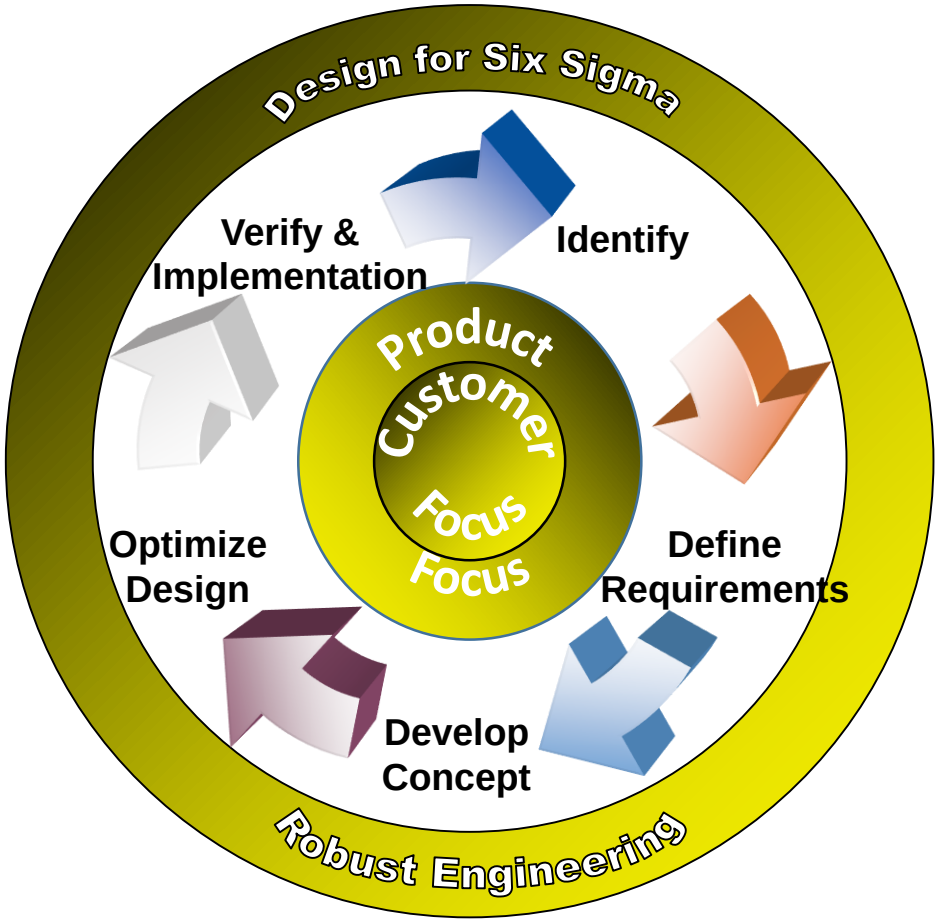
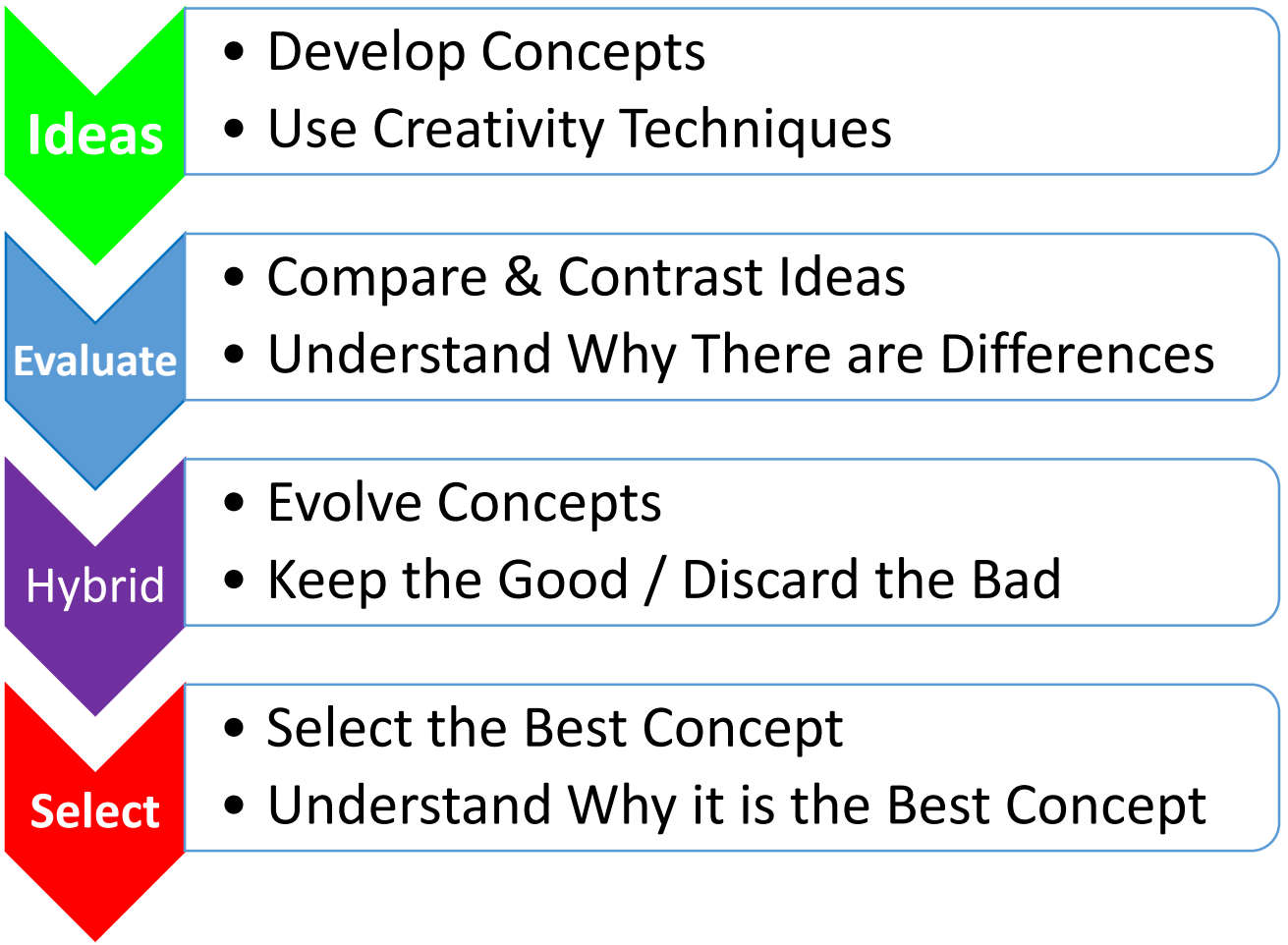
Robust Engineering

- **Identify**
  - What is the decision, why is it important?
- **Define**
  - Define Decision Criteria, what does it take to be a winner?
- **Develop**
  - Do I have the best design Concept?
- **Optimize**
  - Is the performance acceptable and consistent for all operating conditions?
- **Verify**
  - Does it's performance achieve all objectives?



Getting to a single GREAT Concept



What is a Functional Measure?

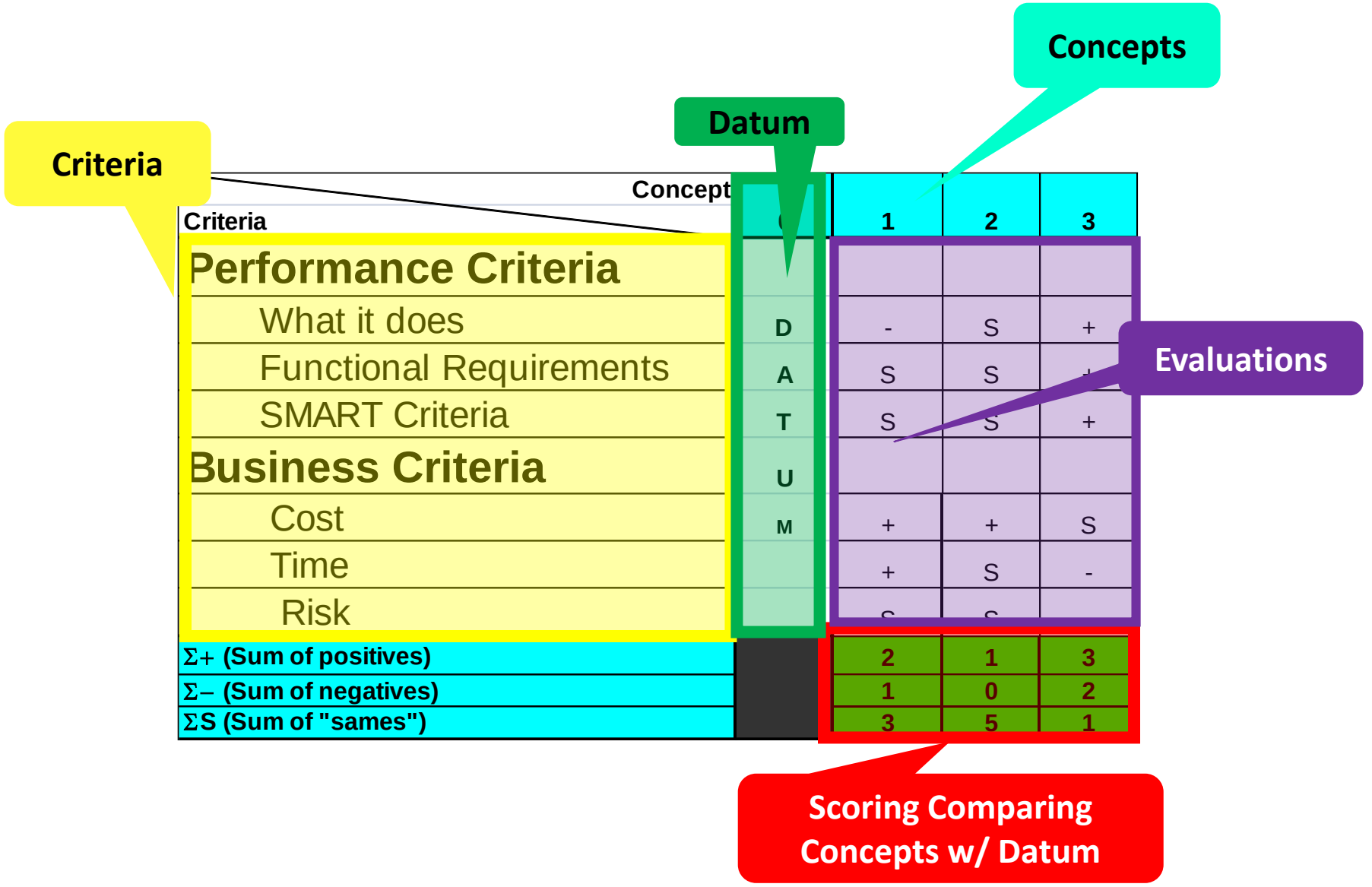
- **A Functional Measure describes *what the system does*.**
- **It is *not* a description of *what the system is*.**
- **A functional measure is a measure of system performance.**
- **Be careful to focus on a measure of performance (e.g. how much force) and not how to achieve the performance (e.g. use a spring).**

- Use **S.M.A.R.T.** criteria to assist in selecting or evaluating functional measures
  - **Specific** – unambiguous (clear) outcome or deliverable.
  - **Measurable** – impact on customer (result) is clear and measurable.
  - **Actionable** – can be accomplished by you and your team with available (or attainable) resources.
  - **Relevant** – clearly moves toward achieving customer satisfaction.
  - **Time Bound** – can be measured during development when results can affect the design solution before release

Criteria for the Evaluation

- Identify Evaluation Criteria
  - How well does it perform its intended function?
    - Use the Functional Requirements from Define Requirements
- You may choose to rank order the criteria
  - How well it performs is most important
  - do not weight the criteria
- Reach consensus on the criteria

Pugh Concept Template



Concept / Criteria	D	1	2	3
Performance Criteria				
What it does		-	S	+
Functional Requirements		S	S	+
SMART Criteria		S	S	+
Business Criteria				
Cost		+	+	S
Time		+	S	-
Risk		S	S	
Σ+ (Sum of positives)		2	1	3
Σ– (Sum of negatives)		1	0	2
ΣS (Sum of "sames")		3	5	1

Pugh Concept Selection

Evaluation Criteria

Performance Criteria from Defined Requirements

Criteria \ Concept	0	1	2	3
Performance Criteria				
What it does	D	-	S	+
Functional Requirements	A	S	S	+
SMART Criteria	T	S	S	+
Business Criteria	U			
Cost	M	+	+	S
Time		+	S	-
Risk		S	S	-
Σ+ (Sum of positives)		**2**	**1**	**3**
Σ− (Sum of negatives)		**1**	**0**	**2**
ΣS (Sum of "sames")		**3**	**5**	**1**

If you have the wrong criteria, will you be guided to the right decision?

Pugh Concept Selection

Understand the Alternatives

Alternatives

Concep / Criteria		0	1	2	3
Performance Criteria					
What it does	D		-	S	+
Functional Requirements	A		S	S	+
SMART Criteria	T		S	S	+
Business Criteria	U				
Cost	M		+	+	S
Time			+	S	-
Risk			S	S	-
Σ+ (Sum of positives)			**2**	**1**	**3**
Σ− (Sum of negatives)			**1**	**0**	**2**
ΣS (Sum of "sames")			**3**	**5**	**1**

Ensure the team understands each concept in detail.
Use supporting sketches and words.

Pugh Concept Selection

Evaluation

Work from left to right evaluating each concept on a given criteria

Criteria \ Concept	0		2	3
Performance Criteria				
What it does	D	-	S	+
Functional Requirements	A	S	S	+
SMART Criteria	T	S	S	+
Criteria	U			
	M	+	+	S
		+	S	-
RISK		S	S	-
Σ+ (Sum of positives)		**2**	**1**	**3**
Σ– (Sum of negatives)		**1**	**0**	**2**
ΣS (Sum of "sames")		**3**	**5**	**1**

Put +, -, or S in each cell to represent if concept is significantly better, worse, or the same as the Datum concept

Total scores for each concept

Evaluation: Fact or Opinion?

Fact or
Opinion?

Fact or Opinion?

- Fact is more important than opinion.
- Document which entries are **fact** different than those that are ***opinion***.
- What would it take to go from opinion to fact?
  - *Think Quick Tests.*

Pugh Concept Selection

First Run - Analysis

- The +'s represent concept strengths and the –'s represent weaknesses.
- The scores for each concept are intended as guides to focus your attention on the development of additional and better concepts.
- Identify the concept(s) that have the most +'s and fewest –'s.
- Look for ways to address the weaknesses. How can you pull strengths from other concepts to change the –'s into S's or +'s.
- As you make changes to convert a weakness, evaluate the impact on other criteria.

Use Pugh Matrix to Create Hybrid Designs

- Use the Pugh analysis to make stronger concepts than the original alternatives.
- Look for areas where concepts differ (+/-/S)
- Determine why the difference exists.
- Create hybrid designs that incorporate the strong features (+’s) and eliminate weaknesses (-’s) in each design.
- Work to eliminate all negatives (-’s)

The Pugh Concept Selection Process usually leads to blended concepts that are substantially better than any of the initial alternatives.

Pugh Concept Selection

Generate Better Alternatives by Understanding Strengths & Weaknesses

Criteria \ Concept	0	1	2	3	4
Performance Criteria					
What it does	D	-	S	+	+
Functional Requirements	A	S	S	+	S
SMART Criteria	T	S	S	+	+
Business Criteria	U				
Cost	M	+	+	S	S
Time		+	S	-	S
Risk		S	S	-	S
Σ+ (Sum of positives)		**2**	**1**	**3**	**2**
Σ– (Sum of negatives)		**1**	**0**	**2**	**0**
ΣS (Sum of "sames")		**3**	**5**	**1**	**4**

Hybrid Concept 4 uses the best of Concepts 2 & 3

Low Performance is an Opportunity for Optimization

Concept / Criteria	0	1	2	3	4
Performance Criteria					
What it does	D	-	S	+	+
Functional Requirements	A	S	S	+	S
SMART Criteria	T	S	S	+	+
Business Criteria	U				
Cost	M	+	+	S	S
Time		+	S	-	S
Risk		S	S	-	S
Σ+ (Sum of positives)		**2**	**1**	**3**	**2**
Σ– (Sum of negatives)		**1**	**0**	**2**	**0**
ΣS (Sum of "sames")		**3**	**5**	**1**	**4**

Improving Concept 4 will make it a real winner!

Pugh Confirmation Run

A critical step in the Pugh process is to confirm the winning design is truly the winner.

1. Make the winning design the new datum.
2. Assess the strengths and weaknesses of each concept relative to the apparent winner (the new datum)
   - If the datum is still the best OK 

   - If the datum is no longer the best—you have a new winner. Reconfirm by going to step 1.
   - Create new hybrid designs using what you learned in confirmation.
   - Repeat as necessary until a clear winner emerges.

Do not skip the confirmation run!

Pugh Analysis

Problems with a Weak Datum

Concept / Criteria	Import. Rating	0	1	2	3	4
Performs intended function	**1**		+	+	+	+
Opening Efforts	**3**	D	+	**S**	**S**	**S**
Closing Efforts	**3**	A	+	**S**	**S**	**S**
Smoothness (Max-Min)	**1**	T	+	+	+	+
Linearity	**1**	U	+	+	+	**S**
Piece Cost	**2**	M	+	+	+	**S**
Investment	**2**		+	+	+	+
Timing	**2**		+	**S**	**S**	+
Σ+			8	5	5	4
Σ–			0	0	0	0
ΣS			0	3	3	4

Concept 1 appears to be a clear winner—confirmation run?

Pugh Analysis

Confirm with New Datum

Concept / Criteria	Import. Rating	1	2	3	4
Performs intended function	**1**		+	+	**S**
Opening Efforts	**3**	D	-	-	-
Closing Efforts	**3**	A	-	-	-
Smoothness (Max-Min)	**1**	T	+	+	**S**
Linearity	**1**	U	+	+	-
Piece Cost	**2**	M	+	+	-
Investment	**2**		+	+	**S**
Timing	**2**		-	-	**S**
Σ+			5	5	0
Σ–			3	3	4
ΣS			0	0	4

Evaluate Concepts 2-4 against Concept 1 – Still think Concept 1 is the winner?

The previous Datum was poor and masked the best concept.