

4. As part of the lifecycle concept analysis and maturation activities the project team developed a prototype to access feasibility. The resulting needs and resulting requirements are based on the prototype and an associated trade study that resulted a specific solution that meets the needs of the stakeholders. Rather than communicating the Design Input Requirements, the design output requirements for the prototype are included in the design input set of requirements while not addressing the “for what purpose?” design input requirement set that would drive the design for the prototype.

## 4.10 Quantifiers

### 4.10.1 R32 – UNIVERSAL QUALIFICATION

#### Definition:

Use “each” instead of “all”, “any”, or “both” when universal quantification is intended.

#### Elaboration:

The use of “all”, “both”, or “any” is confusing because it is hard to distinguish whether the action happens to the whole set or to each element of the set. “All” can also be hard to verify unless “all” can be clearly defined as a closed set. In many cases, the word “all” is unnecessary and can be removed, resulting in a less ambiguous need or requirement statement.

#### Examples:

Unacceptable: The Operation\_Logger shall record **any (or all)** warning messages.

[This is unacceptable because of the use of the word “any”, which is then made worse by the addition of “(or all)”.]

Improved: The Operation\_Logger shall record each Warning\_Message.

[Note that Warning\_Message must be defined in the glossary so that it is clear that the SOI only will record each defined Warning Message. Also, any conditions or performance must also be included in the requirements statement for it to be complete.]

Unacceptable: The Record\_Subsystem shall display per <Display Standard xyz> the Names of **both** of the Line\_Items.

[This is unacceptable because of the use of the word “both”.]

Improved: The Record\_Subsystem shall display per <Display Standard xyz> the Name of each Line\_Item.

Improved: The Record\_Subsystem shall display per <Display Standard xyz> each Line\_Item\_Name.

## 4.11 Tolerance

### 4.11.1 R33 – RANGE OF VALUES

#### Definition:

Define each quantity with a range of values appropriate to the entity to which the quantity applies and against which the entity will be verified or validated.

**Elaboration:**

When it comes to defining performance, single-point values are seldom sufficient and are difficult to test. Ask the question: "if the performance was a little less (or more) than this, would I still buy it?" or "Is it still fit for its intended use?" If the answer is yes, then change the need or requirement statement to reflect an acceptable range of values.

It also helps to consider the underlying goal: are you trying to minimize, maximize or optimize something? The answer to this question will help determine whether there is an upper bound, lower bound, or both.

State the quantities contained in a need or requirement statement with ranges or limits with a degree of accuracy and precision that is appropriate to the entity to which the need or requirement applies and against which the entity will be verified against.

Care should be taken to avoid unspecified value ranges and ensure the quantities are expressed with tolerances or limits. There are two reasons for this:

- 1) Several requirements may have to be traded against each other, and providing tolerances or limits is a way of describing the trade-space. Seldom is a quantity absolute. A range of values is usually acceptable, providing different performance levels.
- 2) Verification against a single absolute value is usually not feasible or at best expensive and time consuming, whereas verification against a defined range of values with upper and lower limits makes verification more manageable.

Care should also be taken to ensure the tolerances are no tighter than needed. Tighter tolerances can drive costs both in system design and manufacturing as well as the costs in verifying the system can perform within the tighter tolerances.

Ranges and tolerances must be described in a consistent and unambiguous way. Examples of possible structures for such information are:

- 10 kg  $\pm$  2 kg
- 10 kg  $\pm$  5%
- 10 kg (+0.0 kg / -0.5 kg)
- ... from 10 kg to 12 kg.
- ... between 10 kg and 12 kg.

Specific scenarios such as '8.0 oz (+0/-0.5 oz)' can be particularly dangerous:

- 1) They require uniformity in terms of decimal format (R40) between the value and the tolerance ranges: '8.0 oz (+0.0/-0.5 oz)'.
- 2) The measurement units must be appropriate and clearly defined for each numerical value (R6): '8.0 oz (+0.0 oz / -0.5 oz)'
- 3) For comprehension reasons, these structures can be simplified as: "from 7.5 oz to 8.0 oz" or "between 7.5 oz and 8.0 oz" (note that the ranges could also be expressed as "from 8.0 oz to 7.5 oz" or "between 8.0 oz and 7.5 oz", but comprehension is facilitated by nominating the lower value first). Also, be aware of tolerance stack up issues. It may be that individual tolerances seem reasonable, but when combined with other related component tolerances, there may be an issue. If one part is at the lower end of the tolerance range and the part it is to interface with is at the higher end of the tolerance range, the parts may not be able to be connected. Thus, the tolerance ranges must be consistent and not in conflict with other related parts of the system architecture in which a part is to interact. See also R40.

**Examples:**

Unacceptable: The Pumping\_Station shall maintain the flow of water at 100 liters per second for 30 minutes.

[This is unacceptable because we do not know whether a solution that addresses more or less than the specified quantities is acceptable. Also, it is not clear under what conditions this applies – when in operations, when powered on, when commanded?]

Improved: When in operations, the Pumping\_Station shall maintain Water\_Flow at 100 ±10 liters for a minimum of 30 minutes.

[Now the range of acceptable flow performance is clear and that the 30 minutes is a minimum acceptable performance. Given that the condition “when in operations”, this requirement applies whenever the Pumping\_Station is active—no matter how long. Also, a question to be asked is what is the intent for how long—31 minutes satisfies the requirement, but what if the real intent is for however long the Pumping Station is in operations which could be hours or days – again depending on the operating conditions and need. What if there is not enough water at the inlet to the pumping station to establish the required flow rate?]

Unacceptable: The Flight\_Information\_System shall display the current altitude to approximately 1 meter resolution.

[This is unacceptable because it is imprecise. What is “approximately” in the context of a distance of 1 meter? Who has the option of deciding what is “approximately”? How will “approximately” be verified? What is the acceptable tolerance?]

[Note that care must be taken to confirm that the units are appropriate in the context of the organizational and project templates. See also R6.]

Improved: The Flight\_Information\_System shall display Current\_Altitude with an accuracy of ±1 meter.

[Note that “Current\_Altitude” must be defined in the glossary since there are a number of possible interpretations of the term.]

Unacceptable: The <SOI> shall limit arsenic contamination in the drinking water to allowable levels. Rationale: Arsenic contamination in drinking water can cause health problems.

[While “allowable” is acceptable in a need statement, it is unacceptable in a requirement statement because allowable is ambiguous - allowable by whom? What specific concentration is allowable? In what market?]

Unacceptable: The <SOI> shall limit arsenic contamination in the drinking water to 1 part per trillion. Rationale Attribute (A1): Arsenic contamination in drinking water can cause health problems.

[This is unacceptable because the EPA contamination limit in drinking water is 10 parts per billion. Requiring a tighter limit may be beyond the ability of current technology to measure or if measuring concentrations of 1 part per trillion are possible, the cost to do so may be unacceptably high. Also, no range is specified. Using ‘less than’ is probably the real intent.]

Improved: The <SOI> shall limit arsenic contamination in the drinking water to less than 10 parts per billion. Rationale Attribute (A1): EPA set the arsenic standard for drinking water at 10 ppb (or 0.010 parts per million). The EPA has determined that concentrations of this level or less will protect consumers from the effects of long-term, chronic exposure to arsenic.

**Exceptions and relationships:**

The use of tolerances in need statements may not be as mandatory as their use in requirement statements—see Appendix D.

## 4.12 Quantification

### 4.12.1 R34 – MEASURABLE PERFORMANCE

#### Definition:

Provide specific measurable performance targets appropriate to the entity to which the need or requirement is stated and against which the entity will be verified to meet.

#### Elaboration:

Some words signal unmeasured quantification, such as "prompt", "fast", "routine", "maximum", "minimum", "optimum", "nominal", "easy to use", "close quickly", "high speed", "medium-sized", "best practices", and "user-friendly." These are ambiguous and need to be replaced by specific quantities within feasible ranges that can be measured.

#### Examples:

Unacceptable: The <SOI> shall **use minimum** power.

[This is unacceptable because both words "use" and "minimum" are ambiguous and unverifiable.]

Improved: The <SOI> shall consume less than or equal to 50W of mains power.

[This both considers the underlying goal—to minimize power consumption—and provides a measurable target.]

Unacceptable: The engine shall achieve an emissions level that is at least 5% less than the competition's emission levels 2 years from now.

[This is an actual requirement from marketing to an engineering department. The statement sets a completely unmeasurable end state.]

Improved: The Engine shall achieve an emissions level that is less than or equal to xxx.

[where xxx represents the required threshold value, including the appropriate units.]

Unacceptable: The <SOI> shall conform to best practices for spurious emissions.

[This statement is vague and unverifiable from number of specifics]

Improved: The <SOI> shall limit Spurious\_Emissions in accordance with <Clause xab of Standard XYZ>.

#### Exceptions and relationships:

Some quantification terms such as "minimum", "maximum", "optimal" are almost always ambiguous. Other terms may be ambiguous at lower levels but sufficient at the higher levels and as need statements. For example, it may be appropriate that the business state that "The Aircraft shall provide class-leading comfort."—while such a requirement is not quantifiable and therefore not measurable, it may be sufficient for the business to communicate its intentions as a need