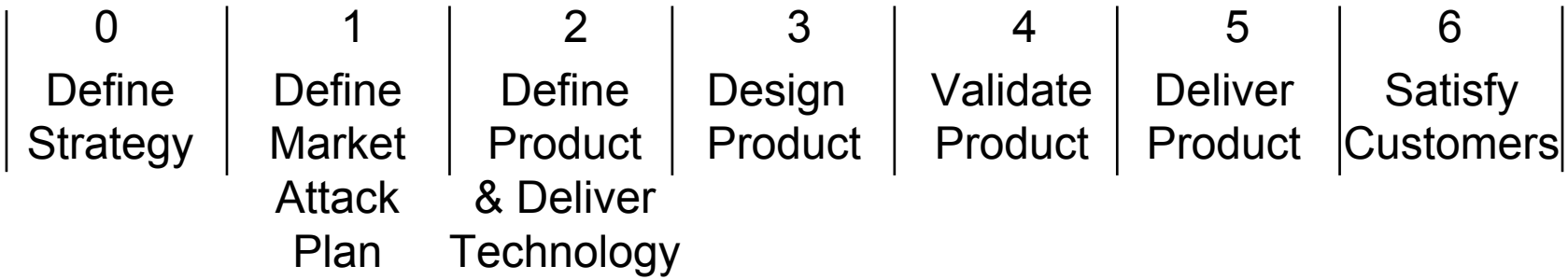
RCI
Systems engineering process

Don Clausing

2004

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

Traditional PPP



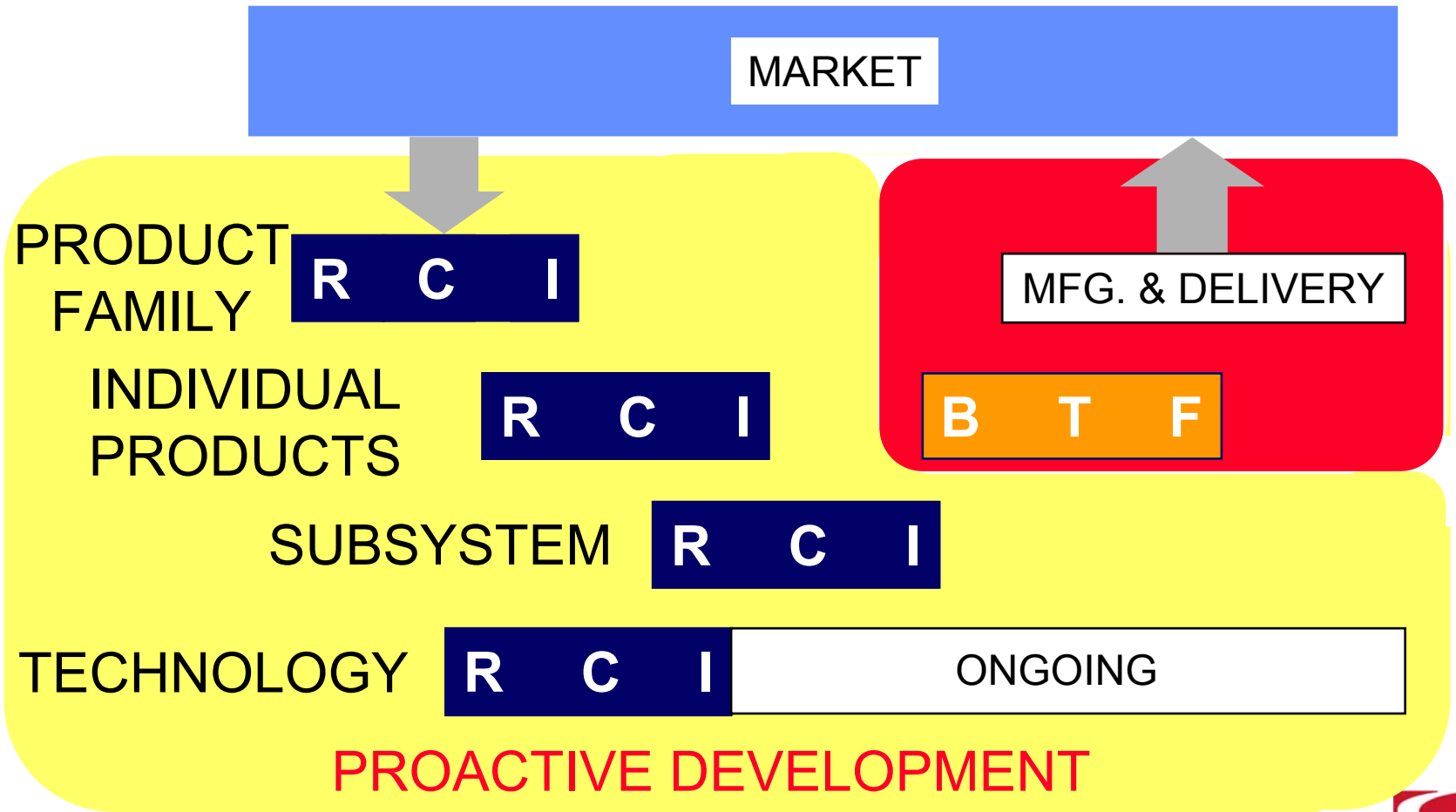
- Phased Program Planning (PPP)
- But how do we do the work?

Three levels of SE process

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

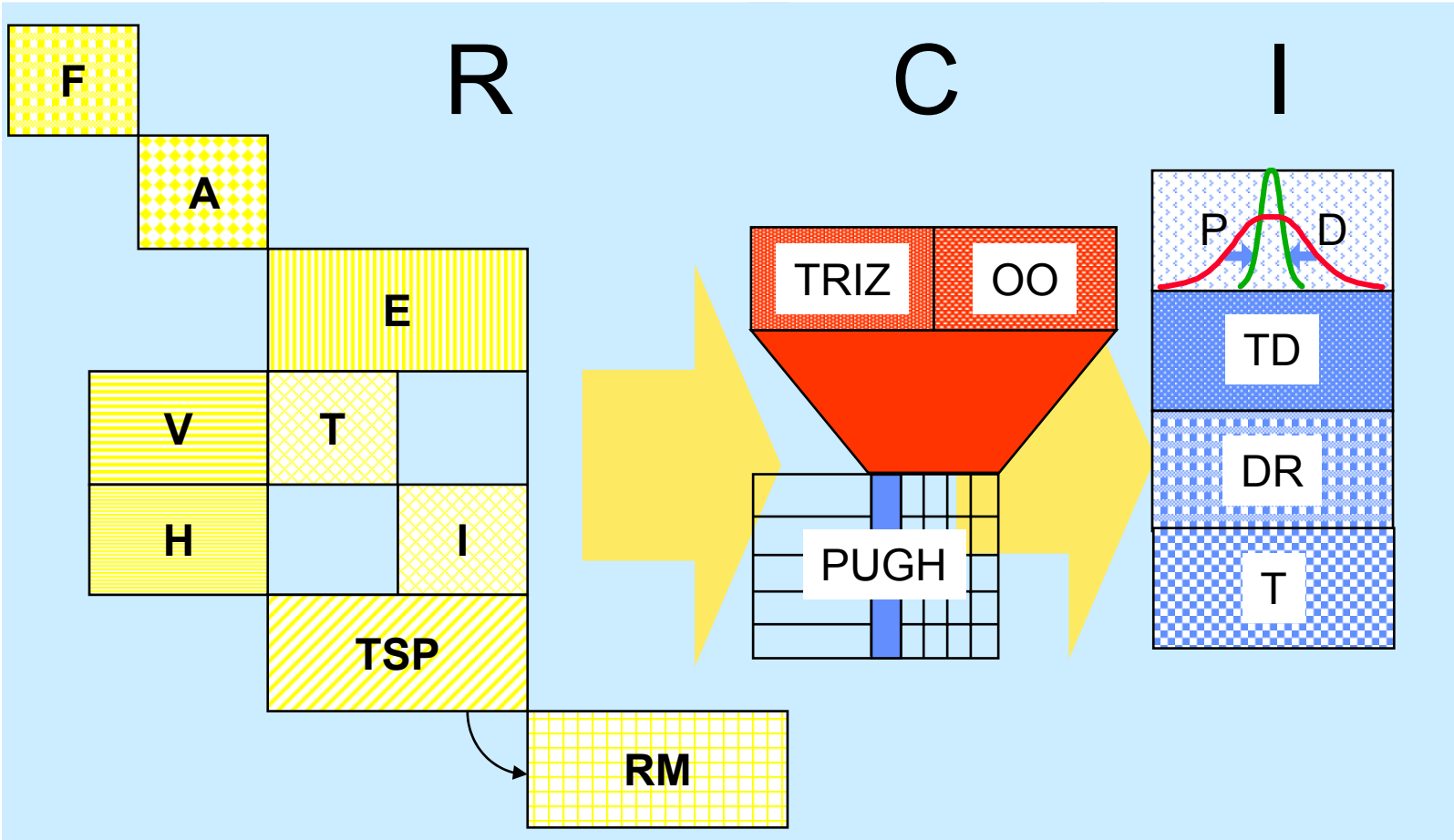

Improvement

Integration level



RCI is the backbone of Systems Engineering

Managerial level



Operational level

- Requirements
- Concepts
- Improvement

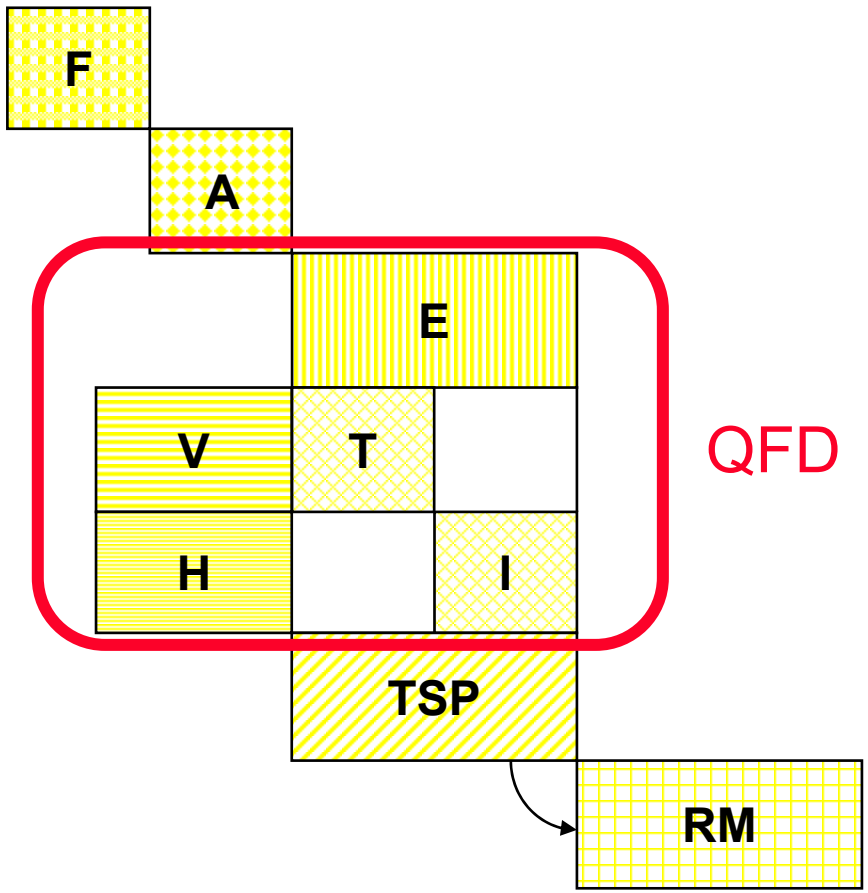
at the operational level of detail.

Requirements

- QFD
- Functional analysis
- Functional amplification
- Reusability

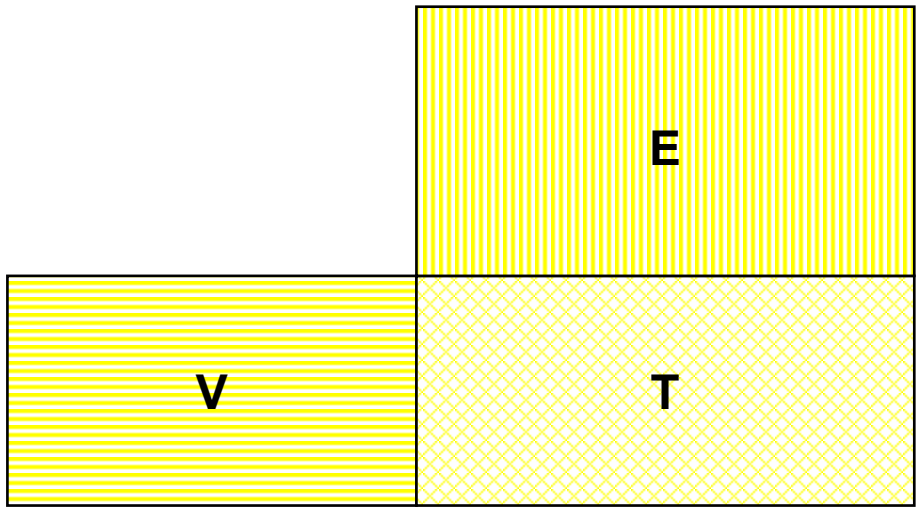
An introduction

QFD, key to customer satisfaction



Traditional House of Quality

3 core rooms

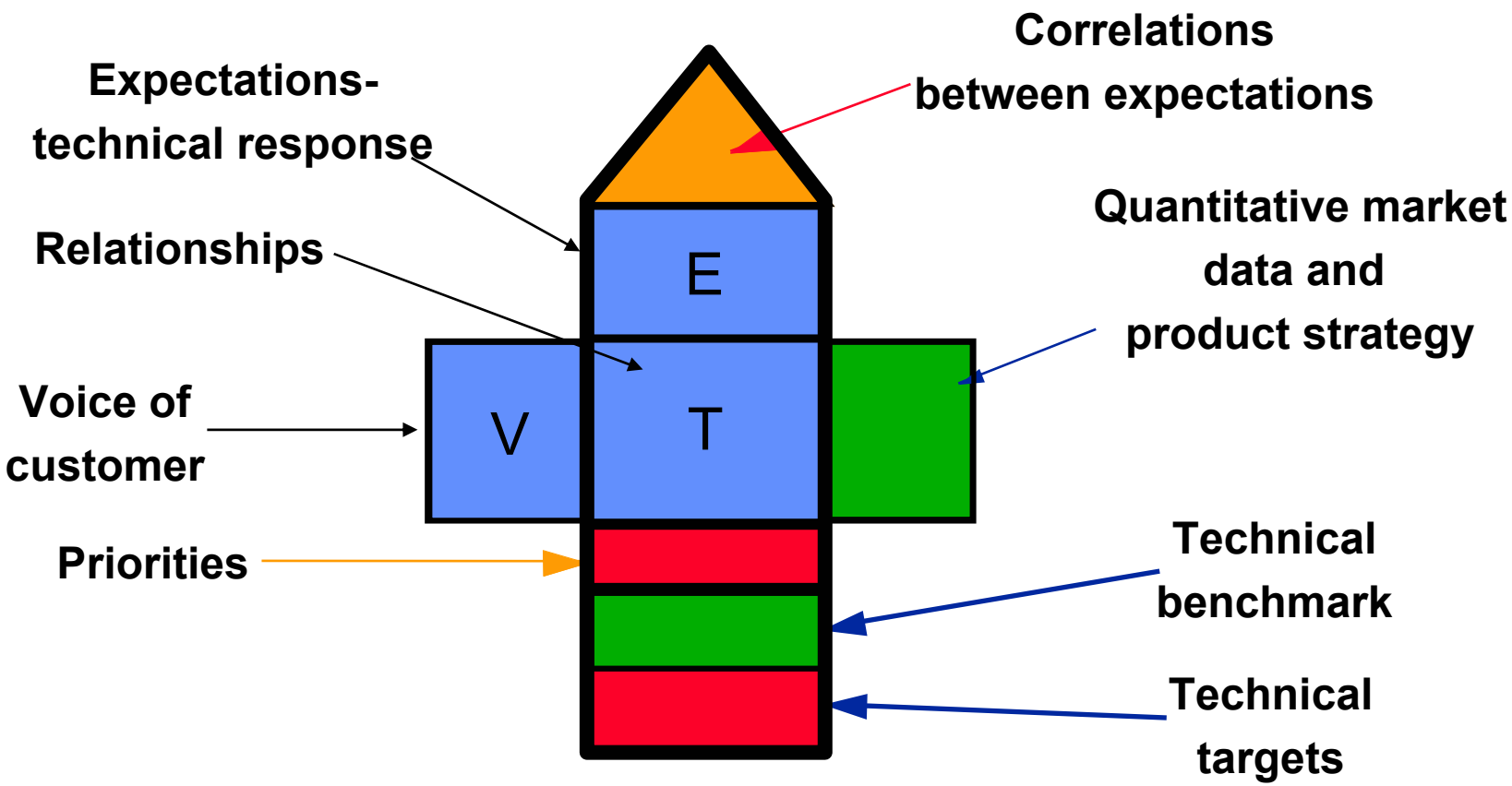


V – VOICE OF EXTERNAL STAKEHOLDERS

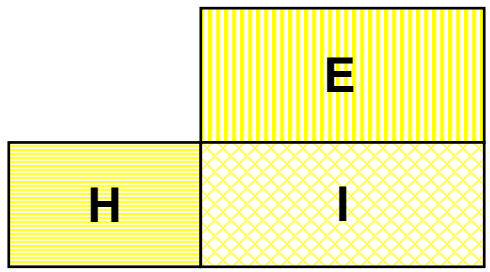
E – EXPECTATIONS OF INTEGRATED DEVELOPMENT TEAM

T – VERIFIES TRANSLATION FROM CUSTOMERS' VOICES TO IDT VOICE

Complete House Of Quality



Expectations are deployed down



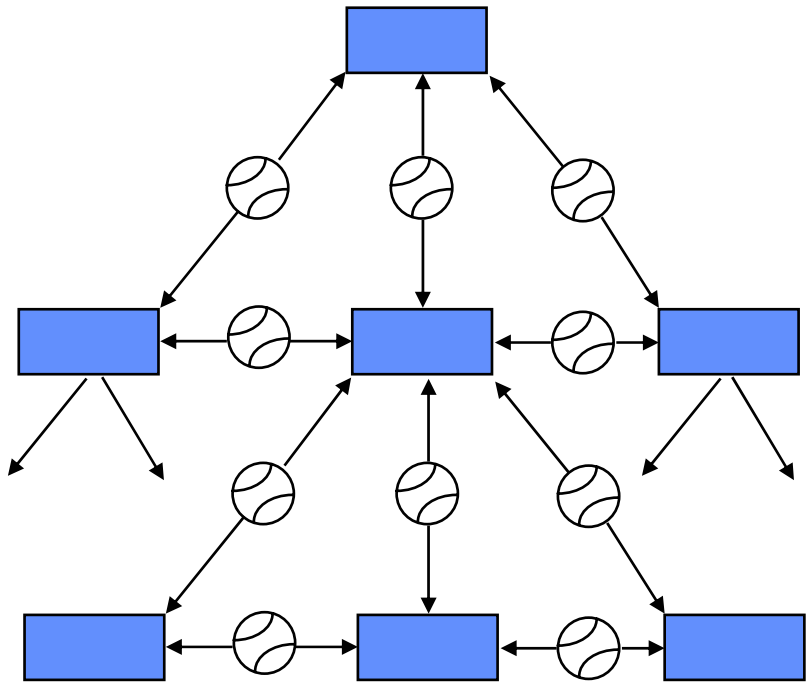
H – EXPECTATIONS FROM HIGHER SYSTEM LEVELS, SUCH AS PRODUCT

E – EXPECTATIONS AT LOWER SYSTEM LEVEL, SUCH AS SUBSYSTEM

I – INTERLEVEL DEPLOYMENT MATRIX

Consistency of levels

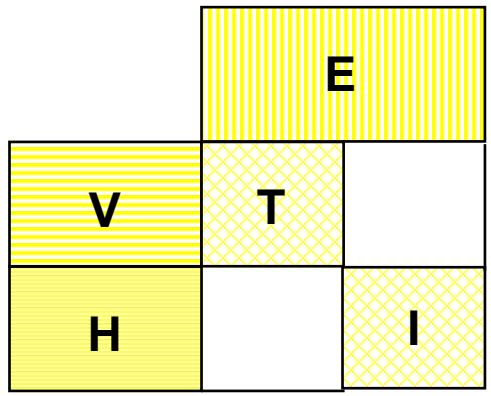
- Use catchball planning
- Iteration to consensus assures consistency
- Make levels N-1, N, and N+1 consistent
- Choose concept before completing requirements deployment to next level



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

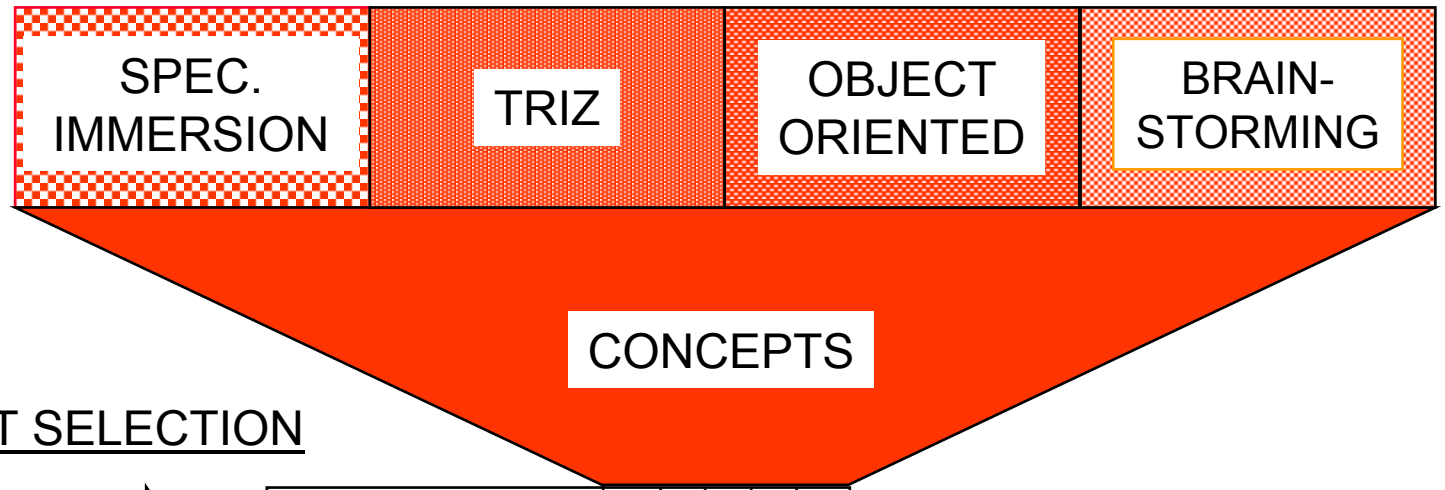
Concepts

- 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)

REQUIREMENTS

Criterion 1	D	+	S	–	+
Criterion 2	A	–	+	+	–
Criterion 3	T	S	–	–	S
……	U	+	–	–	+
Criterion N	M	+	–	+	S

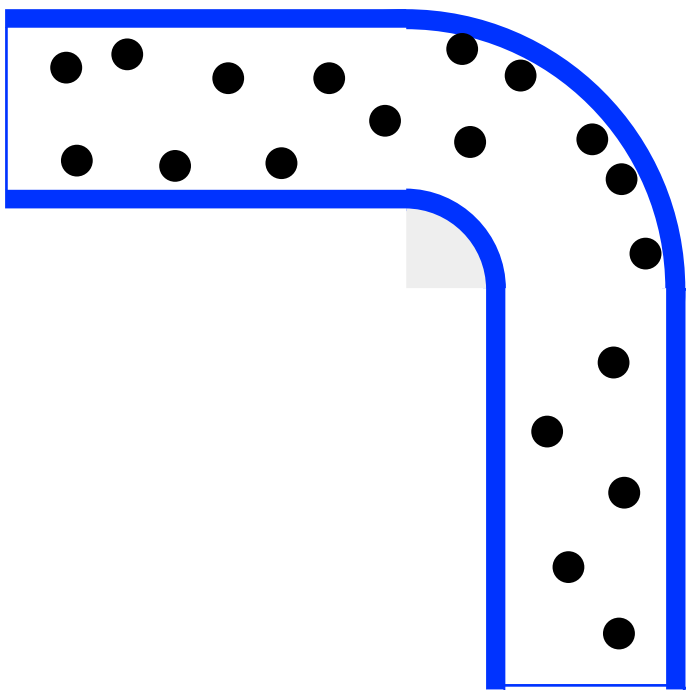
Simple methods

- 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

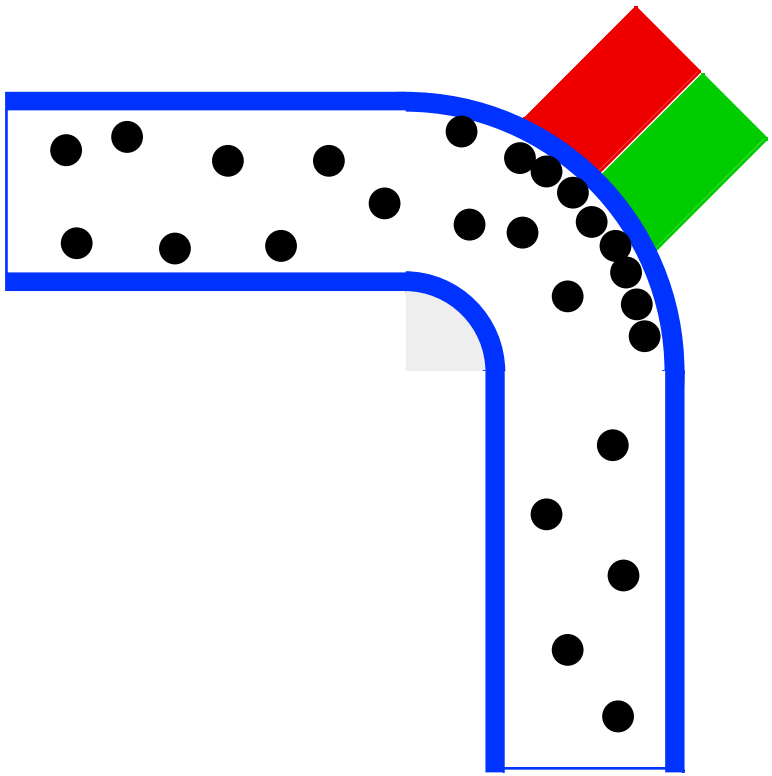
- Invention process – based on studying many patents and observing evolution patterns
- Conflicts are the mother of invention
- Standard solutions applied in diverse fields
- Evolution of technological systems follow certain patterns
- Systematic application of scientific effects

Conflict



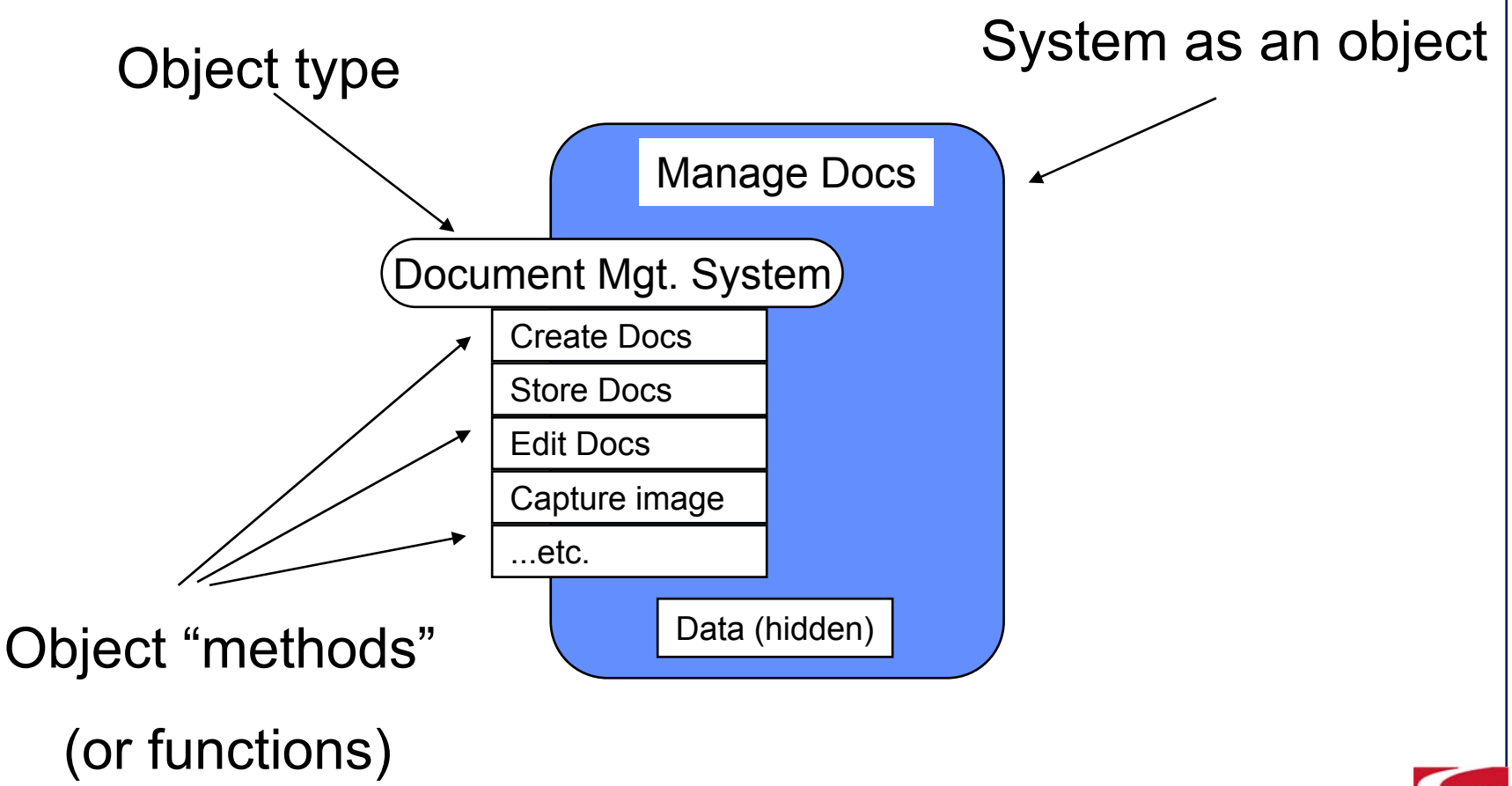
- Shot wear pipe at the turn
- Conflict
  - Need coating
  - Don't want coating
    - Cost
    - Short life

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



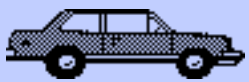
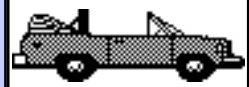
How can objects be useful in Systems Engineering?

- 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

Pugh concept selection

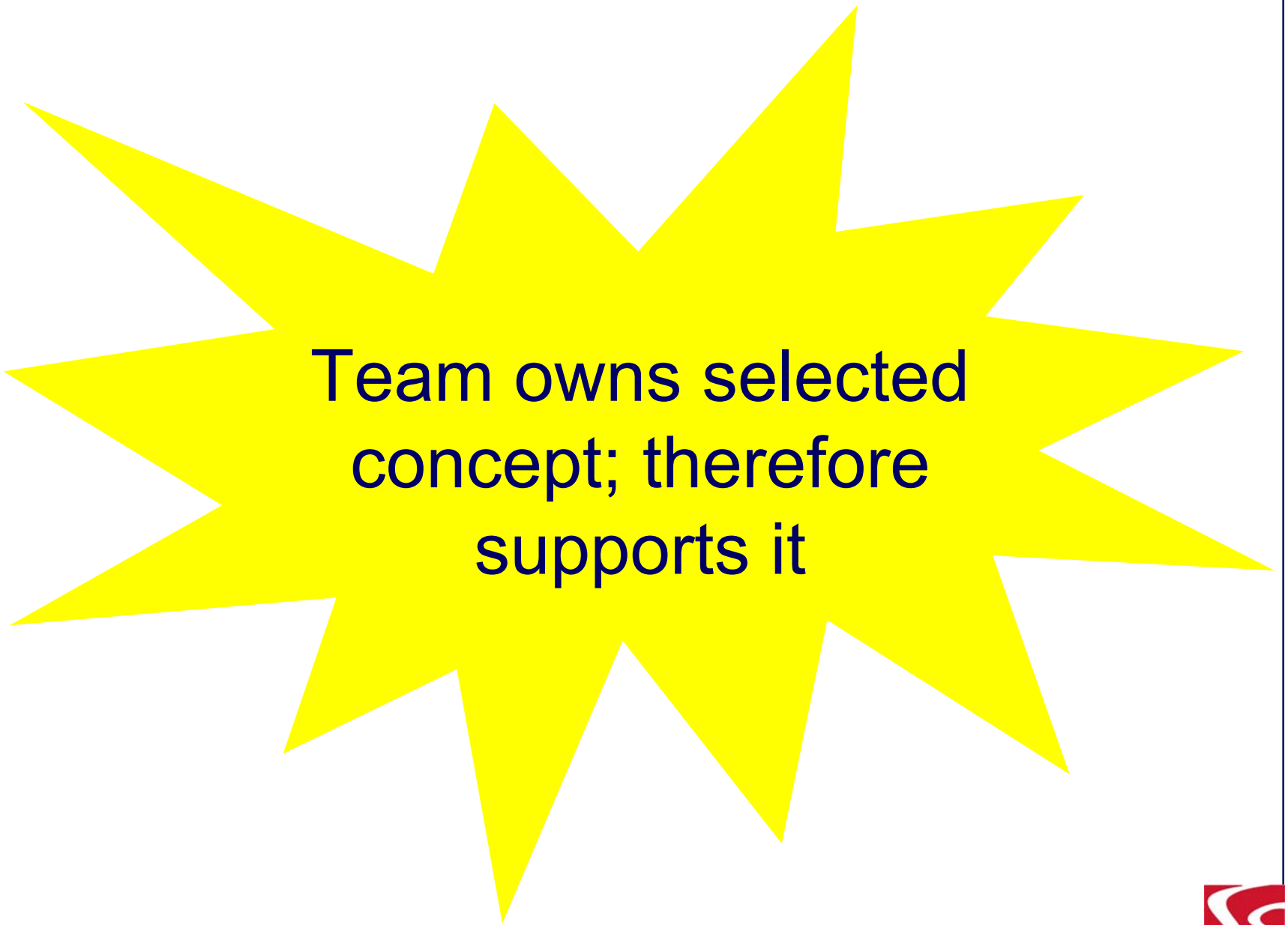
- Qualitatively analyze different concepts
- Combine beneficial aspects
- Eliminate disadvantages
- Evolve to a concept supported by the team, no winners or losers

Pugh Concept Selection Matrix

				
Responsiveness	D	+	+	+
Braking	A	-	-	-
Ease of mfg.	S	S	-	-
Safety	T	+	+	-
Risk	U	-	-	-
Complexity	M	S	-	-
		+ 2 S 2 - 2	+ 2 S 0 - 4	+ 1 S 0 - 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

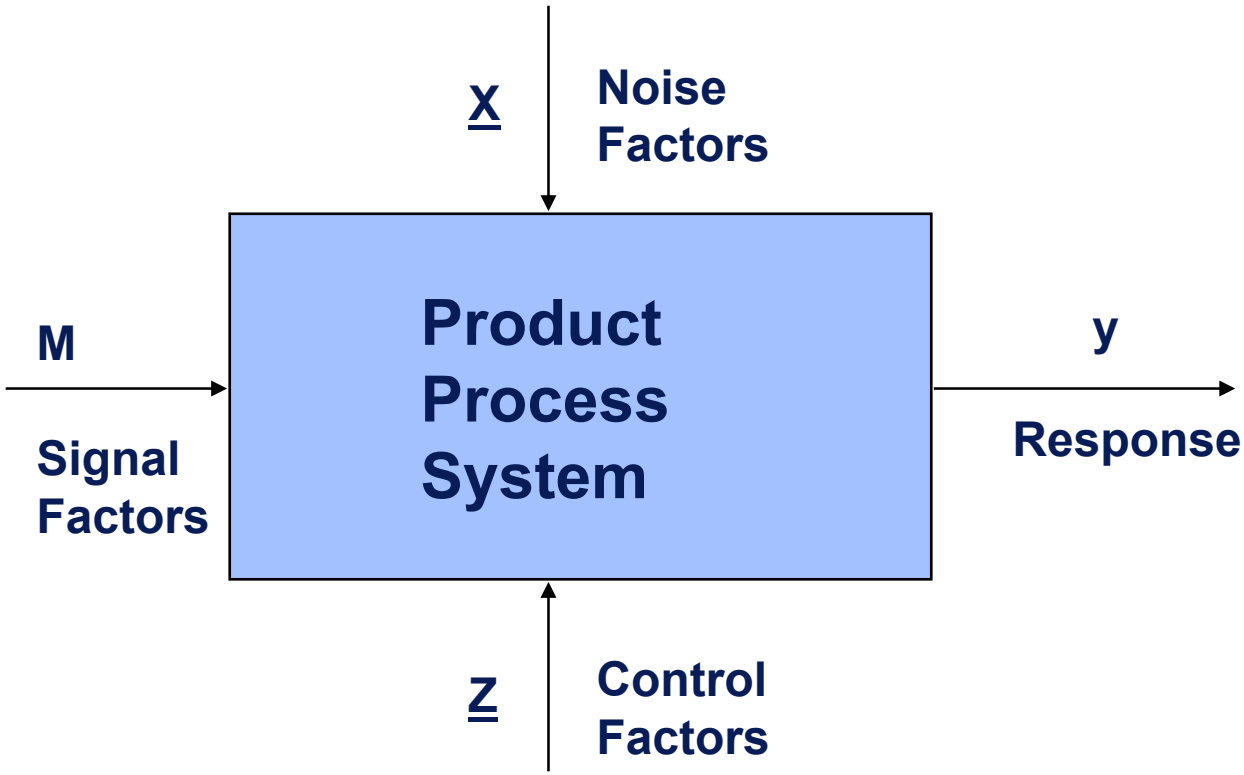
Goal of Parameter Design: Optimization

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

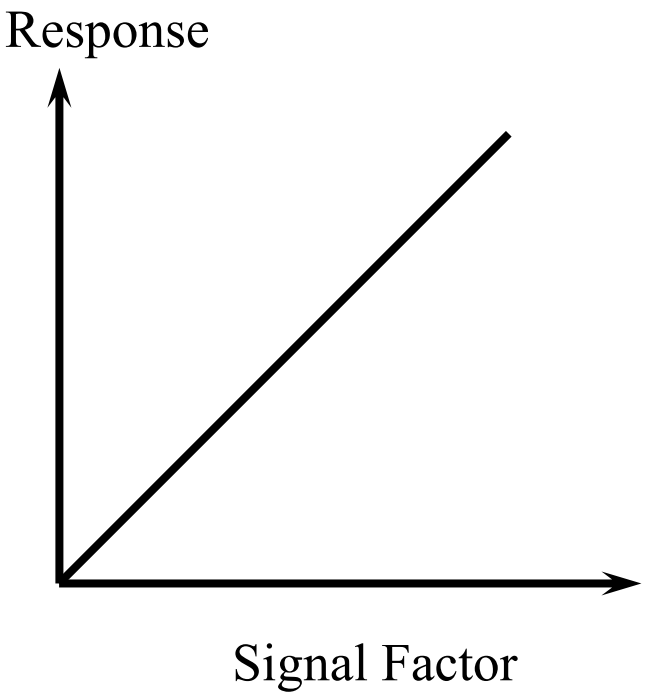
P diagram

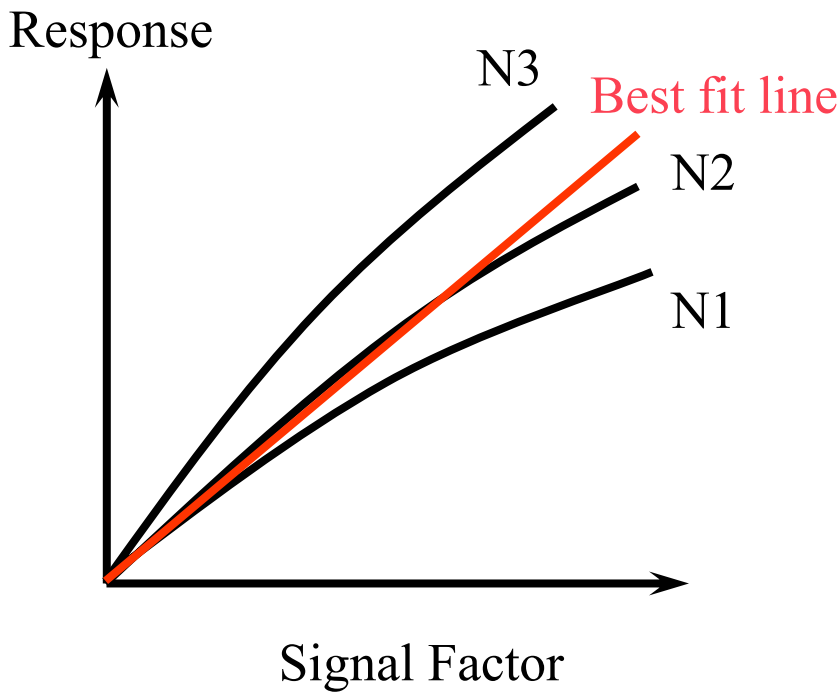

X
Noise
Factors
M
Signal
Factors
Product
Process
System
y
Response
Z
Control
Factors

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

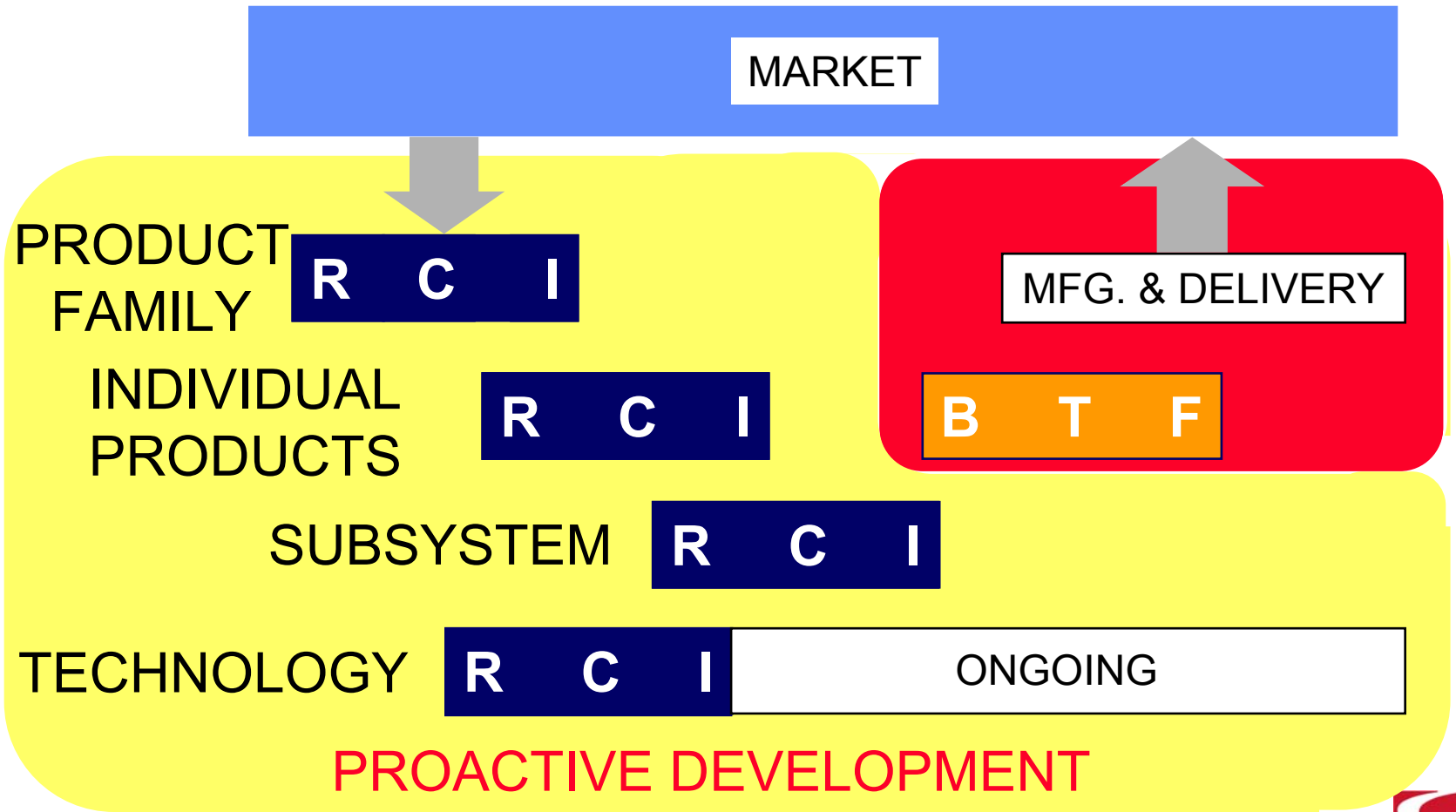
Design Review (Formal inspection)

- 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

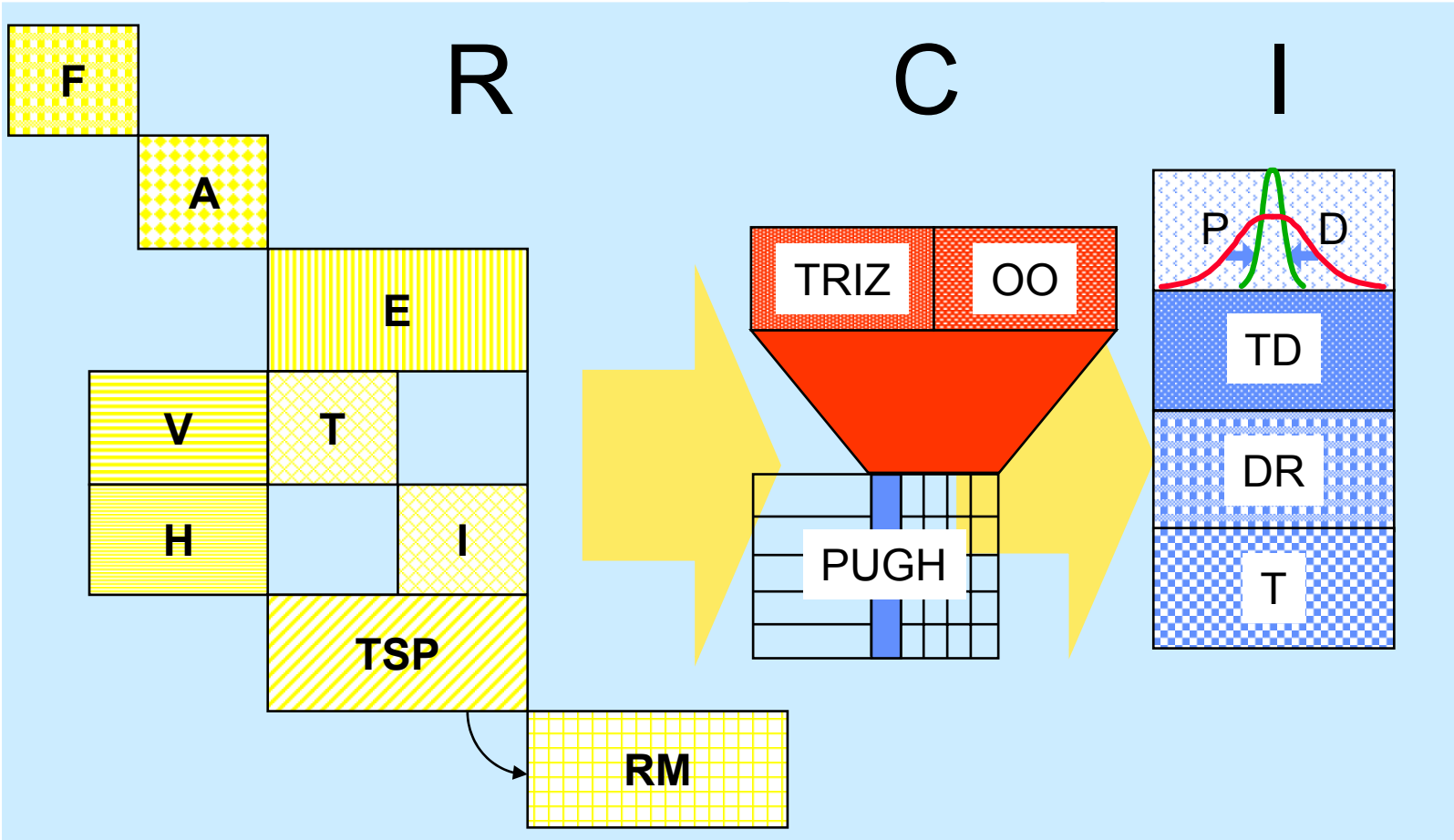
Robust Design and Mistake Elimination: Keys to Reliability

Summary of RCI

Integration level – RCI



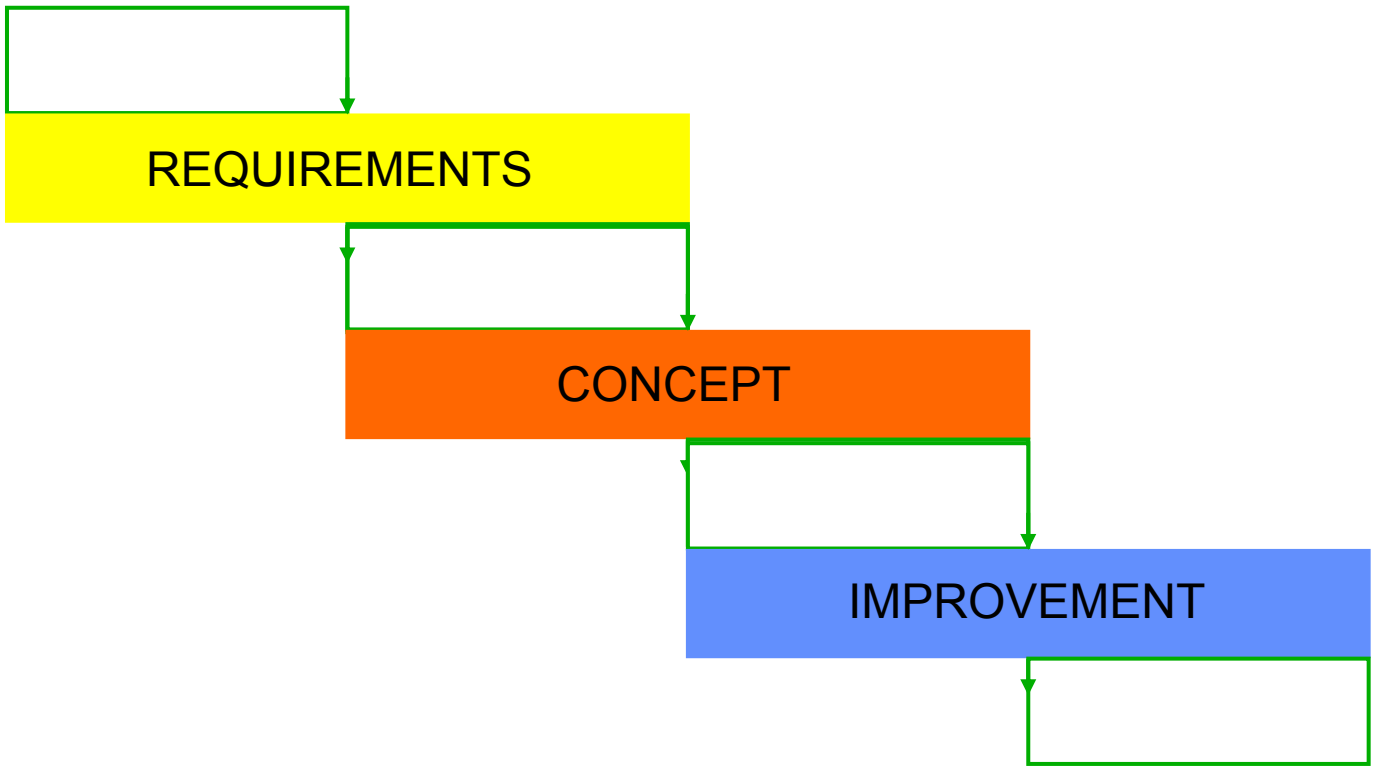
Complete RCI process



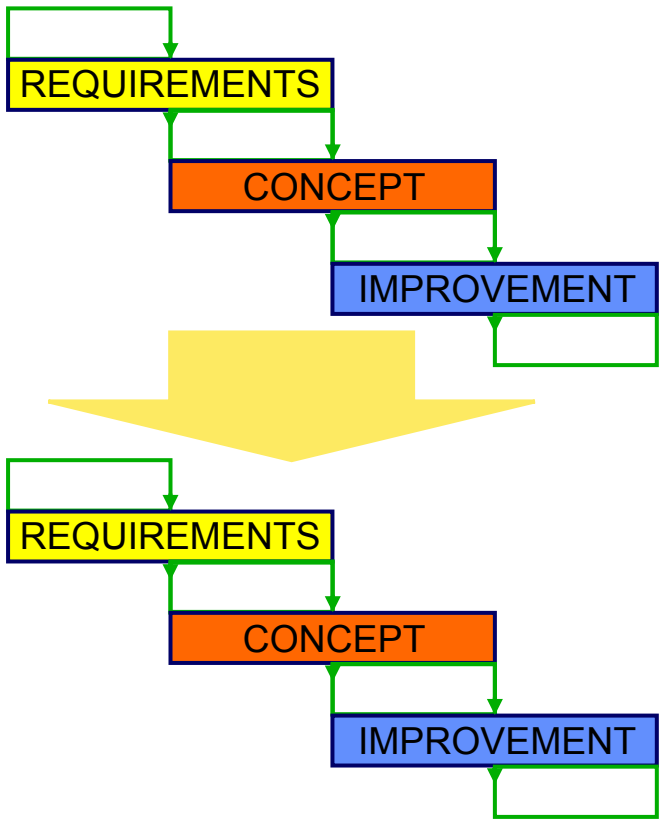
Summary of SE process

- 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



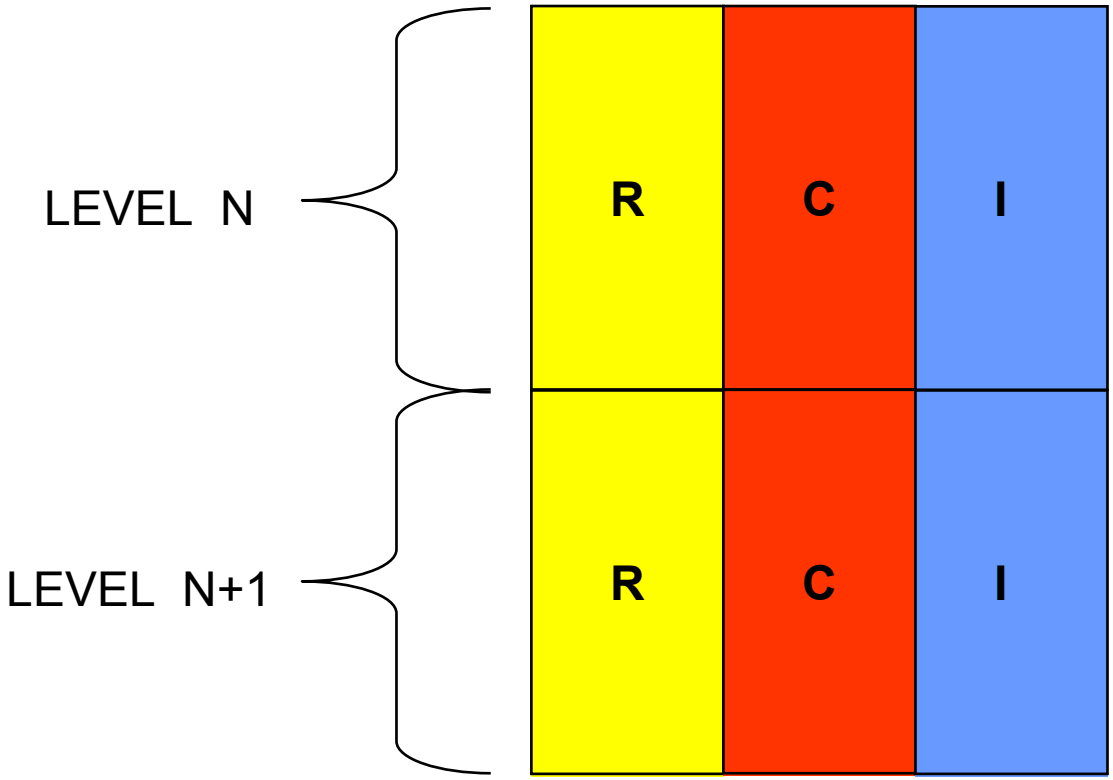
RCI from level N to level N+1



N

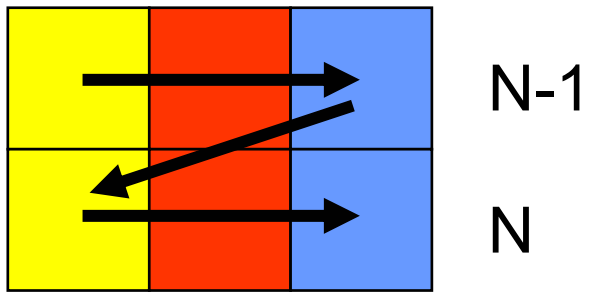
N+1

Sequence through the levels



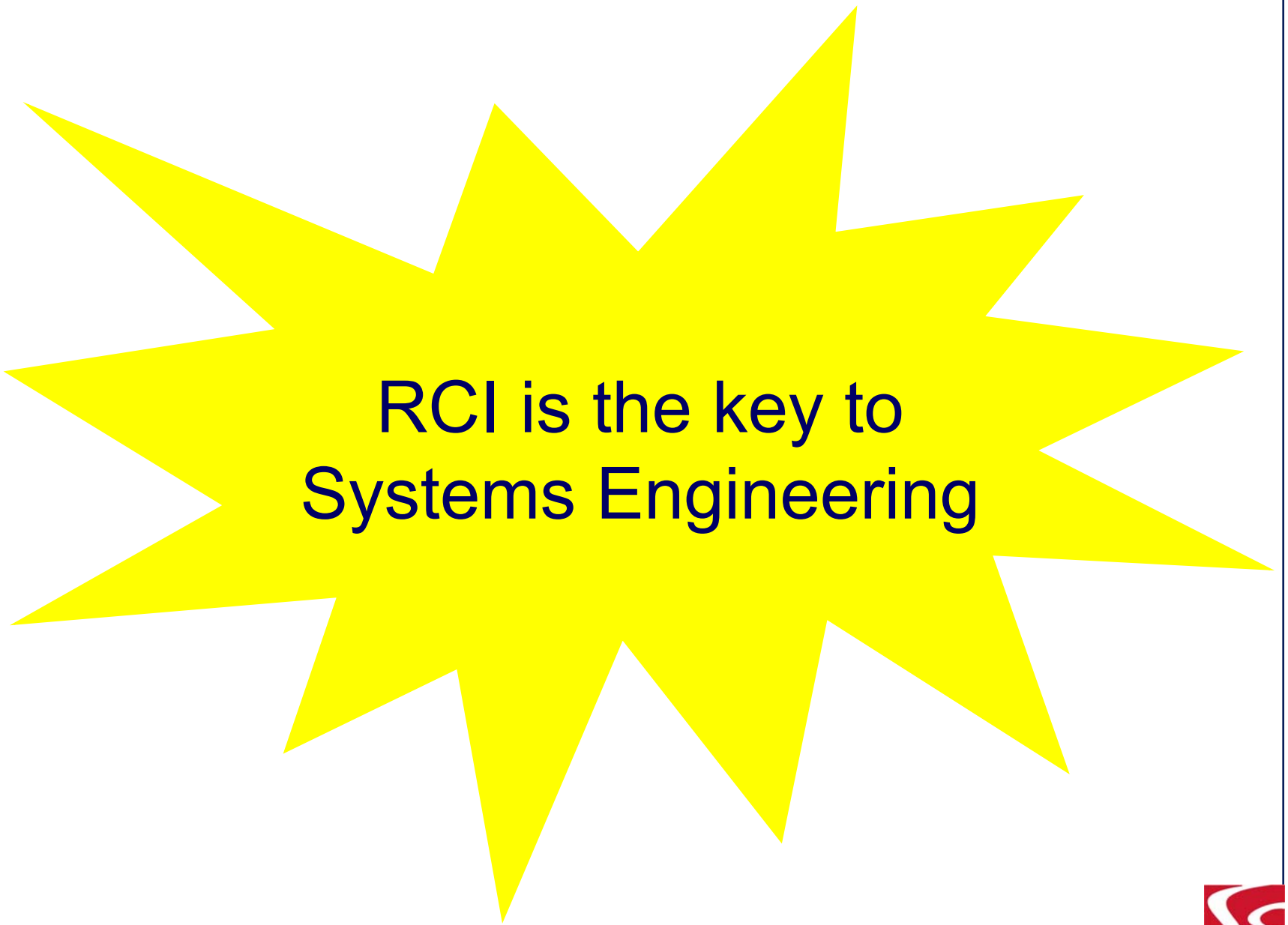
Zigzag flowdown path

- $(RCI)_{N-1}$ 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

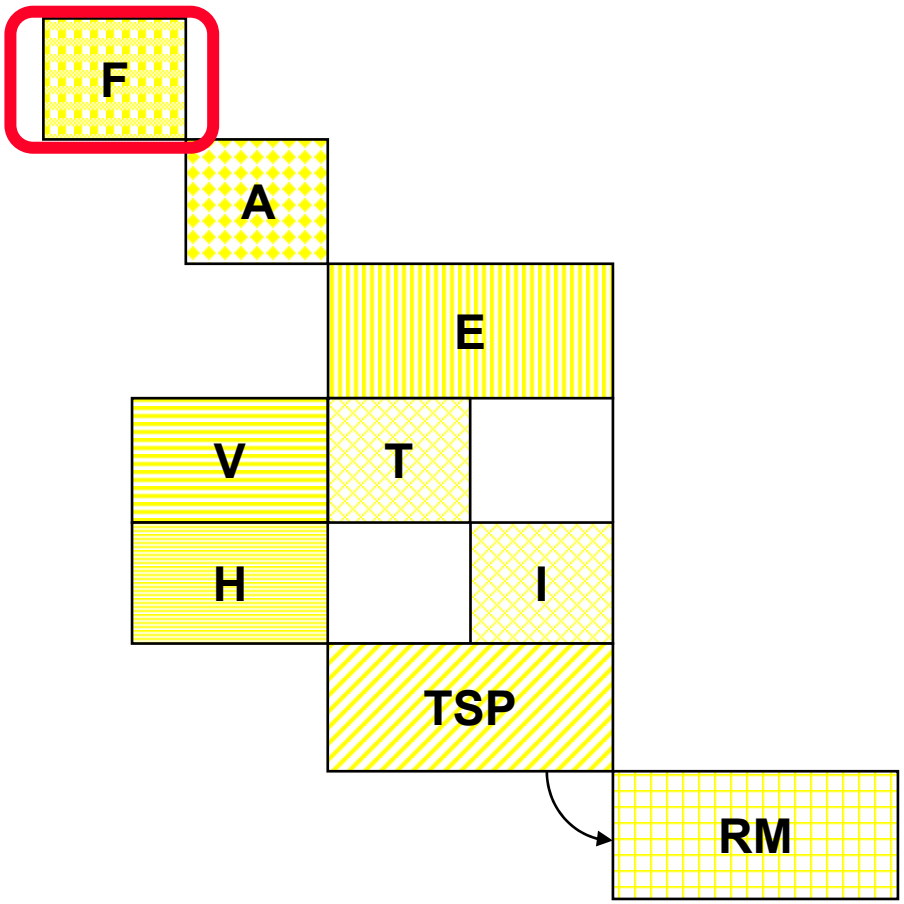
END

Requirements extension

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

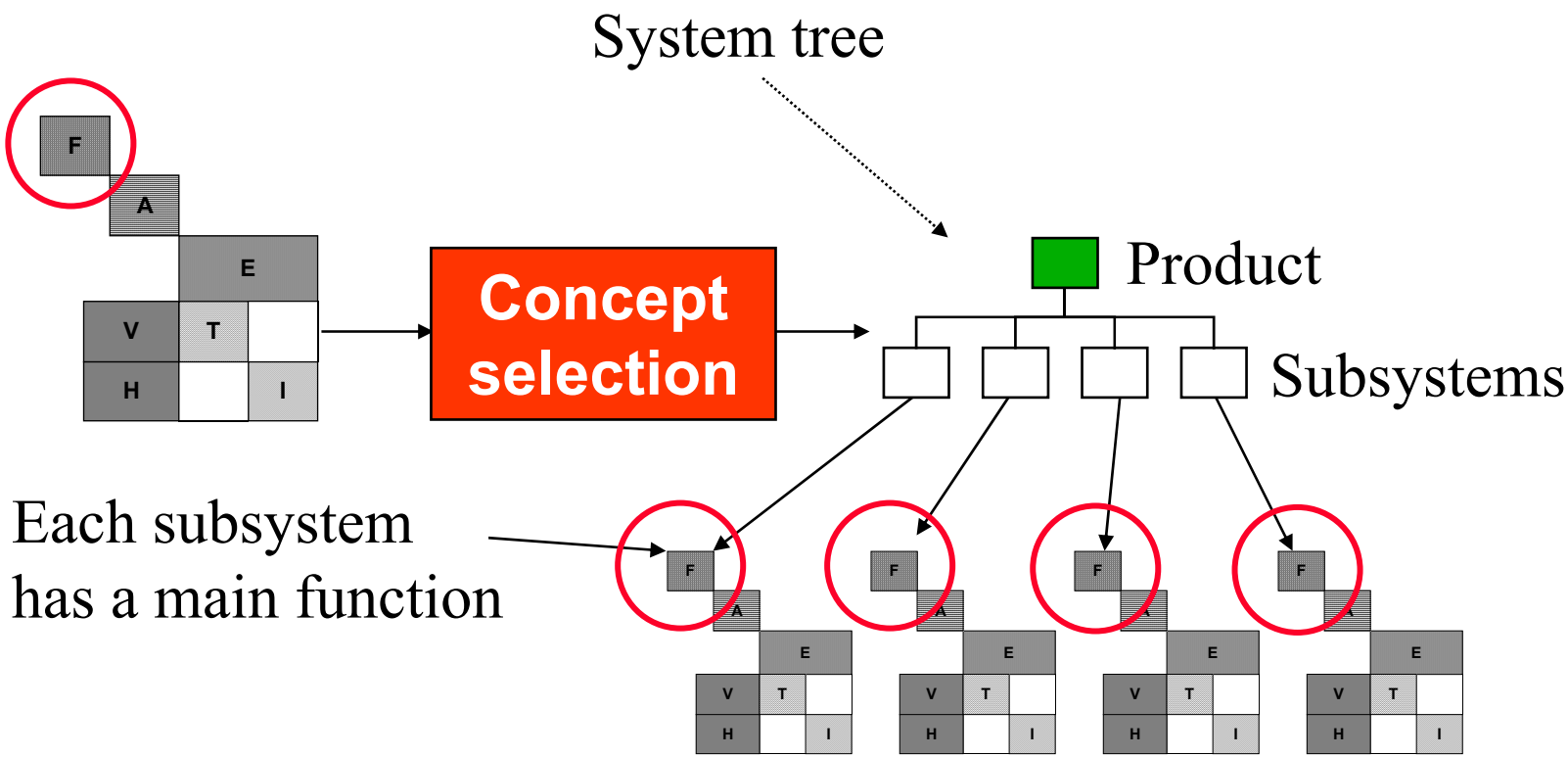
Functional analysis (F)

Path to elegant simplicity

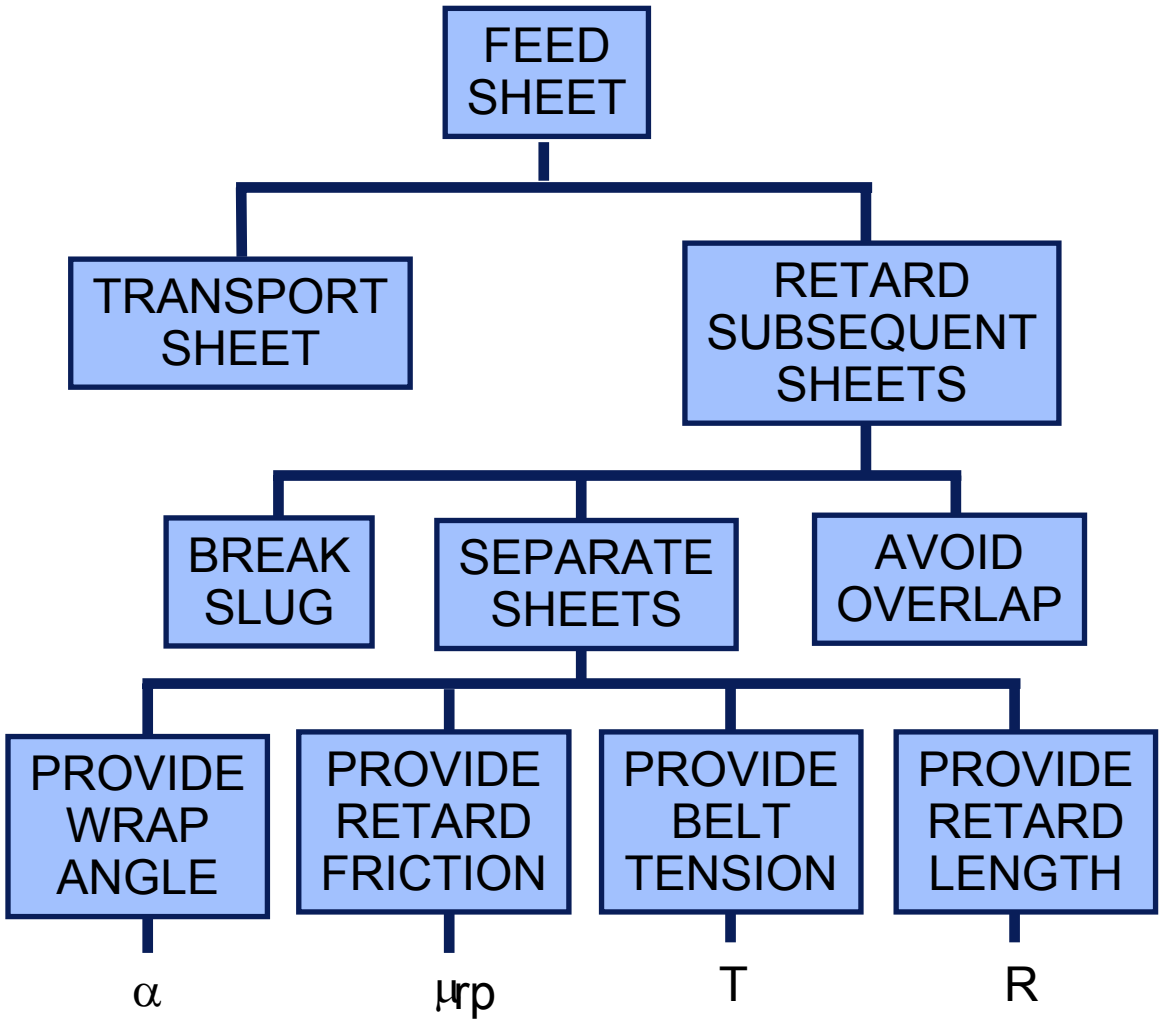


QFD and FA

Functional tree elements are circled



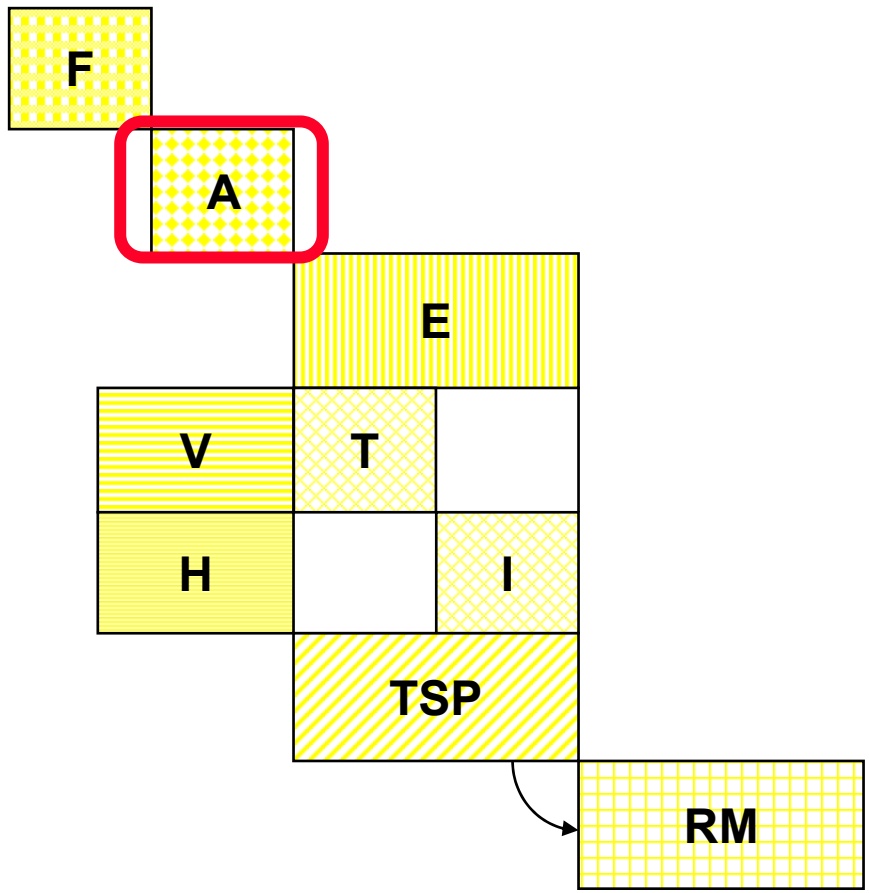
Functional tree




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

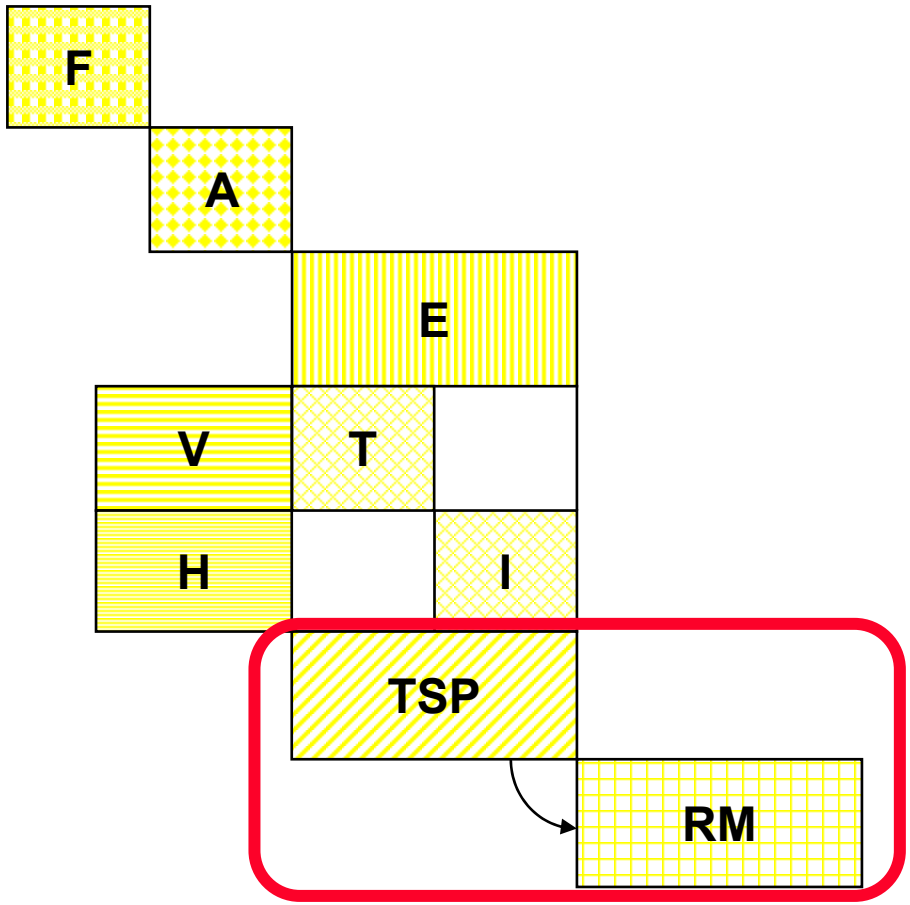

QFD marries functions
to customer needs

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

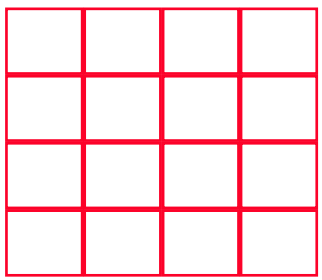
Competitive Products

Analogous products

New technology

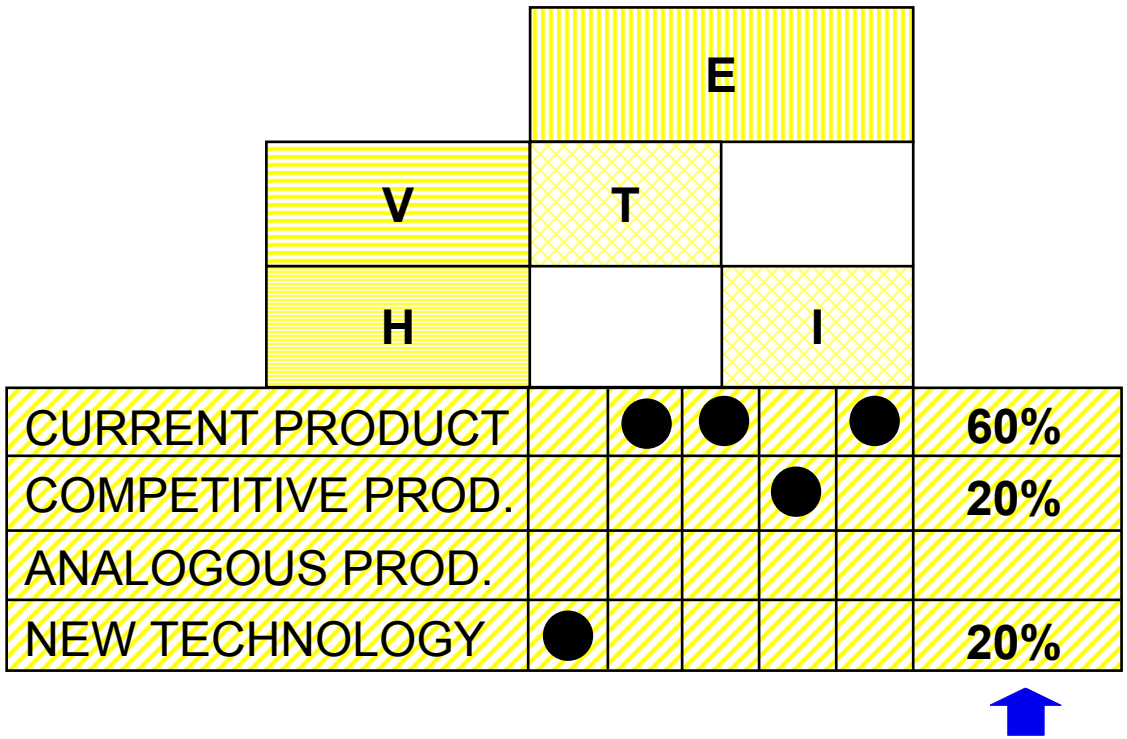
Levels

TSA concept
SS concept
PP concept
PP feature



Legend
TSA-Total System Architecture
SS-Subsystem
PP-Piece Part

Technology sources planning (TSP)



Level N

NEW "BASEMENT" FOR QFD MATRIX

COMPARE WITH REUSABILITY MATRIX PLAN – JUSTIFY CHANGES

LEVEL-N ROW REUSABILITY MATRIX (RM)

QFD marries reusability to customer needs