Comparative Evaluation of Template Systems: Metric Definitions & Detailed Results

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I. Introduction

This document summarizes detailed metric definitions for our *Comparative Evaluation of Template Systems* studies. Figure 1 gives an overview how the ISO 25010 [1] quality model is tailored to identify relevant quality factors.

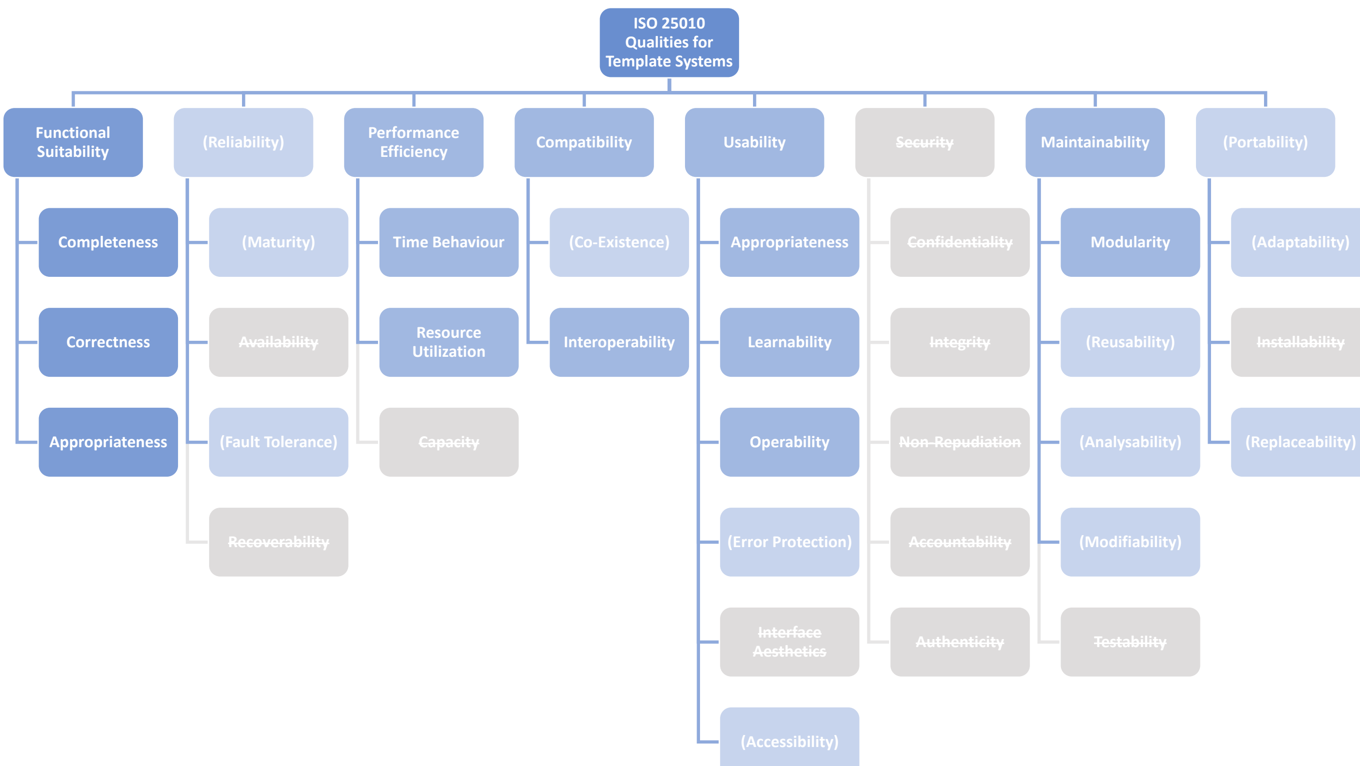

Figure 1. ISO 25010 [1] Quality Model Tailored for Template Systems. Light Grey/Strikethrough not Applicable to Template Systems, Light Blue/in "( )" Strongly Context Dependent Quality-In-Use Factors to be Evaluated in Future Case Studies. Other Factors can be Addresses by Experiments Presented in the Study—Focus on Functional Suitability.

II. Metric definitions

Metrics are documented in Table I-VII, following the template suggested in IEEE 1061 [2] under omission of some attributes not relevant in the context of this evaluation, namely, *costs*, *benefits*, *impact*, *training required*, and *validation history*. For conciseness, several metrics are aggregated in one table based on commonalities in calculation.

The attribution to the seven relevant quality characteristics from ISO29148 [3] is directly extracted from the INCOSE guide [4] and the SOPHIST rules [5] descriptions, as these two guidelines cover the union of all rules. While the INCOSE guide provides this mapping explicitly, SOPHIST rules are mapped to linguistic distortion effects, which are related to the qualities. Figure 2 shows the attribution of rules to guidelines.

Figure 2. Rules for Requirements Phrasing per Guideline

TABLE I. BINARY METRICS FOR RULES (5)-(39)

Name	Individual Compliance to Rules (5)-(39)
Target value	For each requirement r: Binary $[0, 1]$ where 1 means the quality rule is met. For a requirement set R: $[0 - 100]$ % $r \in R$ comply with the rule.
Quality factors	Unambiguous (all but rules (25), (26), & (33)), Appropriate (only rules (7) & (33)), Complete (only rules (12)-(14), (16)-(19), (28), (29), (31), & (34)-(39)), Singular (only rules (19), (24)-(27), & (36)), Verifiable (only rules (5)-(20), (22)-(23), (27)-(28), (30)-(32), & (34)-(39)), Correct (only rules (9)-(12), (16), (21), (34), and (35)), & Conforming (all as guideline, explicitly mapped only rules (21) & (36))
Tools	Spreadsheet program (MS Excel)
Application	Check compliance to rules and detect bad smells.
Data items	Rule evaluation result $GR_j(r)$ for each requirement in the examined set $r \in R$ and each guideline rule $GR_j \vert j \in [5, \ldots, 39]$; $\#r_t$
Computation	$\%GR_j(R) = \frac{\#r_{GR_j}}{\#r_t} * 100, \;\; \#r_{GR_j} = \sum_{i=1}^{\#r_t} GR_j(r_i), \quad GR_j(r) = \begin{cases} 1, & \text{if the respective rule is satisfied,} \\ 0, & \text{else} \end{cases}$ Rules (13) & (14) can be combined to *"clearness of reference point"* [6] (German "Bezugspunkteindeutigkeit" (BPE)) and Rules (8) & (12) are part of *"clearness of process word"* [6] (German "Prozessworteindeutigkeit" (PE))
Interpretation	High numbers indicate many occurrences of the respective bad smell.
Considerations	The same calculations apply for general review results towards the specific quality factors. Too strict application of rules is criticized by some authors. In particular rules (5)+(8) [7], (22) [8], (24) [9, 10], (28) [7–10], and (34) [11].
Example	Let R consist of these two requirements from EagleEye [12]: (1) *"The AOCS subsystem shall account for redundancy of some hardware component to avoid critical and/or catastrophic consequences for the mission."* (2) *"The AOCS subsystem shall account for the following sensors: Star tracker, Three-axis gyros, Sun sensors, Magnetometers, GPS."* Evaluating $\%GR_j(R)$ for rule (25) "separate rationale from sentence": $GR_{25}(r_1) = 0, GR_{25}(r_2) = 1$ and $\%GR_{25}(R) = 50\%$
References	[4–6, 8, 13–18]

TABLE II. COUNTING METRICS FOR RULES (1)-(4)

Name	Number of Sentences, Words, Process Verbs, or Punctuations
Target value	Natural number $\in \mathbb{N}_0\{0, 1, 2, \dots\}$; critical values to meet the quality: - for sentences $\#s$ /process verbs $\#pv$: [1], - for words $\#w$: good $[5, \dots, 15]$, medium $[16, \dots, 20]$, - for punctuations $\#pt$: $< 209/1000$ words
Quality factors	Unambiguity, Comprehensibility, Verifiability (only rule (3)), Singularity (only rules (1) and (3)), and Conforming (as guidelines)
Tools	Spreadsheet program (MS Excel)
Application	Can be applied to an individual requirement wording or a whole set. Check compliance of individual requirements with rules (1)-(4); give impression of phrasing complexity; use as auxiliary metrics within readability metrics, as defined in Table III-V.
Data items	String(s) of requirement wording(s).
Computation	$\#s(r), \#w(r), \#pv(r), \#pt(r) = \|S, W, PV, PT\|$, where $S, W, PV, PT = \{s, w, pv, pt \mid s, w, pv, pt \in r\}$ are sets of sentences s, words w, process verbs pv, and punctuation marks pt of the requirement r. Punctuations are normalized to 1000 words: $\#pt_{/1000w}(r) = \frac{\#pt(r)}{\#w(r)} * 1000$ For sets: $\#s(R), \#w(R), \#pv(R), \#pt(R) = \sum_{i=1}^{\#r_t} \#s(r_i), \#w(r_i), \#pv(r_i), \#pt(r_i)$ Thus, set average values can be calculated: $\varnothing s(R), \varnothing w(R), \varnothing pv(R), \varnothing pt(R) = \frac{\#s(R), \#w(R), \#pv(R), \#pt(R)}{\#r_t}$
Interpretation	Sentences should neither be too short to be complete nor too wordy, punctuations should be below average, and it should be exactly one sentence with one process verb per requirement - divergence from rules indicates a bad smell.
Considerations	Too strict application of rules is criticized by some authors. In particular rule (1) [7]. However, simpler and shorter sentences enhance readability. For readability measures see Table III-V.
Example	Let R consist of these two requirements from EagleEye [12]: (1) *“The AOCS subsystem shall account for redundancy of some hardware component to avoid critical and/or catastrophic consequences for the mission.”* (2) *“The AOCS subsystem shall account for the following sensors: Star tracker, Three-axis gyros, Sun sensors, Magnetometers, GPS.”* $\#s(r_1) = \#s(r_2) = 1$, $\#w(r_1) = 20, \#w(r_2) = 17$, $\#pv(r_1) = 2, \#pv(r_2) = 1$, $\#pt(r_1) = 2, \#pt(r_2) = 6$, $\#pt_{/1000w}(r_1) = 100, \#pt_{/1000w}(r_2) = 352.9$ and $\#pt_{/1000w}(R) = 216.2, \varnothing s(R) = 1, \varnothing w(R) = 18.5, \varnothing pv(R) = 1.5, \varnothing pt(R) = 4$
References	[4, 5, 13–15, 18–20]

TABLE III. FLESCH READING EASE READABILITY SCORE (FRE)

<table>
<tr><td>Name</td><td colspan="3">Flesch Reading Ease Readability Score (FRE)</td></tr>
<tr><td rowspan="9">Target value</td><td colspan="3">Number rounded to Integer $\in [0, 1, \dots, 100]$; critical values to meet the quality:</td></tr>
<tr><td>90–100</td><td>5th grade</td><td>Very easy to read. Easily understood by an average 11 year-old.</td></tr>
<tr><td>80–89</td><td>6th grade</td><td>Easy to read. Conversational English for consumers.</td></tr>
<tr><td>70–79</td><td>7th grade</td><td>Fairly easy to read.</td></tr>
<tr><td>60–69</td><td>8th-9th grade</td><td>Plain English. Easily understood by 13 to 15 year-olds.</td></tr>
<tr><td>50–59</td><td>10th-12th grade</td><td>Fairly difficult to read.</td></tr>
<tr><td>30–49</td><td>13th-16th grade (College)</td><td>Difficult to read.</td></tr>
<tr><td>10–29</td><td>College graduate</td><td>Very difficult to read.</td></tr>
<tr><td>0–9</td><td>Academic</td><td>Extremely difficult to read. Best understood by university graduates.</td></tr>
<tr><td>Quality factors</td><td colspan="3">Comprehensible</td></tr>
<tr><td>Tools</td><td colspan="3">Spreadsheet program (MS Excel), ReadabilityFormulas.com [21],
(Readable [22])</td></tr>
<tr><td>Application</td><td colspan="3">Determine the reading ease or complexity of a given text.</td></tr>
<tr><td>Data items</td><td colspan="3">Number of words $\#w(R)$, number of sentences $\#s(R)$, and number of syllables $\#sy(R)$ for the given set of requirements R. Although it is possible to calculate the formula for an individual requirement wording $r \in R$, it works best on samples of 100-300 words.</td></tr>
<tr><td>Computation</td><td colspan="3">$FRE(R) = 206.835 - 1.015 * \frac{\#w(R)}{\#s(R)} - 84.6 * \frac{\#sy(R)}{\#w(R)}$</td></tr>
<tr><td>Interpretation</td><td colspan="3">The higher the score, the lower the grade level respectively, the better, as this increases reading efficiency and reader persistence [23].</td></tr>
<tr><td>Considerations</td><td colspan="3">General appropriateness discussed in [23]. Original grade level to score mapping [24] is overlapping at interval boundaries and did not include separate academic level; all below 30 is college graduate. The weighting factors within the formula are based on language specific correlation statistics—here for English—and need to be adjusted for other languages. The formula targets “adult” reading and is not sensitive to differences in reading beginners texts < 5th grade.</td></tr>
<tr><td>Example</td><td colspan="3">R = “The AOCS subsystem shall account for redundancy of some hardware component to avoid critical and/or catastrophic consequences for the mission.” from EagleEye [12]
$\#w(R) = 20$, $\#s(R) = 1$, $\#sy(R) = 40$
$FRE(R) = 206.835 - 1.015 * \frac{20}{1} - 84.6 * \frac{40}{20} \approx 17 \widehat{=}$ college graduate level</td></tr>
<tr><td>References</td><td colspan="3">[21, 23–27]</td></tr>
</table>

TABLE IV. DALE-CHALL READABILITY FORMULA (DC)

Name	Dale-Chall Readability Formula (DC)		
Target value	Number; critical values to meet the quality:		
	≤ 4.9	4th grade & below	Very easy to read.
	5.0–5.9	5th-6th grade	Easy to read.
	6.0–6.9	7th-8th grade	Fairly easy to read.
	7.0–7.9	9th-10th grade	Plain English.
	8.0–8.9	11th-12th grade	Fairly difficult to read.
	9.0–9.9	13th-15th grade (College)	Difficult to read.
	≥ 10	College graduate	Very difficult to read.
Quality factors	Comprehensible		
Tools	Spreadsheet program (MS Excel), ReadabilityFormulas.com [21], (Readable [22])		
Application	Determine the reading ease or complexity of a given text.		
Data items	Number of words $\#w(R)$, number of sentences $\#s(R)$, and number of "difficult" words $\#w_d(R)$ for the given set of requirements R. A word w is difficult if $w \notin L_{DC}$, where L_{DC} is a list of commonly known words according to [28]. Although it is possible to calculate the formula for an individual requirement wording $r \in R$, it works best on samples of 100-300 words.		
Computation	$DC_{raw}(R) = 15.79 * \frac{\#w_d(R)}{\#w(R)} + 0.0496 * \frac{\#w(R)}{\#s(R)}$ $DC(R) = \begin{cases} DC_{raw}(R) + 3.6365, & \text{if } \frac{\#w_d(R)}{\#w(R)} * 100 > 5, \\ DC_{raw}(R), & \text{else} \end{cases}$		
Interpretation	The lower the score, the lower the grade level respectively, the better, as this increases reading efficiency and reader persistence [23].		
Considerations	General appropriateness discussed in [23]. The weighting factors within the formula are based on language specific correlation statistics—here for English—and need to be adjusted for other languages. The formula targets "adult" reading and is not sensitive to differences in reading beginners texts $<$ 5th grade.		
Example	R = *"The AOCS subsystem shall account for redundancy of some hardware component to avoid critical and/or catastrophic consequences for the mission." from EagleEye [12]* $\#w(R) = 20$, $\#s(R) = 1$, $\#w_d(R) = 8$, $\frac{\#w_d(R)}{\#w(R)} * 100 = 40 > 5$ $DC(R) = 0.1579 * \frac{8}{20} + 0.0496 * \frac{20}{1} + 3.6365 = 10.9 \widehat{=}$ college graduate level		
References	[21, 23, 26, 28]		

TABLE V. GRADE LEVEL READABILITY FORMULAS

Name	Grade Level Reading Metrics a) Flesch-Kincaid Grade Level (FK) [29] b) Gunning Fog Index (GFI) [30] c) SMOG Index [31] d) Coleman-Liau Index (CLI) [32] e) Automated Readability Index (ARI) [29] f) Linsear Write (LW) [21, 33] g) Fry Readability Graph [34] h) Raygor Estimate Graph [35]
Target value	Number > 0 estimating years of education necessary to understand the text; critical values to meet the quality: < 5 Reading beginners. Formulas not optimized for these levels. 5 Very easy to read. Easily understood by an average 11 year-old. 6 Easy to read. Conversational English for consumers. 7 Fairly easy to read. 8-9 Plain English. Easily understood by 13 to 15 year-olds. 10-12 Fairly difficult to read. 13-16 Difficult to read. College level. > 16 Very difficult to read. College or university graduates.
Quality factors	Comprehensible
Tools	Spreadsheet program (MS Excel), ReadabilityFormulas.com [21], (Readable [22])
Application	Determine the reading ease or complexity of a given text.
Data items	Number of words $\#w(R)$, number of sentences $\#s(R)$, number of syllables $\#sy(R)$, number of letters $\#l(R)$, number of charters (letters and numbers) $\#c(R)$, and number of polysyllabic words $\#w_{\#sy(w)\geq x}(R)$ with $x=3$ for the given set of requirements R. For $\#w_{\#sy(w)\geq x}(R)$, proper names, combinations of easy words, and verbs enlonged by suffixes as -ed, -es, or -ing are ignored. Although it is possible to calculate the formulas for an individual requirement wording $r \in R$, they work best on samples of 100-300 words.
Computation	a) $FK(R) = 0.39 * \frac{\#w(R)}{\#s(R)} + 11.8 * \frac{\#sy(R)}{\#w(R)} - 15.59$ b) $GFI(R) = 0.4 * (\frac{\#w(R)}{\#s(R)} + 100 * \frac{\#w_{\#sy(w)\geq 3}(R)}{\#w(R)})$ c) $SMOG(R) = 1.043 * \sqrt{30 * \frac{\#w_{\#sy(w)\geq 3}(R)}{\#s(R)}} + 3.1291$ d) $CLI(R) = 5.88 * \frac{\#l(R)}{\#w(R)} - 29.6 * \frac{\#s(R)}{\#w(R)} - 15.8$ e) $ARI(R) = 4.71 * \frac{\#c(R)}{\#w(R)} + 0.5 * \frac{\#w(R)}{\#s(R)} - 21.43$ f) $LW_{raw}(R) = \frac{\#w_{\#sy(w)\leq 2}(R) + 3 * \#w_{\#sy(w)\geq 3}(R)}{\#s(R)}$, $LW(R) = \begin{cases} LW_{raw}(R)/2, & \text{if } LW_{raw}(R) > 20, \\ (LW_{raw}(R) - 2)/2, & \text{else} \end{cases}$ g) $Fry(R) = lookup_{FryGraph}(\frac{\#s(R)}{\#w(R)} * 100, \frac{\#sy(R)}{\#w(R)} * 100)$ h) $Raygor(R) = lookup_{RaygorGraph}(\frac{\#s(R)}{\#w(R)} * 100, \frac{\#w_{\#c\geq 6}(R)}{\#w(R)} * 100)$
Interpretation	The lower the grade level, the better, as this increases reading efficiency and reader persistence [23].
Considerations	General appropriateness discussed in [23, 26, 36]. Weighting factors within the formulas optimized for English. Other languages need adjustment. The formulas target "adult" reading and are not sensitive to differences in reading beginners texts < 5th grade.
Example	*R = "The AOCS subsystem shall account for redundancy of some hardware component to avoid critical and/or catastrophic consequences for the mission." from EagleEye [12]* $\#w(R) = 20$, $\#s(R) = 1$, $\#sy(R) = 40$, $\#l(R) = 121 = \#c(R)$, $\#w_{\#sy(w)\geq 3}(R) = 6$, $\#w_{\#sy(w)\leq 2}(R) = 14$, $\#w_{\#c\geq 6}(R) = 10$ a) $FK(R) = 0.39 * \frac{20}{1} + 11.8 * \frac{40}{20} - 15.59 = 15.81 \widehat{=}$ college level b) $GFI(R) = 0.4 * (\frac{20}{1} + 100 * \frac{6}{20}) = 20 \widehat{=}$ college graduate level c) $SMOG(R) = 1.043 * \sqrt{30 * \frac{6}{1}} + 3.1291 \approx 17 \widehat{=}$ college graduate level d) $CLI(R) = 5.88 * \frac{121}{20} - 29.6 \frac{1}{20} - 15.8 = 18.29 \widehat{=}$ college graduate level e) $ARI(R) = 4.71 * \frac{121}{20} + 0.5 * \frac{20}{1} - 21.43 \approx 17 \widehat{=}$ college graduate level f) $LW(R) = \frac{14 + 3 * 6}{1}/2 = 15 \widehat{=}$ college level g) $Fry(R) = lookup_{FryGraph}(\frac{1}{20} * 100 = 5, \frac{40}{20} * 100 = 200) \widehat{=}$ invalid h) $Raygor(R) = lookup_{RaygorGraph}(\frac{1}{20} * 100 = 5, \frac{10}{20} * 100 = 50) \widehat{=}$ invalid
References	[18, 21, 23, 26, 27, 29–32, 34–37]

TABLE VI. ESTIMATED READING TIME

Name	Estimated Reading Time
Target value	Decimal number referring to number of minutes - can be transformed to any time format. There is not absolute critical value, the measure is used relative to compare different results.
Quality factors	Efficiency
Tools	Spreadsheet program (MS Excel), (Readable [22])
Application	Measure how long it takes to read the specification.
Data items	String(s) of requirement wording(s) $r \in R$ and their number of words $\#w(R)$.
Computation	$RT(R) = \frac{\#w(R)}{200} \qquad \varnothing RT(R) = \frac{RT(R)}{\#r_t(R)}$
Interpretation	Faster reading is better. However, absolute reading time depends on length of specification. To compare different specifications the average per requirement should be compared.
Considerations	The formula directly depends on number of words $\#w$. Yet, time is a measure more intelligible in terms of efficiency. Practical reading time depends on reading ease and its fit with the readers capacities. For readability measures see Table III-V. However, average reading time gives impression of time effort needed to process the text in general. Time can also be measured experimentally with test subjects, not only for reading, but also for writing. In general, time is a common efficiency measure [38].
Example	Let R consist of these two requirements from EagleEye [12]: (1) *“The AOCS subsystem shall account for redundancy of some hardware component to avoid critical and/or catastrophic consequences for the mission.”* (2) *“The AOCS subsystem shall account for the following sensors: Star tracker, Three-axis gyros, Sun sensors, Magnetometers, GPS.”* $\#w(r_1) = 20, \#w(r_2) = 17,$ $RT(r_1) = 6sec, RT(r_2) = 5sec, \varnothing RT(R) = 5.5sec$
References	[38–40]

TABLE VII. F-SCORE FORMALITY MEASURE

Name	F-Score
Target value	Percentage of formality within 0 - 100% critical values are unknown due to lack of comparison values.
Quality factors	Formality
Tools	Spreadsheet program (MS Excel), custom Python tool [41]
Application	Measure *deep formality* of the text (level of context needed to understand).
Data items	String(s) of requirement wording(s) $r \in R$ and their percentage of words belonging to a specific category or part of speech (POS) — noun (NN), verb (VB), article (AT), adjective (JJ), preposition (IN), pronoun (PN), adverb (RB), and interjection (UH) $\%w_i(R) = \frac{\#w_i(R)}{\#w(R)} * 100$ with $i \in NN, VB, AT, JJ, IN, PN, RB, UH$.
Computation	$F\!-\!Score(R) = 50 + \frac{\%w_{NN}(R) + \%w_{JJ}(R) + \%w_{IN}(R) + \%w_{AT}(R)}{2} - \frac{\%w_{PN}(R) + \%w_{VB}(R) + \%w_{RB}(R) + \%w_{UH}(R)}{2}$
Interpretation	Higher numbers correspond to less context and thus are better. Yet, reference values are missing, in particular for requirements. Results in related work for different genres range from -55-70% [42, 43]. Thus, values above 40% are expected, but in general the comparison is the goal not the absolute numbers.
Considerations	Discussion on performance in [42]. Works better on larger samples.
Example	R = *“The AOCS subsystem shall account for redundancy of some hardware component to avoid critical and/or catastrophic consequences for the mission.” from EagleEye [12]* $\#w(R) = 20, \%w_{NN}(R) = 35, \%w_{JJ}(R) = 10, \%w_{IN}(R) = 20, \%w_{AT}(R) = 10, \%w_{PN}(R) = 5, \%w_{VB}(R) = 15, \%w_{RB}(R) = 0, \%w_{UH}(R) = 0,$ $F - Score(R) = 50 + \frac{(35 + 10 + 20 + 10) - (5 + 15 + 0 + 0)}{2} = 77.5$
References	[42–45]

Figure 3. Automated and Manually Evaluated Metrics

Wolf and Strößner's [6] unambiguity metric can be calculated as a secondary metric from our results:

$$Unambiguity = \frac{u * PE + v * BPE + w * BE}{\#r_t} * 100, \text{ where}$$

$\#r_t$ is the total number of requirements in the examined set,

PE is the unambiguity of the process words (Ger. "Prozesswortеindeutigkeit") that is the count of all requirements phrased in active voice and using a full verb—a precise verb that is no nominalization and no light verb construction,

BPE is the unambiguity of the reference points (Ger. "Bezugspunkteindeutigkeit") that is the count of all requirements that contain no comparison or where the comparison is clear,

BE is the term unambiguity (Ger. "Begriffseindeutigkeit") that is the count of all requirements where all terms are clear and defined, e.g., in a glossary, and

u, v, w are factors to weight these for the project context.

As term definitions are irrelevant to our experimentation goals, we assume $w = 0$. PE and BPE can be calculated from individual metric evaluations per requirement. Further, as we have no context that provides reason to weight both values, we assume $u = v = 0.5$.

Figure 3 summarizes for which metrics in our experiments the calculation is automated and which are manually evaluated. Auxiliary metrics are depicted in lighter color.

TABLE VIII. DATA ITEM DEFINITION FOR REQUIREMENT PHRASINGS

Name	Requirement Phrasings.
Metrics	Guideline Based Metrics (Table I & II), Readability Scores (Table III-V), Reading-, Writing-, Review-Time (Table VI), F-Score (Table VII), and Subjective Readability, Learnability, & Quality (questionnaire).
Definition	Phrasings of requirements in different template notations.
Source	Rephrased from original documents [46–49].
Collector	Researchers and research assistants, in some cases test subjects.
Timing	Before or during experiments.
Procedures	Manual rephrasing through expert or test subject.
Storage	Spreadsheet.
Representation	Textual.
Sample	Select requirement documents as representative for the targeted domain(s) and abstraction level(s). Include all requirements of the document, if possible.
Verification	Cross-checking through experts or template compliance checking tool.
Alternatives	-
Integrity	Phrasings from user experiments are not to be changed. Expert phrasings as input to experiments can be changed after cross checking quality assessment and discussion.

TABLE IX. DATA ITEM DEFINITION FOR REQUIREMENT QUALITY ASSESSMENT

Name	Requirement Quality Assessment.
Metrics	Guideline Based Metrics (Table I & II), Readability Scores (Table III-V), Reading-Time (Table VI), F-Score (Table VII).
Definition	Binary quality assessment or key data on text characteristics of requirements phrasings necessary to calculate metrics.
Source	Table VIII.
Collector	Researchers (and research assistants), in some cases test subjects.
Timing	Before the measurement of expressiveness.
Procedures	Manual assessment and where possible automated by spreadsheet formula or light weight natural language processing.
Storage	Spreadsheet.
Representation	Matrix requirement:characteristic, binary characteristics (Table I) boolean as [1,0], others (Table II) numeric count.
Sample	Phrasings selected for Table VIII. Characteristics as specified in Table I & II.
Verification	Sample inspection though and discussion with other researchers/experts.
Alternatives	Fully automated through natural language processing.
Integrity	Phrasings from user experiments are not to be changed. Expert phrasings as input to experiments can be changed after cross checking quality assessment and discussion.

III. DATA ITEMS

The different metrics, as introduced above, are applied in different experiments to requirements phrased following different template systems. This data item is summarized in Table VIII following the data item template from IEEE 1061 [2]. Table IX describes in the same way the individual quality ratings of requirements as a data item.

IV. METRIC RESULTS FOR QUALITY REVIEW GROUND TRUTH

Following, we present the detailed metric results that supported the ground truth building for the review task in our user experiment, for the different notation variant of the following requirements:

- Req1 *“It must be substantiated by tests, analysis or a combination thereof that the ECS performs the intended functions in a manner which enables selected values of relevant control parameters to be maintained and the engine kept within the approved operating limits over changing atmospheric conditions in the declared flight envelope.”*
- Req2 *“The ECS must be designed and constructed so that in the full-up configuration, the system is essentially single fault tolerant for electrical and electronic failures with respect to LOTC/LOPC events.”*
- Req3 *“Single failures leading to loss, interruption or corruption of aircraft-supplied data, must not result in a hazardous engine effect for any engine.”*
- Req4 *“Satellite on-board ephemeris table (e.g. earth, sun, stars) shall not require an update from ground more frequently than once every 15 days.”*

concerning the following defect definitions:

vague Is the wording of the requirement free of vagueness? Requirements should have only one possible interpretation by the reader. The requirement should be written in a simple and straightforward language of the user domain and subjective words should be avoided. Check if the wording allows more than one possible interpretation. If this is not the case, the requirement is considered to be vague.

incomplete Is the wording of the requirement complete? The requirement should completely describe every part of the functionality to be delivered. If this is not the case, the requirement is considered to be incomplete.

incorrect Is the wording of the requirement correct? The requirement should accurately describe the functionality to be delivered. If this is not the case, the requirement is considered to be incorrect.

inconcise Is the wording of the requirement concise? The requirement should be marked by brevity of expression or statement and be free from all elaboration and superfluous detail. If this is not the case, the requirement is considered to be inconcise.

TABLE X. VAGUENESS EVALUATION OF FREE FORM REQUIREMENTS READING SAMPLE

	Req1	Req2	Req3	Req4
R1 use only one sentence	✓	✓	✓	✓
R2 use short sentence	✗	✗	✗	✗
R3 use one process-verb	✗	✗	✓	✓
R4 $0 <$ #punctuations/1k words < 209	✓	✓	✓	✗
R5 use modal verb for liability	✓	✓	✓	✓
R6 use simple structured sentence	✗	✗	✓	✗
R7 use appropriate abstraction level	✗	✗	✗	✓
R8 use active voice	✗	✗	✓	✓
R9 use precise verb	✗	✓	✗	✓
R10 avoid nominalization	✗	✗	✗	✓
R11 avoid light-verb construction	✓	✓	✓	✓
R12 use full verb	✗	✗	✗	✓
R13 avoid comparison	✓	✓	✓	✗
R14 use clear comparison	✓	✓	✓	✓
R15 use definite articles	✗	✓	✗	✗
R16 use defined units	✓	✓	✓	✓
R17 avoid vague terms	✗	✓	✗	✓
R18 avoid escape clauses	✓	✓	✓	✓
R19 avoid open-ended clauses	✓	✓	✓	✗
R20 avoid superfluous infinitives	✓	✗	✓	✓
R21 use correct grammar/spelling	✓	✓	✓	✓
R22 avoid negations	✓	✓	✗	✗
R23 avoid /	✓	✗	✓	✓
R24 avoid combinators	✗	✗	✗	✓
R27 avoid group-nouns	✗	✗	✗	✓
R28 avoid pronouns	✗	✓	✓	✓
R29 context free	✗	✗	✗	✓
R30 avoid absolutes	✓	✓	✗	✓
R31 use explicit conditions	✗	✓	✗	✓
R32 use clear condition combinations	✓	✓	✓	✓
R34 use clear quantifiers	✓	✓	✗	✓
R35 use value tolerances	✓	✓	✓	✗
R36 express one atomic need	✗	✓	✗	✓
R37 use clear preconditions	✗	✓	✗	✓
R38 use clear business logic	✗	✗	✗	✓
R39 use clear subject	✗	✓	✗	✓
Readability (ARI [29]) < 10	✗	✗	✗	✓
Review Result (Defect Definition p. 9)	vague	vague	vague	-

TABLE XI. VAGUENESS EVALUATION OF EARS REQUIREMENTS READING SAMPLE

	Req1	Req2	Req3	Req4
R1 use only one sentence	✓	✓	✓	✓
R2 use short sentence	✗	✗	✗	✗
R3 use one process-verb	✗	✓	✓	✓
R4 $0 <$ #punctuations/1k words < 209	✓	✗	✓	✓
R5 use modal verb for liability	✓	✓	✓	✓
R6 use simple structured sentence	✗	✓	✓	✓
R7 use appropriate abstraction level	✗	✓	✗	✓
R8 use active voice	✗	✓	✓	✓
R9 use precise verb	✗	✓	✗	✓
R10 avoid nominalization	✓	✗	✓	✓
R11 avoid light-verb construction	✓	✓	✓	✓
R12 use full verb	✗	✗	✗	✓
R13 avoid comparison	✓	✓	✓	✗
R14 use clear comparison	✓	✓	✓	✓
R15 use definite articles	✓	✗	✗	✗
R16 use defined units	✓	✓	✓	✓
R17 avoid vague terms	✗	✓	✓	✓
R18 avoid escape clauses	✓	✓	✓	✓
R19 avoid open-ended clauses	✓	✓	✓	✓
R20 avoid superfluous infinitives	✓	✓	✓	✓
R21 use correct grammar/spelling	✓	✓	✓	✓
R22 avoid negations	✓	✓	✗	✗
R23 avoid /	✓	✗	✓	✓
R24 avoid combinators	✗	✓	✗	✓
R27 avoid group-nouns	✗	✓	✗	✓
R28 avoid pronouns	✓	✓	✓	✓
R29 context free	✗	✗	✗	✓
R30 avoid absolutes	✓	✓	✓	✓
R31 use explicit conditions	✗	✓	✓	✓
R32 use clear condition combinations	✓	✓	✓	✓
R34 use clear quantifiers	✓	✓	✓	✓
R35 use value tolerances	✓	✓	✓	✗
R36 express one atomic need	✗	✓	✗	✓
R37 use clear preconditions	✗	✓	✗	✓
R38 use clear business logic	✗	✗	✗	✓
R39 use clear subject	✓	✓	✓	✓
Readability (ARI [29]) ¡ 10	✗	✗	✗	✗
Review Result (Defect Definition p. 9)	vague	vague	vague	-

TABLE XII. VAGUENESS EVALUATION OF MASTER REQUIREMENTS READING SAMPLE

	Req1	Req2	Req3	Req4
R1 use only one sentence	✓	✓	✓	✓
R2 use short sentence	✗	✗	✗	✓
R3 use one process-verb	✗	✓	✓	✓
R4 $0 <$ #punctuations/1k words < 209	✓	✓	✓	✓
R5 use modal verb for liability	✓	✓	✓	✓
R6 use simple structured sentence	✓	✓	✓	✓
R7 use appropriate abstraction level	✗	✓	✓	✓
R8 use active voice	✗	✓	✓	✓
R9 use precise verb	✗	✓	✗	✓
R10 avoid nominalization	✓	✗	✓	✓
R11 avoid light-verb construction	✓	✓	✓	✓
R12 use full verb	✗	✗	✗	✓
R13 avoid comparison	✓	✓	✓	✗
R14 use clear comparison	✓	✓	✓	✓
R15 use definite articles	✗	✓	✗	✓
R16 use defined units	✓	✓	✓	✓
R17 avoid vague terms	✗	✓	✓	✓
R18 avoid escape clauses	✓	✓	✓	✓
R19 avoid open-ended clauses	✓	✓	✓	✓
R20 avoid superfluous infinitives	✗	✓	✓	✓
R21 use correct grammar/spelling	✓	✓	✓	✓
R22 avoid negations	✓	✓	✗	✓
R23 avoid /	✓	✗	✓	✓
R24 avoid combinators	✗	✓	✓	✓
R27 avoid group-nouns	✗	✓	✗	✓
R28 avoid pronouns	✓	✓	✓	✓
R29 context free	✗	✗	✗	✓
R30 avoid absolutes	✓	✓	✓	✓
R31 use explicit conditions	✗	✓	✓	✓
R32 use clear condition combinations	✓	✓	✓	✓
R34 use clear quantifiers	✓	✓	✓	✓
R35 use value tolerances	✓	✓	✓	✗
R36 express one atomic need	✗	✓	✗	✓
R37 use clear preconditions	✗	✓	✗	✓
R38 use clear business logic	✓	✗	✗	✓
R39 use clear subject	✓	✓	✓	✓
Readability (ARI [29]) < 10	✗	✓	✗	✓
Review Result (Defect Definition p. 9)	vague	-	vague	-

TABLE XIII. INCOMPLETENESS EVALUATION OF FREE FORM REQUIREMENTS READING SAMPLE

	Req1	Req2	Req3	Req4
R12 use full verb	✗	✗	✗	✓
R13 avoid comparison	✓	✓	✓	✗
R14 use clear comparison	✓	✓	✓	✓
R16 use defined units	✓	✓	✓	✓
R17 avoid vague terms	✗	✓	✗	✓
R18 avoid escape clauses	✓	✓	✓	✓
R19 avoid open-ended clauses	✓	✓	✓	✗
R28 avoid pronouns	✗	✓	✓	✓
R29 context free	✗	✗	✗	✓
R31 use explicit conditions	✗	✓	✗	✓
R34 use clear quantifiers	✓	✓	✗	✓
R35 use value tolerances	✓	✓	✓	✗
R36 express one atomic need	✗	✓	✗	✓
R37 use clear preconditions	✗	✓	✗	✓
R38 use clear business logic	✗	✗	✗	✓
R39 use clear subject	✗	✓	✗	✓
Review Result (Defect Definition p. 9)	incomplete	-	incomplete	-

TABLE XIV. INCOMPLETENESS EVALUATION OF EARS REQUIREMENTS READING SAMPLE

	Req1	Req2	Req3	Req4
R12 use full verb	✗	✗	✗	✓
R13 avoid comparison	✓	✓	✓	✗
R14 use clear comparison	✓	✓	✓	✓
R16 use defined units	✓	✓	✓	✓
R17 avoid vague terms	✗	✓	✓	✓
R18 avoid escape clauses	✓	✓	✓	✓
R19 avoid open-ended clauses	✓	✓	✓	✓
R28 avoid pronouns	✓	✓	✓	✓
R29 context free	✗	✗	✗	✓
R31 use explicit conditions	✗	✓	✓	✓
R34 use clear quantifiers	✓	✓	✓	✓
R35 use value tolerances	✓	✓	✓	✗
R36 express one atomic need	✗	✓	✗	✓
R37 use clear preconditions	✗	✓	✗	✓
R38 use clear business logic	✗	✗	✗	✓
R39 use clear subject	✓	✓	✓	✓
Review Result (Defect Definition p. 9)	incomplete	-	incomplete	-

TABLE XV. INCOMPLETENESS EVALUATION OF MASTER REQUIREMENTS READING SAMPLE

	Req1	Req2	Req3	Req4
R12 use full verb	✗	✗	✗	✓
R13 avoid comparison	✓	✓	✓	✗
R14 use clear comparison	✓	✓	✓	✓
R16 use defined units	✓	✓	✓	✓
R17 avoid vague terms	✗	✓	✓	✓
R18 avoid escape clauses	✓	✓	✓	✓
R19 avoid open-ended clauses	✓	✓	✓	✓
R28 avoid pronouns	✓	✓	✓	✓
R29 context free	✗	✗	✗	✓
R31 use explicit conditions	✗	✓	✓	✓
R34 use clear quantifiers	✓	✓	✓	✓
R35 use value tolerances	✓	✓	✓	✗
R36 express one atomic need	✗	✓	✗	✓
R37 use clear preconditions	✗	✓	✗	✓
R38 use clear business logic	✓	✗	✗	✓
R39 use clear subject	✓	✓	✓	✓
Review Result (Defect Definition p. 9)	**incomplete**	-	-	-

TABLE XVI. INCONCISENESS EVALUATION OF REQUIREMENTS READING SAMPLE

	Req1	Req2	Req3	Req4	
R1 use only one sentence	✓	✓	✓	✓	**Free**
R2 use short sentence	✗	✗	✗	✗	
R3 use one process-verb	✗	✗	✓	✓	
R4 0 < #punctuations/1k words < 209	✓	✓	✓	✗	
R6 use simple structured sentence	✗	✗	✓	✗	
R8 use active voice	✗	✗	✓	✓	
R18 avoid escape clauses	✓	✓	✓	✓	
R19 avoid open-ended clauses	✓	✓	✓	✗	
Review Result (Defect Definition p. 9)	**inconcise**	**inconcise**	-	**inconcise**	
R1 use only one sentence	✓	✓	✓	✓	**EARS**
R2 use short sentence	✗	✗	✗	✗	
R3 use one process-verb	✗	✓	✓	✓	
R4 0 < #punctuations/1k words < 209	✓	✗	✓	✓	
R6 use simple structured sentence	✗	✓	✓	✓	
R8 use active voice	✗	✓	✓	✓	
R18 avoid escape clauses	✓	✓	✓	✓	
R19 avoid open-ended clauses	✓	✓	✓	✓	
Review Result (Defect Definition p. 9)	**inconcise**	-	-	-	
R1 use only one sentence	✓	✓	✓	✓	**MASTeR**
R2 use short sentence	✗	✗	✗	✓	
R3 use one process-verb	✗	✓	✓	✓	
R4 0 < #punctuations/1k words < 209	✓	✓	✓	✓	
R6 use simple structured sentence	✓	✓	✓	✓	
R8 use active voice	✗	✓	✓	✓	
R18 avoid escape clauses	✓	✓	✓	✓	
R19 avoid open-ended clauses	✓	✓	✓	✓	
Review Result (Defect Definition p. 9)	**inconcise**	-	-	-	

TABLE XVII. INCORRECTNESS EVALUATION OF REQUIREMENTS READING SAMPLE

	Req1	Req2	Req3	Req4	
R9 use precise verb	✗	✓	✗	✓	**Free**
R10 avoid nominalization	✗	✗	✗	✓	
R11 avoid light-verb construction	✓	✓	✓	✓	
R12 use full verb	✗	✗	✗	✓	
R16 use defined units	✓	✓	✓	✓	
R21 use correct grammar/spelling	✓	✓	✓	✓	
R34 use clear quantifiers	✓	✓	✗	✓	
R35 use value tolerances	✓	✓	✓	✗	
Review Result (Defect Definition p. 9)	-	-	-	-	
R9 use precise verb	✗	✓	✗	✓	**EARS**
R10 avoid nominalization	✓	✗	✓	✓	
R11 avoid light-verb construction	✓	✓	✓	✓	
R12 use full verb	✗	✗	✗	✓	
R16 use defined units	✓	✓	✓	✓	
R21 use correct grammar/spelling	✓	✓	✓	✓	
R34 use clear quantifiers	✓	✓	✓	✓	
R35 use value tolerances	✓	✓	✓	✗	
Review Result (Defect Definition p. 9)	-	-	-	-	
R9 use precise verb	✗	✓	✗	✓	**MASTeR**
R10 avoid nominalization	✓	✗	✓	✓	
R11 avoid light-verb construction	✓	✓	✓	✓	
R12 use full verb	✗	✗	✗	✓	
R16 use defined units	✓	✓	✓	✓	
R21 use correct grammar/spelling	✓	✓	✓	✓	
R34 use clear quantifiers	✓	✓	✓	✓	
R35 use value tolerances	✓	✓	✓	✗	
Review Result (Defect Definition p. 9)	-	-	-	-	

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