28th Annual INCOSE international symposium

Washington, DC, USA
July 7 - 12, 2018

Formalizing Requirements Verification and Validation

Ronald S. Carson, PhD, ESEP, INCOSE Fellow, Seattle Pacific University
Robert A Noel, Associate Technical Fellow, The Boeing Company

BOEING

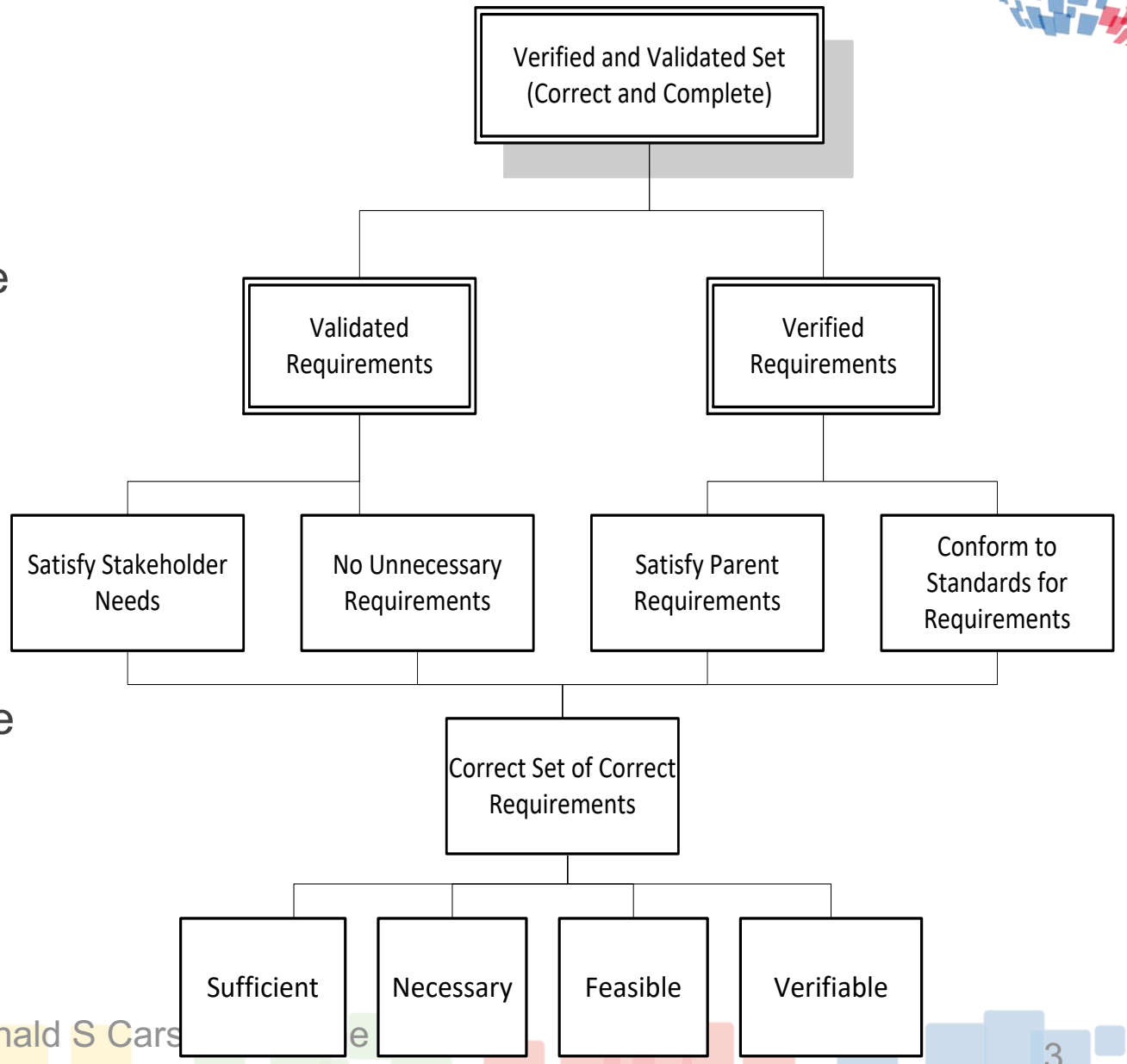
Engaging the culture, changing the world
Seattle Pacific UNIVERSITY

Outline

- What is Requirements Verification and Validation?
- How do these relate to “Correct and Complete” Requirements?
- Relationship to INCOSE Guide “Characteristics” of Requirements
- Measurable Verification/Validation Characteristics for Requirements
- Correct Sets of Correct Requirements
- Conclusions and Questions

What is Requirements Verification and Validation?

- INCOSE SE Handbook v4 identifies verified (4.9) and validated (4.11) requirements but doesn't define how that's done.
- Operational and top-level requirements are *validated* vs. Needs
- Lower-level requirements are *verified* vs. parent requirements and standards
- At each architectural level, these yield "correct set of correct requirements"
- This is what we mean by "verified and validated"
- This paper formalizes and decomposes the definitions and provides measures for "verified and validated requirements" ≡ "correct set of correct requirements"
- "Correct and complete" arises from [ARP4754A sections 5.3, 5.4]

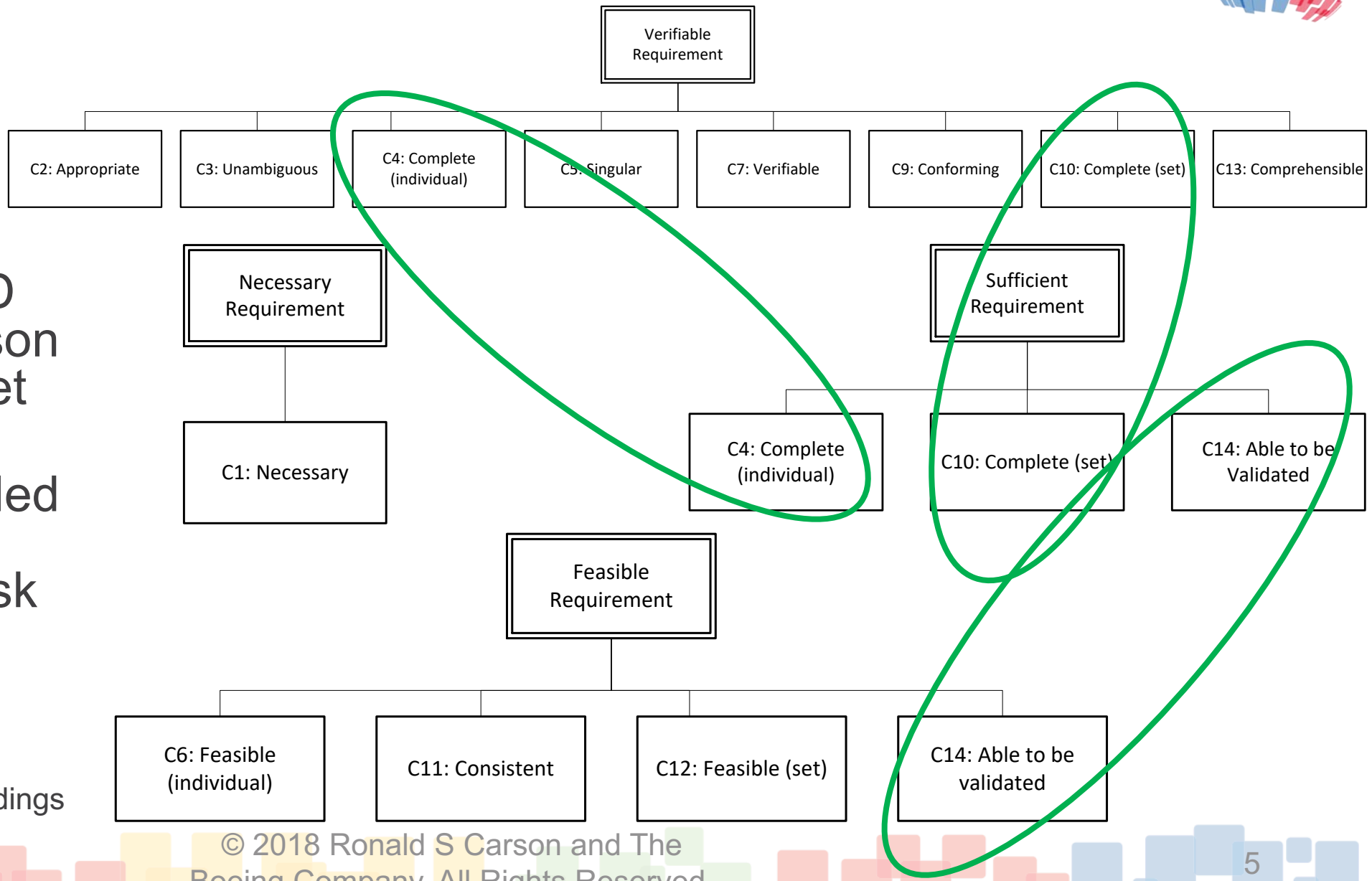


“Characteristics” per INCOSE Guide

INCOSE 2015 Guide Characteristics	INCOSE 2015 Guide Definition	Derived Verification / Validation Criteria
C1 – Necessary	The requirement defines an essential capability, characteristic, constraint, or quality factor	Necessary
C2 – Appropriate	The specific intent and amount of detail of the requirement is appropriate to the level of the entity to which it refers (level of abstraction).”	Verifiable
C3 – Unambiguous	The requirement is stated in such a way that it can be interpreted in only one way.	Verifiable
C4 – Complete (individual)	The requirement sufficiently describes the necessary capability, characteristic, constraint, or quality factor to meet the entity need without needing other information to understand the requirement.	Verifiable, Sufficient
C5 – Singular	The requirement should state a single capability, characteristic, constraint, or quality.	Verifiable
C6 – Feasible (individual)	The requirement can be realized within entity constraints (e.g., cost, schedule, technical, legal, regulatory) with acceptable risk.	Feasible
C7 – Verifiable	The requirement is structured and worded such that its realization can be proven (verified) to the customer’s satisfaction at the level the requirement exists.	Verifiable
C8 – Correct	The requirement must be an accurate representation of the entity need from which it was transformed.	Sufficient
C9 – Conforming	The individual requirements should conform to an approved standard template and style for writing requirements.	Verifiable
C10 – Complete (set)	The requirement set stands alone such that it sufficiently describes the necessary capabilities, characteristics, constraints, and/or quality factors to meet the entity needs without needing other information.	Verifiable, Sufficient
C11 – Consistent	The set of requirements contains individual requirements that are unique, do not conflict with or overlap other requirements in the set, and the units and measurement systems they use is homogeneous. The language used within the set of requirements is consistent (i.e., the same word is used throughout the set to mean the same thing).	Feasible, Verifiable
C12 – Feasible (set)	The requirement set can be realized within entity constraints (e.g., cost, schedule, technical, legal, regulatory) with acceptable risk.	Feasible (set)
C13 – Comprehensible	The set of requirements must be written such that it is clear as to what is expected by the entity and its relation to the system of which it is a part.	Verifiable
C14 – Able to be validated	It must be able to be proven [that] the requirement set will lead to the achievement of the entity needs within the constraints (such as cost, schedule, technical, legal and regulatory compliance).	Sufficient and Feasible

Why Only Four Characteristics

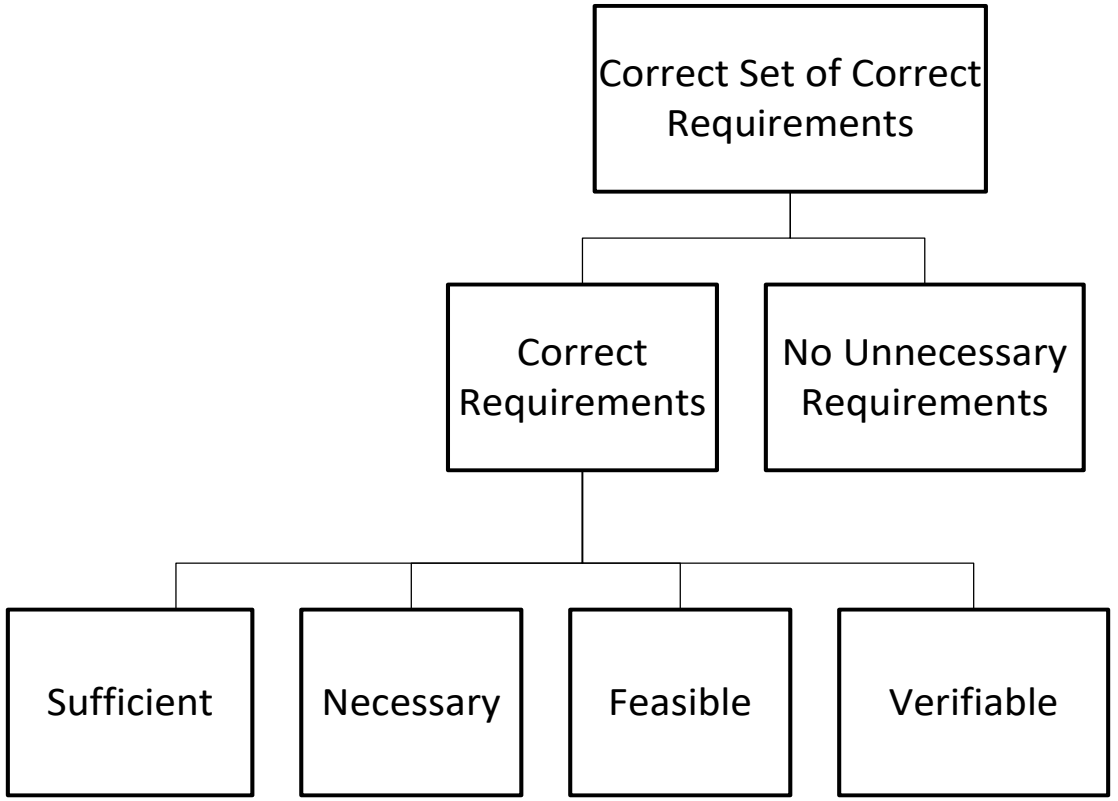
- *Verifiable* included to ensure no ambiguity
- **Complete**: *necessary* AND *sufficient* (Carson 1998, Carson et al. 2004)
- *Feasible* included to ensure manageable risk and detect conflicts



- "Requirements Completeness", Proceedings of INCOSE 1998, 2004

Correct and Complete Requirements

- *Each* requirement and the *set* are "correct"
  1. Verifiable: sufficiently clear and complete to be able to prove that it is needed, satisfied, and feasible
  - Necessary: parent requirement or need *cannot* be satisfied without this requirement
  - Sufficient: if this requirement is satisfied, then the parent requirement or need *will be satisfied* (perhaps in combination with other child requirements)
  - Feasible: requirement can be satisfied within the program constraints with acceptable risk
- These characteristics are disjoint, concise, and complete (necessary and sufficient to determine "correct and complete")



Measurable Characteristics

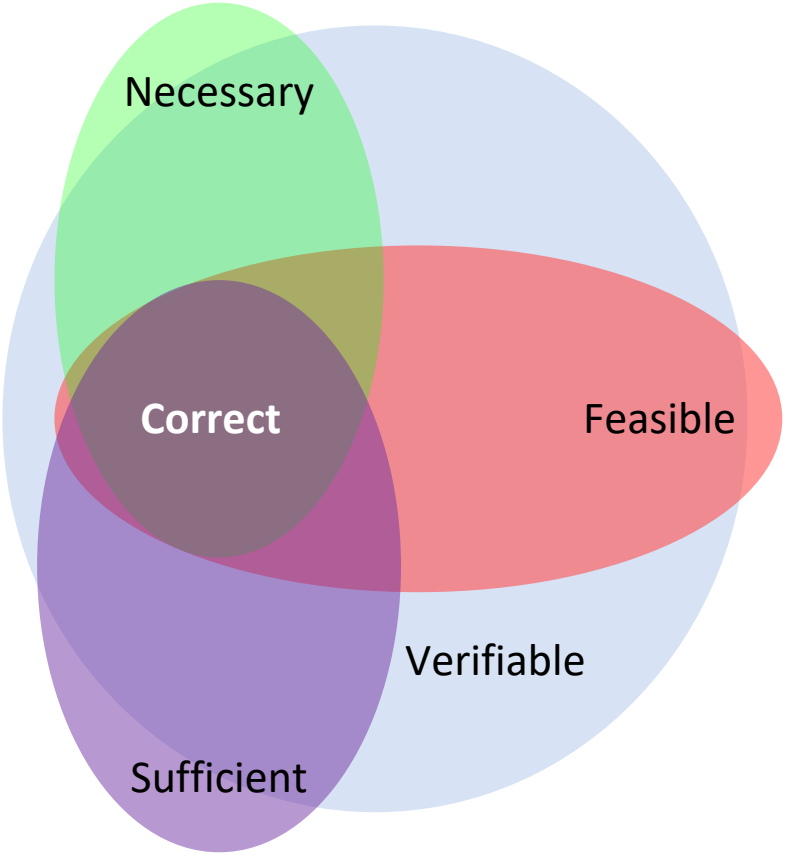
$$Correct = (Feasible \cap Necessary \cap Sufficient \cap Verifiable)$$

$$(\sim Feasible \cup \sim Necessary \cup \sim Sufficient \cup \sim Verifiable) = \sim Correct$$

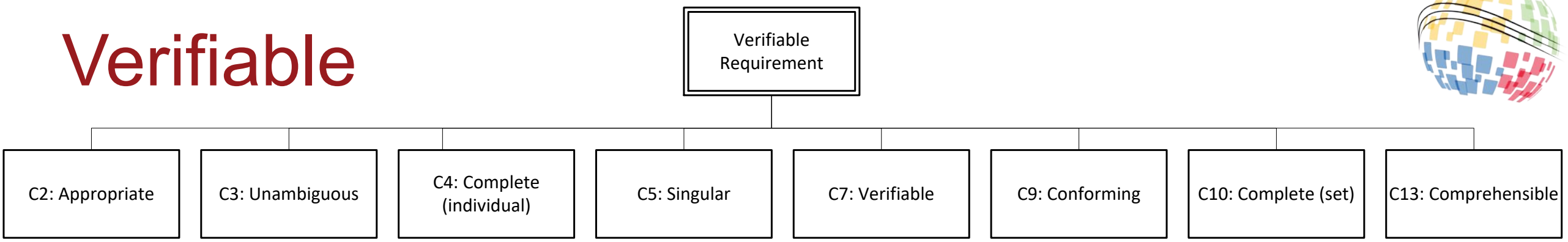
- Verifiable: Quality (0-4)
- Necessary: Binary (0/1)
- Sufficient: Binary (0/1)

} "Complete"

- Feasible: Issue/risk (0 to 1)



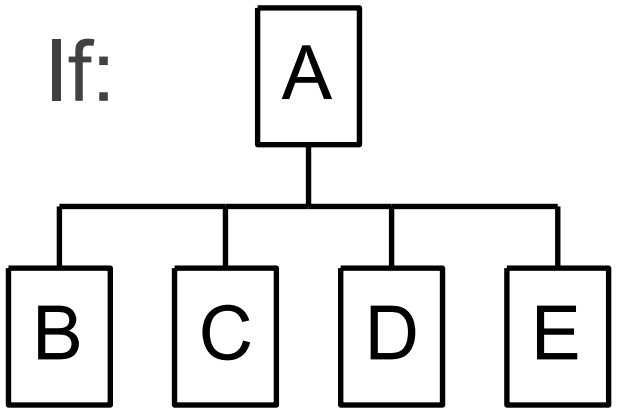
Verifiable



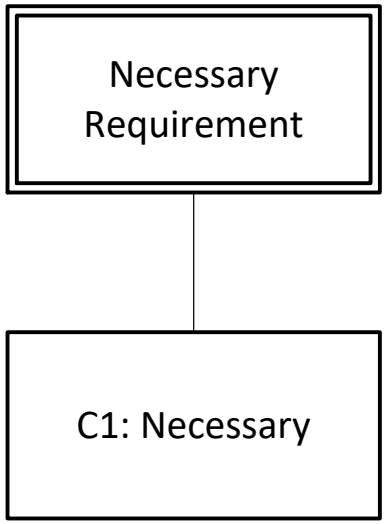
- *Verifiable* is checked first; if the requirement is unclear or missing elements, it cannot necessarily be determined to be either necessary, sufficient, or feasible.
- Example measurement is "requirement quality" per (Carson 2015*)
  - Includes identifying and scoring the essential elements of the requirement: who, what, how well, what conditions
  - Example: Functional/Performance Requirement –
    - The AGENT shall FUNCTION in accordance with INTERFACE-OUTPUT with PERFORMANCE [and TIMING upon EVENT TRIGGER in accordance with INTERFACE-INPUT] while in CONDITION.*
  - * "Implementing Structured Requirements to Improve Requirements Quality", *Proceedings of INCOSE 2015*

Necessary

- C1 – Necessary: The requirement defines an essential capability, characteristic, constraint, or quality factor
- The parent requirement or need *cannot* be satisfied without this requirement



- Measurement is binary: necessary (yes (1) / no (0))



and if: $\sim B \rightarrow \sim A$

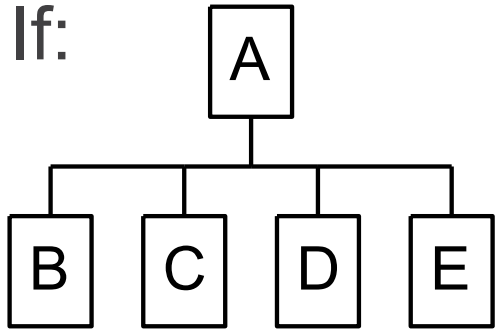
Then: **B** is ***necessary*** for **A**

Note that needs, ***A***, may be derived from other than *parent* requirements (e.g., anomaly handling, safety analysis (ARP 4754A), "completeness" analysis to ensure *deterministic* behavior under all possible conditions (Carson 1998, 2004))

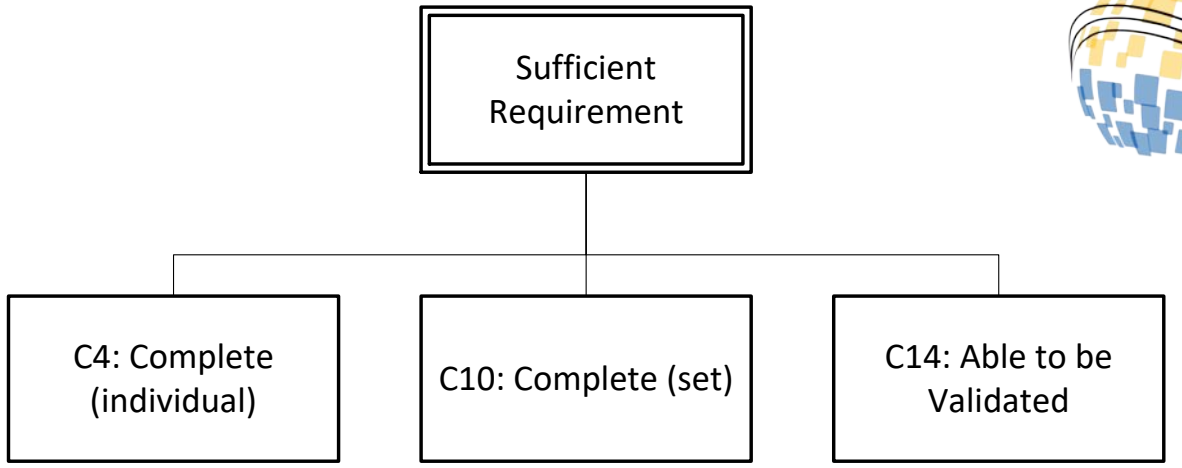
Sufficient

- Satisfying child requirements *ensures* satisfying the parent need or requirement

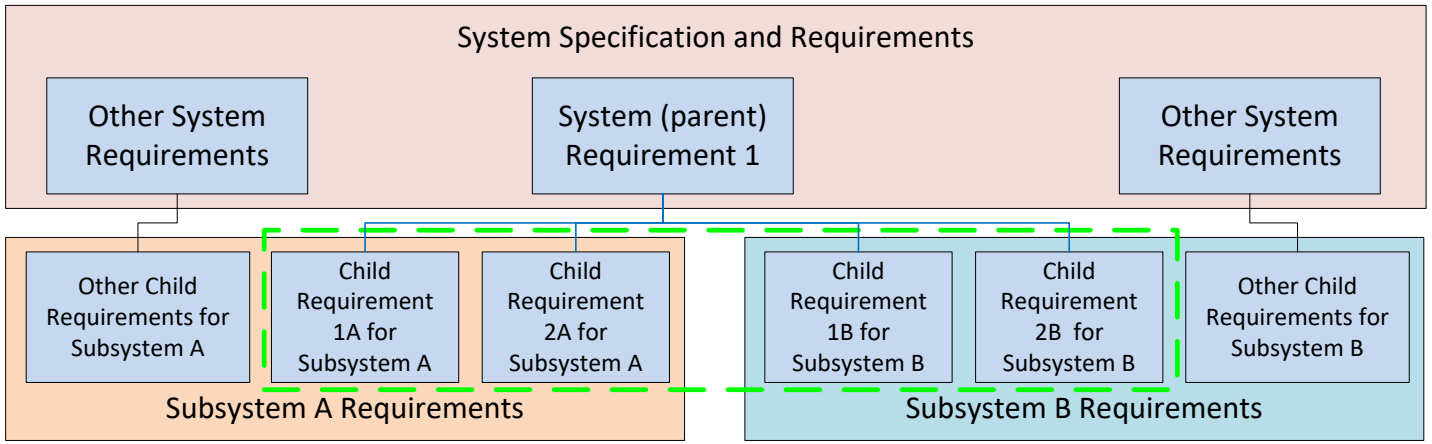
If:



and if $(B \cap C \cap D \cap E) \rightarrow A$



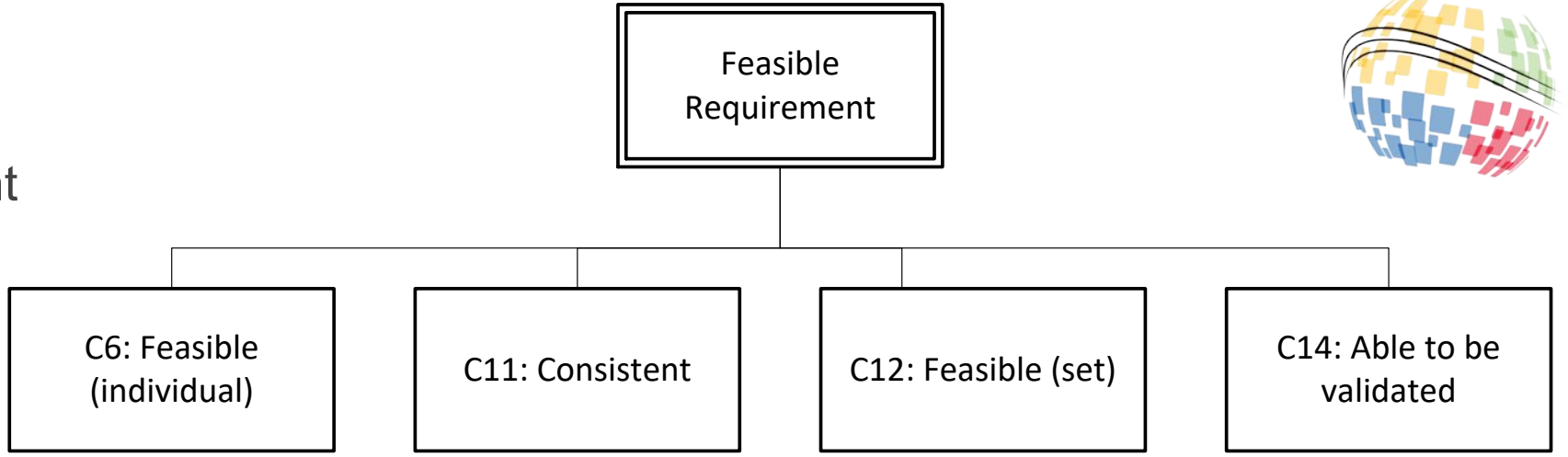
- Then: B, C, D, E are collectively ***sufficient*** to satisfy A

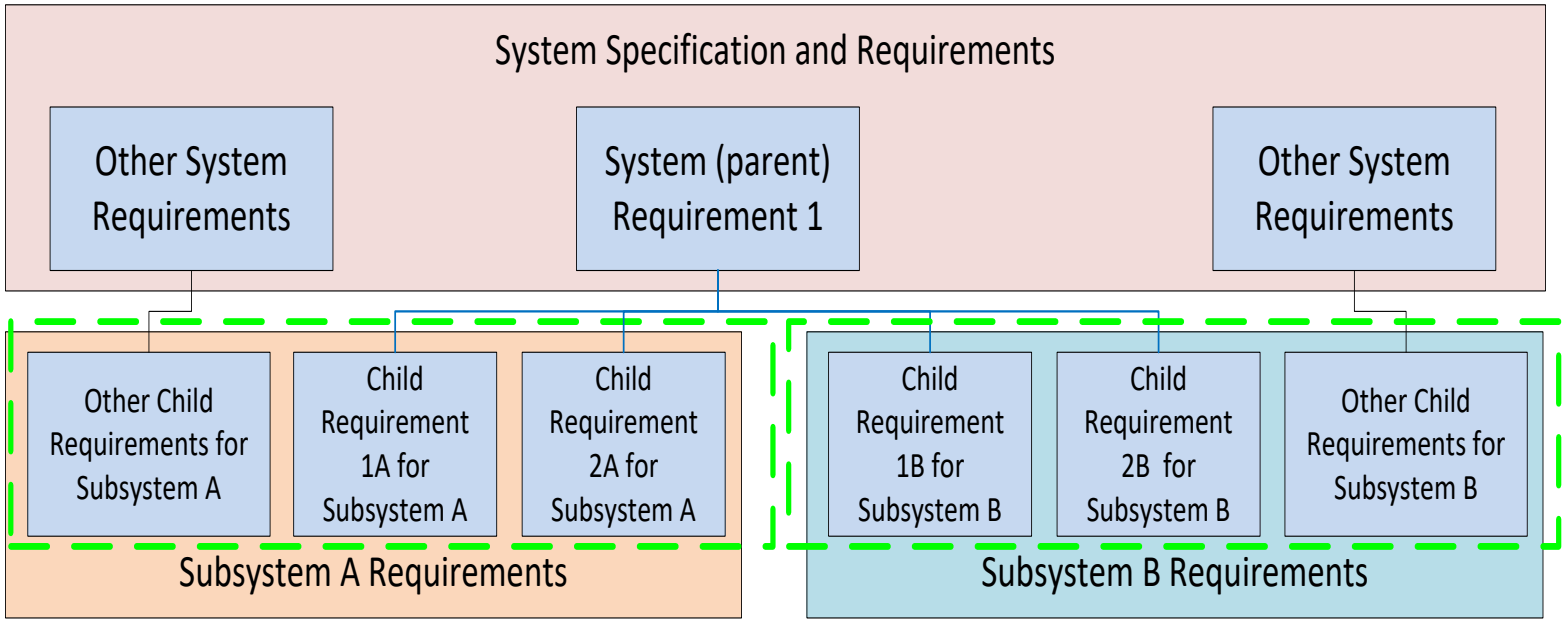


- Requirements may be in multiple subsystems
- Measurement is binary: sufficient (yes (1) / no (0))

Feasible

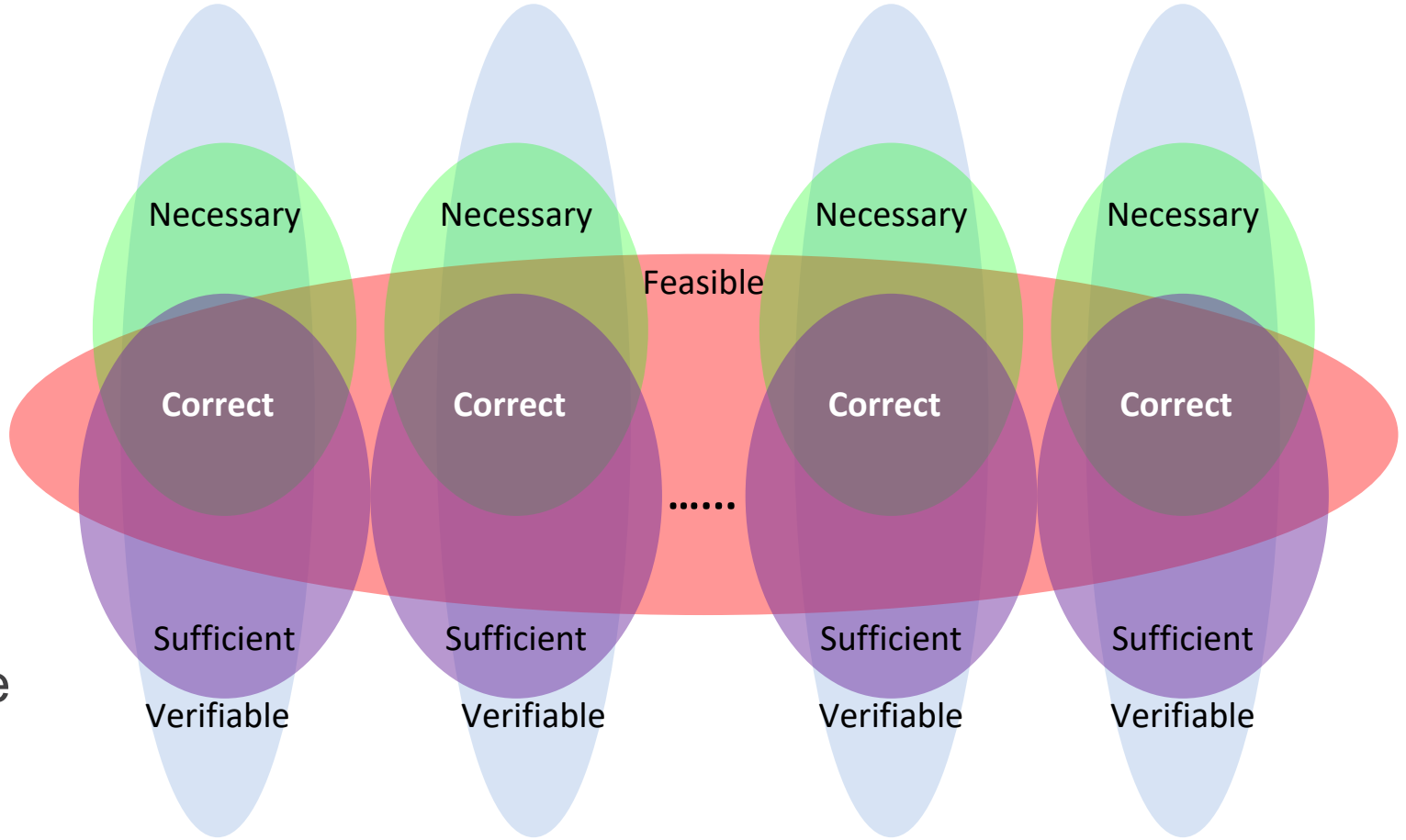
- If *feasible,* then the requirement does not*:*
  - Violate physics
  - Violate laws or regulations
  - Conflict with other requirements
  - Incur excessive program risk
- Can be tested individually and for each System or Subsystem set of requirements
- Do not require parent/child relationships
- Measurement is “degree of risk” (0 to 1)
  - 0 is “issue”; 1 is “no risk”





Correct Sets of Correct Requirements

- Applying four characteristics over all requirements for any element
  - May require including requirements from other element for *sufficiency* check
- *Feasibility* must also be checked at the "set" level (consistency, conflicts, excessive risks)
- If we have "correct sets of correct requirements" we have realized **"verified and validated requirements"**



$$CorrectAndCompleteSet = (Verifiable \cap Feasible \cap Necessary \cap Sufficient) \cap FeasibleSet$$

Conclusions

- Satisfying four disjoint characteristics is necessary and sufficient to “verify and validate” requirements and establish a “correct (and complete) set of correct requirements”
- Measurements for each characteristic enable identifying necessary improvements and corrections

- Questions?

28th Annual INCOSE international symposium

Washington, DC, USA

July 7 - 12, 2018

www.incose.org/symp2018