Poorly Formed Requirements Assessment

Using the characteristics and rules defined in the INCOSE Guide to Writing Requirements (GtWR) to define well-formed design input requirements.

Requirements Working Group

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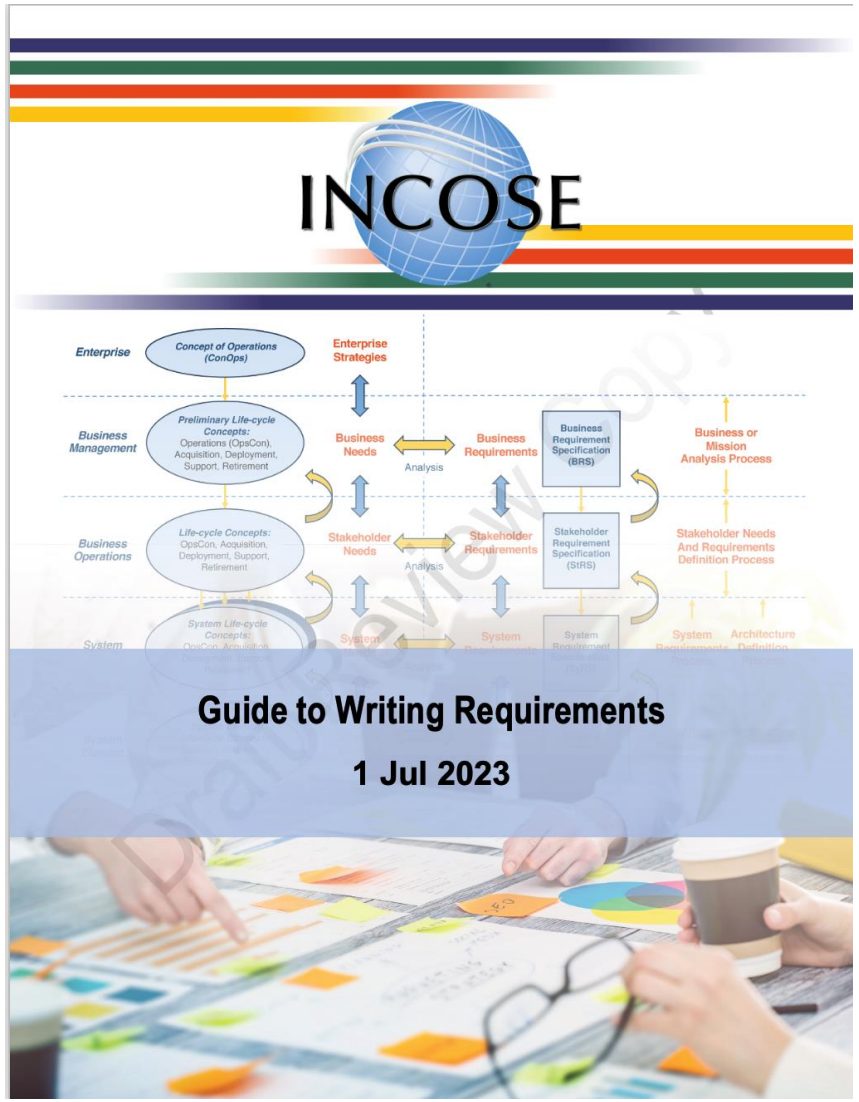
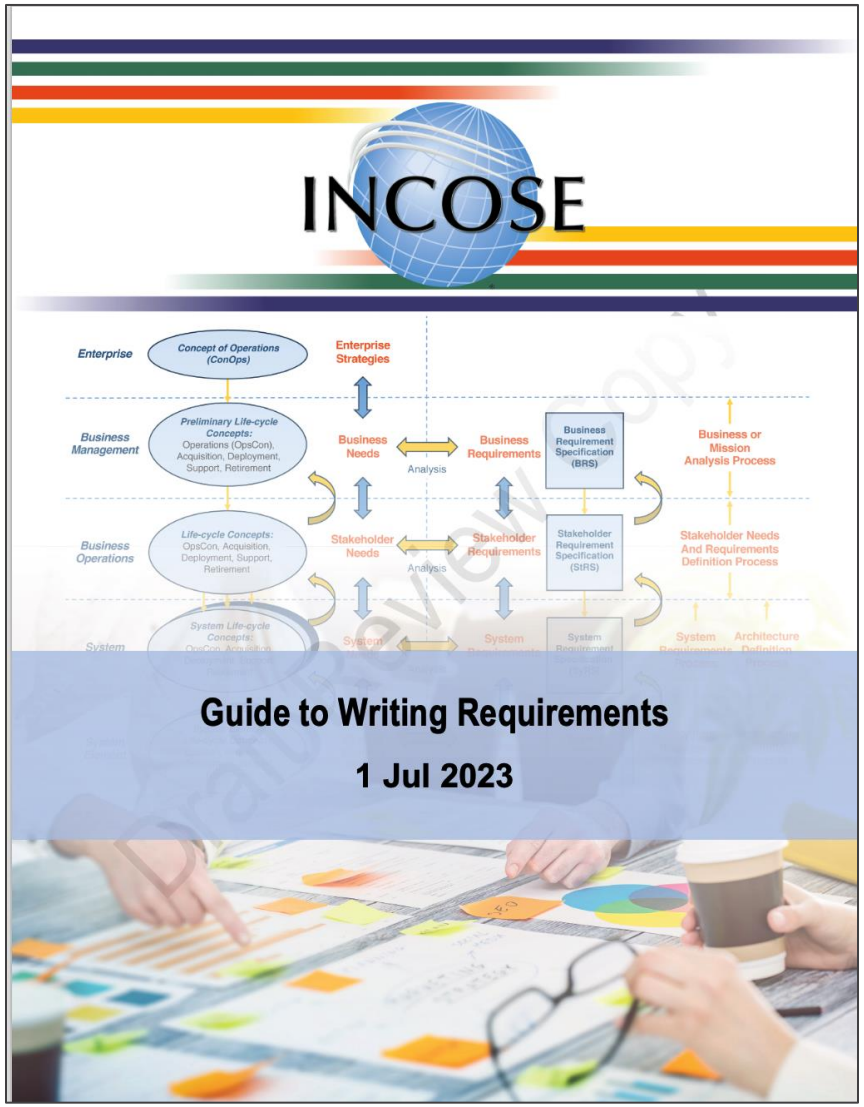
Guide to Writing Requirements



- The Guide to Writing Requirements (GtWR) has been a popular product for many years.
- The **Gold Standard** for writing quality need and requirement statements.
- The RWG released V3.1 in May 2022 update to align the GtWR with the NRM, GtNR, & GtVV.
- V4 was released in June 2023.

GtWR Presentations on YouTube



At IW2023, several presentations were given on the GtWR:

- Section 1 - Introduction and Basic Concepts
- Section 2 - Characteristics of well-formed needs and requirements
- Section 3 - Characteristics of well-formed sets of needs and requirements.

In May, a presentation was given to the ChicagoLand Chapter on Section 4: Rules for Individual Need and Requirement Statements and Sets of Needs and Requirements.

A presentation giving an overview of the GtWR is also available.

Recordings of these presentations are available on the INCOSE RWG YouTube Channel.

It is highly recommended you watch the above presentations available on the INCOSE RWG YouTube Channel.

Agenda

- Overview of the characteristics of well-formed needs and requirements and sets of needs and requirements.
- Overview of the rules for individual need and requirement statements and sets of needs and requirements.
- Case Study Background – Lid Installation Robot (LIR).
- Assessment and rewrite of a set of poorly formed design input requirements for the LIR.

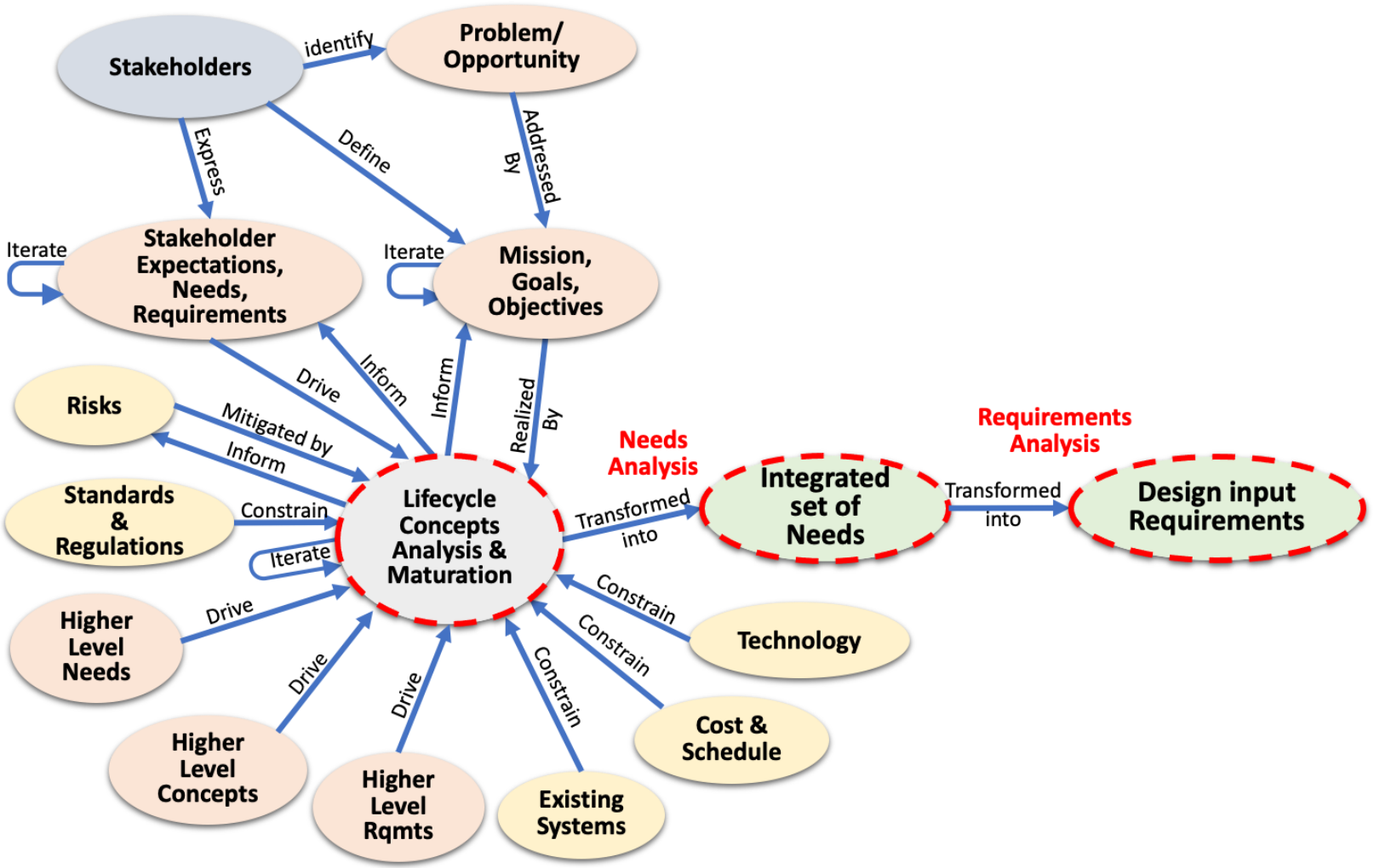
The focus of this presentation is applying the characteristics and rules defined in the GtWR to a case study.

There is a lot of work to be done before defining requirements.

Defining well-formed requirement statements is not an exercise in writing, but an exercise in engineering.

As such, it is important that:

- The necessary upfront work and analysis is done to define lifecycle concepts and an integrated set of needs from which the requirements are transformed.
- The context in which the System of Interest (SOI) exists is well understood.



Define Attributes for each Requirement Statement

While the focus of this presentation is on crafting well-formed requirement statements, it is important that a set of attributes is defined that are combined with the **requirement statements** to form **requirement expressions**.

The inclusion of these attributes helps in understanding intent and contributes to the quality of the requirement statements.

Attributes to Help Define Needs & Requirement and Their Intent
- A1 - Rationale*
- A2 - Trace to Parent*
- A3 - Trace to Source*
- A4 - States and Modes
- A5 - Allocation/Budgeting*

Attributes Associated with System Verification & System Validation
- A6 - System Verification or System Validation Success Criteria*
- A7 - System Verification or System Validation Strategy*
- A8 - System Verification or System Validation Method*
- A9 - System Verification or System Validation Responsible Organization*
- A10 - System Verification or System Validation Level
- A11 - System Verification or System Validation Phase
- A12 - Condition of Use
- A13 -System Verification or System Validation Results
- A14 -System Verification or System Validation Status

Attributes to Help Maintain the Requirements
- A15 - Unique Identifier*
- A16- Unique Name
- A17 - Originator/Author*
- A18 - Date Requirement Entered
- A19- Owner*
- A20 – Stakeholders
- A21 - Change Board
- A22 - Change Proposed
- A23 - Version Number
- A24 - Approval Date
- A25 - Date of Last Change
- A26 - Stability/Volatility
- A27 - Responsible Person
- A28 - Need or Requirement Verification Status*
- A29 - Need or Requirement Validation Status*
- A30 - Status of the Need or Requirement
- A31 - Status (of Implementation)
- A32 - Trace to Interface Definition
- A33 - Trace to Dependent Peer Requirements
- A34 - Priority*
- A35 - Criticality or Essentiality*
- A36 - Risk (of Implementation) *
- A37 - Risk (Mitigation)
- A38 - Key Driving Need or Requirement (KDN/KDR)
- A39 - Additional Comments
- A40 - Type/Category

Attributes to Show Applicability and Allow Reuse
- A41- Applicability
- A42 - Region
- A43 - Country
- A44 - State/Province
- A45 - Market Segment
- A46 - Business Unit

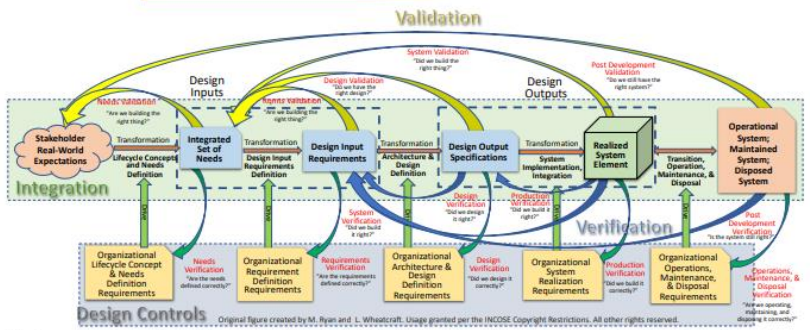
Attributes to Aid in Product Line Management
- A47 – Product Line
- A48 - Product Line Common Needs and Requirements
- A49 - Product Line Variant Needs and Requirements

From INCOSE RWG GtWR Summary sheet

(Refer to the NRM for a detailed discussion on Attributes)

GtWR 7-page Summary Sheet

INCOSE Guide to Writing Requirements V4 – Summary Sheet



Needs and Requirements are the common threads that tie all lifecycle activities and artifacts together. Once the needs are verified and validated, all subsequent artifacts are validated against the needs and once the resulting design input requirements are verified and validated, all subsequent artifacts are verified against those design input requirements.

Definitions

An ***entity*** is a single item to which a concept, need, or requirement applies: an organization, business unit, project, supplier, service, procedure, SOI (system, subsystem, system element), product, process, or stakeholder class (user, operator, tester, maintainer, etc.).

*A **concept** is a textual or graphic representation that concisely expresses how an entity can fulfill the problem, threat, or opportunity it was defined to address within specified constraints with acceptable risk that provides a business in terms of people, process, and products.*

*A set of **lifecycle concepts** includes multiple concepts across the lifecycle for how the organization (and stakeholders within an organization) expects to manage, acquire, define, develop, build/code, integrate, verify, validate, transition, install, operate, support, maintain, and retire an entity.*

*A **need statement** is the result of a formal transformation of one or more sources or lifecycle concepts into an agreed-to expectation for an entity to perform some function or possess some quality within specified constraints with acceptable risk.*

A ***requirement statement*** is the result of a formal transformation of one or more sources, needs, or higher-level requirements into an agreed-to obligation for an entity to perform some function or possess some quality within specified constraints with acceptable risk.

Characteristics

When defining needs and requirements, it is important that they have the characteristics of well-formed needs and requirements. These characteristics are a result of following the rules defined in the Guide to Writing Requirements (GtWR) as well as performing the activities associated with the definition of the needs and requirements as discussed in the Needs and Requirements Manual (NRM) and Guide to Needs and Requirements (GtNR). The underlying analysis from which a need or requirement was derived is as important as how well the need or requirement statement is formed.

Formal Transformation. Given the need and requirement is a result of a formal transformation, the following characteristics of a well-formed need or requirement have been derived:

C1 - Necessary: The need requirement statement defines capability, characteristic, constraint, or quality factor *needed or required* to satisfy a lifecycle concept, need, source, or higher-level requirement.

C2 - Appropriate: The specific intent and amount of detail of the need or requirement statement is appropriate to the level (the level of abstraction, organization, or system architecture) of the entity to which it refers.

C5 - Singular: The need or requirement statement should state a single capability, characteristic, constraint, or quality factor.

C8 - Correct: The need statement must be an accurate representation of the lifecycle concept or source from which it was transformed. The requirement statement must be an accurate representation of the need, source, or higher-level requirement from which it was transformed.

C9 - Conforming: Statements and expressions of individual needs and requirements should conform to an approved standard pattern and style guide or standard for writing and managing needs and requirements.

Agreed-to Obligation. Since the need and requirement is to be a part of a fair agreement to meet an obligation, the following characteristics of a need or requirement have been derived.

C3 - Unambiguous: Need and requirement statements must be stated such that their intent is clear and can be interpreted in only one way by all intended audiences.

C4 - Complete: *The need statement sufficiently describes the necessary capability, characteristic, constraint, conditions, or quality factor to meet the lifecycle concept or source from which it was transformed.* The requirement statement sufficiently describes the necessary capability, characteristic, constraint, conditions, or quality factor to meet the need, source, or higher-level requirement from which it was transformed.

C6 - Feasible: The need or requirement can be realized within entity constraints (for example: cost, schedule, technical, legal, ethical, safety) with acceptable risk.

C7 - Verifiable: The need statement is structured and worded such that its realization can be validated to the approving authority's satisfaction. The requirement statement is structured and worded such that its realization can be verified to the approving authority's satisfaction.

Characteristics of well-formed needs and requirements.

Rules for Need and Requirement Statements and Sets of Needs and Requirements

Accuracy

R1 - Structured Statements: Need and requirement statements must conform to one of the agreed patterns, thus resulting in a well-structured complete statement.

R2 – Active Voice: Use the active voice in the need or requirement statement with the responsible entity clearly identified as the subject of the sentence.

R3 - Appropriate Subject-Verb: Ensure the subject and verb of the need or requirement statement are appropriate to the entity to which the statement refers.

R4 - Defined Terms: Define all terms used within the need statement and requirement statement within an associated glossary and/or data dictionary.

R5 - Definite Articles: Use the definite article "the" rather than the indefinite article "a".

R6 - Common Units of Measure: When stating quantities, all numbers should have appropriate and consistent units of measure explicitly stated using a common measurement system in terms of the thing the number refers.

R7 - Vague Terms: Avoid the use of vague terms that provide vague quantification, such as "some", "any", "allowable", "several", "many", "a lot of", "a few", "almost always", "very nearly", "nearly", "about", "close to", "almost", and "approximate". Avoid vague adjectives such as "ancillary", "relevant", "routine", "common", "generic", "significant", "flexible", "expandable", "typical", "sufficient", "adequate", "appropriate", "efficient", "effective", "proficient", "reasonable" and "customary."

R8 - Escape Clauses: Avoid the inclusion of escape clauses that state vague conditions or possibilities, such as "so far as is possible", "as little as possible", "where possible", "as much as possible", "if it should prove necessary", "if necessary", "to the extent necessary", "as appropriate", "as required", "to the extent practical", and "if practicable".

R9- Open-Ended Clauses: Avoid open-ended, non-specific clauses such as "including but not limited to", "etc." and "and so on".

Concision

R10 - Superfluous Infinitives: Avoid the use of superfluous infinitives such as "to be designed to", "to be able to", "to be capable of", "to enable", "to allow".

R11 - Separate Clauses: Use a separate clause for each condition or qualification.

Non-ambiguity

R12 - Correct Grammar, 13 - Correct Spelling, 14 - Correct Punctuation - Use correct grammar, spelling, punctuation.

R15 - Logical Expressions: Use a defined convention to express logical expressions such as "[X AND Y]", "[X OR Y]", [X XOR Y]", "NOT [X OR Y]".

R16 - Use of "Not": Avoid the use of "not."

R17 - Use of Oblique Symbol: Avoid the use of the oblique ("/") symbol except in units, i.e., Km/hr, or fractions.

Singularity

R18 - Single Thought Sentence: Write a single sentence that contains a single thought conditioned and qualified by relevant sub-clauses.

R19 – Combinators: Avoid words that join or combine clauses, such as "and", "or", "then", "unless", "but", "as well as" "but also", "however", "whether", "meanwhile", "whereas", "on the other hand", or "otherwise".

R20 - Purpose Phrases: Avoid phrases that indicate the "purpose of ", "intent of", or "reason for" the need statement or requirement statement.

R21 – Parentheses: Avoid parentheses and brackets containing subordinate text.

R22 – Enumeration: Enumerate sets explicitly instead of using a group noun to name the set.

R23 - Supporting Diagram, Model, or ICD: When a need or requirement is related to complex behavior, refer to a supporting diagram, model, or ICD.

Completeness

R24 – Pronouns; Avoid the use of personal and indefinite pronouns.

R25 – Headings: Avoid relying on headings to support explanation or understanding of the need or requirement.

Realism

R26 – Absolutes: Avoid using unachievable absolutes such as 100% reliability, 100% availability, all, every, always, never, etc.

Conditions

R27 - Explicit Conditions: State conditions' applicability explicitly instead of leaving applicability to be inferred from the context.

R28 - Multiple Conditions: Express the propositional nature of a condition explicitly for a single action instead of giving lists of actions for a specific condition.

Uniqueness

R29 – Classification: Classify needs and requirements according to the aspects of the problem or system it addresses.

R30 - Unique Expression: Express each need and requirement once and only once.

Abstraction

R31 – Solution Free: Avoid stating implementation in a need statement or requirement statement unless there is rationale for constraining the design.

Quantifiers

R32 - Universal Qualification: Use "each" instead of "all", "any", or "both" when universal quantification is intended.

Tolerance

R33 - Range of Values: 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.

Quantification

R34 - Measurable Performance: 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.

R35 - Temporal Dependencies: Define temporal dependencies explicitly instead of using indefinite temporal keywords such as "eventually", "until", "before", "after", "as", "once", "earliest", "latest", "instantaneous", "simultaneous", and "at last".

Uniformity of Language

R36 - Consistent Terms and Units: Ensure each term and unit of measure used throughout need and requirement sets as well as associated models and other SE artefacts developed across the lifecycle are consistent with the project's defined ontology.

R37 – Acronyms: If acronyms are used, they must be consistent throughout need and requirement sets as well as associated models and other SE artefacts developed across the lifecycle.

R38 – Abbreviations: Avoid the use of abbreviations in needs and requirement statements as well as associated models and other SE lifecycle artefacts.

R39 - Style Guide: Use a project-wide style guide for individual need statements and requirement statements.

R40 - Decimal Format: Use a consistent format and number of signification digits for the specification of decimal numbers.

Modularity

R41 - Related Needs and Requirements: Group related needs and requirements together.

R42 – Structured Sets; Conform to a defined structure or template for organizing sets of needs and requirements.

Attributes of Need and Requirement Statements (defined in the NRM)

A minimum set of attributes that should be defined for each requirement are annotated with an asterisk ("*")

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Attributes to Aid in Product Line Management

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			Characteristics for Individual needs and requirements									Characteristics for Sets of needs requirements				
			Necessary	Appropriate	Unambiguous	Complete	Singular	Feasible	Verifiable	Correct	Conforming	Complete	Consistent	Feasible	Comprehendible	Able to be validated	Correct
Quality Focus	Rule	Subject	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10	C11	C12	C13	C14	C15
Accuracy	R1	Structured Statements			X	X			X	X	X						
	R2	Active Voice		X	X	X			X								
	R3	Appropriate Subject-Verb		X	X				X		X				X		
	R4	Defined Terms			X				X				X		X	X	X
	R5	Definite Articles			X				X								
	R6	Common Units of Measure			X	X			X	X							
	R7	Vague Terms			X	X			X								
	R8	Escape Clauses			X				X								
	R9	Open-ended Clauses			X	X	X		X								
Concision	R10	Superfluous infinitives			X				X								
	R11	Separate Clauses			X	X			X	X							
Non-ambiguity	R12	Correct Grammar			X				X	X	X						
	R13	Correct Spelling			X				X								
	R14	Correct Condition			X					X							
	R15	Logical Expressions			X				X								
	R16	Use of "Not"			X				X	X							
	R17	Use of Oblique Symbol			X				X								
Singularity	R18	Single-thought Sentence			X		X		X		X				X		
	R19	Combinators			X		X										
	R20	Purpose Phrases	X				X										
	R21	Parentheses					X										

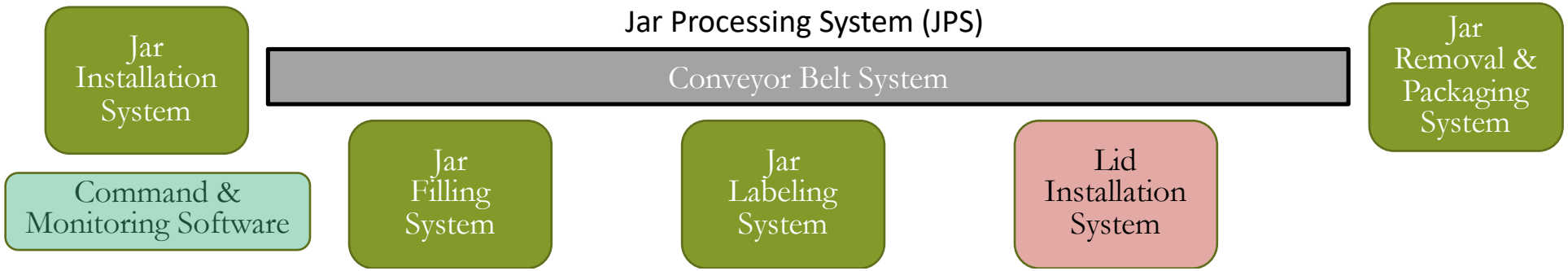
(includes the matrices)

Case Study Background

Lid Installation Robot (LIR)

Background

- The business consists of production facilities where customer supplied products are put into jars of various sizes, labels applied, lids installed, and filled jars are packaged for customer pickup.
- There are 10 production facilities spread across the country
  - Each production facility has 20 Jar Processing Systems (JPS).
  - Each JPS consists of
    - The Command & Monitoring (C&M) software that runs on a computer system in a central Facility Control Room (FCR) with an operator to monitor each of the 20 JPSs visually via cameras, the FCR C&M software, and oversee overall facility operations (fire, security, shipping/receiving, storage, HVAC, power).



  - All systems have been automated except the Lid Installation Robot (LIR) which operates within the Lid Installation System (LIS).

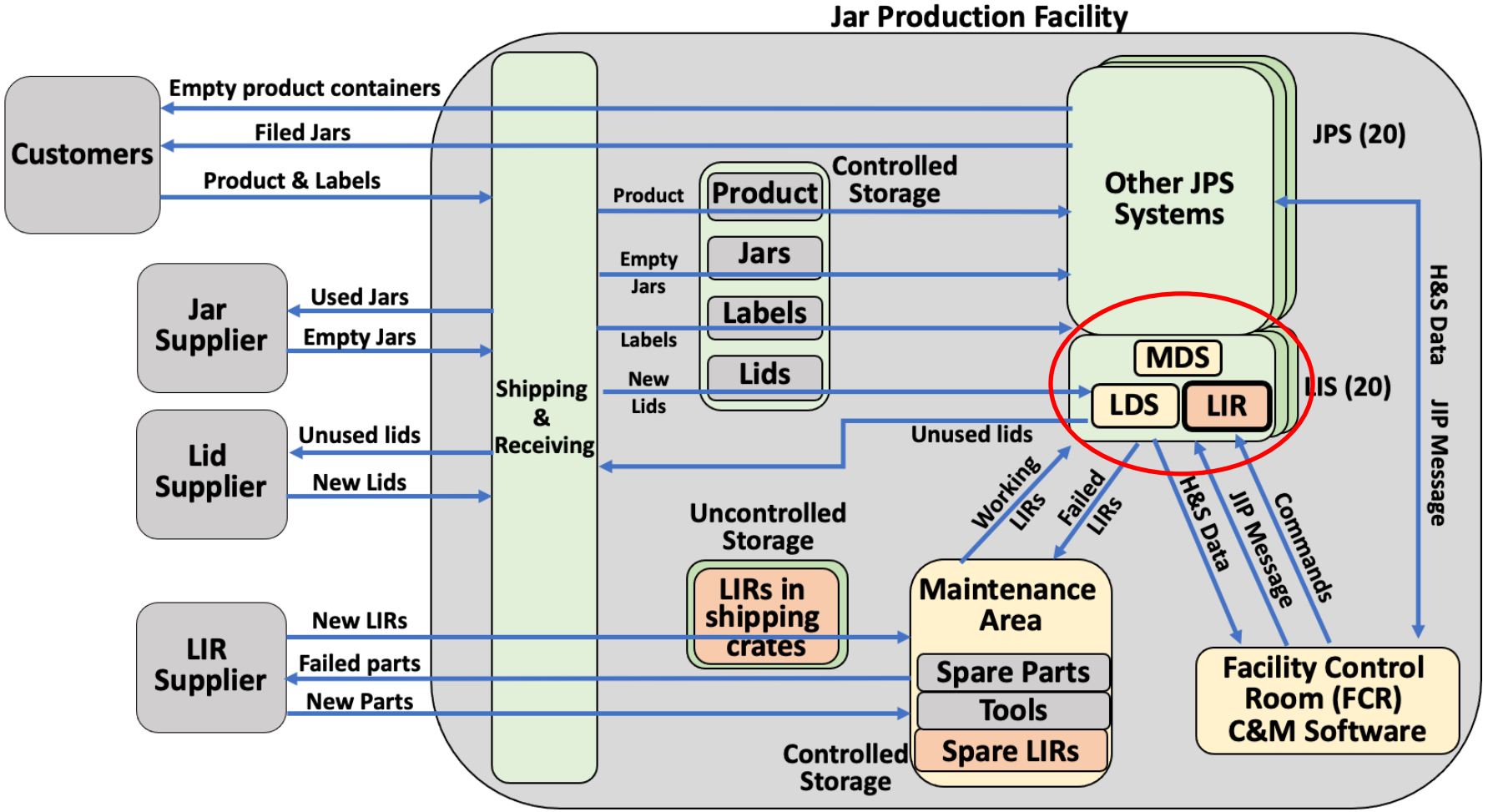
JIS: Jar Installation System,; LIS: Lid Installation System; LIR: Lid Installation Robot; JPS: Jar Processing System; FCR: Facility Control Room; C&M: Command & Monitoring; CBS: Conveyor Belt System

Background

- There is one LIS for each JPS.
  - The LIS consists of a separate, environmentally controlled room with an opening at one end of the room to access jars on the JPS Conveyor Belt System (CBS).
  - The LIS includes a Lid Dispensing System (LDS) from which the LIR will obtain Lids.
    - A maintenance technician installs Lids of the proper size within the LDS prior to shift start.
  - The operating shift for the JPSs are 8 hours/day, 7 days/week, 355 days/year (10 days off for holidays). (Operations are constrained to only 1 shift per day.).
- Each JPS is assigned to a specific product and jar size.
- There are a variety of jars of varying heights, lid sizes, and materials (glass or plastic).
- Jars are delivered to each LIS via the JPS CBS.
- The LIR will replace the existing human lid installers.
  - The LIR must install lids obtained from the LDS on the jars to the proper torque specified by the jar manufacturer based on lid size and jar material at a rate based on the speed the CBS delivers jars.
  - The LIR will be controlled and monitored by the FCR C&M software.

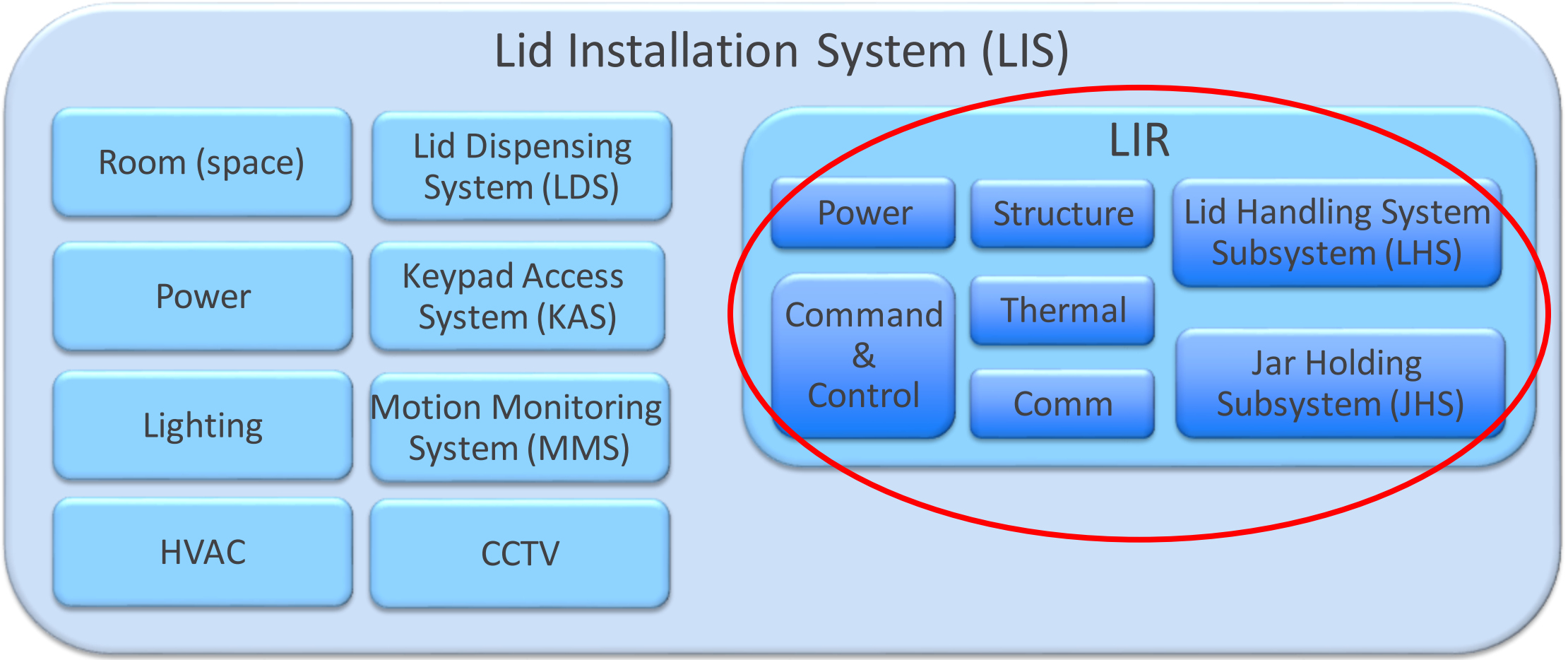
JIS: Jar Installation System,; LIS: Lid Installation System; LIR: Lid Installation Robot; JPS: Jar Processing System; FCR: Facility Control Room; C&M: Command & Monitoring; CBS: Conveyor Belt System

Existing Systems – Context Diagram
(Macro system in which the LIR is a part)



LIS: Lid Installation System; LIR: Lid Installing Robot; JPS: Jar Processing System; FCR: Facility Control Room; JHS Jar Handling Subsystem; LHS: Lid Handling Subsystem; LDS: Lid Distribution System; MDS: Motion Detection System

LIS Conceptual/Logical Architecture



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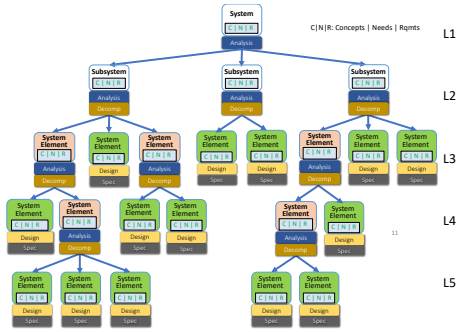
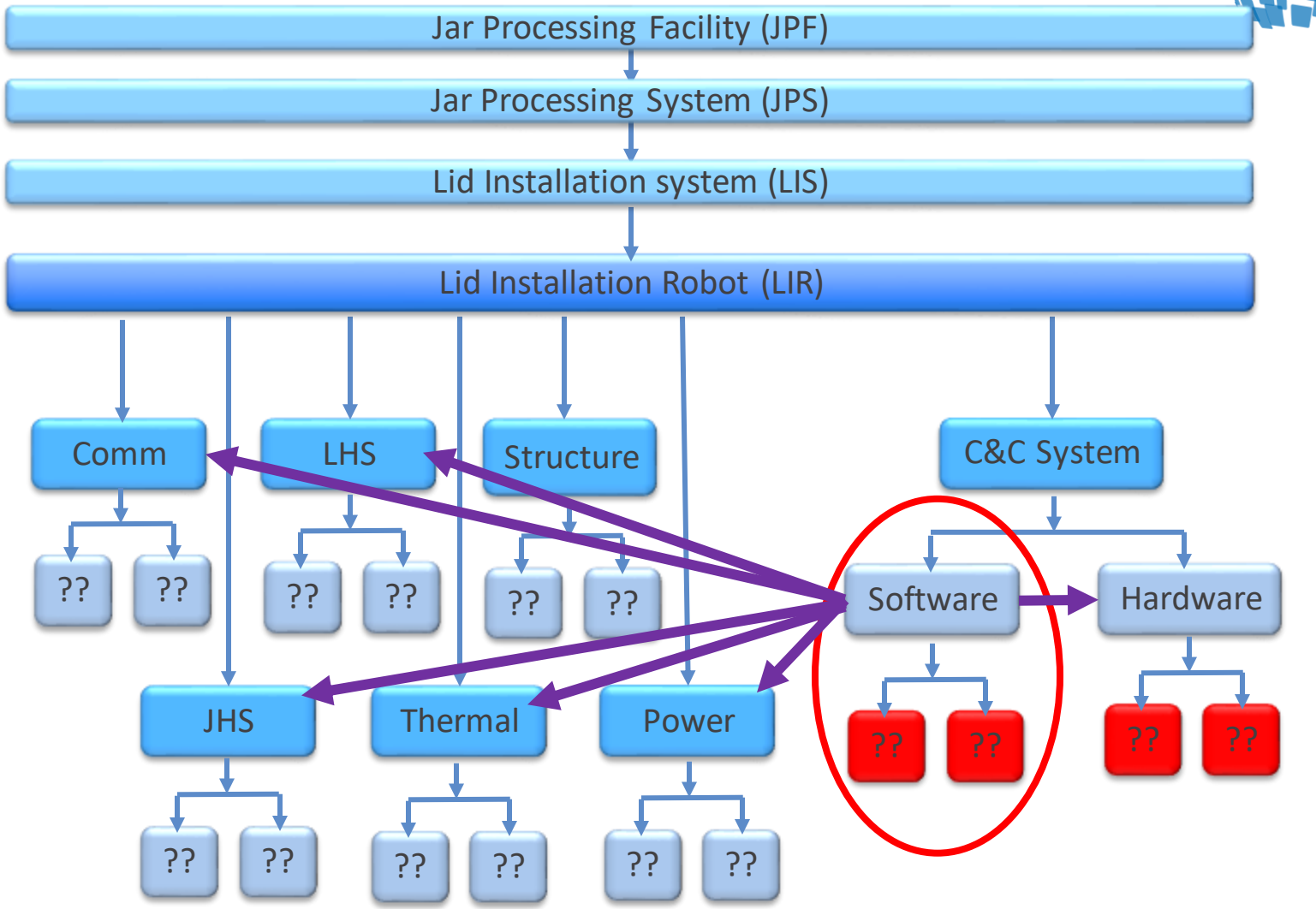
LIR Hierarchical Architecture View



The LIR is a part of the LIS which is a part of the JPS, which operates within the JPF.

The LIR is expected to be a software intensive system.



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LIS Architecture Descriptions

- **LIR: Lid Installation Robot (LIR):** The system that installs lids on the jars.
- **Lid Dispensing System (LDS):** Receives and stores daily supply of lids (960) from facility maintenance technician prior to shift start. Dispenses (makes available) lids to the LIR LHS. The LDS has not been developed yet. Specifics concerning how the LDS presents a lid to the LIR LHS is TBD. Once defined, the definition will be included in an LDS/LIR ICD.
- **Motion Detection System (MDS)**: Monitors for motion within the LIS. Provides health and status data and motion alerts to LIR and FCR C&M Software.
- **Power**: Provides power outlets within the LIS room.
- **Lighting**: Provides variable lighting within the LIS room.
- **HVAC**: Distributes facility conditioned air within the LIS room. Flowrate, temperature, and humidity are controllable for each LIS room via the FCR C&M Software.
- **Room** (space): Provides floor space and volume and access to jars n the CBS.
- **Keypad Access System (KAS)**: Provides controlled entry to the LIS room via the door. Notifies the LIR and FCR C&M Software whenever the KAS is accessed.
- **CCTV:** Cameras that allow the FCR operator to observe all activities within the LIS room.

LIS: Lid Installation System; LIR: Lid Installing Robot; JPS: Jar Processing System; FCR: Facility Control Room; JHS Jar Handling Subsystem; LHS: Lid Handling Subsystem; LDS: Lid Dispensing System; MDS: Motion Monitoring System; KAS: Keypad Access System

LIS Architecture Descriptions

- **LIR Subsystems:**
  - **Power:** Obtains power from the LIS and distributes power within the LIR
  - **Structure:** Provides the mechanical structure to which parts are attached
  - **Thermal:** Includes fans & venting to help control the internal temperature of parts within the LIR.
  - **Comm:** Enables the communication between the LIR and LIS MDS, LIS KAS, and the FCR C&M Software for supplying data and messages to the FCR C&M Software as well as the receipt of commands and messages from the FCR C&M Software, LIS MDS, and LIS KAS.
  - **Command & Control (C&C)**: Hardware processors and software. Processes commands received from the FCR C&M Software, commands the various subsystems that make up the LIR, monitors and collects health and operational status data from the parts that make up the LIR, sends messages, and health and status data to the FCR C&M Software. Also monitors for critical failures and receives messages from the LIS MDS and LIS KAS via the Comm Subsystem.
  - **Lid Handling (LHS)**: Obtains lids from LDS and grasps a lid with the required force and in the proper orientation to install the lid on a jar, positions lid to jar top location, and installs lids on the jars with proper torque. Provides health and status data to LIR C&C software.
  - **Jar Handling (JHS)**: Grasps Jars and holds the jar with sufficient force to prevent the jar from rotating during lid installation, without moving or breaking the jars. Provides health and status data to LIR C&C software.

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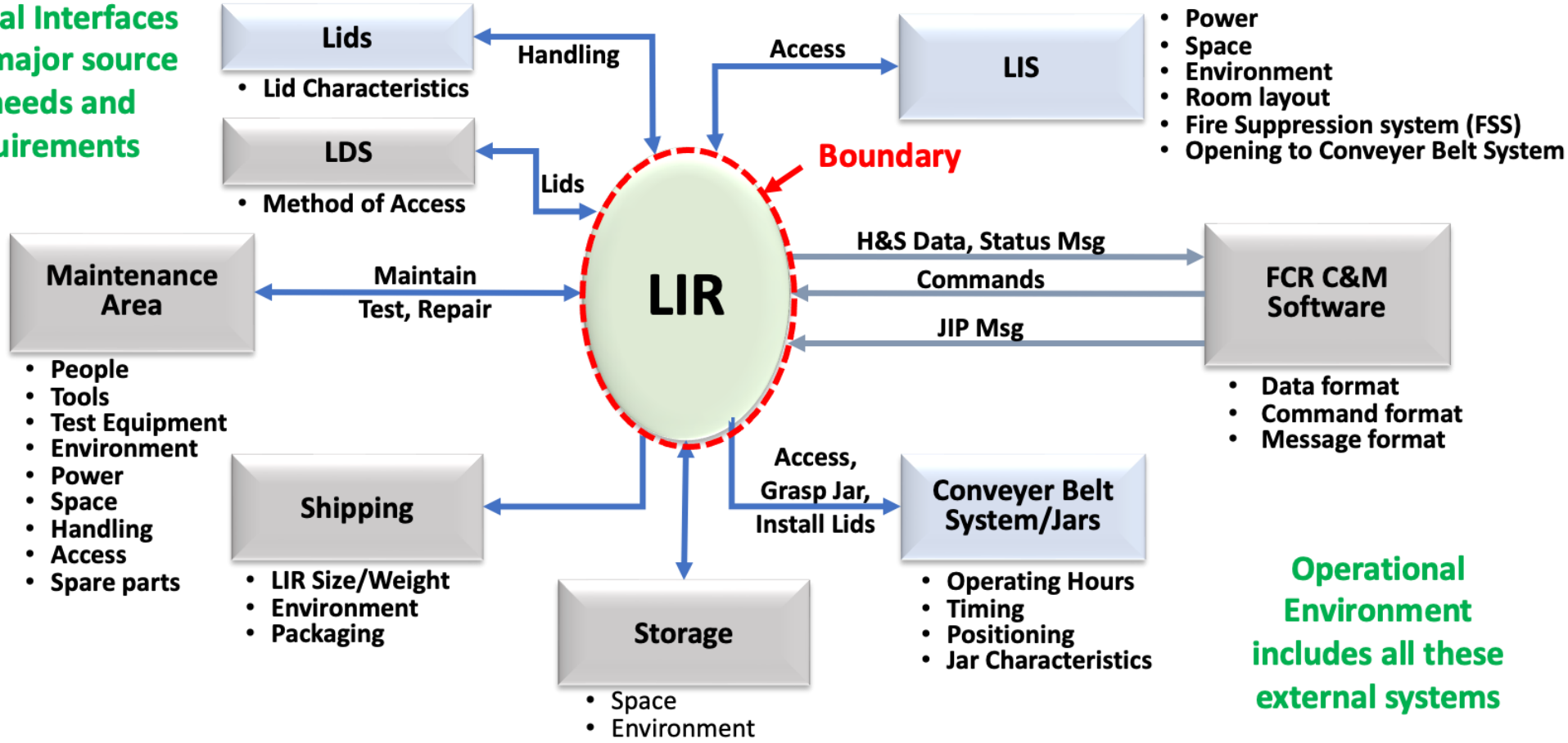
LIR External Interfaces

External Interfaces are a major source of needs and requirements



Operational Environment includes all these external systems

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Interactions between the LIR and external systems are defined within Interface Control Documents (ICDs)

Characteristics of Well-Formed Needs and Requirements and Sets of Needs and Requirements

Characteristics of Individual Requirement Expressions

Formal Transformation. Given the need and requirement is a result of a formal transformation, the following characteristics of a well-formed need or requirement have been derived:

C1 - Necessary: The need requirement statement defines capability, characteristic, constraint, or quality factor needed or required to satisfy a lifecycle concept, need, source, or higher-level requirement.

C2 - Appropriate: The specific intent and amount of detail of the need or requirement statement is appropriate to the level (the level of abstraction, organization, or system architecture) of the entity to which it refers.

C5 - Singular: The need or requirement statement should state a single capability, characteristic, constraint, or quality factor.

C8 - Correct: The need statement must be an accurate representation of the lifecycle concept or source from which it was transformed. The requirement statement must be an accurate representation of the need, source, or higher-level requirement from which it was transformed.

C9 - Conforming: Statements and expressions of individual needs and requirements should conform to an approved standard pattern and style guide or standard for writing and managing needs and requirements.

Agreed-to Obligation. Since the need and requirement is to be a part of a fair agreement to meet an obligation, the following characteristics of a need or requirement have been derived.

C3 - Unambiguous: Need and requirement statements must be stated such that their intent is clear and can be interpreted in only one way by all intended audiences.

C4 - Complete: The need statement sufficiently describes the necessary capability, characteristic, constraint, conditions, or quality factor to meet the lifecycle concept or source from which it was transformed. The requirement statement sufficiently describes the necessary capability, characteristic, constraint, conditions, or quality factor to meet the need, source, or higher-level requirement from which it was transformed.

C6 - Feasible: The need or requirement can be realized within entity constraints (for example: cost, schedule, technical, legal, ethical, safety) with acceptable risk.

C7 - Verifiable: The need statement is structured and worded such that its realization can be validated to the approving authority's satisfaction. The requirement statement is structured and worded such that its realization can be verified to the approving authority's satisfaction.

From the INCOSE GtWR v4

Characteristics of Sets of Requirements

Formal Transformation. Given the set of needs and requirements is the result of a formal transformation, the following characteristics of the need and requirement set have been derived:

C10 - Complete: The set of needs and set of requirements for an entity should stand alone such that it sufficiently describes the necessary capabilities, characteristics, functionality, performance, drivers, constraints, conditions, interactions, standards, regulations, safety, security, resilience, and quality factors without requiring other sets of needs or sets of requirements at the appropriate level of abstraction.

C11 - Consistent: A set of needs and a set of requirements is consistent if contains individual needs or requirements that are:

- unique;
- do not conflict with or overlap with others in the set;
- makes use of homogeneous units and measurement systems; and
- are developed using a consistent language (that is, the same words are used throughout the set to mean the same thing); and use terms that are consistent with the architectural model, project glossary, and project data dictionary.

C15 - Correct: The set of needs must be an accurate representation of the lifecycle concepts or sources from which it was transformed. The set of requirements must be an accurate representation of the needs, sources, or higher-level requirements from which it was transformed.

Agreed-to Obligation. Since the set of need and requirements is to be a result of a fair agreement to meet an obligation, the following characteristics of the set have been derived:

C12 - Feasible: A set of needs and a set of requirements is feasible if it can be realized within entity constraints (such as cost, schedule, technical) with acceptable risk.

C13 - Comprehensible: The set of needs and the set of resulting requirements must each be written such that it is clear as to what is expected of the entity and its relation to the macro system of which it is a part.

C14 - Able to be validated: It must be possible to validate that the set of needs will lead to the achievement of the product goals and objectives, stakeholder expectations, risks, and lifecycle concepts within the constraints (such as cost, schedule, technical, legal and regulatory compliance) with acceptable risk.

It must be possible to validate that the set of requirements will lead to the achievement of the set of needs and higher-level requirements within the constraints (such as cost, schedule, technical, and regulatory compliance) with acceptable risk.

From the INCOSE GtWR v4

Rules for writing well-formed requirement statements and sets of requirements

The GtWR provides a set of rules that **contribute to** requirement statements having the desired characteristics of well-formed individual requirements and sets of needs and requirements.

- While following the rules is necessary, it is not sufficient.
- The overall quality of the requirements is also dependent on the concepts and activities defined in the INCOSE Needs and Requirements Manual (NRM) and Guide to Needs and Requirements (GtNR).

The rules for needs and requirements discussed in the GtWR apply to needs and requirements for any entity no matter the level within an organization or system architecture.

The rest of this presentation focus is

- on assessing the quality of a set of LIR requirements based on the GtWR set of rules,
- discussing defects in the requirements, and then
- proposing an improved version of the requirement that follows the GtWR rules resulting in requirement statements that have the characteristics of well-formed requirements.

From the INCOSE GtWR v4

			Characteristics for Individual needs and requirements									Characteristics for Sets of needs requirements					
			Necessary	Appropriate	Unambiguous	Complete	Singular	Feasible	Verifiable	Correct	Conforming	Complete	Consistent	Feasible	Comprehensible	Able to be validated	Correct
Quality Focus	Rule	Subject	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10	C11	C12	C13	C14	C15
Accuracy	R1	Structured Statements			X	X			X	X	X						
	R2	Active Voice		X	X	X			X								
	R3	Appropriate Subject-Verb		X	X				X			X				X	
	R4	Defined Terms			X				X				X		X	X	X
	R5	Definite Articles			X				X								
	R6	Common Units of Measure			X	X			X	X							
	R7	Vague Terms			X	X			X								
	R8	Escape Clauses			X				X								
	R9	Open-ended Clauses			X	X	X		X								
Concision	R10	Superfluous infinitives			X				X								
	R11	Separate Clauses			X	X			X	X							
Non-ambiguity	R12	Correct Grammar			X				X	X	X						
	R13	Correct Spelling			X				X								
	R14	Correct Condition			X					X							
	R15	Logical Expressions			X				X								
	R16	Use of “Not”			X				X	X							
	R17	Use of Oblique Symbol			X				X								
Singularity	R18	Single-thought Sentence			X		X		X		X				X		
	R19	Combinators			X		X										
	R20	Purpose Phrases	X				X										
	R21	Parentheses					X										
	R22	Enumeration			X		X										
	R23	Supporting Diagram, Model or ICD			X	X	X										
Completeness	R24	Pronouns			X	X			X								
	R25	Headings				X											
Realism	R26	Absolutes						X	X	X				X			
Conditions	R27	Explicit Conditions				X			X	X							
	R28	Multiple Conditions			X				X								
Uniqueness	R29	Classification										X	X				
	R30	Unique Expression	X								X		X				
Abstraction	R31	Solution Free		X													
Quantifiers	R32	Universal Qualification			X				X	X							
Tolerance	R33	Range of Values			X	X		X	X	X				X			
Quantification	R34	Measurable Performance			X	X			X					X			
	R35	Temporal Dependencies			X	X			X								
Uniformity of Language	R36	Consistent Terms and Units			X					X	X		X		X	X	X
	R37	Acronyms			X						X		X		X	X	X
	R38	Abbreviations									X		X		X	X	X
	R39	Style Guide				X	X				X		X		X	X	X
	R40	Decimal Format			X	X					X		X				
Modularity	R41	Related Needs and Requirements				X					X	X	X		X		X
	R42	Structured Sets										X	X		X	X	X

Rules to Characteristics Cross Reference Matrix

GtWR Rules

R1 - Structured Statements: Need and requirement statements must conform to one of the agreed patterns, resulting in a well-structured complete statement.

R2 - Active Voice: Use the active voice in the need or requirement statement with the responsible entity clearly identified as the subject of the sentence.

R3 - Appropriate Subject-Verb: Ensure the subject and verb of the need or requirement statement are appropriate to the entity to which the statement refers.

R4 - Defined Terms: Define all terms used within the need statement and requirement statement within an associated glossary and/or data dictionary.

R5 - Definite Articles: Use the definite article “the” rather than the indefinite article “a”.

R6 - Common Units of Measure: When stating quantities, all numbers should have appropriate and consistent units of measure explicitly stated using a common measurement system in terms of the thing the number refers.

R7 - Vague Terms: Avoid the use of vague terms that provide vague quantification, such as “some”, “any”, “allowable”, “several”, “many”, “a lot of”, “a few”, “almost always”, “very nearly”, “nearly”, “about”, “close to”, “almost”, and “approximate”. Avoid vague adjectives such as “ancillary”, "relevant”, “routine”, “common”, “generic”, “significant”, “flexible”, “expandable”, “typical”, “sufficient”, “adequate”, “appropriate”, “efficient”, “effective”, “proficient”, “reasonable” and “customary.”

R8 - Escape Clauses: Avoid the inclusion of escape clauses that state vague conditions or possibilities, such as “so far as is possible”, “as little as possible”, “where possible”, “as much as possible”, “if it should prove necessary”, “if necessary”, “to the extent necessary”, “as appropriate”, “as required”, “to the extent practical”, and “if practicable”.

GtWR Rules

R9 - Open-Ended Clauses: Avoid open-ended, non-specific clauses such as “including but not limited to”, “etc.” and “and so on”.

R10 - Superfluous Infinitives: Avoid the use of superfluous infinitives such as “to be designed to”, “to be able to”, “to be capable of”, “to enable”, “to allow”.

R11 - Separate Clauses: Use a separate clause for each condition or qualification.

R12 - Correct Grammar, 13 - Correct Spelling, 14 - Correct Punctuation - Use correct grammar, spelling, punctuation.

R15 - Logical Expressions: Use a defined convention to express logical expressions such as “[X AND Y]”, “[X OR Y]”, [X XOR Y]”, “NOT [X OR Y]”.

R16 - Use of “Not”: Avoid the use of “not.”

R17 - Use of Oblique Symbol: Avoid the use of the oblique ("/") symbol except in units, i.e., Km/hr, or fractions.

R18 - Single Thought Sentence: Write a single sentence that contains a single thought conditioned and qualified by relevant sub-clauses.

R19 - Combinators: Avoid words that join or combine clauses, such as “and”, “or”, “then”, “unless”, “but”, “as well as” “but also”, “however”, “whether”, “meanwhile”, “whereas”, “on the other hand”, or “otherwise”.

R20 - Purpose Phrases: Avoid phrases that indicate the “purpose of “, “intent of”, or “reason for” the need statement or requirement statement.

GtWR Rules

R21 - Parentheses: Avoid parentheses and brackets containing subordinate text.

R22 - Enumeration: Enumerate sets explicitly instead of using a group noun to name the set.

R23 - Supporting Diagram, Model, or ICD: When a need or requirement is related to complex behavior, refer to a supporting diagram, model, or ICD.

R24 - Pronouns: Avoid the use of personal and indefinite pronouns.

R25 - Headings: Avoid relying on headings to support explanation or understanding of the need or requirement.

R26 - Absolutes: Avoid using unachievable absolutes such as 100% reliability, 100% availability, all, every, always, never, etc**.**

R27 - Explicit Conditions: State conditions' applicability explicitly instead of leaving applicability to be inferred from the context.

R28 - Multiple Conditions: Express the propositional nature of a condition explicitly for a single action instead of giving lists of actions for a specific condition.

R29 - Classification: Classify needs and requirements according to the aspects of the problem or system it addresses.

R30 - Unique Expression: Express each need and requirement once and only once.

R31 - Solution Free: Avoid stating implementation in a need statement or requirement statement unless there is rationale for constraining the design.

R32 - Universal Qualification: Use "each" instead of "all", "any", or "both" when universal quantification is intended.

GtWR Rules

R33 - Range of Values: 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.

R34 - Measurable Performance: 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.

R35 - Temporal Dependencies: Define temporal dependencies explicitly instead of using indefinite temporal keywords such as “eventually”, “until”, “before”, “after”, “as”, “once”, “earliest”, “latest”, “instantaneous”, “simultaneous”, and “at last”.

R36 - Consistent Terms and Units: Ensure each term and unit of measure used throughout need and requirement sets as well as associated models and other SE artefacts developed across the lifecycle are consistent with the project’s defined ontology.

R37 - Acronyms: If acronyms are used, they must be consistent throughout need and requirement sets as well as associated models and other SE artefacts developed across the lifecycle.

R38 - Abbreviations: Avoid the use of abbreviations in needs and requirement statements as well as associated models and other SE lifecycle artefacts.

R39 - Style Guide: Use a project-wide style guide for individual need statements and requirement statements.

R40 - Decimal Format: Use a consistent format and number of signification digits for the specification of decimal numbers.

R41 - Related Needs and Requirements: Group related needs and requirements together.

R42 - Structured Sets: Conform to a defined structure or template for organizing sets of needs and requirements.

Quality assessment of poorly-formed LIR design input requirements.

General Statements

- For the resulting well-formed requirements, the following applies:
  - All terms have been defined in the project glossary or data dictionary (R4) and used consistently (R36).
    - Terms defined in the project glossary or data dictionary have the general form of Mabc_Hxyz.
  - All acronyms have been defined in the project glossary or data dictionary and used consistently (R36, R37).
  - The organization's set of attributes has been defined for each requirement.
    - Especially Rationale and Verification attributes
  - Traceability of each requirement to its need, source, or parent requirement has been established to help ensure the requirement is necessary (C1)
  - The feasibility of each requirement has been assessed (C6) as well as the feasibility of the set (C12).

Many of the poorly-formed example requirements being assessed would be acceptable if stated as need statements (The stakeholders need to the LIR to …)

Use of NLP/AI Tools

- Given the large number of rules, it is hard for a person to keep track of them all.
- What is needed is a “digital assistant” to help the writer and assess the quality of the requirements.
- Fortunately, there are tools that are available as a “digital assistant”.
  - The ReUse Company (TRC) has a requirement authoring tool that can be integrated with other requirement management and modeling tools.
  - QVScribe that can be integrated with other requirement management and modeling tools
  - IBM Requirements Quality Assistant (RQA)
  - Jama Connect has their requirements advisor, Jama Connect Advisor, integrated into their authoring function.
  - Others ……
- The digital assistants, address a subset of the rules, are rules focused, not characteristics focused.
- Online AI/LLM applications
  - ChatGPT, Bing, Bard, Others ……
  - Online AI applications can be useful but have serious limitations and have limited knowledge of the characteristics and rules and ability to apply them properly, consistently, and reliably.

None of the digital assistants available, nor online AI/LLM applications, will do as a complete assessment as is done in the following slides.

It is important that you understand the limitations of these tools and not make the assumption that if a tool finds no defects that the requirements and sets of requirements are well-formed, having the characteristics defined in the GtWR.

Poorly Formed LIR Requirement Assessment

Defective: The Maintainence Technician wiil provide a daily supply of lids to every installation robot at the beginning of the shift.

- Written as a statement of fact (will) of what the Maintenance Tech will do and when rather than a requirement (shall) on the LIR. Must use proper term (shall) that makes it clear this is a requirement rather than a goal (should) or a statement of fact (will).
- Ensure the subject and verb of the need or requirement statement are appropriate to the entity to which the statement refers (R3). The requirement should be written on what the LIR is required to do and when - not the Maintenance Technician who provides the lids to the LDS which dispenses the lids to the LIR.
- Use correct spelling (R13).
- Avoid the use of absolutes such as “every” (R26).
- Use “each” instead of “every” when universal quantification is intended (R32).
- Because there is an interaction between two systems, this is an interface requirement which must refer to where the interactions between the LDS and LIR are defined (R1), i.e., an ICD - else the requirement is not complete (C4) and not verifiable (C7).

Improved: (Written as two requirements.)

The LIR shall obtain Lids from the LDS as described in the LIR/LDS ICD xyz, Section 123.

The LIR shall obtain Lids from the LDS per the timing defined in JPS ICD xyz, Section 123.

LIS: Lid Installation System; LIR: Lid Installing Robot; JPS: Jar Processing System; FCR: Facility Control Room; JHS: Jar Handling Subsystem; LHS: Lid Handling Subsystem; LDS: Lid Dispensing System; MMS: Motion Monitoring System

Poorly Formed LIR Requirement Assessment

Defective: It must power up quickly once commanded.

- Avoid the use of personal and indefinite pronouns (R24).
- Convention states a requirement is indicated using the word “shall” rather than “must” or ”may” – “The LIR shall …’ (C9, R1, R4, R36, R39).
- Must define what is meant by “power up” – Given the LIR must respond to a remote command to power up, it must be in a “sleep state” able to “listen” for the command.
- Commanded by whom? In what form? Using which media? This action involves interaction with another entity so it is an interface requirement and must point to where the interaction is defined (an ICD) else the requirement is not complete (C4).
- Avoid the use of vague terms (R7) like “quickly” - else the requirement is ambiguous (C3) and not verifiable (C7).
- Define temporal dependencies explicitly instead of using indefinite temporal keywords such as “once” (R35) else the requirement is ambiguous (C3) and not verifiable (C7).
- A performance value must be included as to when the power up sequence must begin once the command is received. Functional requirements must include a performance value (R1, C9) else the requirement is not complete (C4) nor verifiable (C7).

Improved: The LIR shall perform the Power_Up_Sequence within 1 sec of receipt of a Power_Up_Command from the FCR C&M Software having the characteristics defined in the FCR ICD xyz, Section 123.

LIS: Lid Installation System; LIR: Lid Installing Robot; JPS: Jar Processing System; FCR: Facility Control Room; JHS: Jar Handling Subsystem; LHS: Lid Handling Subsystem; LDS: Lid Dispensing System; MMS: Motion Monitoring System

Poorly Formed LIR Requirement Assessment

Defective: Normally, a self test should be performed at power up.

- Passive voice (should be). Use the active voice with the responsible entity (LIR) clearly identified as the subject of the sentence (R2).
- Written as a goal (should) rather than a requirement (shall). Must use the proper term that makes it clear this is a requirement rather than a goal (should) or a statement of fact (will).
- Avoid the use of escape clauses like "normally" (R8) which are ambiguous (C3) and not verifiable (C7).
- "Self test" must be clearly defined in the project data dictionary or glossary (R4) as to what is meant e.g., what is to be tested and what constitutes success or failure.
- A performance value must be included as to when the Self_Test must begin. Functional requirements must include a performance value (R1, C9) else the requirement is not complete (C4) nor verifiable (C7).
- The results of the self-test must be reported to the FCR C&M software.

Improved: (written as two requirements)

The LIR shall perform a Self_Test within 1 sec after Power_Up_Sequence is complete.

The LIR shall Report LIR_Health_and_Status to the FCR C&M Software as defined in the FCR ICD xyz, Section 123 within 1 sec of the completion of the Self_Test.

LIS: Lid Installation System; LIR: Lid Installing Robot; JPS: Jar Processing System; FCR: Facility Control Room; JHS: Jar Handling Subsystem; LHS: Lid Handling Subsystem; LDS: Lid Dispensing System; MMS: Motion Monitoring System

Poorly Formed LIR Requirement Assessment

Defective: The System_Health_and_Status message format shall follow the structure specified within the FCR Software ICD.

- Requirement is not written on the LIR, rather it is written concerning the format of a message as defined within an ICD. All requirements within the LIR set of requirements must be written on the LIR (R1, R3).
- Ensure the subject and verb of the need or requirement statement are appropriate to the entity to which the statement refers (R3).
- Within the ICD, the use of "shall" should be avoided. ICDs contain definitions of specific interaction between entities. "The System_Health_and_Status message format is shown in Table xx."
- Should all messages sent to the FCR use the same message format?

Improved:

When sending messages to the FCR, the LIR shall use the message format defined in FCR ICD xyz, Section 123 paragraph 1.2.5.

LIS: Lid Installation System; LIR: Lid Installing Robot; JPS: Jar Processing System; FCR: Facility Control Room; JHS: Jar Handling Subsystem; LHS: Lid Handling Subsystem; LDS: Lid Dispensing System; MMS: Motion Monitoring System

Poorly Formed LIR Requirement Assessment

Defective: The supplied lids shall be used by the LIR.

- Passive voice (shall be). Use the active voice with the responsible entity clearly identified as the subject of the sentence (R2) - ”The LIR shall…….”.
- The specific lids that will be used must be clearly defined as to which lids and their characteristics as defined in the Lid Specification - else the requirement is not complete (C4), ambiguous (C3), and not verifiable (C7).

Improved: The LIR shall install on the Jars, Lids having the characteristics defined in Lid Specification LID1234.

LIS: Lid Installation System; LIR: Lid Installing Robot; JPS: Jar Processing System; FCR: Facility Control Room; JHS: Jar Handling Subsystem; LHS: Lid Handling Subsystem; LDS: Lid Dispensing System; MMS: Motion Monitoring System

Poorly Formed LIR Requirement Assessment

Defective: The LHS and JHS shall be able to install a lid on the supplied jars.

- This set of requirements are for the LIR. The LHS and JHS are LIR subsystems. Given this is the LIR set of requirements, the requirement must be written on the parent system, the LIR (R3).
- Avoid superfluous infinitives (R10) like “be able to” which are ambiguous (C3), and the requirement is clearer if the phase is not included - ”shall install” vs. “shall be able to install”.
- The specific jars that the lids will be installed on must be clearly defined as to which jars and their characteristics as defined in the Jar Specification if the Jar Specification in not referred to in the requirement statement - - else the requirement is not complete (C4), ambiguous (C3), and not verifiable (C7).

Improved: The LIR shall install Lids on Jars having the characteristics defined in Jar Specification JAR1235.

LIS: Lid Installation System; LIR: Lid Installing Robot; JPS: Jar Processing System; FCR: Facility Control Room; JHS: Jar Handling Subsystem; LHS: Lid Handling Subsystem; LDS: Lid Dispensing System; MMS: Motion Monitoring System

Poorly Formed LIR Requirement Assessment

Defective: The Automated Machine shall install lids on Jars aboout every 30, when it can.

- Must be consistent in use of terms (C11, R36) – must use "LIR" consistently throughout the LIR requirement set rather than any other synonyms like "Automated Machine". In the LIR set of requirements all requirement should begin with "The LIR shall …" .
- "Aboout" is misspelled (R13).
- Avoid the use of vague terms (R7) such as "About" which is ambiguous (C3) and not verifiable (C7).
- Avoid the use of escape clauses (R8) like "when it can" which is ambiguous (C3) and and not verifiable (C7).
- When stating quantities, common units of measure must be used (R6). "30" is a value that must have proper units included – 30 of what? Seconds?.
- Because the LIR is interacting with an existing system, the timing is defined in that system's ICD. Rather than pulling out the value from the ICD, it is better to refer to the ICD that defines the timing.

Improved: The LIR shall install Lids on Jars per the timing defined in JPS ICD xyz, Section 123.

LIS: Lid Installation System; LIR: Lid Installing Robot; JPS: Jar Processing System; FCR: Facility Control Room; JHS: Jar Handling Subsystem; LHS: Lid Handling Subsystem; LDS: Lid Dispensing System; MMS: Motion Monitoring System; CBS: Conveyer Belt System

Poorly Formed LIR Requirement Assessment

Defective: The LRI shall be capable of installing lids on jars (as positioned on the conveyer belt).

- LRI is misspelled (R13) (should be LIR).
- Avoid the use of superfluous infinitives (R10) like “be capable of” which are ambiguous (C3) and the requirement is clearer if the phase is not included – “shall install” rather than “shall be capable of installing”.
- Use of parenetical phrases (…..) must be avoided (R21).
- Because the LIR is interacting with an existing system (the CBS), it must refer to the ICD that clearly defines the exact position of the Jars on the conveyer belt.

Improved: The LIR shall install Lids on Jars positioned on the JPS CBS conveyor belt as defined in the JPS ICD xyz, Section 123.

LIS: Lid Installation System; LIR: Lid Installing Robot; JPS: Jar Processing System; FCR: Facility Control Room; JHS: Jar Handling Subsystem; LHS: Lid Handling Subsystem; LDS: Lid Dispensing System; MMS: Motion Monitoring System; CBS: Conveyer Belt System

Poorly Formed LIR Requirement Assessment

Defective: The jar's position should not move on the conveyer belt during lid installation, if possible.

- Written as a goal (should). Must be written as a requirement “shall” on the entity to which it applies – “The LIR shall …’.
- Avoid the use of the word “Not” (R16) – rather than “not move”, use “shall maintain"
- The allowable amount of movement is not specified; thus, the requirement is ambiguous (C3), not verifiable (C7), and not complete (C4).
- Avoid the use of escape clauses (R8) like “If possible” which are ambiguous (C3) and not verifiable (C7).

Improved: The LIR shall maintain the Jar position within +/- 0.1 inches on the conveyer belt during lid installation.

- *Note: Be consistent in the expression of decimals and the number of significant digits used (R40).*

LIS: Lid Installation System; LIR: Lid Installing Robot; JPS: Jar Processing System; FCR: Facility Control Room; JHS: Jar Handling Subsystem; LHS: Lid Handling Subsystem; LDS: Lid Dispensing System; MMS: Motion Monitoring System

Poorly Formed LIR Requirement Assessment

Defective: Lids shall be installed on the Jars with a torque consistent with the jar size and material such that the jar is not broken, a good seal is established, and a human can easily remove the lid without special tools or aids.

- Passive voice (shall be). Use the active voice with the responsible entity (LIR) clearly identified as the subject of the sentence (R1, R2) – "LIR shall…." .
- The actual torque values consistent with the jar size and material must be clearly defined else the requirement is ambiguous (C3), not verifiable (C7), and not complete (C4).
- Statements of purpose (rationale) must not be included in the requirement statement, but rather included in the Rationale attribute.

Improved: The LIR shall install Lids on the Jars with a torque within the torque ranges specified in Table 6 for the Jar size and material.

Rationale: Proper torque must be used when tightening the lids such that the jar is not broken, a tight seal is established, while still enabling a person to remove the lid without special tools or aids.

Note: Given the table contains multiple parameters defining the required torque based on jar characteristics, some would say that to address the characteristic C5 - Singular and rule R18 – single thought, there should be multiple requirements each addressing a single parameter. In doing this, others have a valid concern associated with the characteristic C13 – Comprehensible. No matter the approach taken, the system must be verified for each of the parameters. It is up to the organization to decide which approach they choose to take – and then be consistent in the application of this approach.

LIS: Lid Installation System; LIR: Lid Installing Robot; JPS: Jar Processing System; FCR: Facility Control Room; JHS: Jar Handling Subsystem; LHS: Lid Handling Subsystem; LDS: Lid Dispensing System; MMS: Motion Monitoring System

Poorly Formed LIR Requirement Assessment

Defective: The Robot shall be available to install lids on Jars during the normal operating shifts (year-round).

- Must be consistent in use of terms (C11, R36) – must use "LIR" consistently throughout the LIR requirement set rather than any other synonyms like "Robot" .
- In the LIR set of requirements all requirement should begin with "The LIR shall …"
- As written "be available to" is a superfluous infinitive (R10) which should be avoided else the requirement is ambiguous (C3), not verifiable (C7).
- Ambiguous (C3). Not clear whether the intent is for this to be an "availability" quality requirement or a requirement defining the shifts in which the LIR must install lids. The project team should decide if both perspectives should be reflected within the requirement set.
- Having a rationale statement would help understand the intent.

Improved: (assuming the requirement is about the shift in which the LIR must operate.)

The LIR shall install lids on Jars during the Shift defined in the JPS ICD, Section 123, 355 days/year.
Rationale: The LIR must install Lids during the JPS operating hours.

Improved: (assuming the requirement is about the quality characteristic "availability".)

The LIR shall have an Availability of at least .98% during JPS operating hours. (Is this requirement needed?)

Note: 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 (R33) – "at least .98%" rather than stating an absolute ".98%".

Note: The qualifying phrase "during JPS operating hours" is necessary as that is the only time the requirement applies.

LIS: Lid Installation System; LIR: Lid Installing Robot; JPS: Jar Processing System; FCR: Facility Control Room; JHS: Jar Handling Subsystem; LHS: Lid Handling Subsystem; LDS: Lid Dispensing System; MMS: Motion Monitoring System

Poorly Formed LIR Requirement Assessment

Defective: The LIR shall try to install a lid on a Jar within approximately every 10 sec of receiving a "Jar_in_Place" message and report when lid installation is complete.

- Avoid the use superfluous infinitives (R10) or escape clauses (R8) like "try to" else the requirement is ambiguous (C3) and not verifiable (C7).
- Avoid the use of vague terms (R7) "approximately" else the requirement is ambiguous (C3) and not verifiable (C7).
- Avoid combinators like "and" (R19). Write a single sentence that contains a single thought conditioned and qualified by relevant sub-clauses (R18, C5). "Installing" and "Reporting" are two separate actions.
- Receiving message from which system? What form? What media? This action involves an interaction with another entity so it is an interface requirement and must point to where the interaction is defined (an ICD) else the requirement is not complete (C4).
- Report to which system? What form? What media? This action involves an interaction with another entity so it is an interface requirement and must point to where the interaction is defined (an ICD) else the requirement is not complete (C4).

Improved: (Written as two requirements)

The LIR shall install a Lid on a Jar within 10 sec of receiving from the FCR C&M software a "Jar_in_Place" message having the characteristics defined in the FCR ICD xyz, Section 123.

The LIR shall report the completion of Lid_Installation to the FCR C&M Software as defined in the FCR ICD xyz, Section 123 within 1 sec.

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Poorly Formed LIR Requirement Assessment

Defective: The Robot Lid Installer shall install lids on all of the jars every shift.

- Must be consistent in use of terms (C11, R36) – must use "LIR" consistently throughout the LIR requirement set rather than any other synonyms like "Robot Lid Installer" . In the LIR set of requirements all requirement should begin with "The LIR shall …"
- Avoid absolutes (R26) such as "all" and "every" else the requirement is ambiguous (C3) and not verifiable (C7).
- Lids, Jars, and Shift must be defined terms (R4).
- It seems the intent of the requirement is to define a quality requirement concerning an acceptable and feasible percentage of lids to be successfully installed per shift given the Jars are delivered per the JPS ICD positioning and timing.

Improved: The LIR shall install Lids on at least 99% of the Jars presented as defined in the JPS ICD xyz, Section 123 during each Shift.

- *Note: 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 (R33) – "at least 99%" rather than stating an absolute "99%".*
- *Note: Be careful when stating performance values from a feasibility and cost perspective. Is 99% really what the LIR must achieve? A lower value like 97% or 98% may be all that is needed at a lower cost.*

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Poorly Formed LIR Requirement Assessment

Defective: The LIR should monitor its health and status frequently and shall report its health and status about every 60 (when it can).

- The first part is written as a goal (should). Must be written as a requirement "shall" on the entity to which it applies – "The LIR shall …". (C9, R1, R4, R36, R39)
- Requirements should be a single thought (C5, R18) – avoid combinators like "and" (R19).
- Avoid vague terms (R7) like "frequently" and "about" else the requirement is ambiguous (C3) and not verifiable (C7).
- 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 (R34).
- When stating quantities, common units of measure must be used (R6). "60" is a value that must have proper units included – 60 of what? Seconds?.
- Avoid escape clauses (R8) like "when it can" else the requirement is ambiguous (C3) and not verifiable (C7); however, using a qualifying clause to state when the requirement applies is acceptable (R27).
- Avoid parentheses and brackets containing subordinate text (R21).

Improved: (Written as two requirements.)

The LIR shall update LIR_Health_and_Status every [TBD minutes +/- .1 minute] when the LIR is powered.

The LIR shall Report LIR_Health_and_Status data every [TBD minutes +/- .1 minute] to the FCR C&M software as defined in FCR ICD xyz, Section 123.

- *Note: Except under exceptional circumstances, baselined requirement statements must not contain "To Be Defined (TBD)", "To Be Specified (TBS)", or "To Be Resolved (TBR)' clauses – else the requirement is not complete (C4).*

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Poorly Formed LIR Requirement Assessment

Defective: The LIR must report changes in state or status immediately.

- Convention states a requirement is indicated by the use of the word “shall” rather than “must” or ”may” – “The LIR shall …’ (C9, R1, R4, R36, R39),
- Report to which entity? In what form? Using which media? This action involves interaction with another entity so it is an interface requirement and must point to where the interaction is defined (an ICD) else the requirement is not complete (C4).
- “System state” must be defined in the data dictionary (R4). Does change in state and change in status imply the same thing or are they two distinct things that must be reported? What are the various states of the system? Use of rationale would help remove this ambiguity.
- Define temporal dependencies explicitly instead of using indefinite temporal keywords such as “immediately” (R35) else the requirement is ambiguous (C3) and not verifiable (C7).

Improved: The LIR shall report changes in System_State to the FCR C&M software as defined in the FCR ICD xyz, Section 123 within 1 sec of occurrence.

Rationale: The FCR Software must be notified of any change of state or change in status of the LIR in order to properly control and manage the LIR, especially when the change prevents the LIR from installing Lids, which would require the JPS to be commanded to cease operations until the LIR is repaired and returned to service.

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Poorly Formed LIR Requirement Assessment

Defective: The LIR shall execute all commands received quickly and it should report when it has completed any command as soon as possible.

- The second part is written as a goal (should). Must be written as a requirement "shall" on the entity to which it applies – "The LIR shall …'.
- Requirements should be a single thought (C5, R18) – avoid combinators like "and" (R19).
- Use "each" instead of "all", "any", or "both" when universal quantification (R32) is intended.
- Avoid the use of vague terms (R7) like "quickly", rather include a specific measure in which the action is to be performed else the requirement is ambiguous (C3) and not verifiable (C7).
- Avoid escape clauses (R8) such as "as soon as possible" else the requirement is ambiguous (C3) and not verifiable (C7).
- Received from which entity? What are the characteristics of the received commands? What media is used to receive the commands? These actions involve an interaction with another entity so are an interface requirements. As such the requirement must refer to an ICD where these things are defined – else the requirement is not complete (C4).
- Also, must consider security and only accept valid commands from the FCR C&M Software.

Improved: (Written as four requirements. Each is a separate action that must be verified.)

The LIR shall receive from the FCR C&M software Commands defined in the FCR ICD xyz, Section 123.

The LIR shall only accept Valid_Commands from the FCR C&M Software that meet the Security_Protocols defined in the FCR ICD xyz, Section 123.

The LIR shall execute each Valid_Command defined in the FCR ICD xyz, Section 123 within 1 sec of receipt from the FCR C&M software.

The LIR shall report the completion of each Valid_Command to the FCR C&M software as defined in FCR ICD xyz, Section 123 within 1 sec.

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Poorly Formed LIR Requirement Assessment

Defective: Shutdown shall occur automatically.

- Written in passive voice without stating the entity responsible for the action "The LIR Shall …"
- "Shutdown" must be clearly defined. Does it mean to remove power from all parts of the LIR or does it mean to enter a sleep state such that it can still respond to a command to power up yet conserve power for all other subsystems?
- What is the trigger for end of shift shutdown?
- An expected performance value must be specified stating the time in which the action must be completed.
- Avoid the use of vague terms (R7) and define temporal dependencies (R35) explicitly instead of using indefinite temporal keywords such as "automatically."

Improved: The LIR shall execute the End_of_Shift_Shutdown_Sequence within 1 sec of End_of_Shift.

- *Note: "End_of_Shift_Shutdown_Sequence" and "End_of_Shift" must be clearly defined. What actions does the LIR take when "End_of_Shift" occurs? What triggers the "End_of_Shift" message? Given the expectation of "automatically", this would imply the LIR is aware of the time a shift ends and sets this parameter to "True" when this time is reached without any outside indication from the LCR C&M Software. This line of thinking then leads to the next requirement.*

LIS: Lid Installation System; LIR: Lid Installing Robot; JPS: Jar Processing System; FCR: Facility Control Room; JHS: Jar Handling Subsystem; LHS: Lid Handling Subsystem; LDS: Lid Dispensing System; MMS: Motion Monitoring System

Poorly Formed LIR Requirement Assessment

Defective: The FCR C&M Software shall provide the LIR with the current time about every minute.

- Ensure the subject and verb of the requirement statement is appropriate to the entity to which the statement refers (R3). This requirement is written on the FCR C&M Software. All requirements in the LIR requirements set must be written for the LIR – "The LIR shall…….".
- "Current time" must be clearly defined (R4).
- Avoid vague terms (R7) like "about" else the requirement is ambiguous (C3) and not verifiable (C7).
- What are the characteristics of the time parameter provided? What media is used to receive the current time? These actions involve an interaction with another entity so are an interface requirements. As such the requirement must refer to an ICD where these things are defined – else the requirement is not complete (C4).
- From an off-nominal perspective, what happens if the FCR fails to send the current time to the LIR? If this happens, then there is a likelihood that the FCR C&M Software has a fault, which should trigger all the systems commanded and monitored by the FCR C&M Software to halt operations.

Improved: (Written as two requirements.)

The LIR shall update LIR_Current_Time to the FCR_Current_Time received from the FCR C&M Software as defined in the FCR ICD xyz, Section 123.

If the FCR_Current_Time fails to be updated at lease once a minute, the LIR shall execute the End_of_Shift_Shutdown_Sequence within 1 sec of when the fault is discovered.

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Poorly Formed LIR Requirement Assessment

Defective: Facility power shall be used to operate the LIR using standard power connectors.

- Passive voice (shall be). Use the active voice with the responsible entity (LIR) clearly identified as the subject of the sentence (R1, R2).
- Need to define what is meant by ”operate” (R4).
- Avoid the use of vague terms (R7) like “standard” else the requirement is ambiguous (C3) and not verifiable (C7).
- Power is being obtained from the facility, so this is an interface requirement which must point to where the interaction is defined in terms of both the characteristics of the power as well as the physical interface (plug and pin assignments.) As such the requirement must refer to an ICD where these things are defined – else the requirement is not complete (C4).
- Requirements must communicate a single thought; power characteristics and connectors are two different things.
- Must also consider the off-nominal case of an over voltage condition (which must be defined).

Improved: (Written as three requirements.)

The LIR shall Operate using 110-120 VAC, 60 Hz, 30-amp Facility_Power having the characteristics defined in Facility Drawing xyz.

The LIR shall receive Facility_Power using an EIC 320-compatible electrical 3 prong connectors defined in Facility Drawing xyz.

If an Over_Voltage_Condition, the LIR shall remove power from all internal systems within 1 Sec.

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Poorly Formed LIR Requirement Assessment

Defective: The LIR shall be able to install lids in a normal operating environment.

- Avoid superfluous infinitives (R10) like “be able to”.
- Avoid vague terms (R4) like “normal” else the requirement is ambiguous (C3) and not verifiable (C7).
- Need to clearly define what the operating environment is. Given there are multiple parameters used to define the operating environment (temperature, humidity, air flow), it is common practice for the requirement to point to where these parameters are defined – either within the set of requirements or another configuration-controlled form that defines the operating environment in which the system is to operate. For this example, the electro magnetic environment is addressed separately in the next requirement.

Improved: The LIR shall meet the LIR Design Input Requirements while Operating in the Operating_Environment defined in Table 1.

- *Note: Given the table contains multiple parameters defining the operating environment, some would say that to address the characteristic C5 - Singular and rule R18 – single thought, there should be multiple requirements each addressing a single parameter. In doing this, others have a valid concern associated with the characteristic C13 – Comprehensible. No matter the approach taken, the system must be verified for each of the parameters. It is up to the organization to decide which approach they choose to take – and then be consistent in the application of this approach.*
- *Note: ”meet the LIR Design Input Requirements” is used as it communicates more comprehensively the intent rather than other terms like “meet all functional requirements” which excludes what is referred to as “non-functional” requirements.*

LIS: Lid Installation System; LIR: Lid Installing Robot; JPS: Jar Processing System; FCR: Facility Control Room; JHS: Jar Handling Subsystem; LHS: Lid Handling Subsystem; LDS: Lid Dispensing System; MMS: Motion Monitoring System

Poorly Formed LIR Requirement Assessment

Defective: The LIR shall operate in the presence of any electro magnetic emissions.

- Need to define “Operate”.
- Avoid the use of vague terms (R7) that provide vague quantification, such as “any” else the requirement is ambiguous (C3) and not verifiable (C7)
- Must specifically define the specific electro magnetic emissions within which the LIR must operate. Given that the definition of magnetic electro emissions must be done as a function of frequency and magnitude, a diagram is more appropriate than specific values. When a requirement is related to complex behavior, refer to a supporting diagram (R23).

Improved: The LIR shall meet the LIR Design Input Requirements while Operating in the presence of electro magnetic emissions up to and including those shown in Diagram 2.

- *Note: ”meet the LIR Design Input Requirements” is used as it communicates more comprehensively the intent rather than other phrases like “meet all functional requirements” which excludes what is referred to as “non-functional” requirements.*

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Poorly Formed LIR Requirement Assessment

Defective: The LIR shall be able to work after being shipped in shipping crates exposed to the shipping environment for approximately 24.

- Avoid superfluous infinitives (R10) like “be able to”.
- “Work” is ambiguous as would be “survive” or ”function”; what is really the intent?
- Must clearly define what the shipping environment is. Given there are multiple parameters (temperature, humidity, loads, particulates, etc.) used to define the shipping environment, it is common practice for the requirement to point to where these parameters are defined – either within the set of requirements or another configuration-controlled form that defines the shipping environment in which the system is to operate.
- Must avoid vague terms (R7) like “approximately”.
- “24” what? When stating quantities, all numbers should have appropriate and consistent units of measure explicitly stated using a common measurement system in terms of the thing the number refers (R6).

Improved: The LIR shall meet the LIR Design Input Requirements after being shipped in shipping crates exposed to the Shipping_Environment defined in Table 3 for up to 24 hours.

- *Note: ”meet the LIR Design Input Requirements” is used as it communicates more comprehensively the intent rather than other terms like “meet all functional requirements” which excludes what is referred to as “non-functional requirements.*
- *See previous note concerning singular, one thought vs comprehensibility when referring to tables.*

LIS: Lid Installation System; LIR: Lid Installing Robot; JPS: Jar Processing System; FCR: Facility Control Room; JHS: Jar Handling Subsystem; LHS: Lid Handling Subsystem; LDS: Lid Dispensing System; MMS: Motion Monitoring System

Poorly Formed LIR Requirement Assessment

Defective: The LIR shall be capable of operating after being exposed to an unconditioned storage environment for more than 3 years.

- Avoid superfluous infinitives (R10) like “be capable of”.
- Is “operating” the proper word to communicate the intent? What about all other requirements beside just those associated with operating?
- Must clearly define what the unconditioned storage environment is. What is meant by “unconditioned”? Given there are multiple parameters used to define the storage environment, it is common practice for the requirement to point to where these parameters are defined – either within the set of requirements or another configuration-controlled form that defines the storage environment in which the system is to be stored.
- “More than 3 years” is open ended. 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 (R33).

Improved: The LIR shall meet the LIR Design Input Requirements after being stored in shipping crates exposed to the Unconditioned_Storage_Environment defined in Table 5 for up to 3 years.

Note: ”meet the LIR Design Input Requirements” is used as it communicates more comprehensively the intent rather than other terms like “meet all functional requirements” which excludes what is referred to as “non-functional requirements.

Note: See previous note concerning singular, one thought vs comprehensibility when referring to tables.

LIS: Lid Installation System; LIR: Lid Installing Robot; JPS: Jar Processing System; FCR: Facility Control Room; JHS: Jar Handling Subsystem; LHS: Lid Handling Subsystem; LDS: Lid Dispensing System; MMS: Motion Monitoring System

Poorly Formed LIR Requirement Assessment

Defective: The LIR shall not be damaged after being sprayed with a liquid from the fire suppression system.

- Avoid the use of the word “not” (R16).
- Avoid the use of vague terms (R7) that provide vague quantification like “damaged” else the requirement is ambiguous (C3) and not verifiable (C7).
- What is meant by “damaged”? How can the intent be communicated such that it is clear what is meant?
- What kind of liquid? Sprayed at what rate? For how long?
- Is there a drying time after being sprayed before the requirement applies?

Improved: The LIR shall meet the LIR Design Input Requirements after being sprayed with a 15 +/- 2 gal/minute water spray for up to 5 minutes AND allowed to dry for at least 24 hours.

Note: ”meet the LIR Design Input Requirements” is used as it communicates more comprehensively the intent rather than other terms like “meet all functional requirements” which excludes what is referred to as “non-functional requirements”.

Note: The use of “AND” (all upper case) is a convention to express logical expressions (R15) rather than the use of “and” (lower case) which is a combinator (R19) which often ties two thoughts together violating (R18) concerning single thought sentences.

LIS: Lid Installation System; LIR: Lid Installing Robot; JPS: Jar Processing System; FCR: Facility Control Room; JHS: Jar Handling Subsystem; LHS: Lid Handling Subsystem; LDS: Lid Dispensing System; MMS: Motion Monitoring System

Poorly Formed LIR Requirement Assessment

Defective: It should be able to operate within the space provided within the work area.

- Avoid the use of personal and indefinite pronouns (R24).
- Written as a goal (should). Must be written as a requirement "shall" on the entity to which it applies – "The LIR shall …'. (C9, R1, R4, R36, R39)
- Avoid superfluous infinitives (R10) like "be able to".
- Need to define what is meant by "operate".
- Need to define specifically the space in which the LIR must limit operations else the requirement is ambiguous (C3) and not verifiable (C7).
- A supporting diagram (R23) will clearly show the space in which the LIR must operate.

Improved: The LIR shall limit Operations to within the 4-foot-wide x 16-foot-long x 8-foot-high volume within the LIS shown in Figure 1.

LIS: Lid Installation System; LIR: Lid Installing Robot; JPS: Jar Processing System; FCR: Facility Control Room; JHS: Jar Handling Subsystem; LHS: Lid Handling Subsystem; LDS: Lid Dispensing System; MMS: Motion Monitoring System

Poorly Formed LIR Requirement Assessment

Defective: The LIR dimensions shall be less than 4-foot-wide x 16-foot-long x 8-foot-high.

- Requirement should be written on the LIR, not a part or characteristic of the LIR: "The LIR shall….."
- The specific intent and amount of detail of the need or requirement statement must be appropriate (C3) to the level (the level of abstraction, organization, or system architecture) of the entity to which it refers.
- As worded, the real intent of the need was misinterpreted – the intent was to define the volume in which the LIR must limit operations, not the specific size of the LIR.

Improved: The LIR shall limit Operations to within the 4-foot-wide x 16-foot-long x 8-foot-high volume within the LIS as shown in Figure 1.

LIS: Lid Installation System; LIR: Lid Installing Robot; JPS: Jar Processing System; FCR: Facility Control Room; JHS: Jar Handling Subsystem; LHS: Lid Handling Subsystem; LDS: Lid Dispensing System; MMS: Motion Monitoring System

Poorly Formed LIR Requirement Assessment

Defective: The LIR must be capable of quickly fitting through a 3 x 7 door when fully assembled.

- Convention states a requirement is indicated by the use of the word “shall” rather than “must” or ”may” – “The LIR shall …’ (C9, R1, R4, R36, R39),
- Avoid superfluous infinitives (R10) like “be capable of”.
- Define temporal dependencies explicitly (R35) instead of using indefinite temporal keywords such as “quickly”.
- What does 3 x 7 mean? When stating quantities, all numbers should have appropriate and consistent units of measure (R6) explicitly stated using a common measurement system in terms of the thing the number refers.
- Not clear whether the LIR is being moved on its own set of wheels or on some type of transport mechanism when it is being moved through the door opening.

Improved: The LIR shall fit through a 3-foot-wide x 7-foot-high door opening when fully assembled AND on the Supplier_Provided_Dolly, without having to remove the door.

- *Note: The use of “AND” (all upper case) is a convention to express logical expressions (R15) rather than the use of “and” (lower case) which is a combinator (R19) which often ties two thoughts together violating (R18) concerning single thought sentences. In this context the total height of the LIR and dolly must be less than 7 ft.*
- *Note: The qualifying clause “without having to remove the door”, makes clear as to the intent in the use of the word “quickly” in the original requirement. Having to remove the door would add considerable time when moving the LIR through the door opening.*

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Poorly Formed LIR Requirement Assessment

Defective: Anyone within the production facility should be able to move the robot.

- Avoid vague terms (R7) like "Anyone" this is too large a population, members of which may have difficulties doing the task - need to be more specific. Also does this imply a single person? What are the assumed capabilities of this person?
- Written as a goal "should" and not as a requirement "shall" on the LIR. "The LIR shall …." (C9, R1, R4, R36, R39),
- Avoid superfluous infinitives (R10) like "be able to".
- Not clear whether the LIR is being moved on its own or on some type of transport mechanism.
- To be verifiable (C7) a specific value of force needs to be included within the requirement statement. The reason and source of this number should be addressed in the rationale.

Improved: The LIR shall limit the force needed to move the LIR to less than 10 pounds when the LIR is loaded on the Supplier_Furnished_Dolly.

Rational: *Given there is only a single maintenance technician on call during operations, a single maintenance technician must be able to move (push or pull) the LIR within the facility when the LIR is placed on the Supplier_Furnished_Dolly. Studies have been done to show 10 pounds of force to start and stop movement of the LIR when on the Supplier_Furnished_Dolly is within the capabilities of the maintenance technicians employed within the facility. Once in motion, this force is reduced to less than this value. All maintenance technicians that are employed must demonstrate an ability to apply a push and pull force of 10 pounds when placed on a dolly as a condition of employment. This requirement is stated in this manner to give the supplier options concerning the mass of the LIR and design of the dolly. This capability is also factored into the MTTR requirement.*

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Poorly Formed LIR Requirement Assessment

Defective: The LIR shall be capable of installing lids on the jars located on the conveyer belt through the opening.

- Avoid superfluous infinitives (R10) like “be capable of”.
- What conveyer belt? What opening?
- What is the location and what are the dimensions of the opening?
- A supporting diagram (R23) will clearly show the location and dimensions of the opening in which the LIR must operate.

Improved: The LIR shall install Lids on the Jars located on the JPS CBS conveyor belt through the 3 ft by 3 ft inch opening located between the LIS and CBS as shown in Figure 2.

- *Note: There is a previous requirement concerning the location of the jars on the CBS, this requirement addresses the fact that the CBS is located on the other side of the 3 ft x 3 ft opening in the LIS wall. The figure shows where the opening is located on the wall and how high the bottom of the opening is above the floor.*

LIS: Lid Installation System; LIR: Lid Installing Robot; JPS: Jar Processing System; FCR: Facility Control Room; JHS: Jar Handling Subsystem; LHS: Lid Handling Subsystem; LDS: Lid Dispensing System; MMS: Motion Monitoring System; CBS: Conveyor Belt System

Poorly Formed LIR Requirement Assessment

Defective: The LIR shall shutdown as fast as possible whenever any failure is detected.

- Need to clearly define what is meant by "shutdown" – what specific actions are intended to be performed?
- Avoid the use of vague terms (R7) like "fast" rather provide specific measurable performance targets (R34) appropriate to the entity to which the need or requirement is stated and against which the entity will be verified to meet.
- Avoid the inclusion of escape clauses (R8) that state vague conditions or possibilities, such as "as fast as possible".
- Avoid the use of vague terms (R7) like "any".
- Rather than "any failure", need to define specifically which type of failures are intended to be acted upon; all failures or only critical failures that result in the LIR unable to install lids?

Improved: The LIR shall execute the End_of_Shift_Shutdown_Sequence within 1 sec whenever a Critical_System_Failure is identified.

Note: End_of_Shift_Shutdown_Sequence and Critical_System_Failure must be clearly defined for this requirement to be verifiable (C7).

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Poorly Formed LIR Requirement Assessment

Defective: The LIR shall report all system failures as soon as they occur, if detected.

- Need to define specifically which type of failures are intended to be reported.
- Define temporal dependencies (R35) explicitly instead of using indefinite temporal keywords such as “as soon as”, rather include a specific measure in which the action is to be performed.
- Report to which entity? In what form and what media is to be used? Because this involves an interaction with another entity, this is an interface requirement. As such the requirement must refer to an ICD where these things are defined – else the requirement is not complete (C4).
- Avoid escape clauses (R8) like “if detected”.

Improved: The LIR shall Report a Critical_System_Failure within 1 sec to the FCR C&M software per the FCR ICD xyz, Section 123.

LIS: Lid Installation System; LIR: Lid Installing Robot; JPS: Jar Processing System; FCR: Facility Control Room; JHS: Jar Handling Subsystem; LHS: Lid Handling Subsystem; LDS: Lid Dispensing System; MMS: Motion Monitoring System

Poorly Formed LIR Requirement Assessment

Defective: The LIR shall take appropriate actions when system failures occur and report their occurrence as soon as practical.

- Need to define specifically which type of failures are intended to be identified and reported else the requirement is ambiguous (C3) and not verifiable (C7).
- Avoid the inclusion of escape clauses (R8) that state vague conditions or possibilities, such as “appropriate”.
- Need to define which specific actions are intended when a failure occurs else the requirement is ambiguous (C3) and not verifiable (C7)
- Report to which entity? In what form and what media is to be used? Because this involves an interaction with another entity, this is an interface requirement. As such the requirement must refer to an ICD where these things are defined – else the requirement is not complete (C4).
- Define temporal dependencies explicitly (R35) instead of using indefinite temporal keywords such as “as soon as”, rather include a specific measure in which the action is to be performed.
- Avoid escape clauses (R8) like “as practical” else the requirement is ambiguous (C3) and not verifiable (C7).
- Requirements should be single thought (R18) , avoid combinators (R19) such as “and”.

Improved: (Written as two requirements.)

The LIR shall execute the End_of_Shift_Shutdown_Sequence within 1 sec of when a Critical_System_Failure is identified.

The LIR shall report Critical_System_Failures to the FCR C&M software per the FCR ICD xyz, Section 123 within 1 sec of occurrence.

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Poorly Formed LIR Requirement Assessment

Defective: The LIR shall automatically stop operations when someone enters the room or motion is detected within the room.

- This is an example of a need statement communicated as a requirement (shall).
- Define temporal dependencies (R35) explicitly instead of using indefinite temporal keywords such as "automatically".
- Is the "or" intended to be inclusive or exclusive? If both actions are intended, then each action should be expressed as a separate requirement.
- The project team must do an assessment concerning how the LIR would know whether someone enters the LIS room via the door or if there is motion detected within the LIS room. While the MMS and KAS currently communicate directly with the FCR C&M software, from a safety perspective, the LIR should also communicate directly with both of these systems, not depending on the FCR C&M software providing the notification in cases when the communication link between the LIR and FCR C&M software is broken.

Improved: (Written as four requirements.)

The LIR shall set the Motion_in_the_Room parameter to TRUE when a Motion_Detected message is received from the LIS MMS having the characteristics defined in the LIS ICD xyz.

The LIR shall set Door_Open to TRUE when a KAS Keypad_Accessed message is received from the LIS KAS having the characteristics defined in the LIS ICD xyz.

The LIR shall enter Safe_State within 1 sec of the MMS Motion_in_the_Room parameter being set to TRUE.

The LIR shall enter Safe_State within 1 sec of the KAS Door_Open parameter being set to TRUE.

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Poorly Formed LIR Requirement Assessment

Defective: The Maintenance Technician shall be capable of resuming lid installation activities within about 15 min of when a LIR fails.

- Ensure the subject and verb of the need or requirement statement are appropriate to the entity to which the statement refers (R3). This requirement is written on the Maintenance Technician, rather than the LIR – "LIR shall ……."
- Avoid superfluous infinitives (R10) like "be capable of".
- Avoid vague terms (R7) like "about" else the requirement is ambiguous (C3) and not verifiable (C7). .
- The intent seems to be the time it should take to resume operations if an LIR fails. This is commonly referred to as "Mean Time to Repair (MTTR)" and should be communicated as such.
- To help meet this requirement, should the LIR both report the failures electronically to the FCR C&M Software as well as provide some means that allows a Maintenance Technician to identify which LIR component needs to be replaced when the LIR is not in communication with the FCR C&M Software? This capability would decrease the time to repair.
- Is there an expectation as to the LIR's ability to identify which system components have failed and to what level? This capability would decrease the time to repair.

Improved: (Written as three requirements)

The LIR shall have a Mean Time to Repair (MTTR) not to exceed 15 minutes.

The LIR shall identify Critical_System_Failures to the Line Replaceable Unit (LRU) level.

The LIR shall provide LIR_Health_and_Status data to the Maintenance Technician when the LIR is not in communication with the FCR C&M Software.

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Poorly Formed LIR Requirement Assessment

Defective: The LIR shall try to limit noise so as not to hurt people's ears, as much as possible.

- Avoid superfluous infinitives (R10) like "try to".
- Avoid purpose phrases (R20) like "so as not to hurt people's ears, as much as possible" - rather include them in the rationale.
- The real issue is damage to a person's hearing, not their ears.
- Must define specifically which noise levels are acceptable and across what frequency range. Provide specific measurable performance (R34) targets appropriate to the entity to which the need or requirement is stated and against which the entity will be verified to meet.
- Avoid escape clauses (R8) like "as much as possible" else the requirement is ambiguous (C3) and not verifiable (C7).
- State conditions' applicability explicitly (R27) instead of leaving applicability to be inferred from the context. Should be specific as to under what conditions this requirement applies- during operations? At what distance from the LIR does the requirement apply?

Improved: During Operations, the LIR shall limit sound levels such that the time weighted average sound level is less than 85 decibels measured on the A scale across the frequency range of 20 – 20,000 hz, when measured at 1 +/-0.1 feet from at least 10 equally spaced locations surrounding the LIR shown in Figure 8.

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Poorly Formed LIR Requirement Assessment

Defective: Failures shouldn't occur no less than about 90 days.

- Ensure the subject and verb of the need or requirement statement are appropriate to the entity to which the statement refers (R3). This requirement is written on "Failures", rather than the LIR – "LIR shall ……."
- Written as a goal (shouldn't), not written as a requirement "shall" on the LIR. "The LIR shall …."
- Avoid the use of "not." (R16) "Shouldn't is really "should not".
- Poor grammar (R12) "shouldn't occur no ……"
- Avoid the use of vague terms (R7) like "about" else the requirement is ambiguous (C3) and not verifiable (C7).
- Is "days" the correct unit of measure? "Hours" seems more appropriate as well as only hours of operation. Given the LIR operates 8 hours/day, 720 operational hours is more appropriate.
- The intent seems to be to address the allowable rate of failure over time. This is commonly communicated as Mean Time to Failure (MTTF).
- State conditions' applicability explicitly (R27) instead of leaving applicability to be inferred from the context. Should be specific as to under what conditions this requirement applies.

Improved: The LIR shall have a Mean Time to Failure (MTTF) of less than or equal to 720 operational hours, when maintained per Maintenance procedure xyz AND operating in the Operating_Environment defined in Table 1.

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Poorly Formed LIR Requirement Assessment

Defective: The LIR shall have a long lifetime.

- Avoid the use of vague terms (R7) like “long”.
- Must define a specific lifetime expectation. 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 (R34).
- Under what conditions does this requirement apply. State conditions’ applicability explicitly (R27) instead of leaving applicability to be inferred from the context.
- Lifetime can have different meanings – operational life, storage life, or total life. Given there is a previous requirement concerning storge, this requirement can deal with operational life. Another consideration concerning lifetime (beyond the scope of this presentation) includes whether there is an allowance for degradation of performance and quality across the lifetime or is the intent that all performance and quality requirements apply at end of life and not just at beginning of life? This is an important consideration that is often overlooked but must be addressed clearly in the definition of the term.

Improved: The LIR shall have an Operational_Lifetime of at least 5 years when operating per the Shift defined in the JPS ICD 355 days/year AND when maintained per Maintenance Procedure xyz AND operating in the Operational_Environment defined in Table 1.

Note: The use of “AND” (all upper case) is a convention to express logical expressions (R15) rather than the use of “and” (lower case) which is a combinator (R19) which often ties two thoughts together violating (R18) concerning single thought sentences.

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Poorly Formed LIR Requirement Assessment

Defective: After being dropped exactly 4 feet onto a reasonably hard surface, damage should be minimal.

- Passive voice (should be). Use the active voice with the responsible entity (LIR) clearly identified as the subject of the sentence (R1, R2).
- Written as a goal (should), not written as a requirement "shall" on the LIR. "The LIR shall …."
- Avoid using unachievable absolutes (R26) such as "exactly".
- Avoid vague terms (R7) like "reasonably" and "minimal" else the requirement is ambiguous (C3) and not verifiable (C7).
- What is meant by the word "damage" - what is the intent? What do you verify the system against? Requirement statements must be stated such that their intent is clear and can be interpreted in only one way by all intended audiences. (C3).
- Under what conditions? State conditions' applicability explicitly (R27) instead of leaving applicability to be inferred from the context.

Improved: The LIR shall meet its Design Input Requirements after being dropped 4 +/-.1 feet onto a concrete surface while unpowered AND in its shipping crate or crates.

Note: The use of "AND" (all upper case) is a convention to express logical expressions (R15) rather than the use of "and" (lower case) which is a combinator (R19) which often ties two thoughts together violating (R18) concerning single thought sentences.

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Poorly Formed LIR Requirement Assessment

Defective: The LIR shall be packaged such that the packaging is within acceptable shipping crate size and weight limits.

- Passive voice. Use the active voice (R2) in the requirement statement with the responsible entity clearly identified as the subject of the sentence.
- Inappropriate subject/verb. The LIR does not package itself; people do. Ensure the subject and verb of the need or requirement statement are appropriate to the entity to which the statement refers (R3).
- Avoid vague terms (R7) such as "acceptable" else the requirement is ambiguous (C3) and not verifiable (C7).
- Need to clearly state what shipping crate sizes and weight limits are acceptable. Provide specific measurable performance targets (R34) appropriate to the entity to which the need or requirement is stated and against which the entity will be verified to meet.
- Under what conditions: assembled or unassembled? State conditions' applicability explicitly instead of leaving applicability to be inferred from the context (R27).

Improved: The LIR shall fit within shipping packaging that meet the crated size and weight limits for the shipping methods defined in Table 4, when either assembled or unassembled.

Note: See previous note concerning singular, one thought vs comprehensibility when referring to tables.

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Poorly Formed LIR Requirement Assessment

Defective: All LIR parts must be interchangeable.

- Convention states a requirement is indicated by the use of the word “shall” rather than “must” or ”may” – “The LIR shall …’ (C9, R1, R4, R36, R39),
- Use “each” instead of “all” when universal quantification (R32) is intended.
- Using ”parts” only may be too limiting as to the intent.
- Must define what the intent of ”interchangeable” is – any part used in one LIR can be used in any other LIR without modification.

Improved: The LIR shall have Parts, Components, and Assemblies that are Interchangeable with the same parts, components, and assemblies contained within other LIRs.

Note: Written as a physical characteristic of the system “shall have”. ”Shall have” is an acceptable form for many quality and physical characteristic type requirements.

Note: Even though the combinator “and” is used (R19), the single thought intent (R18) is “interchangeability”, which is verifiable once defined.

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Poorly Formed LIR Requirement Assessment

Defective: The LIR shall use only the tools currently available within the facility for repair and maintenance.

- Inappropriate subject/verb. The LIR doesn't use tools, people do. Ensure the subject and verb of the need or requirement statement are appropriate to the entity to which the statement refers (R3).
- The specific tools that are available for use must be clearly defined. 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 (R34).

Improved: The LIR shall have Parts, Components, and Assemblies that can be disassembled, removed, repaired and maintained using those tools listed in [TBD] document.

Note: Written as a physical characteristic of the system "shall have". "Shall have" is an acceptable form for many quality and physical characteristic type requirements.

Note: Even though the combinator "and" is used (R19), the single thought intent (R18) is the tools that can be used which is verifiable once defined.

Note: Except under exceptional circumstances, baselined requirement statements must not contain "To Be Defined (TBD)", "To Be Specified (TBS)", or "To Be Resolved (TBR)' clauses – else the requirement is not complete (C4).

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Poorly Formed LIR Requirement Assessment

Defective: The LIR shall meet all its functional requirements when common off-the-shelve lubricants, fluids, and fuels are used.

- Only its functional requirements? What about all other non-functional requirements?
- Avoid the use of vague terms (R7) like “common” else the requirement is ambiguous (C3) and not verifiable (C7).
- What is the real intent? From a fire safety perspective flammability is a concern.

Improved: The LIR shall meet the LIR Design Input Requirements when Lubricants, Fluids, and Fuels that meet UL 546xx non-flammability standard are used for lubrication.

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Poorly Formed LIR Requirement Assessment

Defective: The LIR shall not contaminate food stuffs contained within the jars the lids are being installed on.

- Avoid the use of "not."
- This is another example of a need statement communicated as a requirement (shall).
- The project team must do an assessment concerning common sources of contamination and define requirements that mitigate those risks.
- Any parts that come in contact with the jars must be considered. To prevent food contamination these parts would need to be sanitized daily. From a sanitizing perspective the parts to be sanitized must be made from non-porous materials such that liquids and other substances can not be absorbed into the surface and the liquids use for sanitation must be approved by the FDA for their intended use. From a lubrication perspective, all lubricants of these parts would need to be approved non-contaminating lubricants.

Improved: (Written as three requirements).

The LIR shall have Parts that come in contact with the lids and jars that are non-porous meeting the requirements defined in FDA Standard xyz, Section 123.

The LIR shall have Parts that come in contact with the lids and jars that can be sanitized using sanitizing liquids or materials approved in FDA Standard xyz, Section 123.

The LIR shall meet the LIR Design Input Requirements when lubricants that meet non-contamination lubricant FDA Standard xyz are used for lubrication of the parts that come in contact with the lids and jars.

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Poorly Formed LIR Requirement Assessment

Defective: Each LIR component shall be able to be measured with English units of measure.

- Written on the LIR components – for the LIR level requirements, the requirements should be written on the LIR – "The LIR shall –".
- Avoid superfluous infinitives like "be able to".
- "Measured" could be misleading – in that people do the measuring, not the LIR. In order for the measurements to be made using English units of measure, the LIR must include parts, components, and assemblies whose physical characteristics are defined using English units of measure.
- With this requirement, all other requirements would need to be also communicated using English units of measure per R6 - When stating quantities, all numbers should have appropriate and consistent units of measure explicitly stated using a common measurement system in terms of the thing the number refers.

Improved: The LIR shall have Parts, Components, and Assemblies whose physical characteristics are defined using English units of measure.

Note: Written as a physical characteristic of the system "shall have". "Shall have" is an acceptable form for many quality and physical characteristic type requirements.

Note: Even though a list is included, the single thought intent is parts that use the English units of measure, which is verifiable.]

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Poorly Formed LIR Requirement Assessment

Defective: All LIR labels shall be in English.

- Written on the LIR labels – for the LIR level requirements, the requirements should be written on the LIR – "The LIR shall –".
- Rather than "shall be", which often indicates the passive voice, physical characteristic of the system are usually communicated as "shall have". "Shall have" is an acceptable form for many quality and physical characteristic type requirements.
- The language used is only one aspect concerning labels (size, fonts, font size, colors, symbols, etc.). Must include a pointer to a standard for labels to be used for this particular type of system.

Improved: (Written as two requirements.)

The LIR shall have Labels that communicate using the English language.

The LIR shall have Labels having the characteristics defined in Label Standard xyz.

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Poorly Formed LIR Requirement Assessment

Defective: Anyone physically interacting with the LIR need to be notified of any hazards that may cause them harm.

- Another example of a need statement being included within the set of requirements.
- This concern must be communicated in the form of a verifiable requirement.
- The means of communication can be assumed to be in the form of labels.
- Must include a pointer to a standard or regulation the defines the hazards that must be addressed by labels and the format of the label (size, fonts, font size, colors, symbols, etc.). In most cases these would have been addressed during the risk assessment and FMEA done at the beginning of the project. The use of labels would be one of the agreed to means of risk mitigation.

Improved: (Written as two requirements.)

The LIR shall have labels that communicate hazards defined in OSHA Cautions and Warnings Regulation xyz that may cause harm to people physically interacting with the LIR.

The LIR shall have labels that communicate hazards formatted as defined in OSHA Cautions and Warnings Regulation xyz, Section 123.

Note: Now we have both an internal company standard for labels (addressed in the previous slide) as well as a regulation included in the requirement set concerning labels associated with cautions and warnings. If there is a conflict, it must be made clear which takes precedence - the regulation.

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Poorly Formed LIR Requirement Assessment

Defective: The LIR shall be certified as "FIT FOR PURPOSE" in an xyzz - Class D environment prior to plant operations.

- Passive voice (shall be). Use the active voice with the responsible entity (LIR) clearly identified as the subject of the sentence (R2). In this case the requirement begins with "The LIR shall .." but the "be certified as" is an activity to be performed by either the supplier or the customer, not the LIR.
- Ensure the subject and verb of the need or requirement statement are appropriate to the entity to which the statement refers (R3). The LIR as a system, doesn't do any activity concerning "certification" – people do.
- "an xyzz - Class D environment" isn't accurate, the requirement should refer to the actual operating environment. The phrase "prior to plant operations" implies this requirement is addressing the operating environment only.
- "be certified as" implies there are requirements concerning certification. Some could be needs and requirements for the LIR as well as requirements on how the certification is performed. These need to be clearly identified.
- Another consideration is whether the word 'certification" is what is really meant; certification, qualification, acceptance, or readiness for use? Each has its own definitions. See the INCOSE V5 SE HB Section 2.3.5.11 on the Validation Process.

Improved: More analysis needed, but the final requirement(s) should be in the form "The [responsible organization] shall [proper action] [as defined somewhere] in the operating environment defined in Table 1.

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Poorly Formed LIR Requirement Assessment

Defective: All applicable EPA, OSHA, and FDA requirements shall be complied with, when reasonably achievable.

- Passive voice not stating the entity to which the requirement applies. If written for the LIR, "The LIR shall ……."
- Avoid vague terms like "all applicable" – who determines which are applicable?
- References organizational requirements- where are these documented? What Standards and Regulations? Within these standards and regulations, some requirements may apply to the organization and some to the SOI.
- Avoid escape clauses like "when reasonably achievable."

Improved: (How requirements invoking standards and regulations have been expressed in the past.)

The LIR shall comply with [TBD] EPA Regulation xyz concerning the use and handling of hazardous materials.

The LIR shall comply with OSHA Regulation xyz concerning human/machine interfaces.

The LIR shall comply with OSHA Regulation xyz concerning the safety of humans working with robots.

The LIR shall comply with FDA Regulation xyz concerning the handling of food.

In reality, these are more appropriate to be stated as need statements.
See next slides for more discussion.

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Common issues when communicating needs and requirements for standards and regulations.

- In the past, it has been a customary practice to call out entire standards or regulations or sections of a standard or regulation within a requirement statement.

  "The <SOI> shall be complaint with *all applicable ISO standards*". Or

  "The <SOI> shall be complaint with *all* requirements within FDA regulation xyz". Or

  "The <SOI> shall meet *all requirements* within OSHA regulation xyz, Section 4.5.9.11."

  - In the first example, who determines which requirements are applicable?
  - Because the first two requirements are written using passive voice, which entity do they really apply (SOI or project?)
  - In the second and third examples, how certain is it that all requirements in the standard or regulation are applicable and if applicable to which entity are they applicable?
  - This is like kicking the can down the road and letting someone else determine which requirements are applicable or not.

Best Practices and Guidance

- It is dangerous to call out a complete standard or regulation when only a portion of the requirements apply.
  - All requirements invoked within the set of design input requirements will have to be implemented in the design and the system verified to meet those requirements.
  - This is a real issue if contracting to a supplier who is contracted to implement all requirements in the set.
- What should happen when transforming needs dealing with standards and regulations into design input system requirements, is that the project team responsible for the transformation, must do an engineering analysis to determine:
  - Which specific requirements within the standard or regulation sited in the need, apply to the SOI under development (vs project or process requirements);
  - Whether these requirements are design inputs for the SOI or requirements on the design team and resulting design output specifications or requirements on production; and
  - For those that apply to the SOI, determine specifically what the SOI must do to meet the intent of the applicable requirements within the standard or regulation.

Best Practices and Guidance

- Based on that analysis, the project team would then derive specific well-formed design input requirements that when implemented by the design would result in the intent of the parent requirements within the standard or regulation referenced in the integrated set of needs to be met.
- While this could result in a larger number of requirements, each would be well-formed making it clear what is expected to be addressed by the design and against which both the design and realized system can be verified against.

For a much more detailed discussion on standards and regulations compliance, refer to the RWG presentation on the INCOSE RWG YouTube Channel: https://youtu.be/LQmLt4eL_JA

Lou Wheatcraft

- **Lou Wheatcraft** is a senior consultant and managing member of Wheatland Consulting, LLC. Lou is an expert in systems engineering with a focus on needs and requirements development, management, verification, & validation. Lou provides consulting and mentoring services to clients on the importance of well-formed needs & requirements helping them implement needs & requirement development and management processes, reviewing and providing comments on their needs and requirements, and helping clients write well-formed needs & requirements.
- Specialties include: Understanding and documenting the problem; defining project & product scope; defining and maturing system concepts; assessing, mitigating, & managing risk; documenting stakeholder needs; transforming needs into well formed design input requirements; allocation, budgeting, and traceability; interface management, requirement management; & verification and validation.
- Lou's goal is to help clients practice better systems engineering from a needs & requirements perspective across all life cycle stages of system/product development. Getting the needs & requirements right upfront is key to a successful project. Poor needs & requirements can triple the chances of project failure.
- Lou has over 50 years' experience in systems engineering, including 22 years in the United States Air Force. Lou has taught over 200 requirement seminars over the last 23 years. Lou supports clients from all industries involved in developing and managing systems and products including aerospace, defense, medical devices, consumer goods, transportation, and energy.
- Lou has spoken at Project Management Institute (PMI) chapter meetings and INCOSE conferences and chapter meetings. Lou has published and presented many papers concerning needs and requirement for NASA's *PM Challenge*, INCOSE, INCOSE *INSIGHT Magazine*, and *Crosstalk Magazine*. Lou is a member of INCOSE, past Chair and current Co-Chair of the INCOSE Requirements Working Group (RWG), a member of the Project Management Institute (PMI), the Software Engineering Institute (SEI), the World Futures Society, and the National Honor Society of Pi Alpha Alpha.
- Lou has a BS degree in Electrical Engineering from Oklahoma State University; an MA degree in Computer Information Systems; an MS degree in Environmental Management; and has completed the course work for an MS degree in Studies of the Future from the University of Houston – Clear Lake.