirne 2005) (Rajalingham et al. 2000)	Errors when cell contents are inserted or deleted incorrectly **Check:** visual inspection and using R1C1 reference style to show errors in formulae. Steer from interview and test case.
5			E15 - Input data is accurate (Powell et al. 2009a, Raffensburger 2008)	Incorrect input data can result in incorrect output. **Check:** test case followed by interview and then visual inspection, output 'reality check'
6			E16 - All necessary input values are entered (no empty precedence cells) (O'Beirne 2005, Ayalew et al. 2000, Powell et al. 2008a, Raffensburger 2008, Javaid 2010)	Possibility of incorrect output in precedence cells are left empty. **Check:** visual inspection of precedence cells and formulae. Using R1C1 reference style and 'Trace Precedents' for 'Formulas' menu, Formula Auditing tab.
7			E17 - There are no inputs incompatible with cell format (O'Beirne 2005, Powell et al. 2008a)	Possibility of incorrect outputs or misunderstandings e.g. Dates in number cells. **Check:** visual and setting check of formatting - cell by cell
8			E18 - There are no invalid characters in input cells	Possibility of incorrect output. **Check:** visual inspection and 'Error Checking' function on 'Formula Auditing' tab of 'Formulas' menu
9			F76 - Month names are used not numeric dates (individual errors not formatting error) (O'Beirne 2005)	Error in individual cells (not general formatting error). Possibility of confusion due to international differences. **Check:** visual inspection.
10			E19 - Spaces are not used to delete contents of the cell (O'Beirne 2005)	Possibility of incorrect output if cell content contain space character. **Check:** select 'Find & select on 'Editing' tab of 'Home' menu. Enter space into find 'Find what' and in Options select 'Match entire cell contents'. Find All. Review results.

11	Use	Input		E20 - There are no occurrences of the same colour font as cell shading (O'Beirne 2005, Ferguson 2011)		Hidden data possibly causing incorrect output. **Check:** select whole worksheet and change font colour. Follow with cell by cell inspection looking for new content.
12		Output – errors occurring in what appears in the output cells	Formulae	E21 - Dependents / formula are inserted in all necessary output cells (O'Beirne 2005, Powell et al. 2008a, Croll and Butler 2006)		Missing formulae will probably result in incorrect bottom-line outputs. **Check:** visual inspection of input cells and dependants and formulae cells. Use 'Trace Dependants' on 'Formulas' menu, 'Formula Auditing' tab.
13				E22 - All formulae / functions are correct (Powell et al. 2009a, Croll and Butler 2006, Raffensburger 2008, Maditinos et al. 2012, Panko 2008)		Incorrect formulae will probably result in incorrect bottom-line output. **Check:** Inspect all formulae / functions types. Enter '0' or '1' into input cells and check output is accurate
14				E27 - No hard coding in formula cells (O'Beirne 2005, Panko and Aurigemma 2010, Powell et al. 2009b, Rajalingham et al. 2000, Caulkins et al. 2006, Powell et al. 2008a, Powell et al. 2009a, Croll and Butler 2006, Ferguson 2011, Raffensburger 2008)		Incorrect formulae will probably result in incorrect bottom-line output. **Check:** Inspect all formulae / functions select 'Show Formulas' on 'Formulas' menu, 'Formula Auditing' tab.
15				E23 - No instances of formula in wrong cell		Formulae in wrong cell will probably result in incorrect bottom-line output. **Check:** visual inspection of all formulae / functions select 'Show Formulas' on 'Formulas' menu, 'Formula Auditing' tab.
16				E24 - No instances of cell formatting resulting in wrong output		Formatting setting can result in incorrect bottom-line output. **Check:** visual inspection of all cell outputs and formatting.
17				E26 - Formulae ranges accurate (O'Beirne 2005, Bewig 2005, Ayalew et al. 2000, Ferguson 2011)		Incorrect formulae ranges will probably result in incorrect bottom-line output. **Check:** visual inspection of all formulae. Select 'Show Formulas' on 'Formulas' menu, 'Formula Auditing' tab.
18				E25 - Cross check totals agree (O'Beirne 2005, Simkin 2004, Ferguson 2011)		Disagreement of cross check totals (where used) shows an error in input or output cells. Check: visual inspection and 'Trace Precedents' from 'Formula Auditing' tab on 'Formulas' menu.

19	Use	Output	Formulae	E28 - There is no overtyping in formula cells (hardwiring) (Panko 2000, Ayalew et al. 2000, Ferguson 2011, Raffensburger 2008)	Overtyping of formula will probably result in incorrect bottom-line output - may be a latent error i.e. future error if inputs change. **Check:** visual inspection of all formulae. Select 'Show Formulas' on 'Formulas' menu, 'Formula Auditing' tab.
20				E29 - There are no other valid negative value errors (Javaid 2010)	Incorrect negative value will probably result in output error **Check:** visual inspection.
21				E30 - There are no temporary fixes (Bewig 2005)	Temporary fixes will probably result in latent errors i.e. not error at current time but will be an error if any of the inputs change. **Check:** visual inspection of all cells.
22			Error types	E31 - There are no circular references (O'Beirne 2005, Powell et al. 2008a, Spreadsheet Standards Review Board 2014)	Excel standard error reporting. **Check:** select 'Error Checking' on 'Formula Auditing' tab of 'Formulas' menu.
23				E32 - There are no other valid green triangle inconsistencies (O'Beirne 2005)	Excel standard error reporting. **Check:** select 'Error Checking' on 'Formula Auditing' tab of 'Formulas' menu.
24				E33 - There are no other valid ##### errors (O'Beirne 2005)	Excel standard error reporting. **Check:** select 'Error Checking' on 'Formula Auditing' tab of 'Formulas' menu.
25				E34 - There are no other valid #VALUE! Errors (O'Beirne 2005)	Excel standard error reporting. **Check:** select 'Error Checking' on 'Formula Auditing' tab of 'Formulas' menu.
26				E35 - There are no other valid #NAME! Errors (O'Beirne 2005)	Excel standard error reporting. **Check:** select 'Error Checking' on 'Formula Auditing' tab of 'Formulas' menu.
27				E36 - There are no other valid #N/A! Errors(O'Beirne 2005, Javaid 2010)	Excel standard error reporting. **Check:** select 'Error Checking' on 'Formula Auditing' tab of 'Formulas' menu.
28				E37 - There are no other valid #REF! Errors (O'Beirne 2005, Ayalew et al. 2000, Powell et al. 2009b)	Excel standard error reporting. **Check:** select 'Error Checking' on 'Formula Auditing' tab of 'Formulas' menu.
29				E38 - There are no other valid #NUM! Errors (O'Beirne 2005)	Excel standard error reporting. **Check:** select 'Error Checking' on 'Formula Auditing' tab of 'Formulas' menu.

30	Use	Output	Error Types	E39 - There are no #NULL! Errors (O'Beirne 2005)	Excel standard error reporting. **Check:** select 'Error Checking' on 'Formula Auditing' tab of 'Formulas' menu.
31				E40 - There are no #DIV/0! Errors (Javaid 2010)	Excel standard error reporting. **Check:** select 'Error Checking' on 'Formula Auditing' tab of 'Formulas' menu.

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