

RCI

Systems engineering process

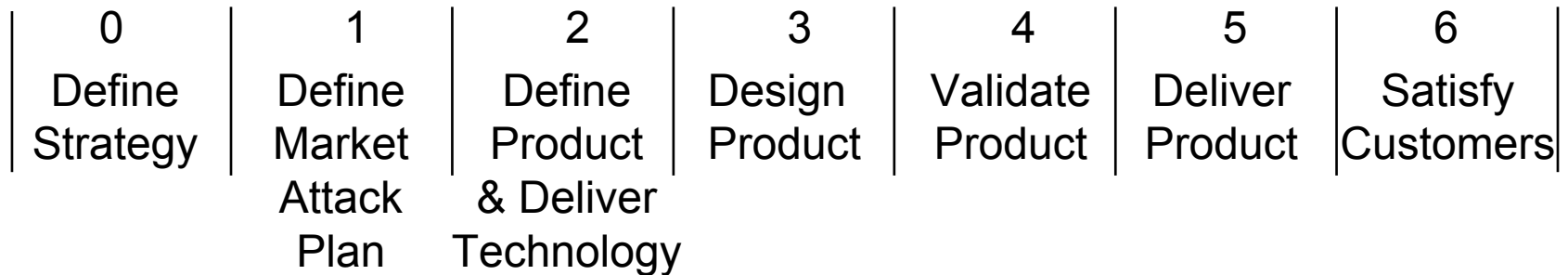
Don Clausing

2004

Developed by Don Clausing, Lou Cohen, and
Madhav Phadke, 1996-2000



Traditional PPP



- Phased Program Planning (PPP)
- But how do we do the work?



Three levels of SE process

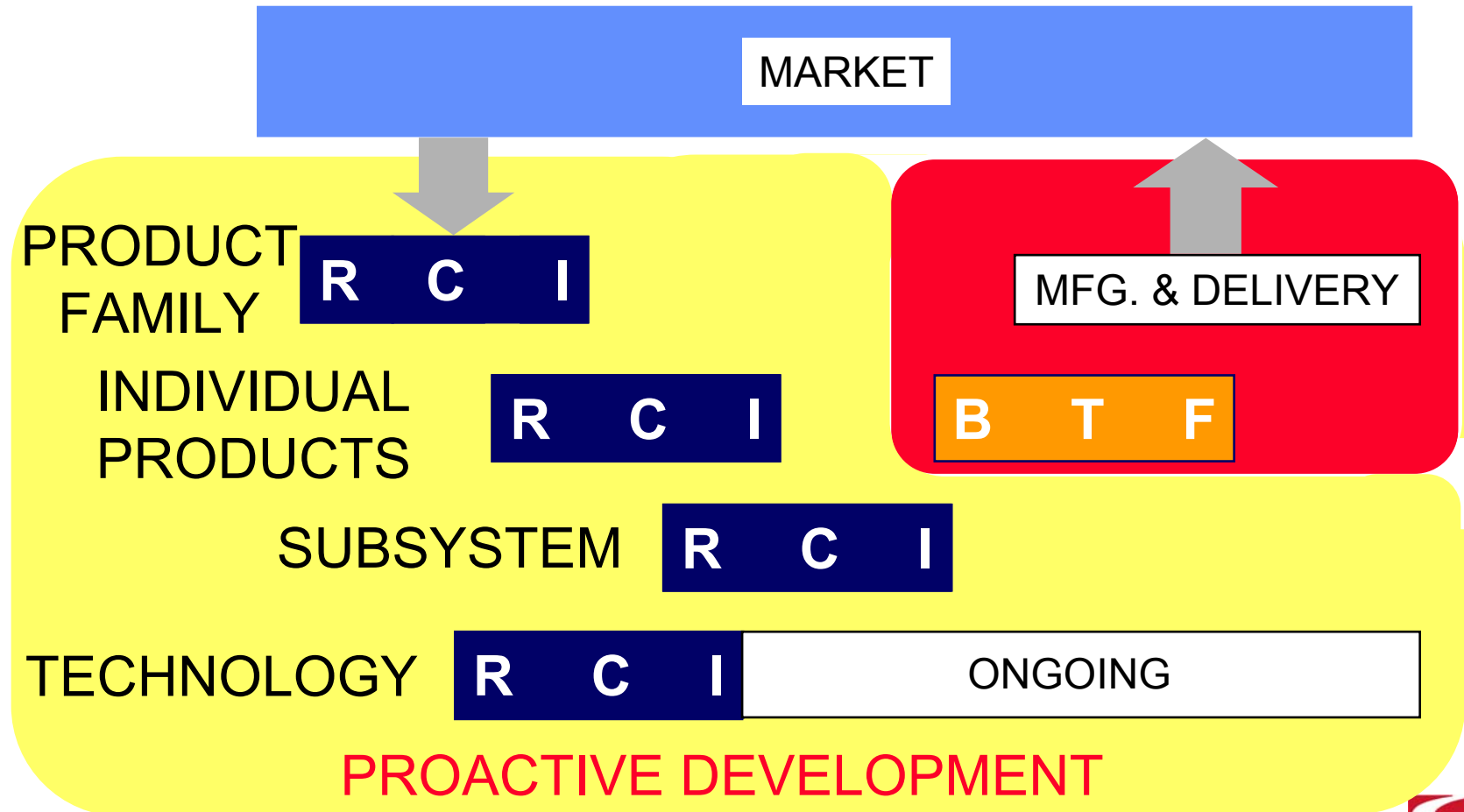
- Integration level - emphasizes system levels
- Managerial level - emphasizes RCI
- Operational level - emphasizes skills





Improvement

Integration level

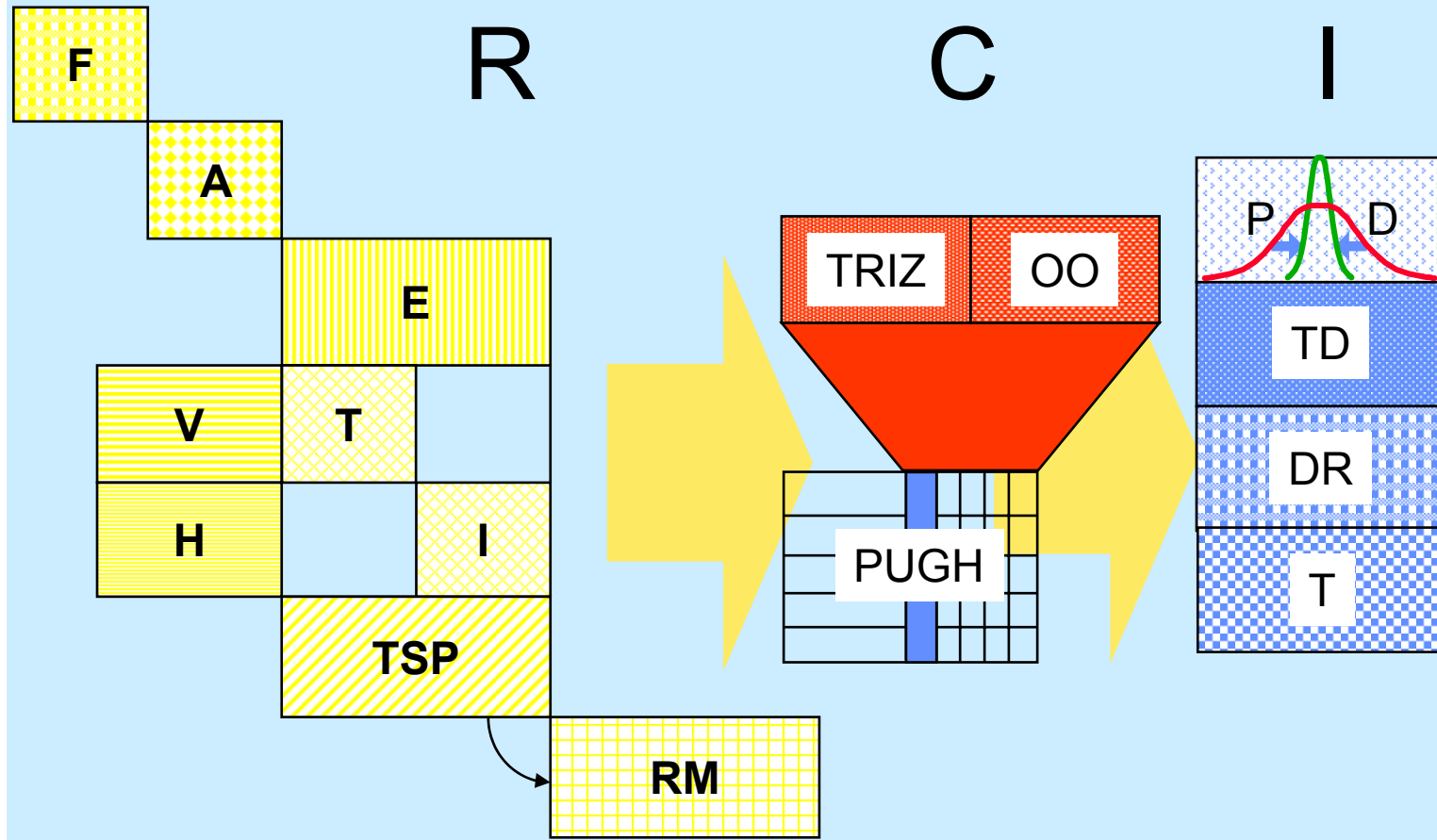




**RCI is the backbone of
Systems Engineering**



Managerial level



Operational level

- Requirements
- Concepts
- Improvement

at the operational level of detail.



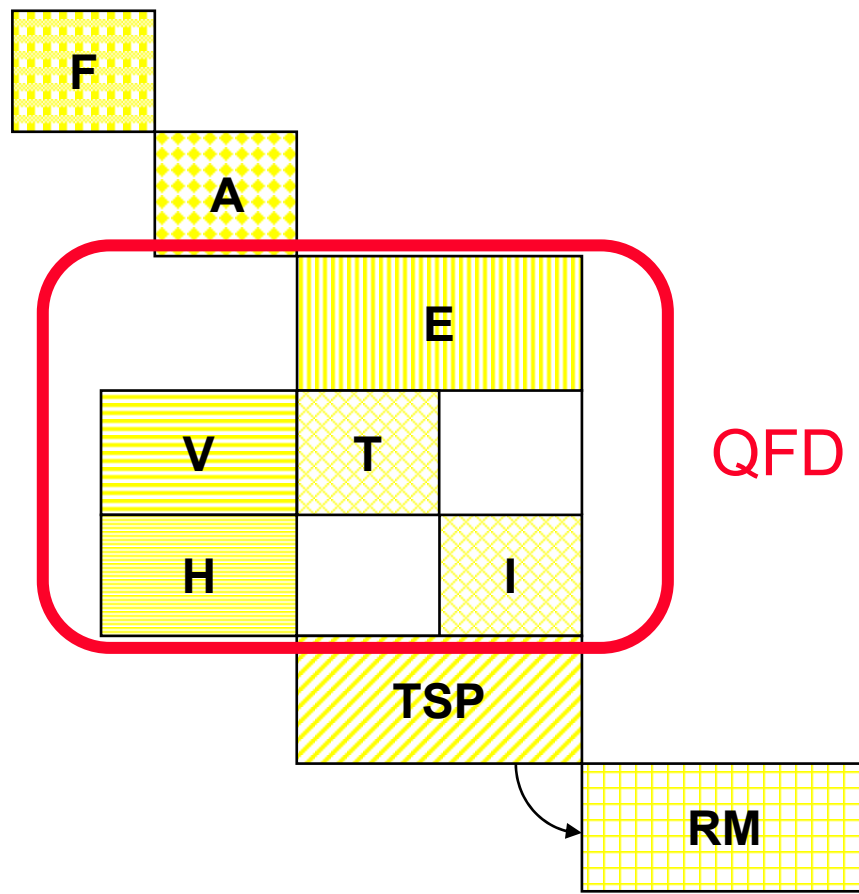
Requirements

- QFD
- Functional analysis
- Functional amplification
- Reusability

An introduction

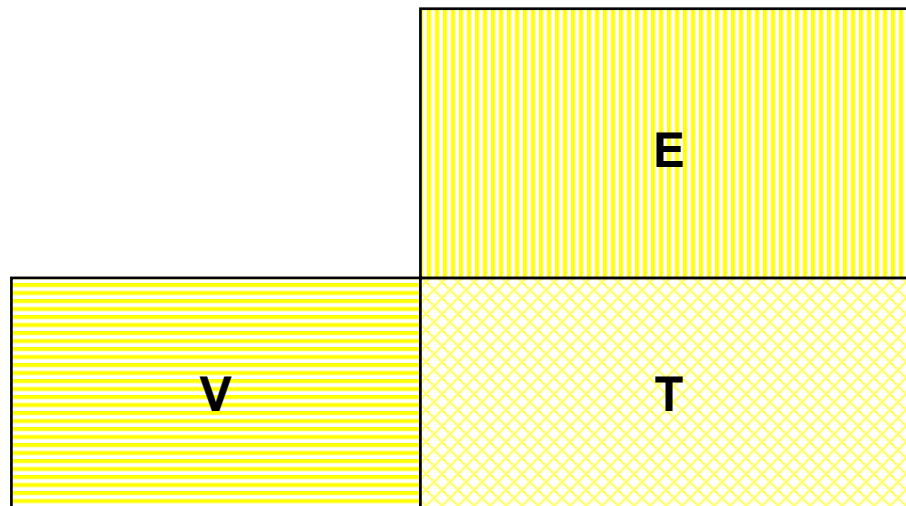


QFD, key to customer satisfaction



Traditional House of Quality

3 core rooms



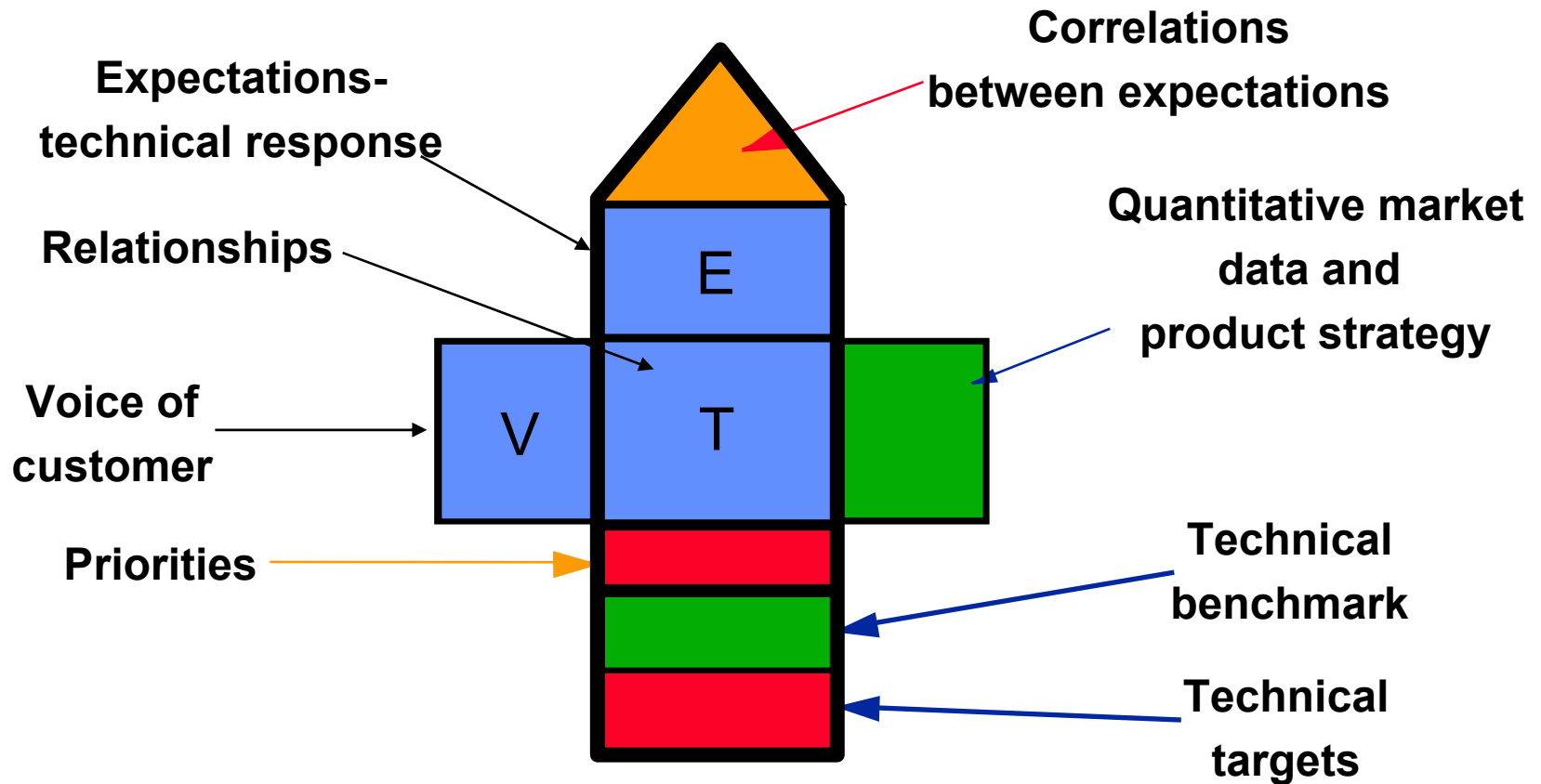
V – VOICE OF EXTERNAL STAKEHOLDERS

E – EXPECTATIONS OF INTEGRATED DEVELOPMENT TEAM

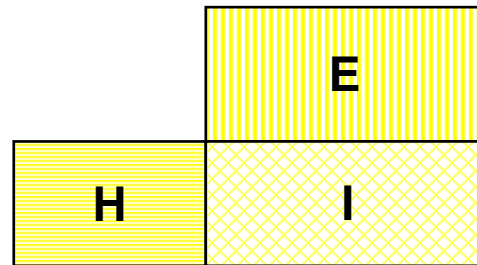
T – VERIFIES TRANSLATION FROM CUSTOMERS' VOICES
TO IDT VOICE



Complete House Of Quality



Expectations are deployed down



H – EXPECTATIONS FROM HIGHER SYSTEM LEVELS,
SUCH AS PRODUCT

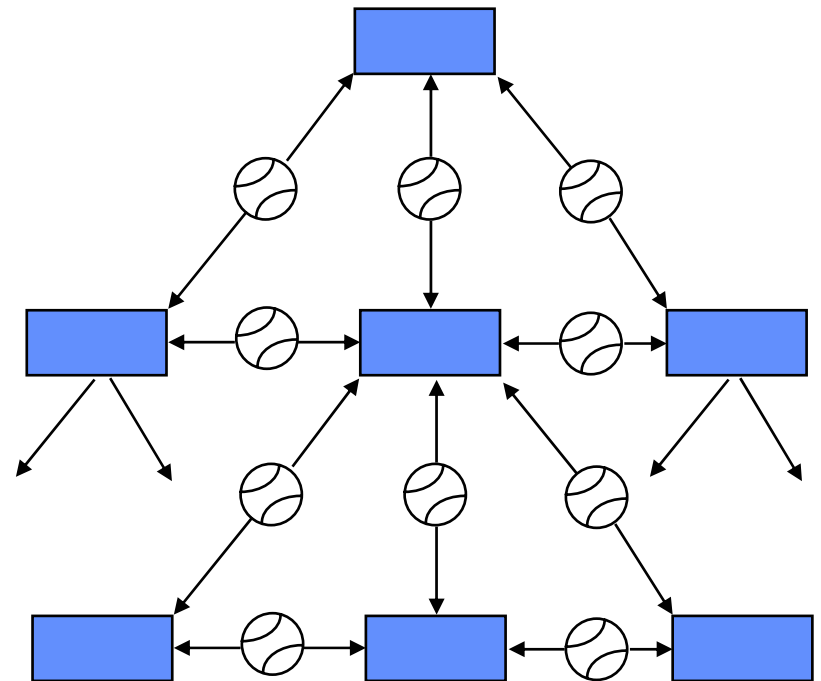
E – EXPECTATIONS AT LOWER SYSTEM LEVEL,
SUCH AS SUBSYSTEM

I – INTERLEVEL DEPLOYMENT MATRIX



Consistency of levels

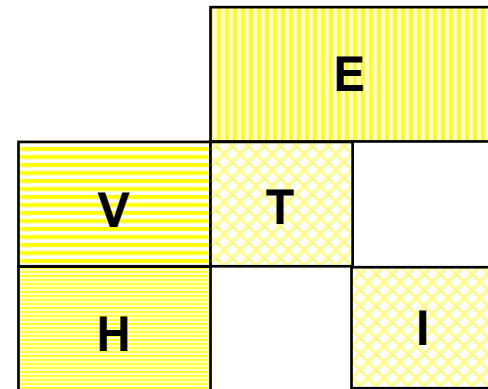
- Use catchball planning
- Iteration to consensus assures consistency
- Make levels N-1, N, and N+1 consistent
- Choose concept before completing requirements deployment to next level



Combined QFD

House of Quality and Interlevel

- Inputs:
 - Voice of external stakeholders (V)
 - Higher level expectations (H)
- Output: prioritized expectations



Requirements output

- QFD matrix
 - Voice of external stakeholders (VOES)
 - Providers' expectations
- Complete requirements development includes functions & reusability planning

Use all of these to guide, inspire, and select concepts

Following are characteristics by which to evaluate the **quality of requirements**, what is needed to get to world-class concepts:

- Complete
- Evocative
- True surrogate of the customer
- Prioritized
- Verifiable
- Comprehensible structure



Concepts

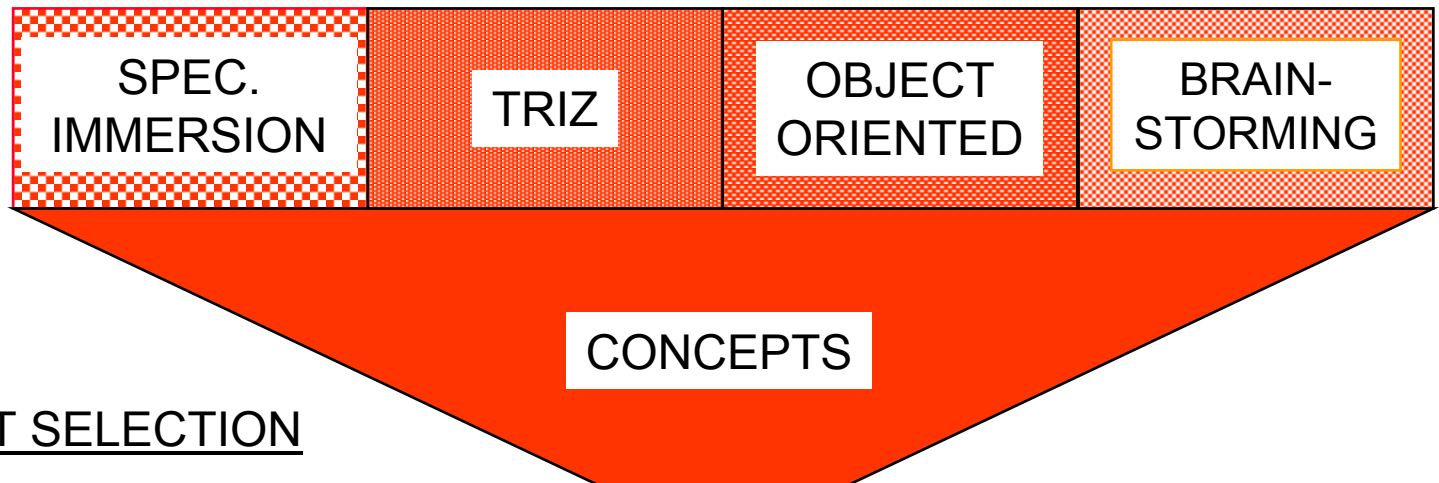
- Concept generation
 - Specification immersion
 - Object-oriented systems analysis
 - TRIZ (theory of inventive problem solving)
 - Brainstorming
- Concept selection – Pugh process

An introduction

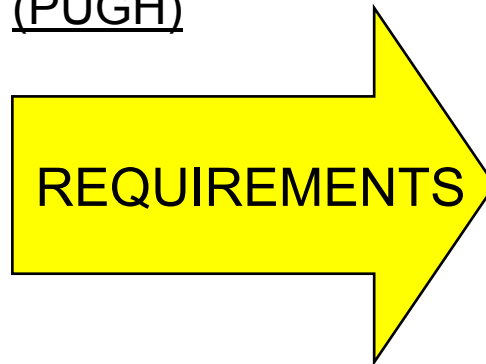


Operational level: Concepts

CONCEPT GENERATION



CONCEPT SELECTION (PUGH)



Criterion 1	D	+	S	-	+
Criterion 2	A	-	+	+	-
Criterion 3	T	S	-	-	S
.....	U	+	-	-	+
Criterion N	M	+	-	+	S



Simple methods

- Specification immersion
 - Creative people, immersed in developing the specifications, generate concepts
 - In creative environment it works well
- Brainstorming
 - Started in advertising
 - Weak record of success in engineering

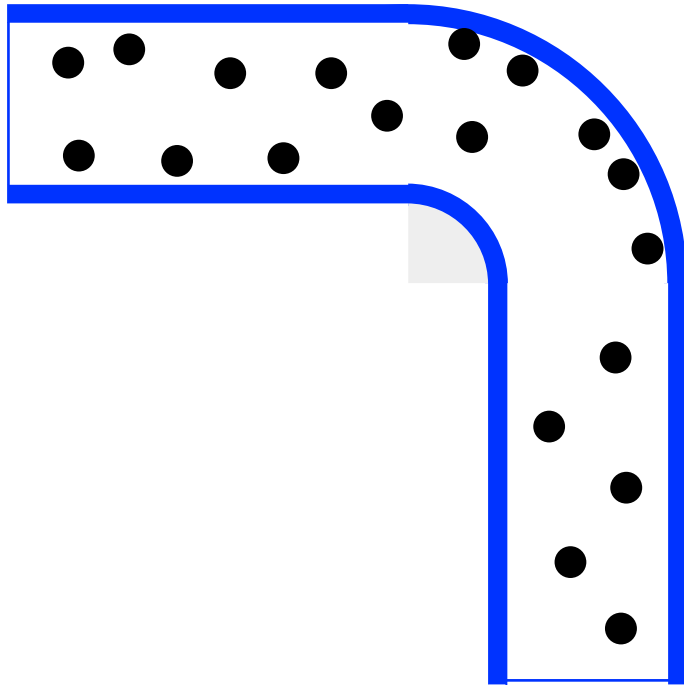


TRIZ/TIPS

- Invention process – based on studying many patents and observing evolution patterns
- Conflicts are the mother of invention
- Standard solutions applied in diverse fields
- Evolution of technological systems follow certain patterns
- Systematic application of scientific effects



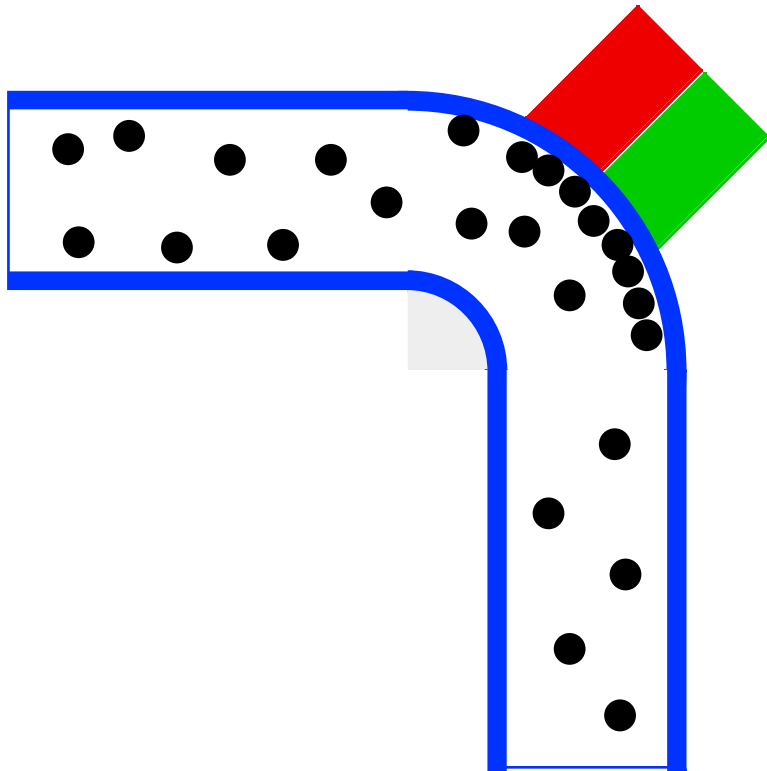
Conflict



- Shot wear pipe at the turn
- Conflict
 - Need coating
 - Don't want coating
 - Cost
 - Short life



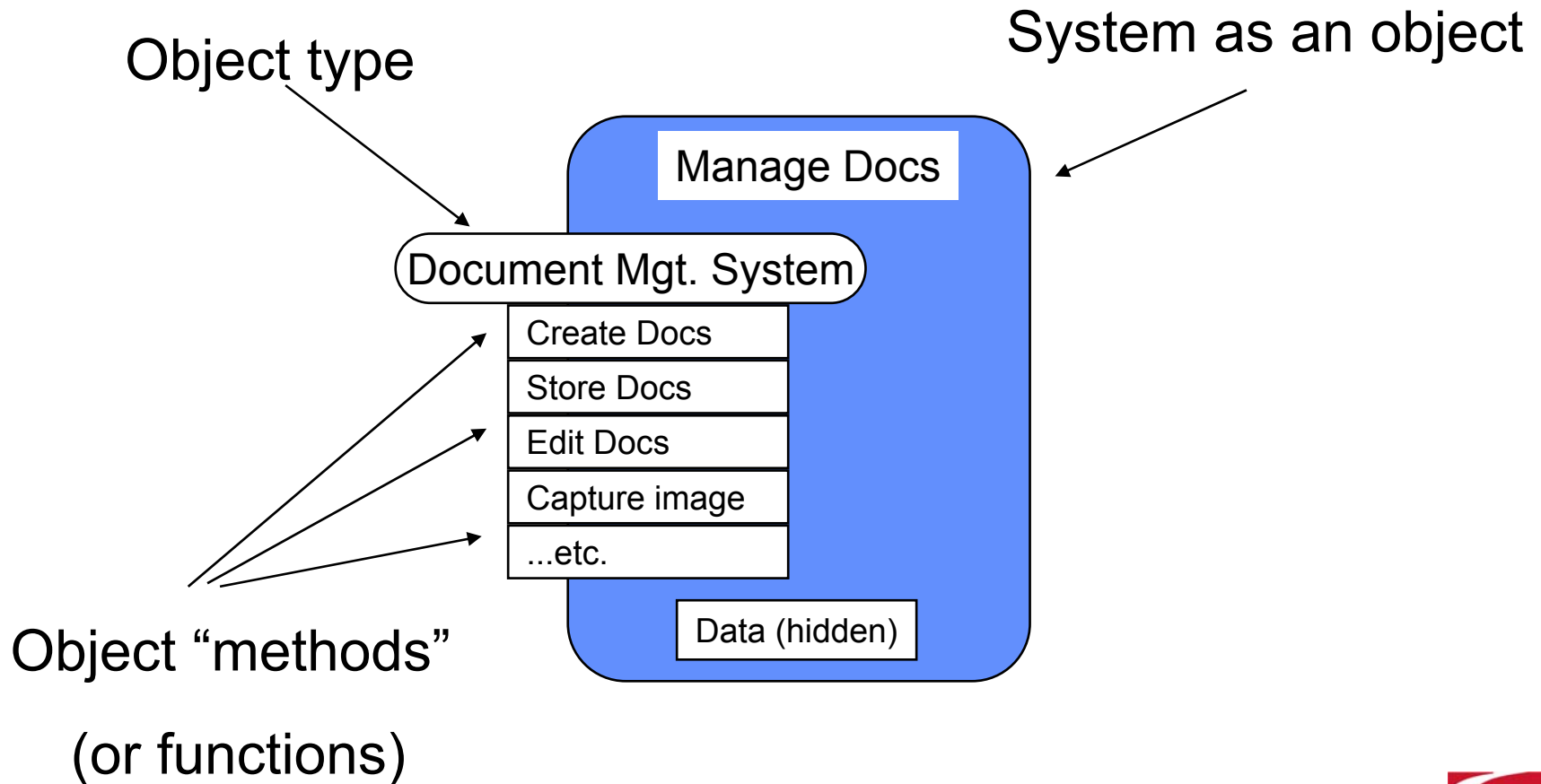
Solution



- Magnets form protective layer of shot
- Continuously replenishable
- Is one standard approach – use one of interfacing materials to form interface



Objects are abstractions of the real world



How can objects be useful in Systems Engineering?

- Easy to test alternate system decompositions
- Bridges the gap between HW and SW
- Provides path for simulation (manual or automated)
- Provides path for allocating responsibility
- Facilitates reusability

Don has added reusability to this slide as per our notes. -LC


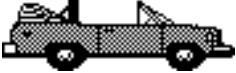

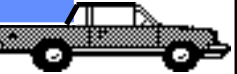


Pugh concept selection

- Qualitatively analyze different concepts
- Combine beneficial aspects
- Eliminate disadvantages
- Evolve to a concept supported by the team, no winners or losers



Pugh Concept Selection Matrix

				
Responsiveness	D	+	+	+
Braking	A	-	-	-
Ease of mfg.	T	S	-	-
Safety	U	+	+	-
Risk	M	-	-	-
Complexity		S	-	-

+ 2

+ 2

+ 1

S 2

S 0

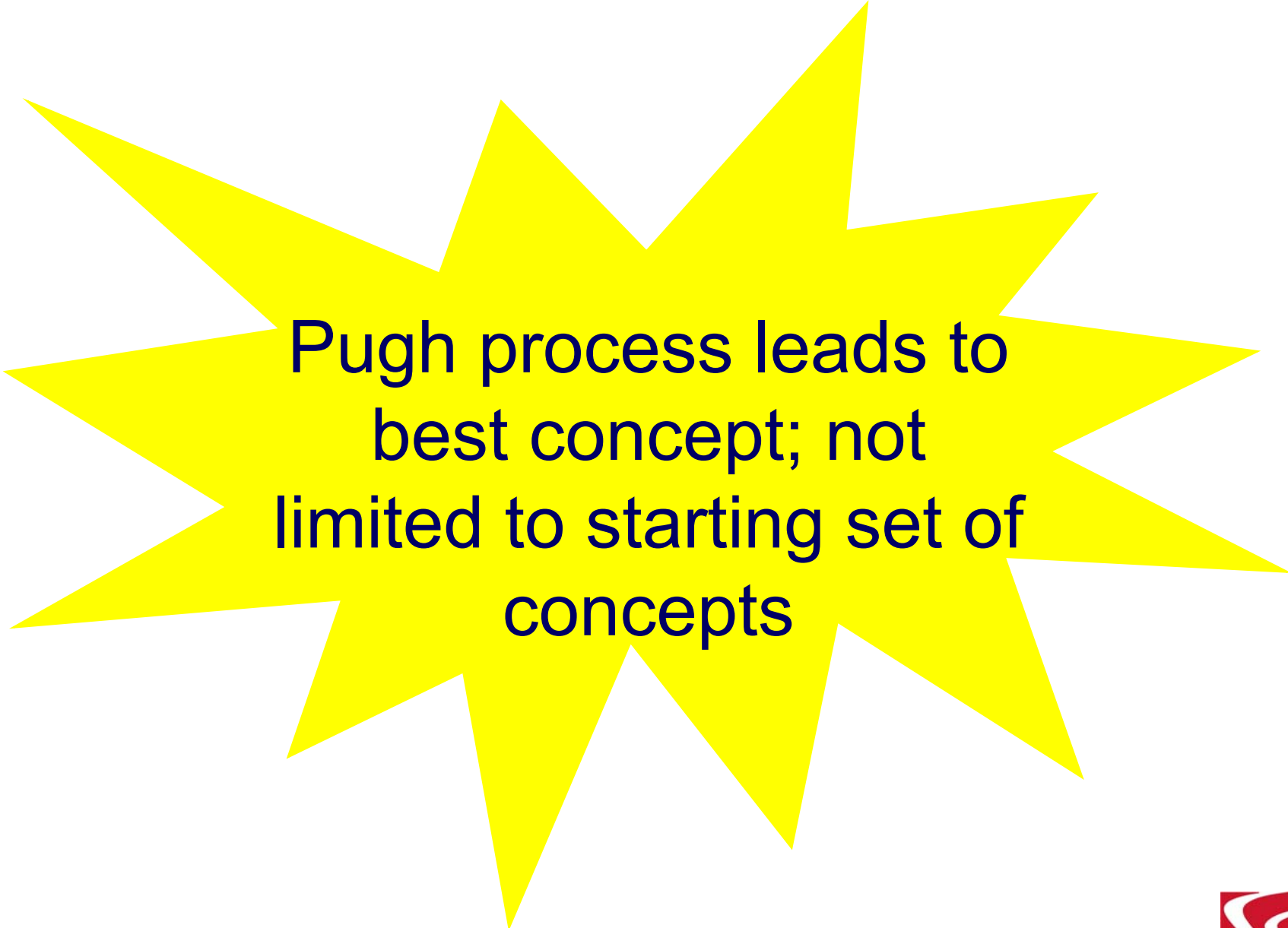
S 0

- 2

- 4

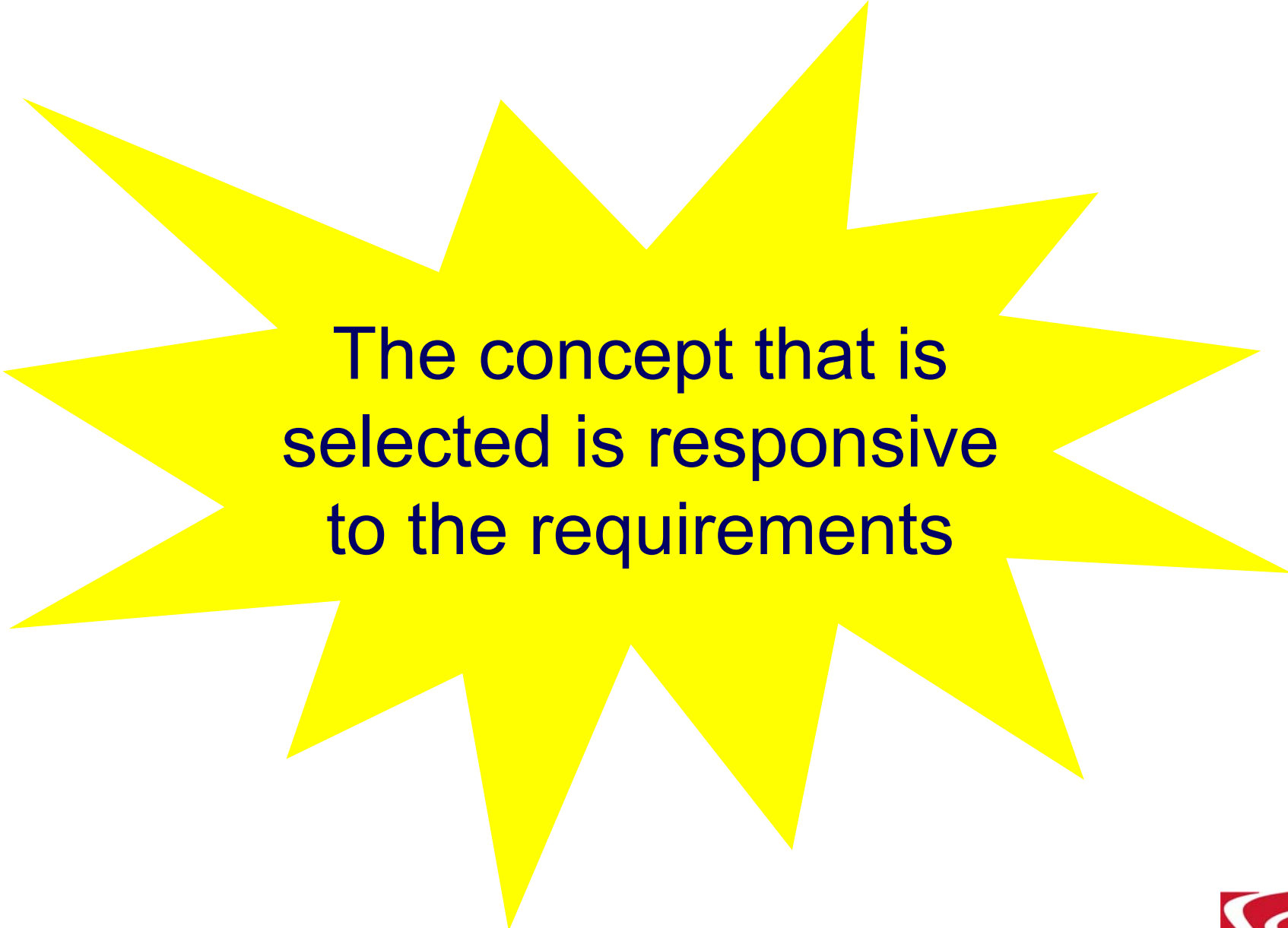
- 5





**Pugh process leads to
best concept; not
limited to starting set of
concepts**





The concept that is
selected is responsive
to the requirements





**Team owns selected
concept; therefore
supports it**



Improvement

- Robust Design
 - Parameter design
 - Tolerance design
- Mistake avoidance

An introduction



Goal of Parameter Design: Optimization

Select the best levels of the **control factors** to achieve the **ideal function** under all **noise factor** conditions

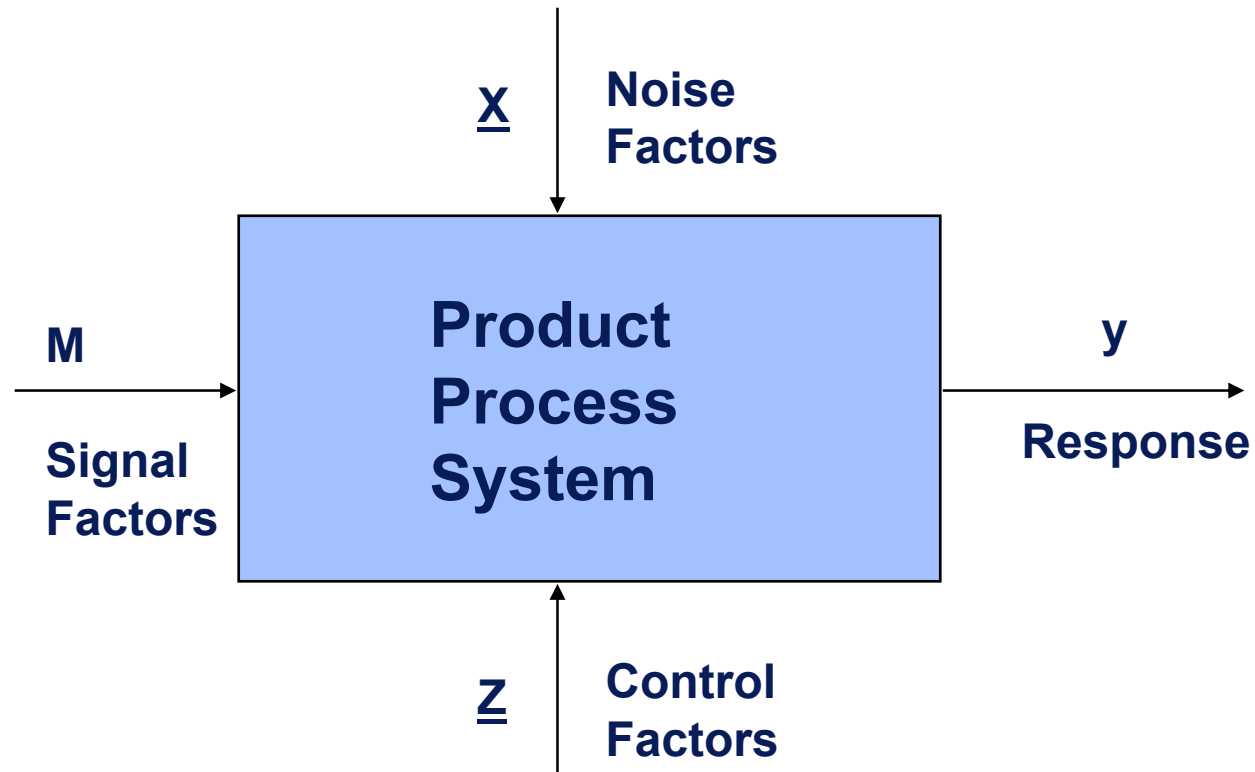


Tools of Robust Design

- P-diagram
- Ideal function and S/N ratio
- Quality loss function
- Orthogonal arrays



P diagram

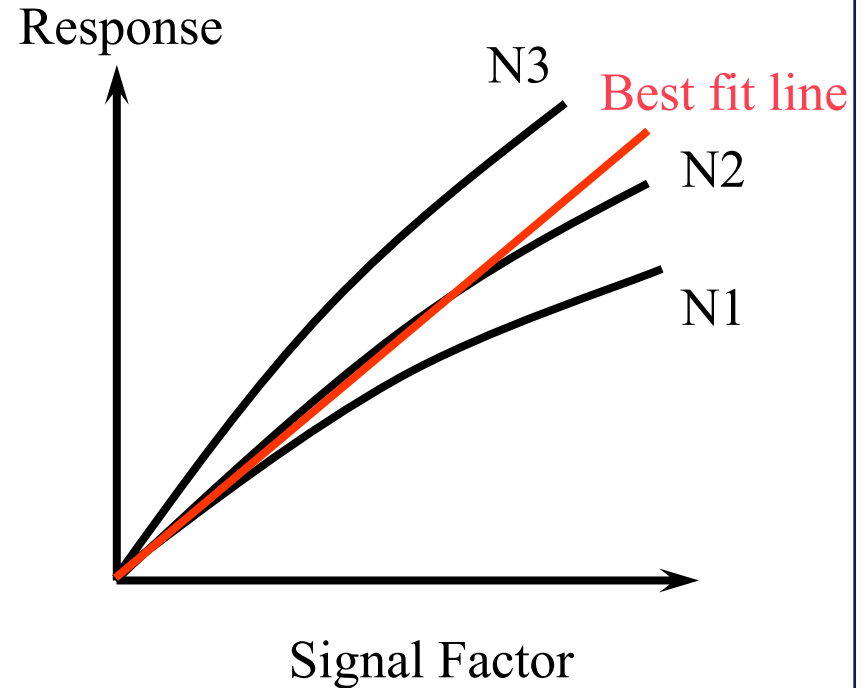
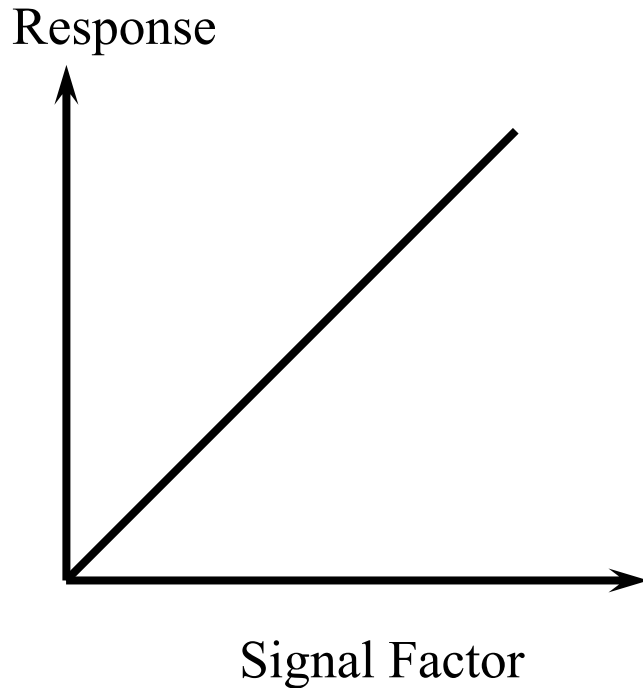


Ideal function

- Ideal function is a mathematical representation of the behavior of the “product” as expected by the higher level system
- Insightful definitions of P-diagram, ideal function, and S/N ratio are essential for technology reuse across many products



Ideal function



$$\text{S/N Ratio} = 10 \log \left((\text{slope})^2 / \text{Variance} \right)$$



Parameter Design Steps

- Prepare P-diagram
- Define ideal function and S/N ratio
- Define S-N tests to evaluate S/N ratio
- Select and conduct an orthogonal array experiment
- Optimize the S/N ratio and tune the mean response





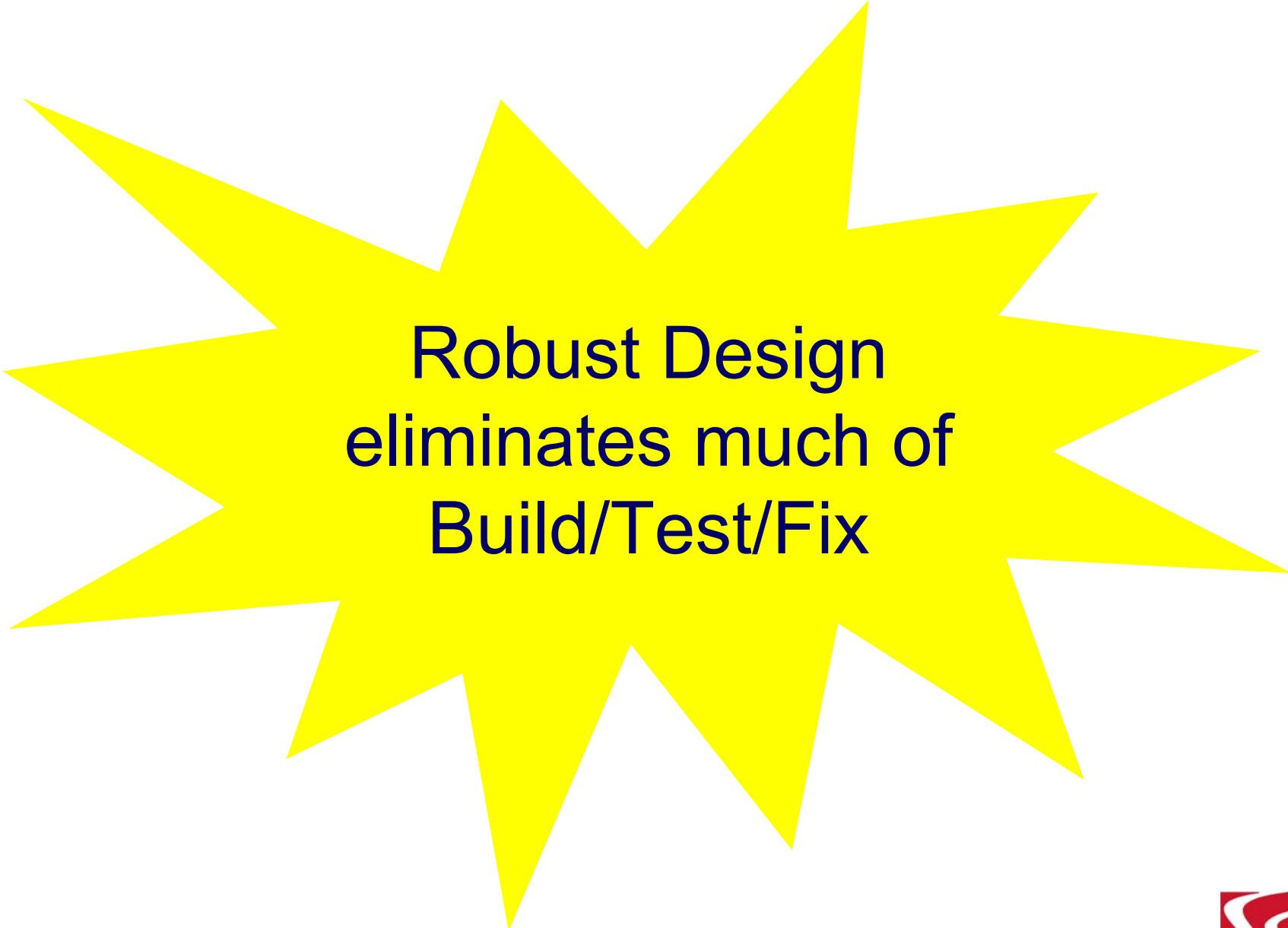
Parameter Design
produces **ready**
technology



Tolerance Design

- Select the cost effective quality of component or production process
- Determine best tolerances for product and production parameters
- Use quality loss function to quantify the quality loss





**Robust Design
eliminates much of
Build/Test/Fix**



Eliminate Mistakes

KNOWLEDGE-BASED ENGINEERING (KBE)	DESIGN REVIEW	VALIDATION & TESTING
--------------------------------------	------------------	-------------------------



Knowledge-based engineering (KBE)

- Standard engineering practice
- Reduced to handbooks and software
- Example: bearings – well understood for more than a century
 - Bearing overload is simply a mistake
 - Use KBE to select proper bearing



Design Review (Formal inspection)

- Clear definition of design defect
- Defined, repeatable process
- Defined roles for all reviewers
- Ensures 100% coverage
- Design defects are documented and classified
- Defect database used for product and process improvement



A large, bright yellow starburst graphic with multiple sharp points, centered on the slide. The text is written in a bold, dark blue font within the starburst.

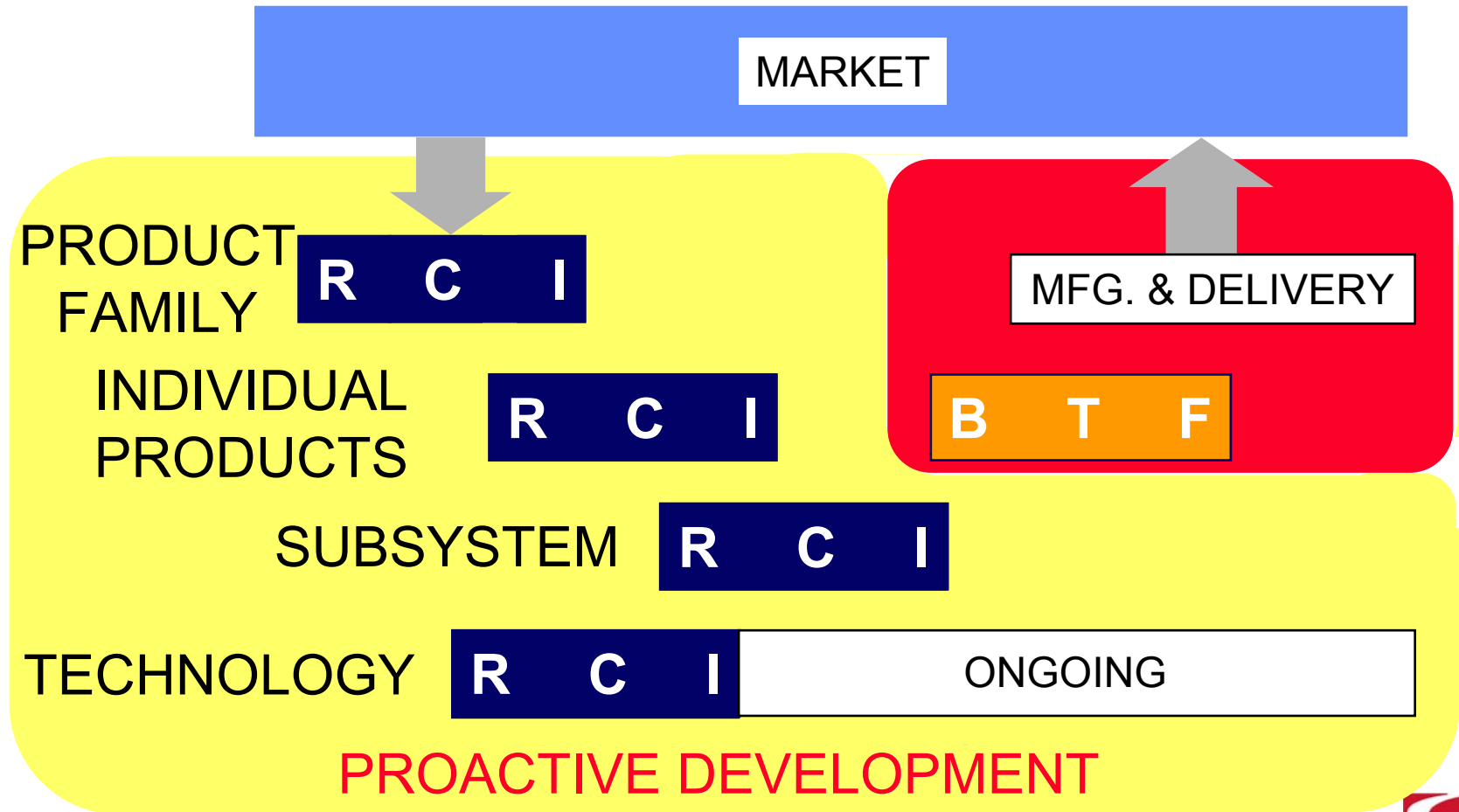
Robust Design and Mistake Elimination: Keys to Reliability



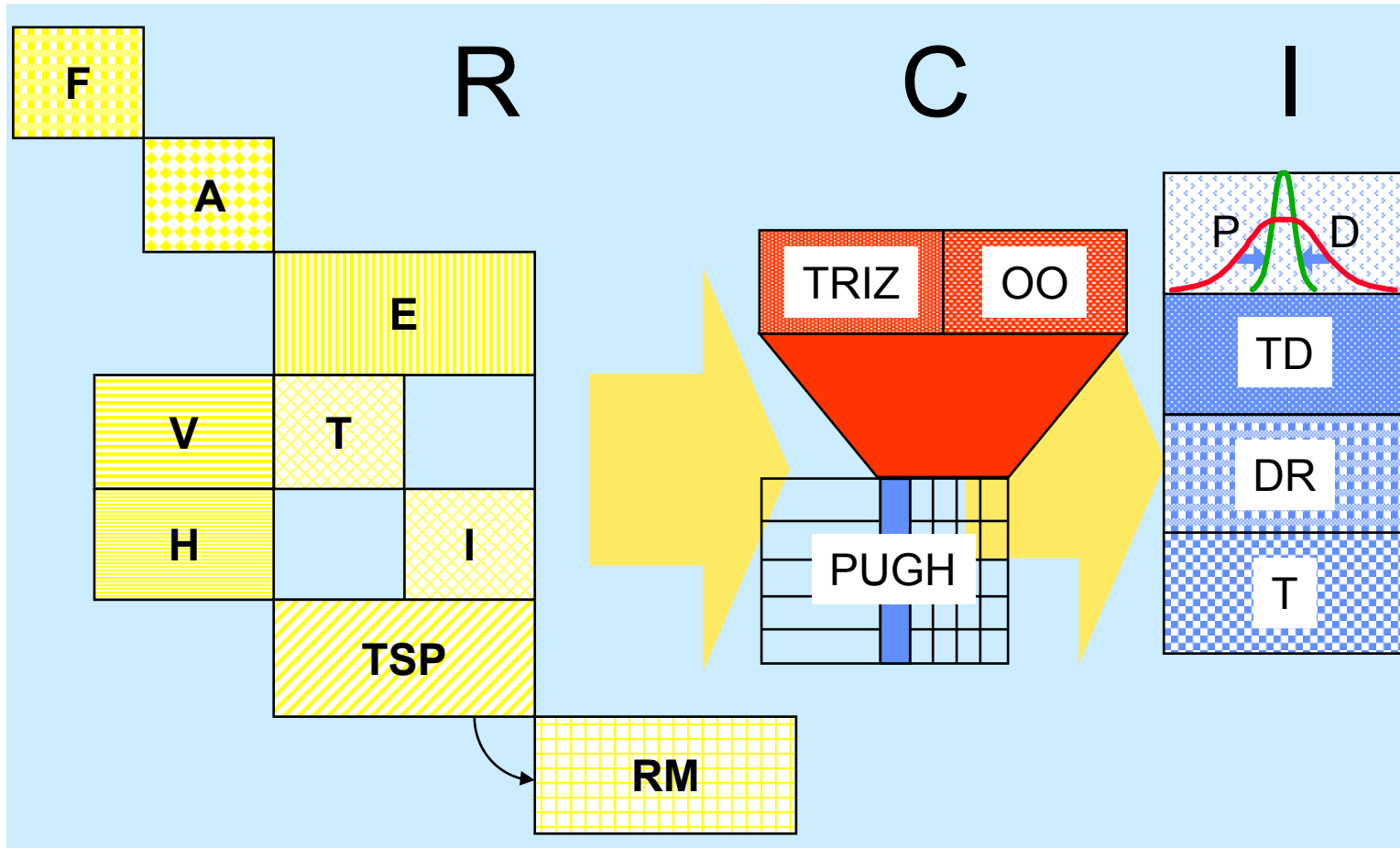
Summary of RCI



Integration level – RCI



Complete RCI process

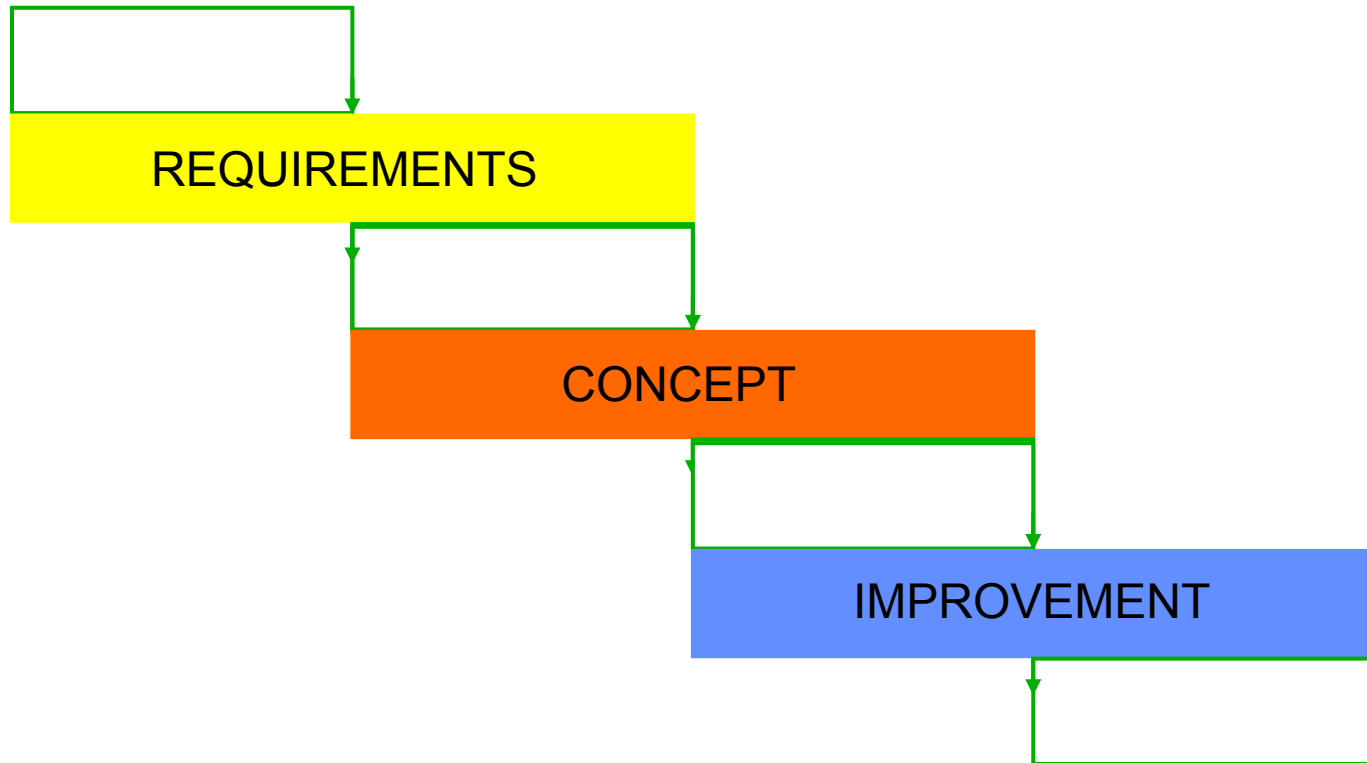


Summary of SE process

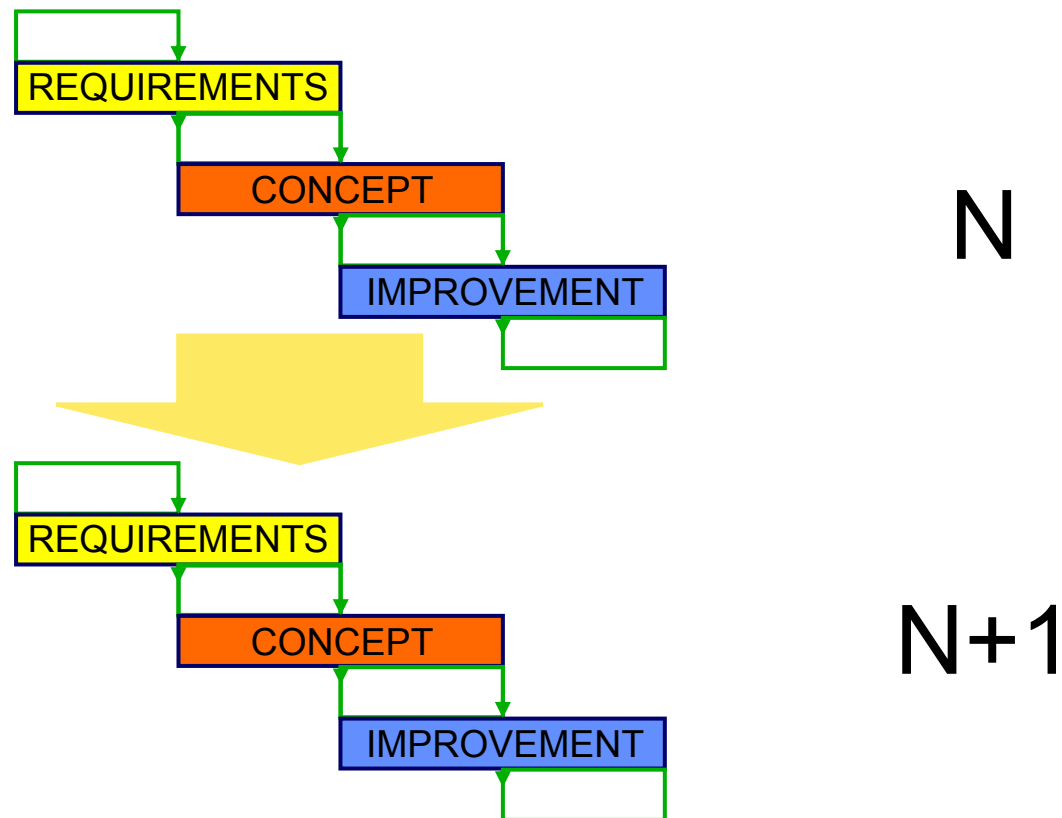
- RCI at each system level
- Detailed path is not linear - tailored to project
- Start next step when there is enough information to make good start
 - Will help quality of completion of previous step
 - Freeze any step when feedback from subsequent steps no longer provides new insights



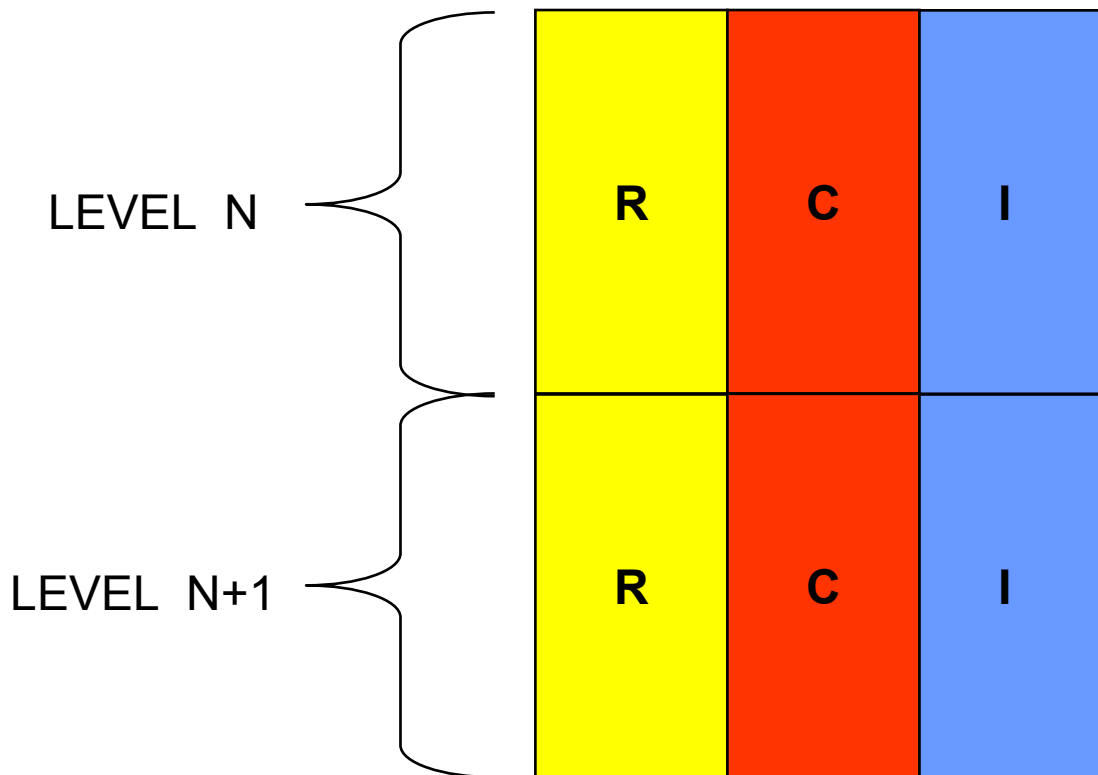
RCI at level N



RCI from level N to level N+1

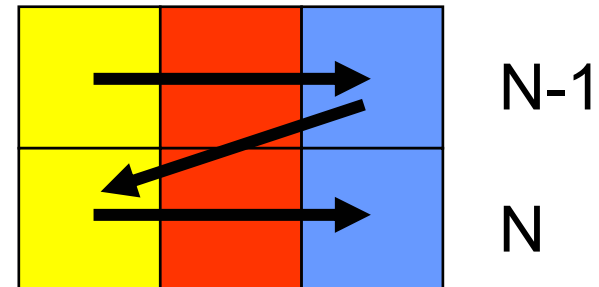


Sequence through the levels



Zigzag flowdown path

- $(RCI)_{N-1}$ to $(RCI)_N$
- Zigzag path
- Flowdown from level N-1 to sub-units at level N
- However, much micro iteration
- Cannot directly flow down R_{N-1} to R_N , unless conceptually static

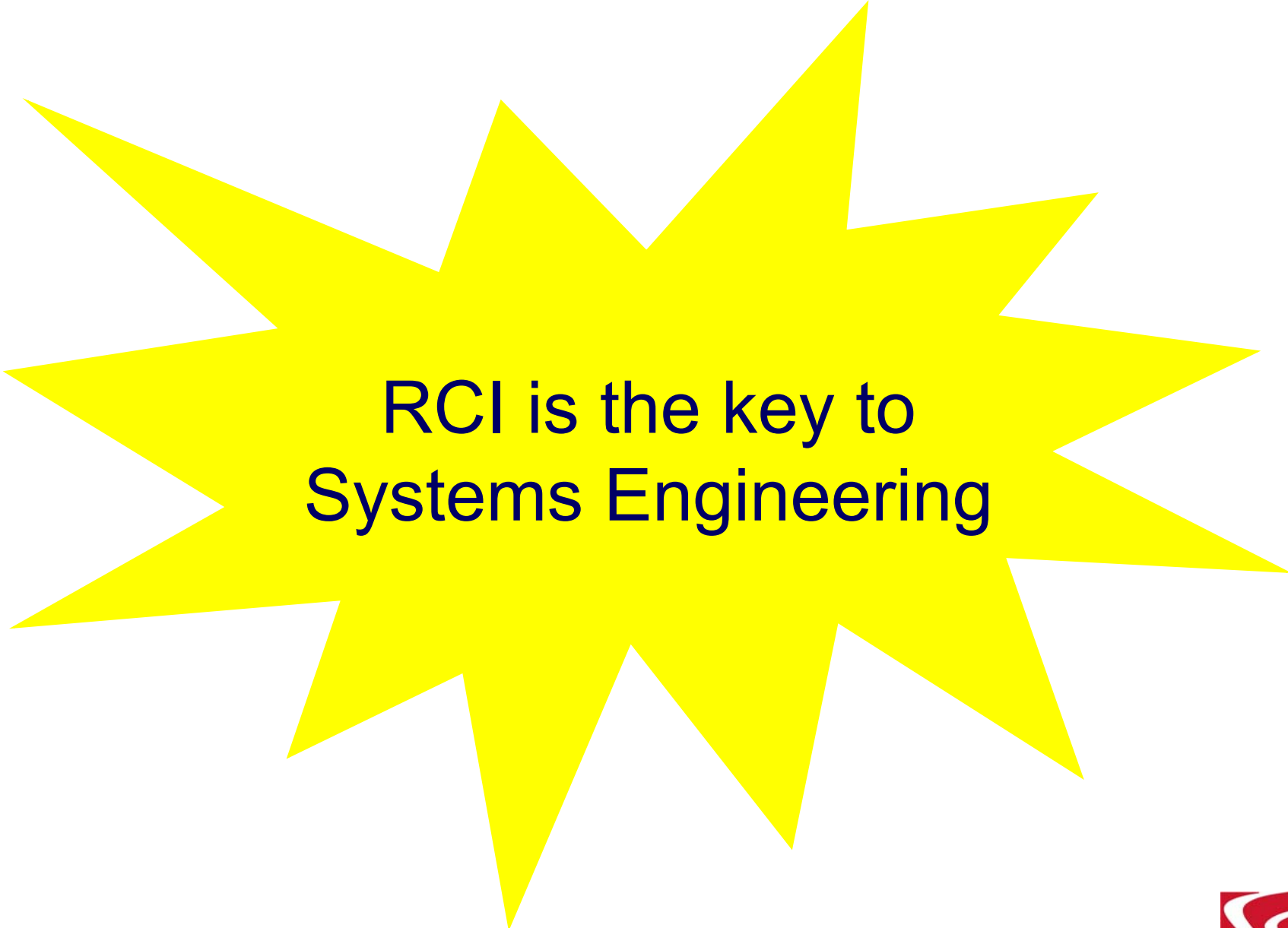


Level N typically has multiple units from each unit at Level N-1



Flowdown is zigzag





**RCI is the key to
Systems Engineering**



END



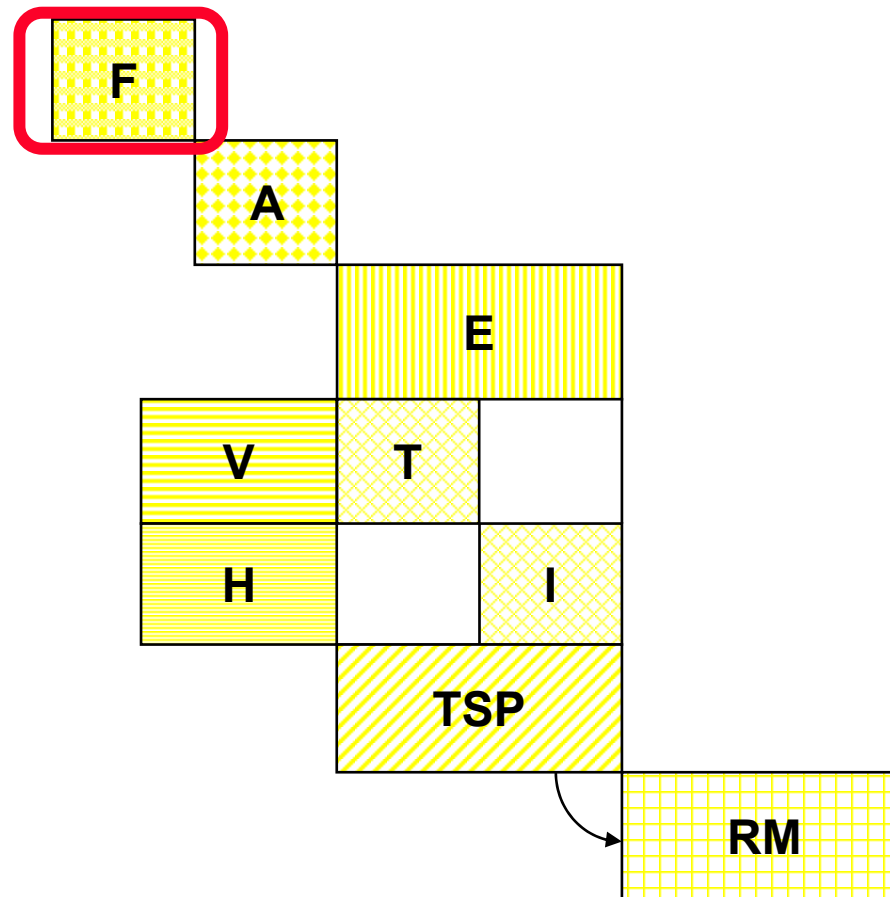
Requirements extension

- The following slides show more detail about the requirements process
- They outline the integration of functional analysis and reusability planning with QFD



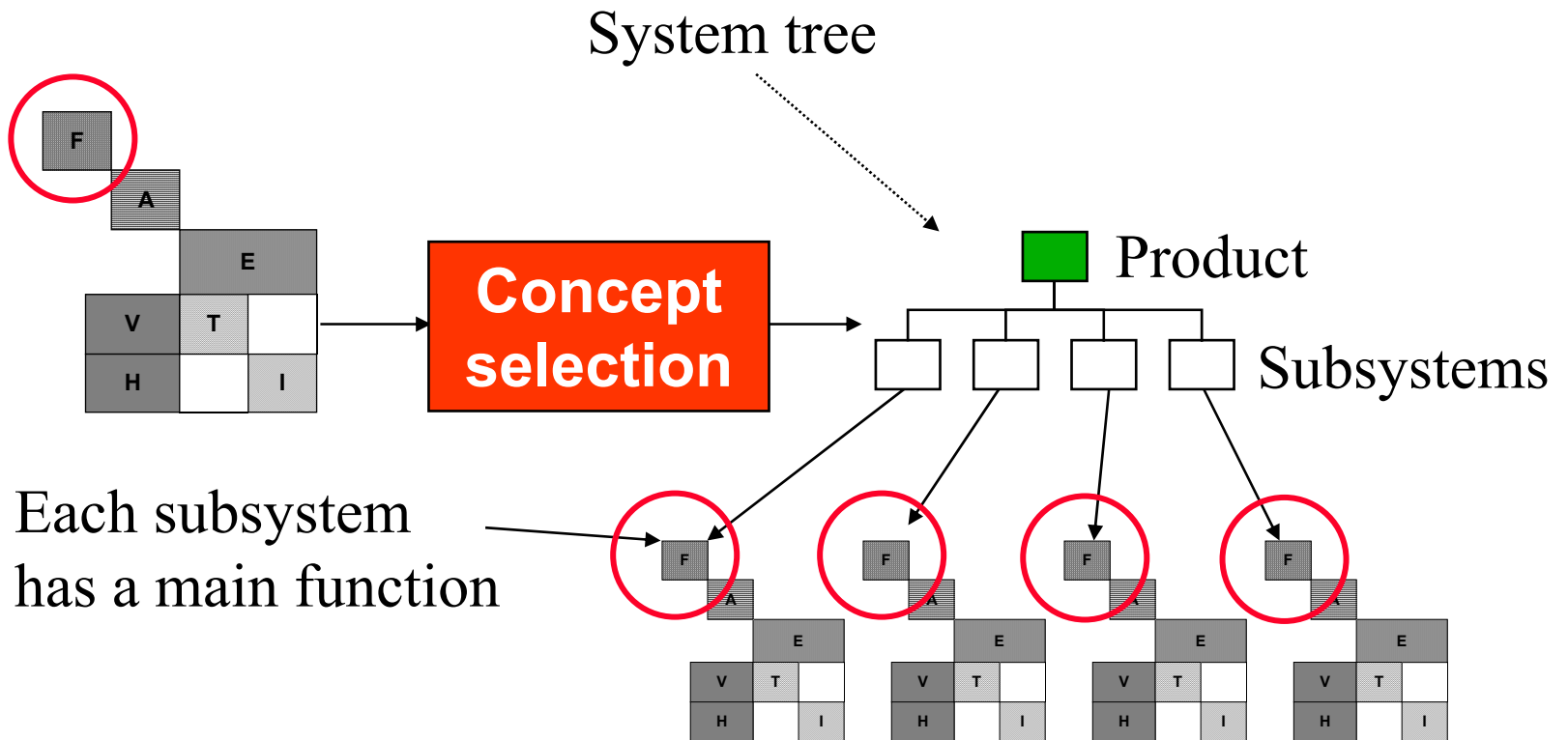
Functional analysis (F)

Path to elegant simplicity

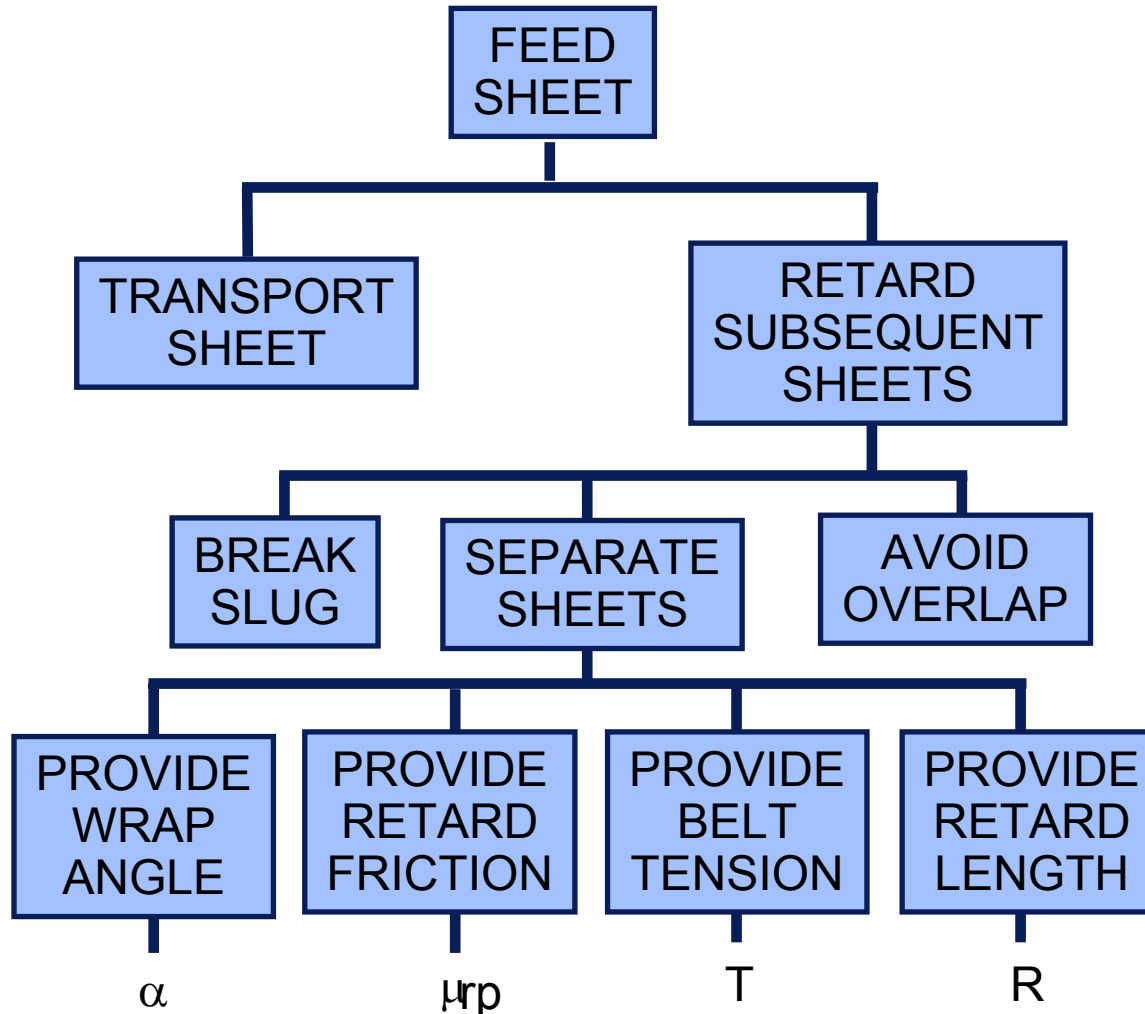


QFD and FA

Functional tree elements are circled



Functional tree



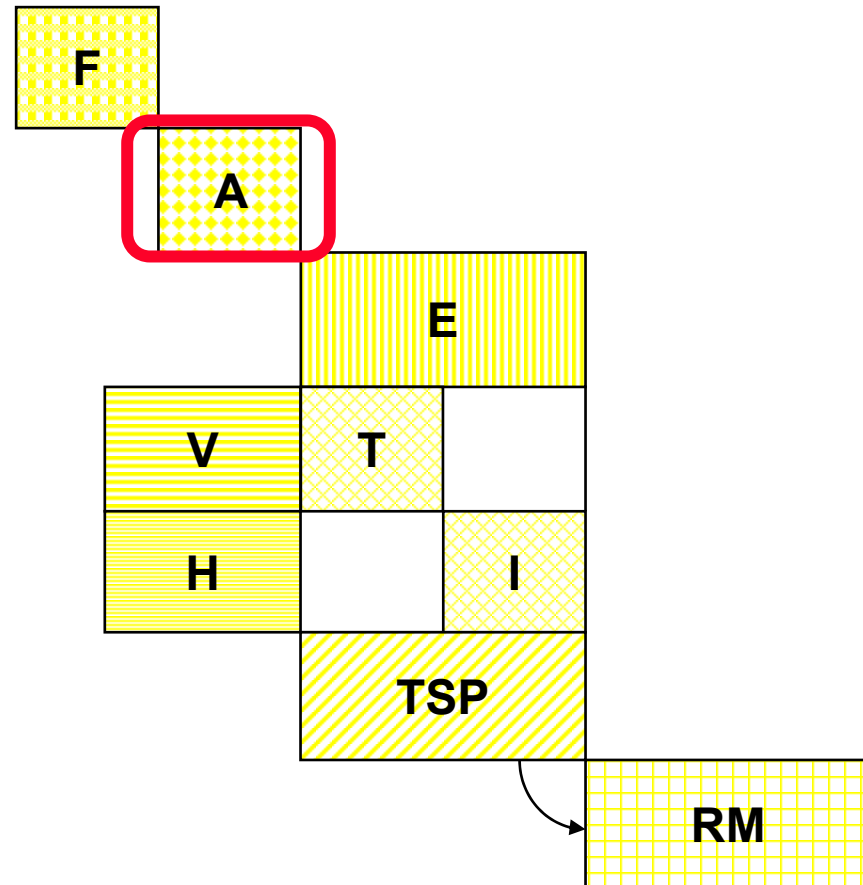


Every system has one
function



Amplification

Marries functional analysis to QFD



Amplify function

- Function “Feed sheet” is amplified to describe expectations as to what the feeder will **be** and **do**
- **Do**: speed, paper-size-and-weight ranges, paper-stack height, etc. – changes of energy, geometry, and information in process
- **Be**: size, mass, manufacturing, safety, etc





**QFD marries functions
to customer needs**



Summary: 3 sources for expectations

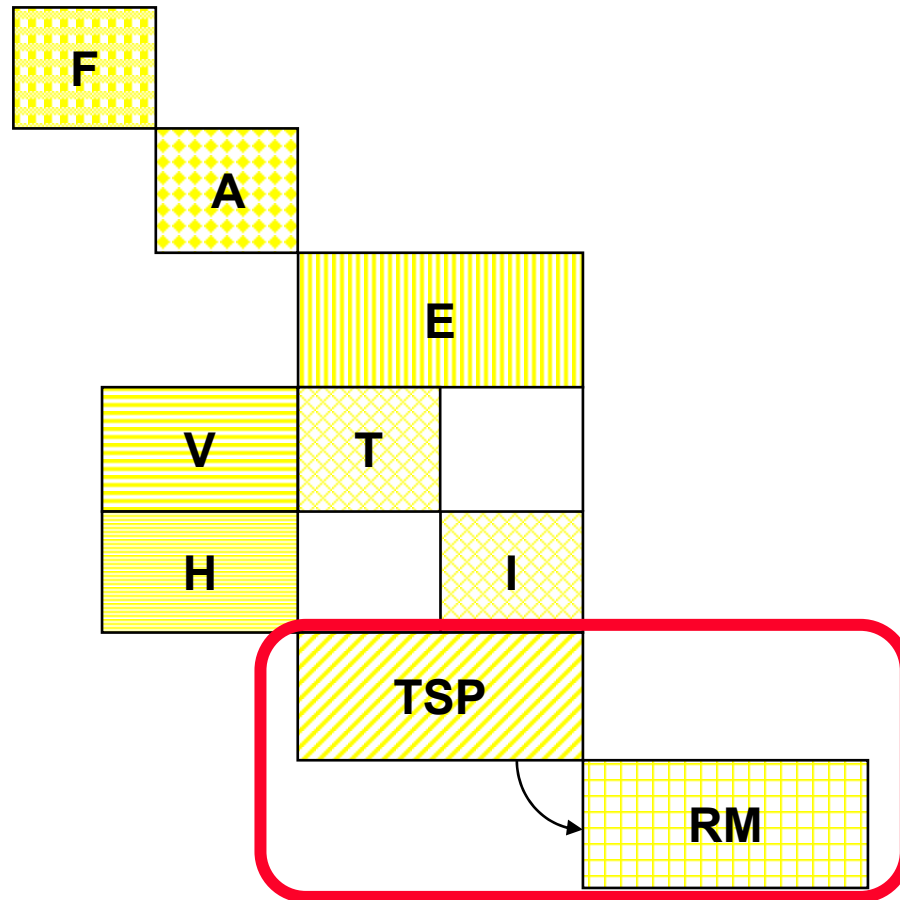
(columns of QFD matrix)

- Higher-level expectations from level N-1
- Voices of external stakeholders at level N
- Amplifications of functions at level N



Reusability

Customer satisfaction at a low cost



Reusability matrix (RM)

Sources

Current Products



Competitive Products



Analogous products



New technology



Levels

TSA concept

SS concept

PP concept

PP feature

Legend

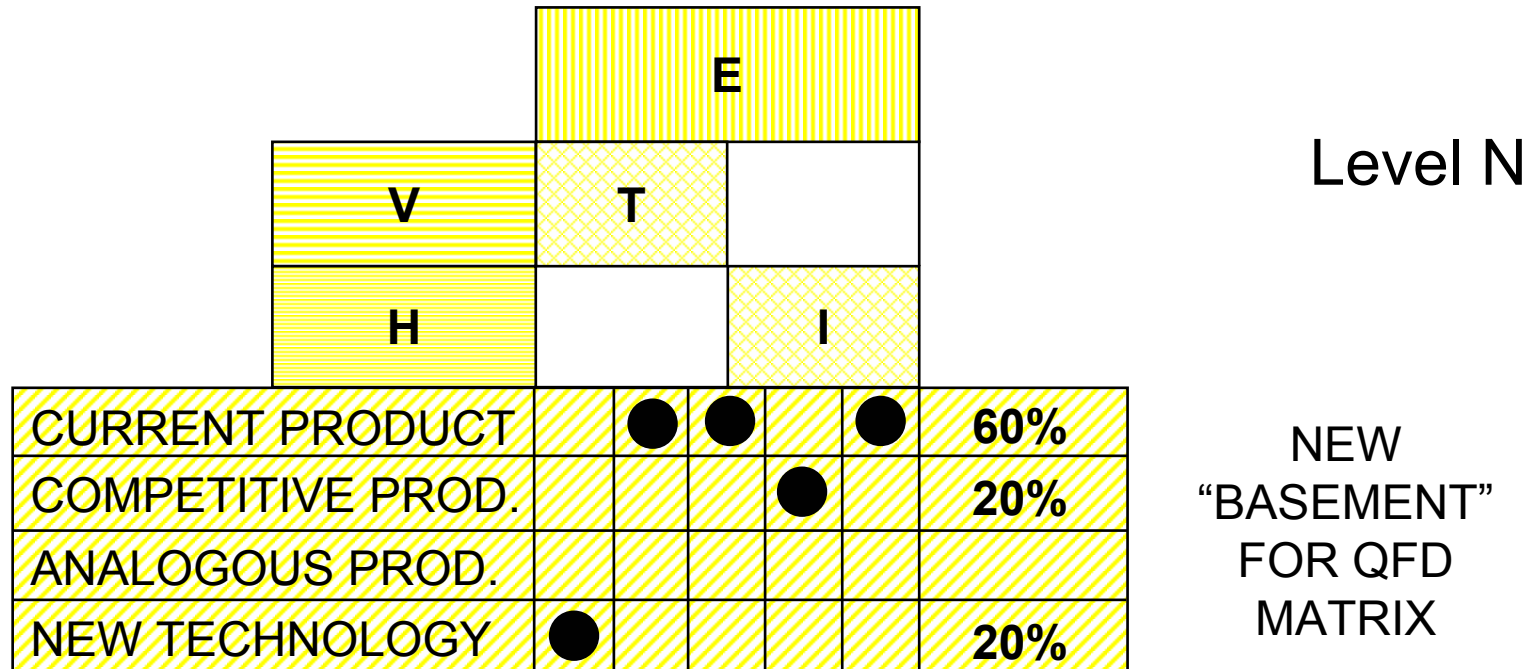
TSA-Total System Architecture

SS-Subsystem

PP-Piece Part



Technology sources planning (TSP)



COMPARE WITH
REUSABILITY MATRIX PLAN –
JUSTIFY CHANGES

LEVEL-N ROW
REUSABILITY
MATRIX
(RM)





**QFD marries
reusability to
customer needs**

