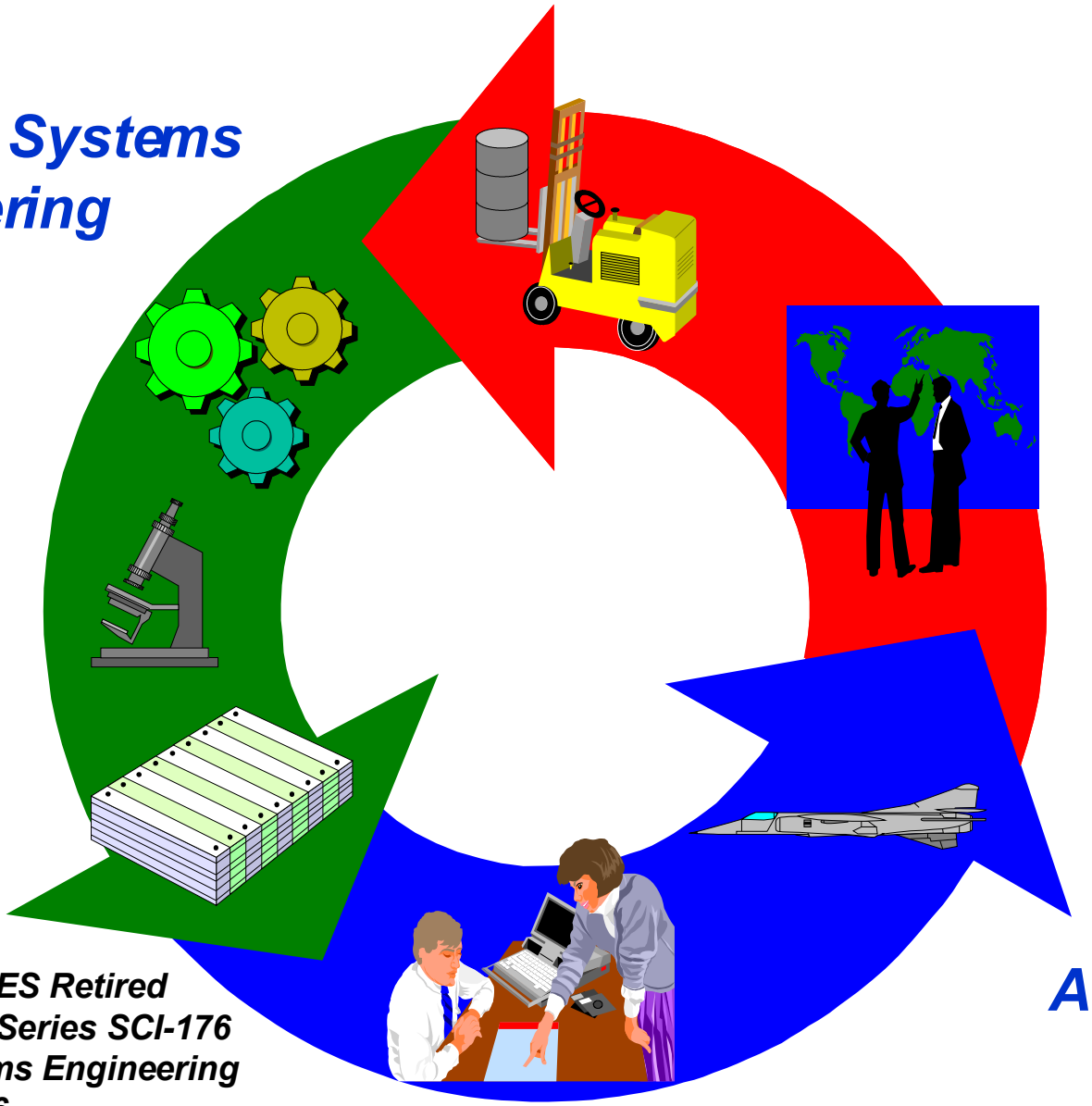
# Systems Engineering Process

*Applied Systems Engineering*



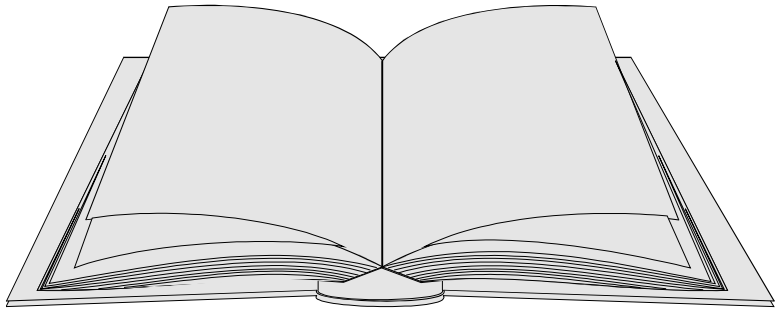
*An Everyday Process*

*Les Bordelon*
*US Air Force SES Retired*
*NATO Lecture Series SCI-176*
*Mission Systems Engineering*
*November 2006*

# Systems Engineering Process

**Most Acquisition Documents and Standards say:**

**“Thou Shalt Do Systems Engineering”**



# Systems Engineering Process

## Policy

**Translate Operational Needs Into Stable, Affordable Programs**

- **Strike Balance Among Cost, Schedule, and Performance Given Affordability Constraints**
- **Evolve Operational Performance Requirements from Broad Needs to System-Specific Performance Requirements**
- **Major Milestone Considerations:**
  - **Threat Projections**
  - **Affordability Constraints**
  - **Cost-Performance-Schedule Trade Offs**
  - **Life Cycle Costs**
  - **Risk Management**

# Systems Engineering Process

## Policy

### Acquiring Quality Products (Highlights)

- Event-Driven Acquisition Strategies, Major Commitments & Milestone Decisions Linked to Demonstrated Development & Test Accomplishments
- Systems Engineering
- Practicable Use of Commercial & Nondevelopmental Items
- Streamlined Solicitations and Contract Requirements
- Initial Broad Cost, Schedule & Performance Objectives Refined and Expanded in Program Baselines
- Performance Objectives Must Satisfy Operational Needs and be Verifiable by Testing

# Policy

## Acquiring Quality Products (Continued)

- Risk Management
  - Identify and Manage Critical Parameters
  - Technology Demonstrations & Prototyping
  - Test & Evaluation to Assess Maturity and Identify Risk
    - Assess Risk In: Threat, Technology, Schedule, Cost, Manufacturing, Support, Concurrency, Design, and Engineering
- User Participation

# SE Policy

**Applied Throughout the System Life Cycle as a Comprehensive, Iterative Technical Management Process**

- **Translate Operational Need into a Configured System *Through a Systematic, Concurrent Approach to Integrated Design of the System and Its Processes***
- **Integrate the Technical Inputs and All Technical Disciplines into a Coordinated Effort to *Meet Cost, Schedule, and Performance Objectives***
- **Ensure:**
  - **Compatibility of All Interfaces**
  - **System Definition and Design Reflect the Requirements for all System Elements**
  - **Develop Risk Abatement Approaches and Characterize and Reduce Technical Risks**

# SE Procedures

## Performance of Key Tasks

- Requirements Collection & Translation Methodology
  - Translate Operations Requirements into Design Requirements
  - With User, Establish Feasible Operations Requirements and Identify Critical Operations Characteristics and Constraints
  - Detailed Design Specifications
  - Establish Process to Balance Design Specs, Conduct Trades, Studies, Optimize System Design
  - Transition Technology
    - Establish Approach
    - Define Criteria & Methods

# SE Procedures

## Performance of Key Tasks

- Manage Risks: Identify & Assess Throughout Acquisition Cycle
  - Eliminate/Reduce via Acquisition Strategy
  - At Milestone Start: Cost, Schedule, Risk Reduction Measures, Assumptions & Strategy Alternatives are Assessed
- Verify Design Meets Operational Need
  - Integration Analysis, Simulation, Test & Demonstration
  - All Critical Characteristics Verified by Test & Demonstration

# SE Procedures

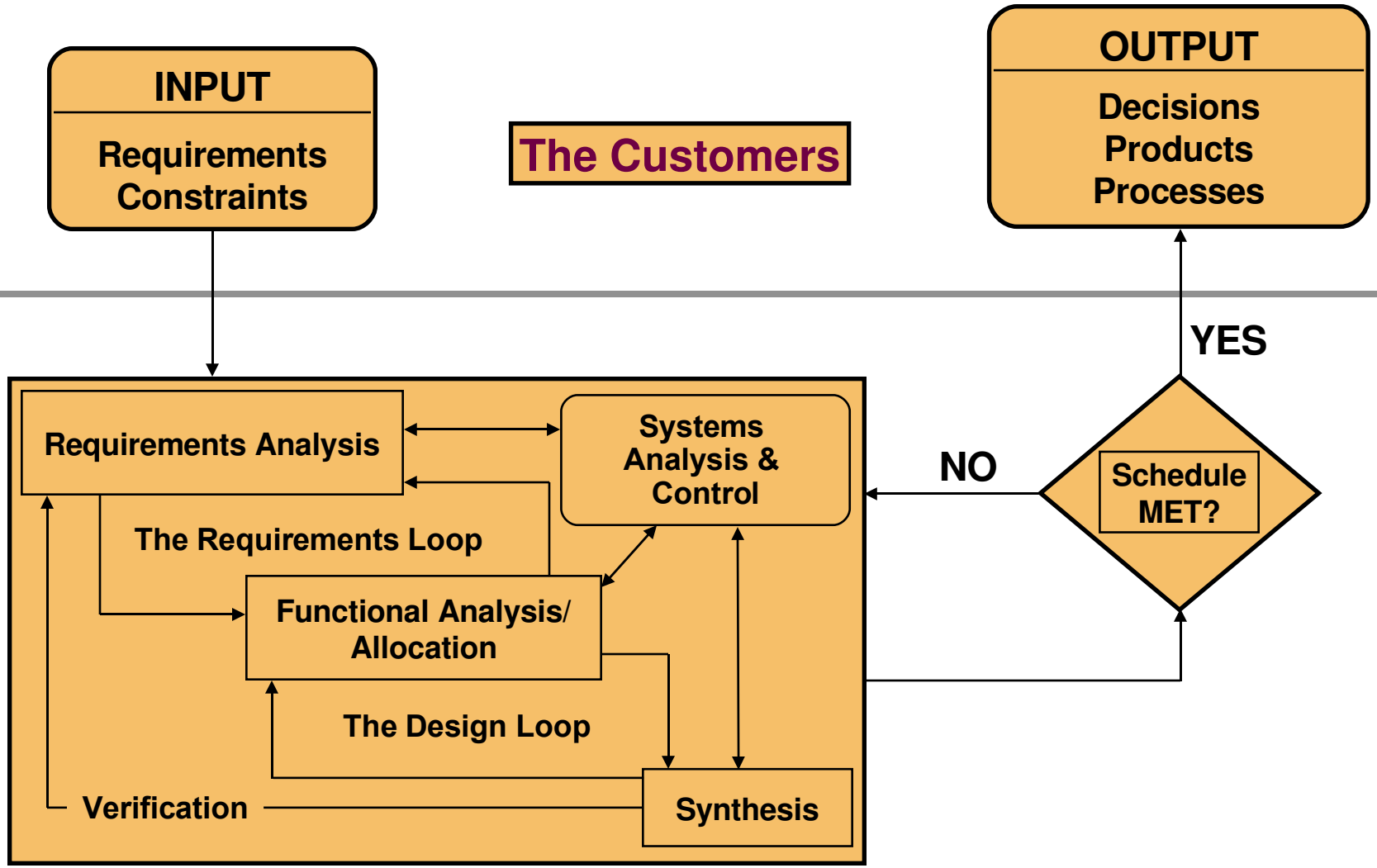
## Integration of Technical Disciplines

## Implementation of Planning and Control

- Engineering Planning
- Technical Performance Measures
- Configuration Management
- Technical Data

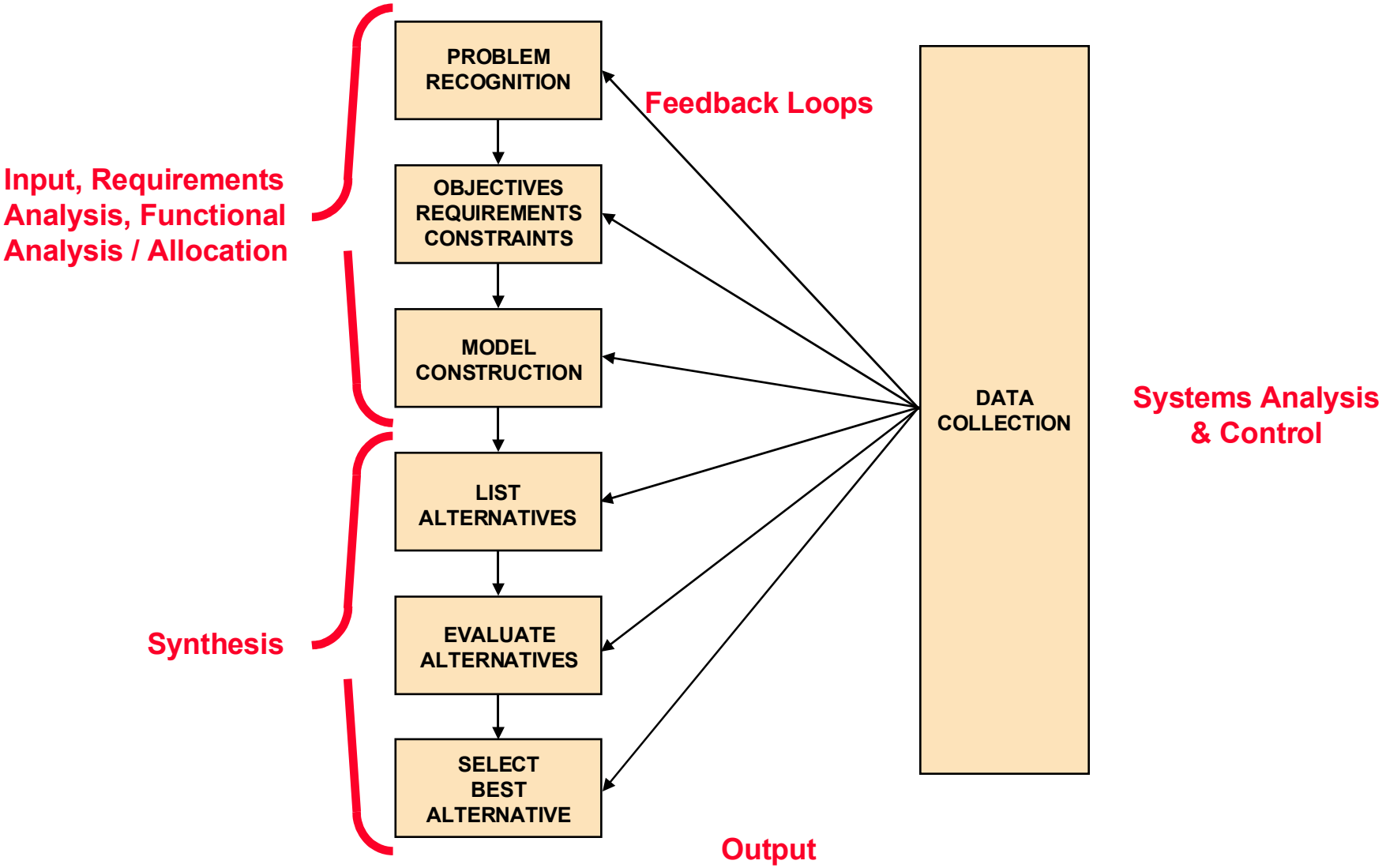
## Definition of a Work Breakdown Structure

# Systems Engineering Process

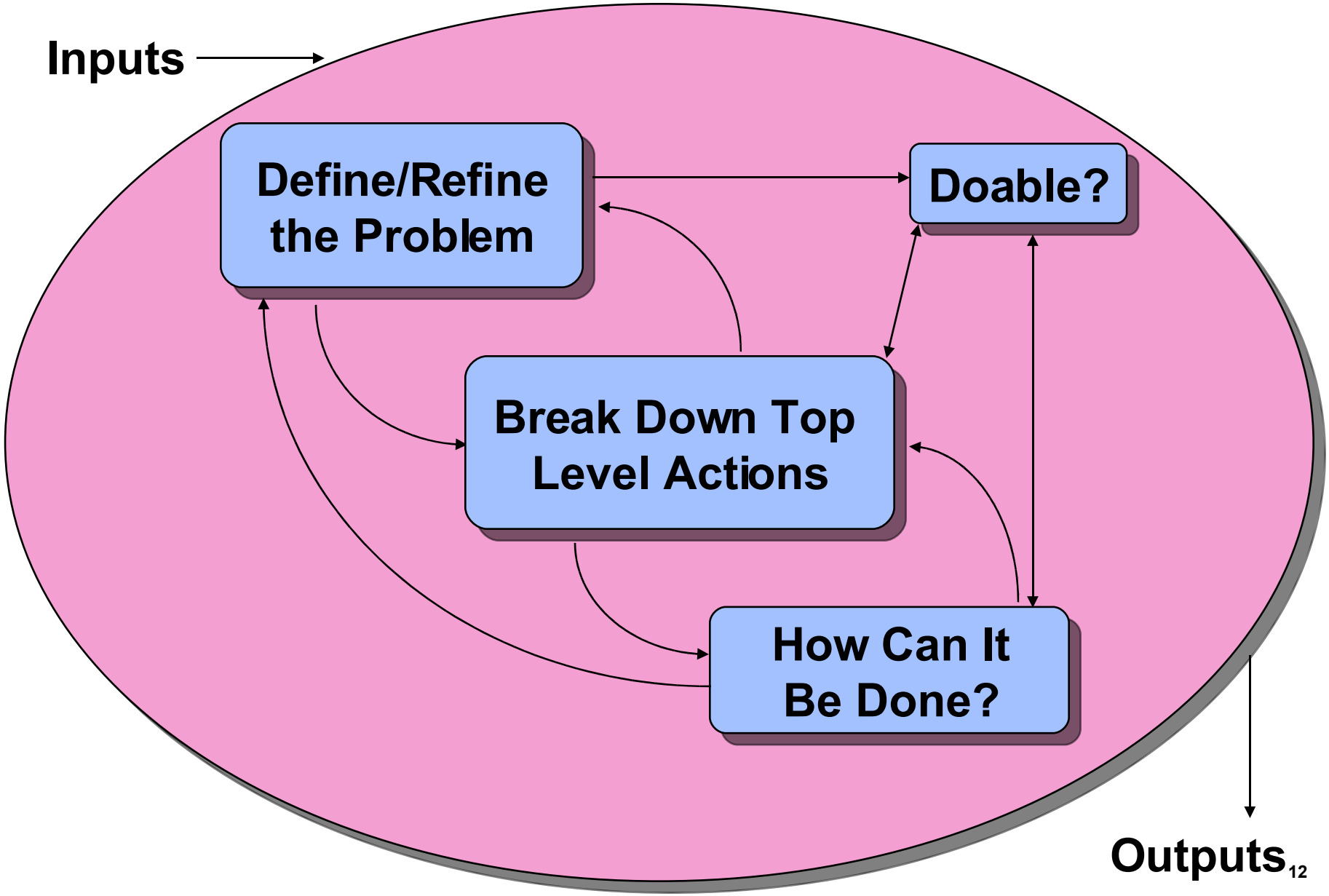


# Systems Engineering Process

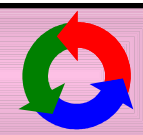
## GENERIC PROBLEM SOLVING TECHNIQUE



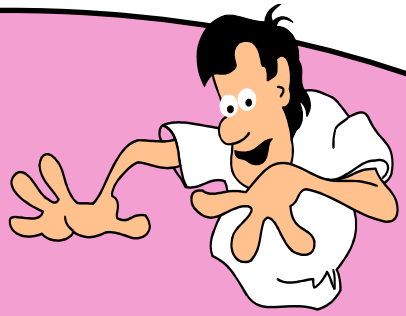
# Systems Engineering Process



# Systems Engineering Process



Inputs →



**Define/Refine the Problem**

**REQUIREMENTS ANALYSIS**

# Defining the Inputs

## Requirements Analysis

**What Job(s) Do the Customers Need to Do?**

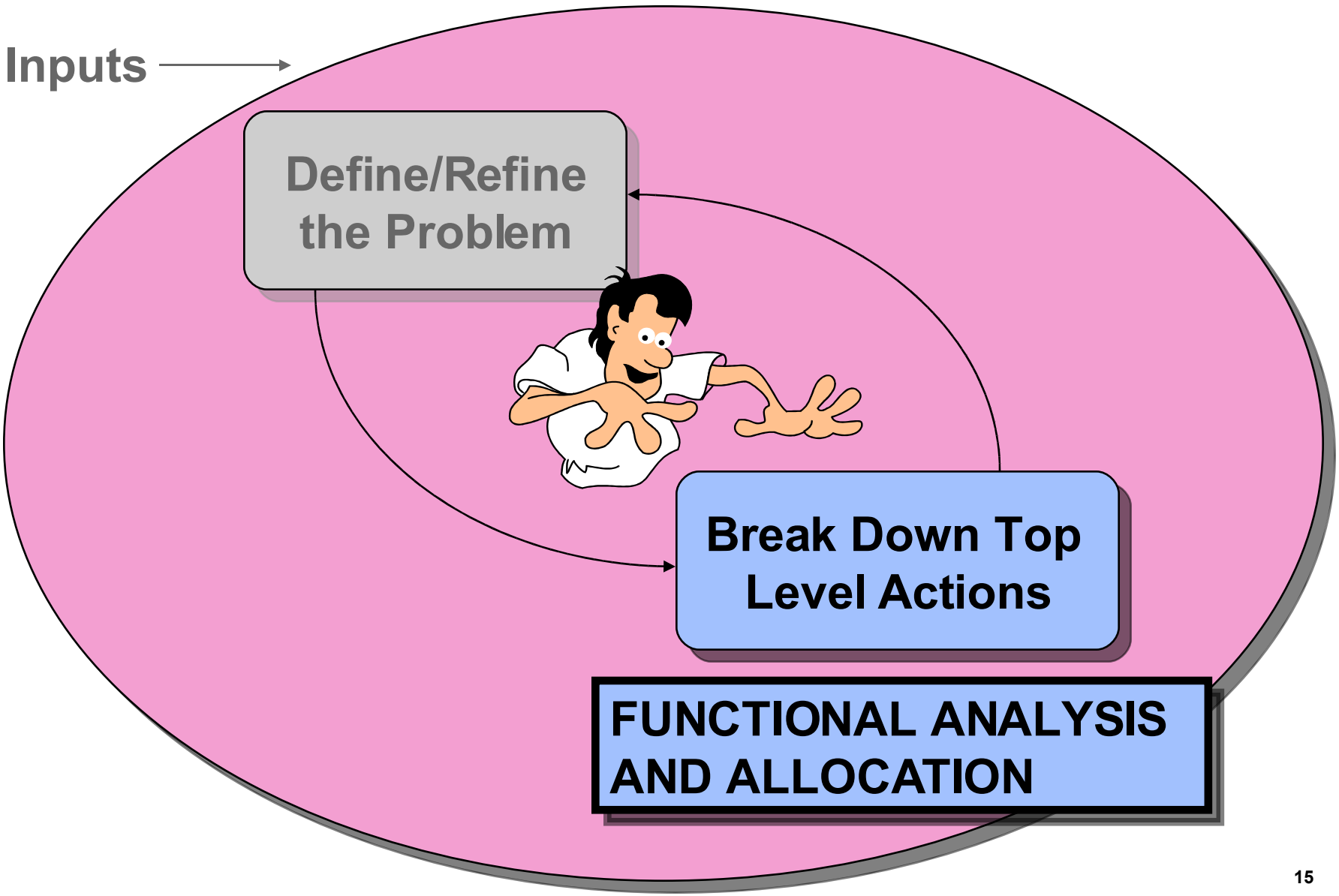
- What Are the Customers Trying to Do?
- How Well Must They be Done?
- What Are the Environments?
- What Are the Boundaries (e.g., $, Time...)?
- How Do We Measure Goodness?

**What Technologies Might be Available?**

**What Types of Information Do Decision Makers Need?**

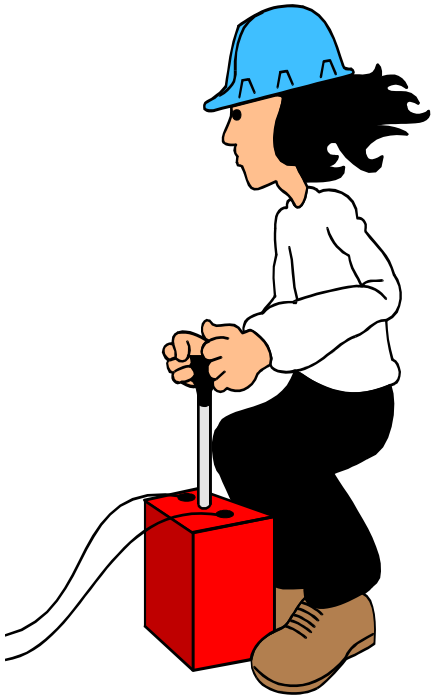
**What Procedures Need to be Employed to Get to a Solution (or In the Solution)?**

# Systems Engineering Process



# Systems Engineering Process

## Break Down Top-Level Actions
### "Turning Big Ones Into Little Ones"



## Functional Analysis and Allocation

**Simplify Complex Actions Into a Set of Less Complex Actions**

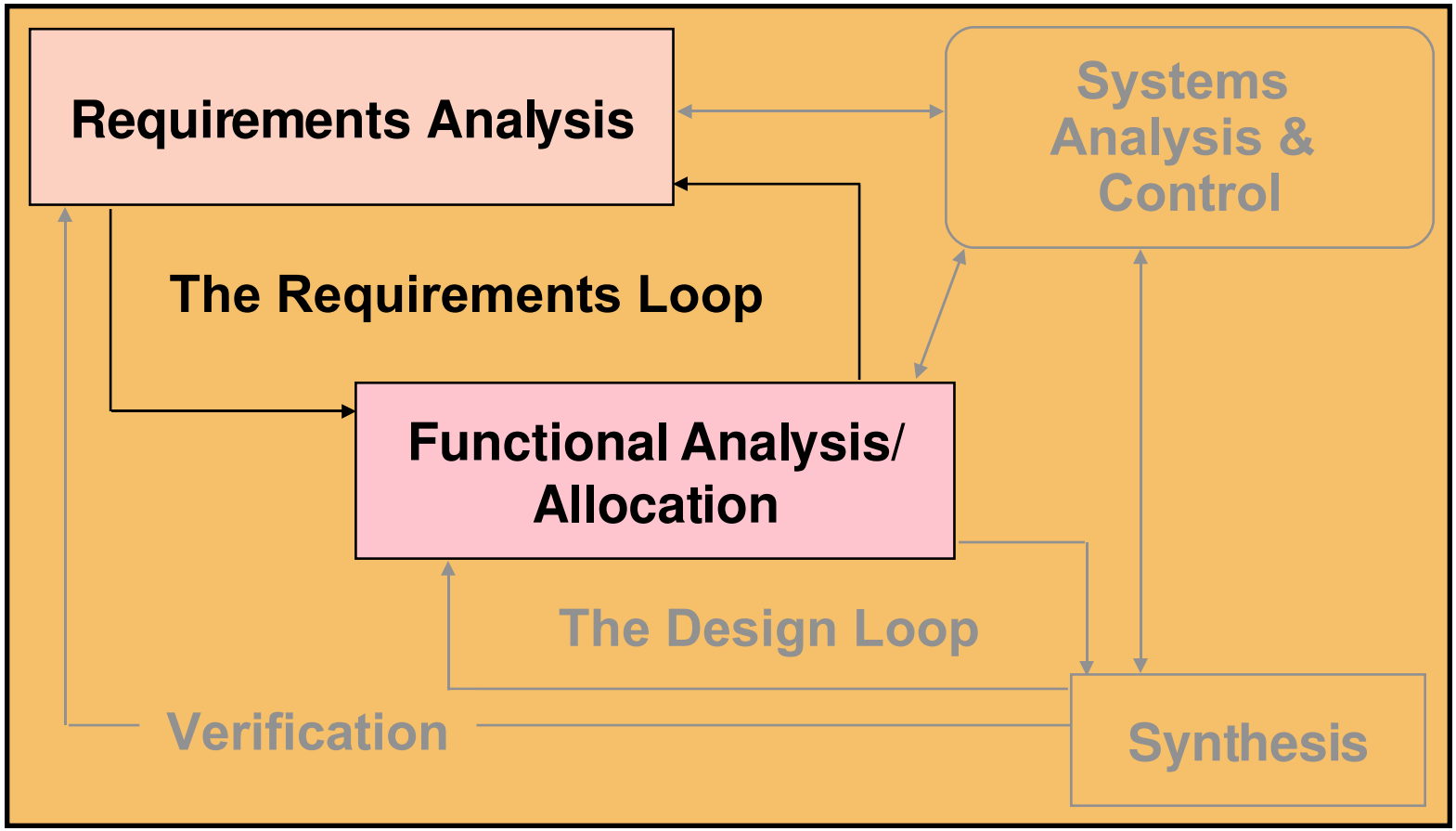
**Define the Relationships Between Actions (i.e., Inputs, Outputs, Sequences, etc.)**

- Back to the "Parent"
- Across the Set of Less Complex Actions
- Across Other Sets of Actions (Including External Relationships)

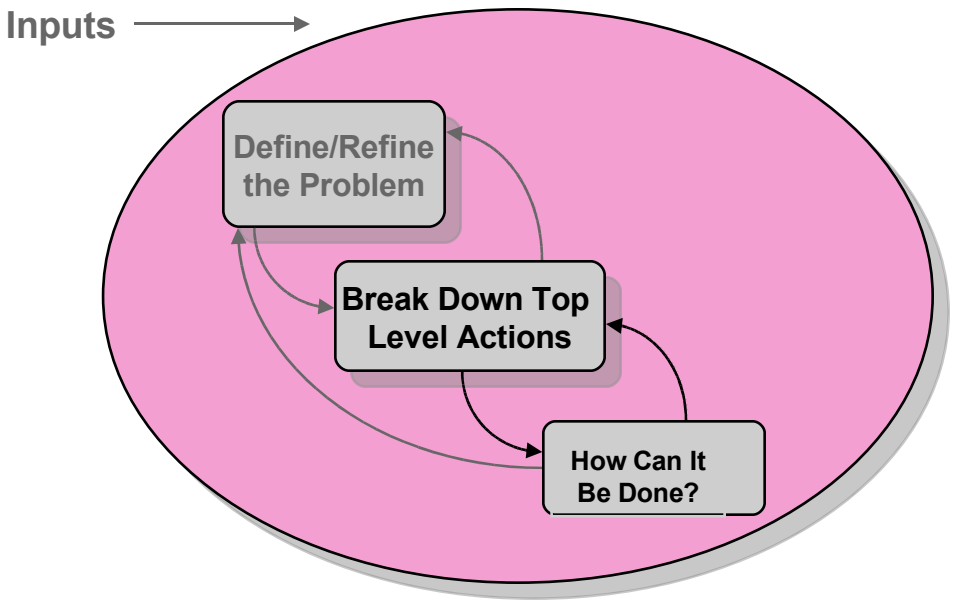
**Spread "How Well" the Complex Actions Must Be Done (& Constraints) Across the Set of Less Complex Actions**

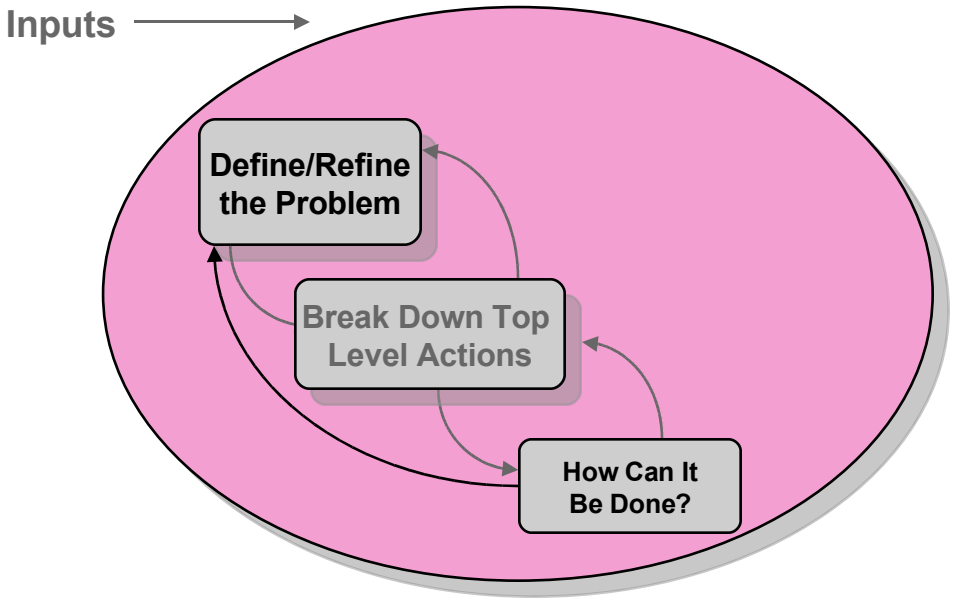
- "Summing" the "How Wells" Across the Set of Less Complex Actions Must Equal "How Well" the Complex Actions Needed to be Done

# Systems Engineering Process



# Systems Engineering Process




## Feedback Loops Confirm Completeness

- Have All Actions Been Addressed?
- Do Some "Solutions" Require New or Modified Actions?
- Do "Solutions" Still Solve the Top-Level Problem?

# Systems Engineering Process

Inputs →

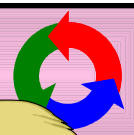
Define/Refine the Problem

Break Down Top Level Actions

How Can It Be Done?

SYNTHESIS (Design)

# Systems Engineering Process



## How It Can Be Done

"Develop Solution(s)"

## Synthesis (Design)

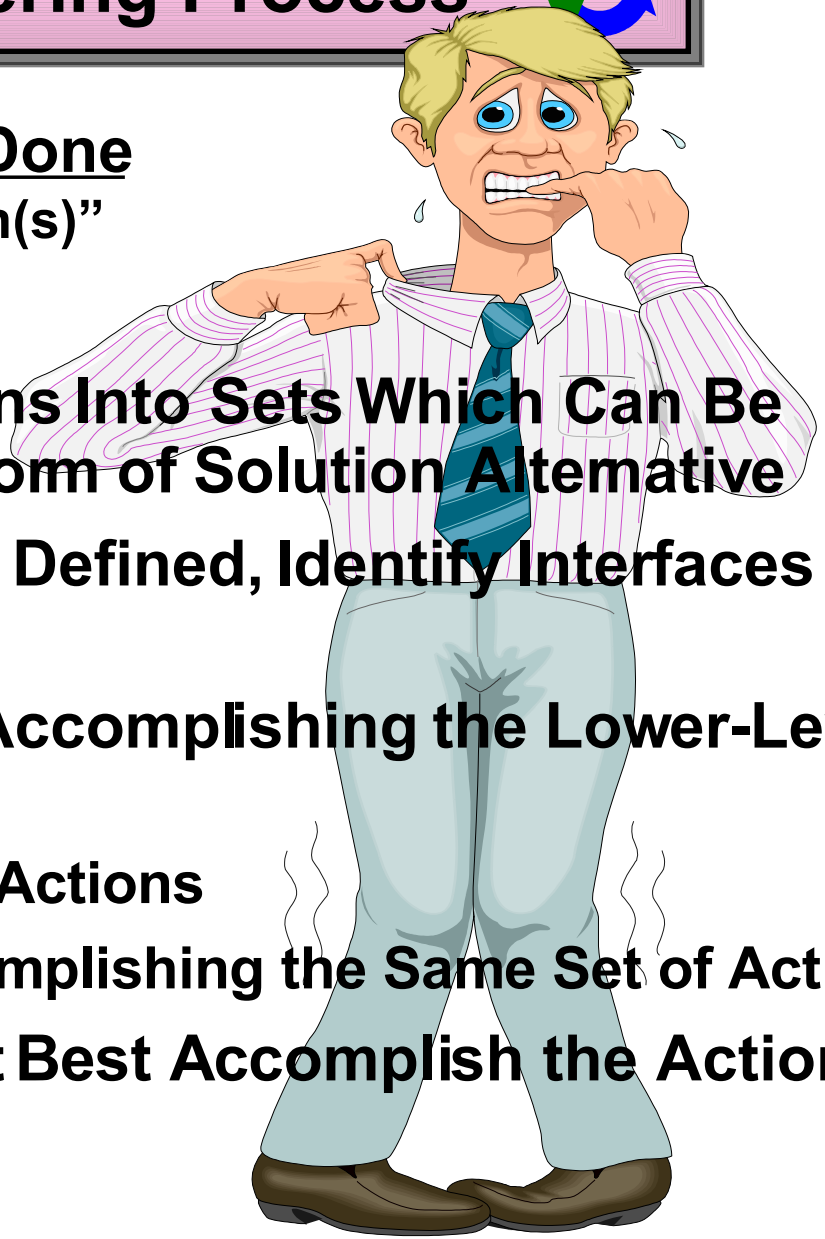
Organize Lower-Level Actions Into Sets Which Can Be Accomplished by Some Form of Solution Alternative

As Solution Alternatives are Defined, Identify Interfaces Between Them

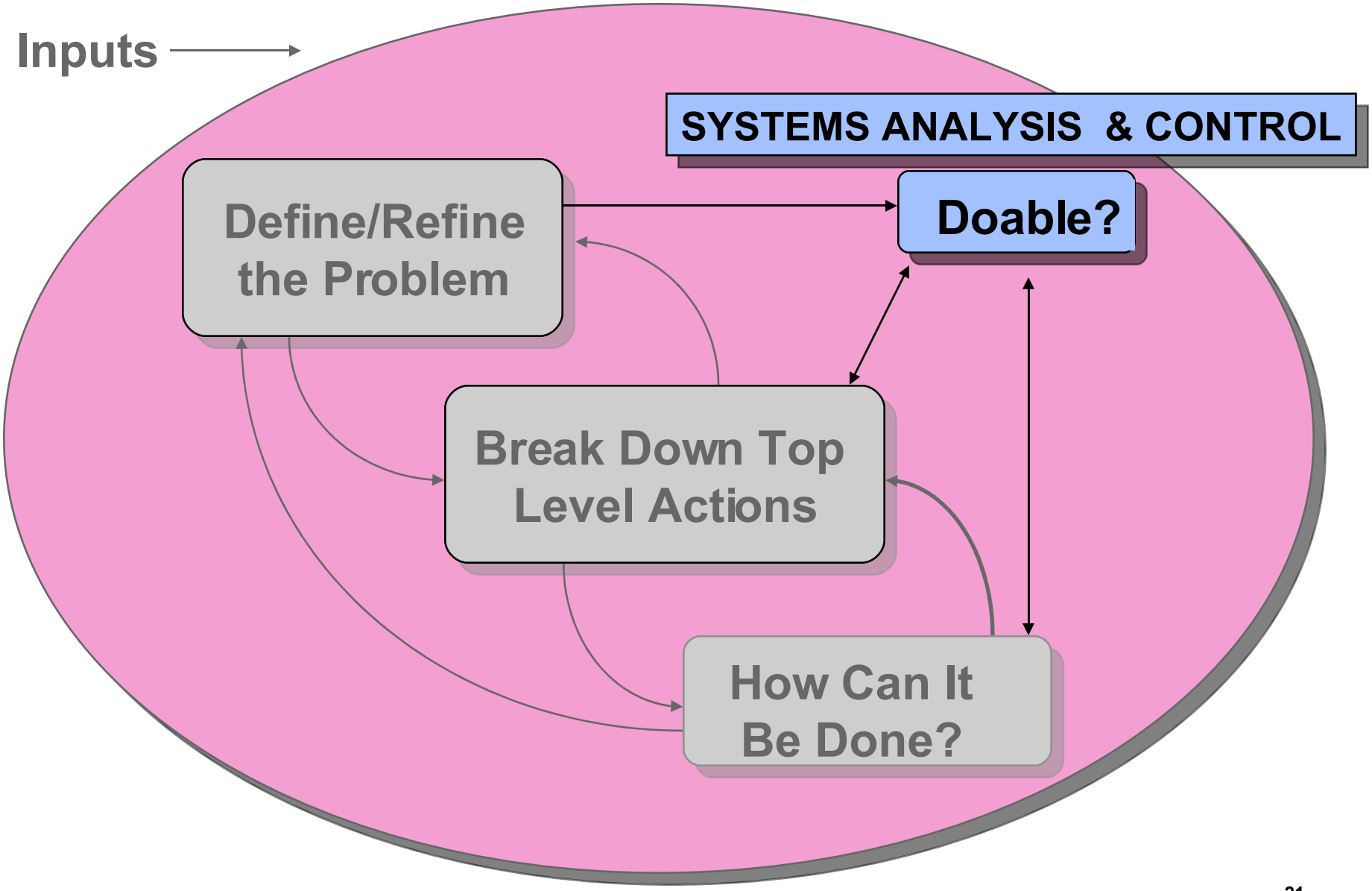
Define Alternative Ways of Accomplishing the Lower-Level Actions

- Alternative Groupings of Actions
- Alternative Ways of Accomplishing the Same Set of Actions

Looking for Solution(s) That Best Accomplish the Actions



# Systems Engineering Process



# Systems Engineering Process

## Doable?

"Deconflict & Balance Requirements"

## Systems Analysis & Control

### Determine "Best" Solution(s)

- Analyze Alternatives
- Identify & Understand Risks Involved

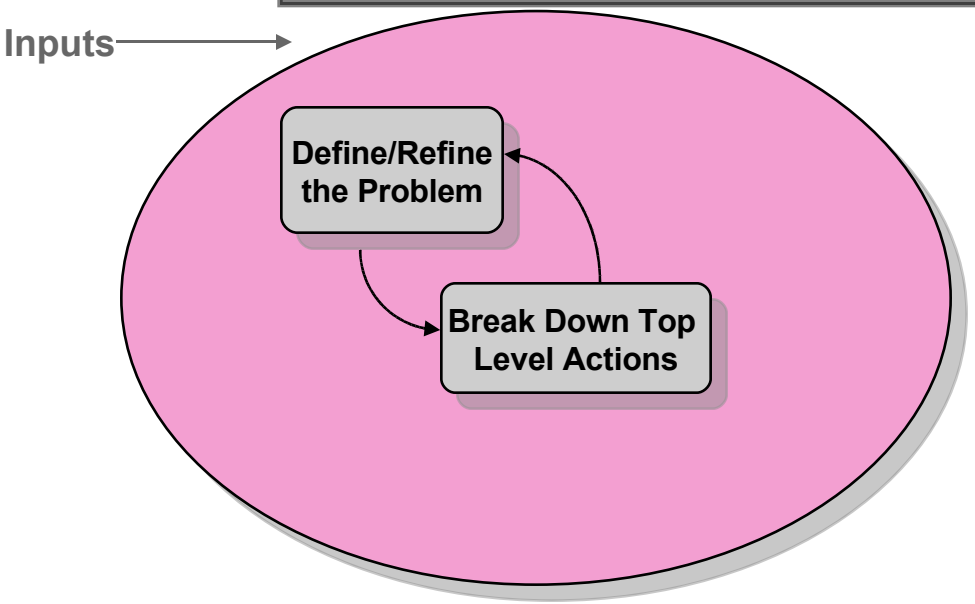
### Measure Problem Solution Progress

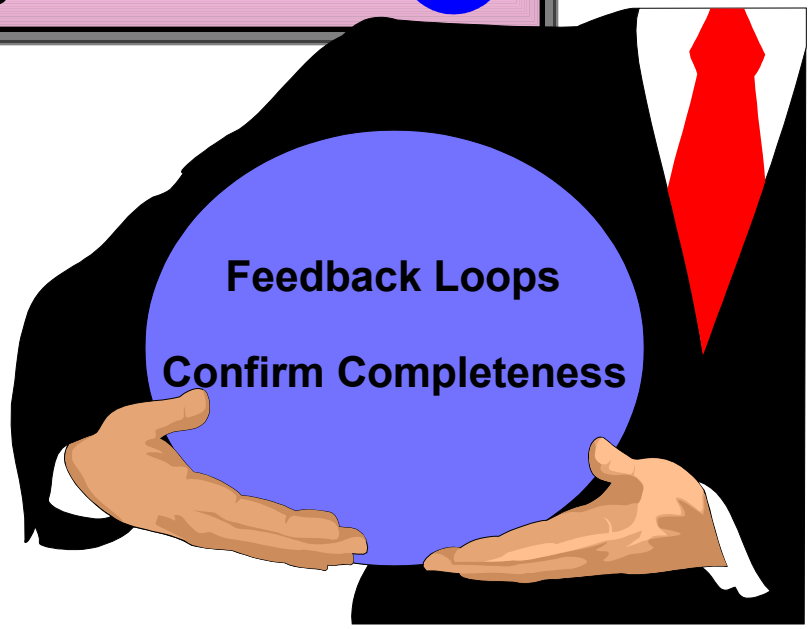
- Maintain a Master Schedule of Work to be Done
- Review Work Done
- Measure How Well Solution Solves Problem

### Manage Documentation

- Ensure EVERYTHING has Been Documented
- Latest Versions are Being Used

# Systems Engineering Process

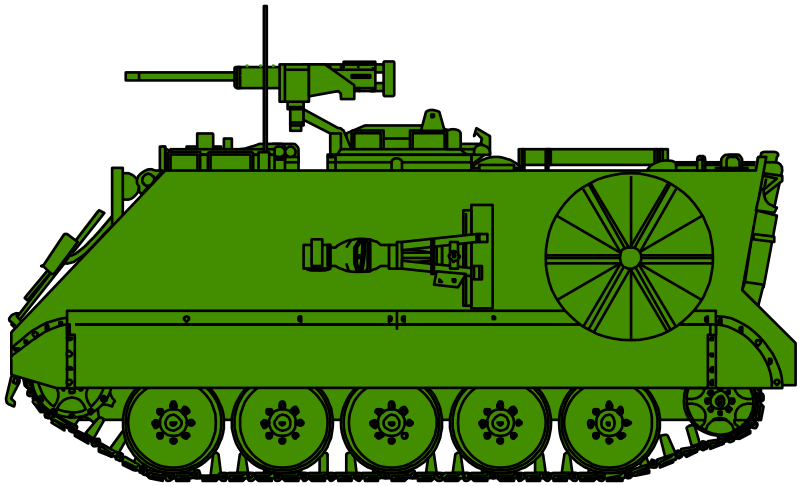



- Have All Aspects of the Problem Been Addressed?
- Do Lower-Level Actions Still Add Up to Top-Level Actions?
- Have Any of the Lower-Level Actions Caused a New Constraint, or Modification to an Existing Constraint?
- Have All Defined Constraints Been Addressed in Lower-Level Actions?
- Did Less Complex Set of Actions Require Additional Problem Definition to Define "How Well" They Needed to be Done?

# An Illustrative Example

## Armored Personnel Carrier (APC) Requires Oil Change

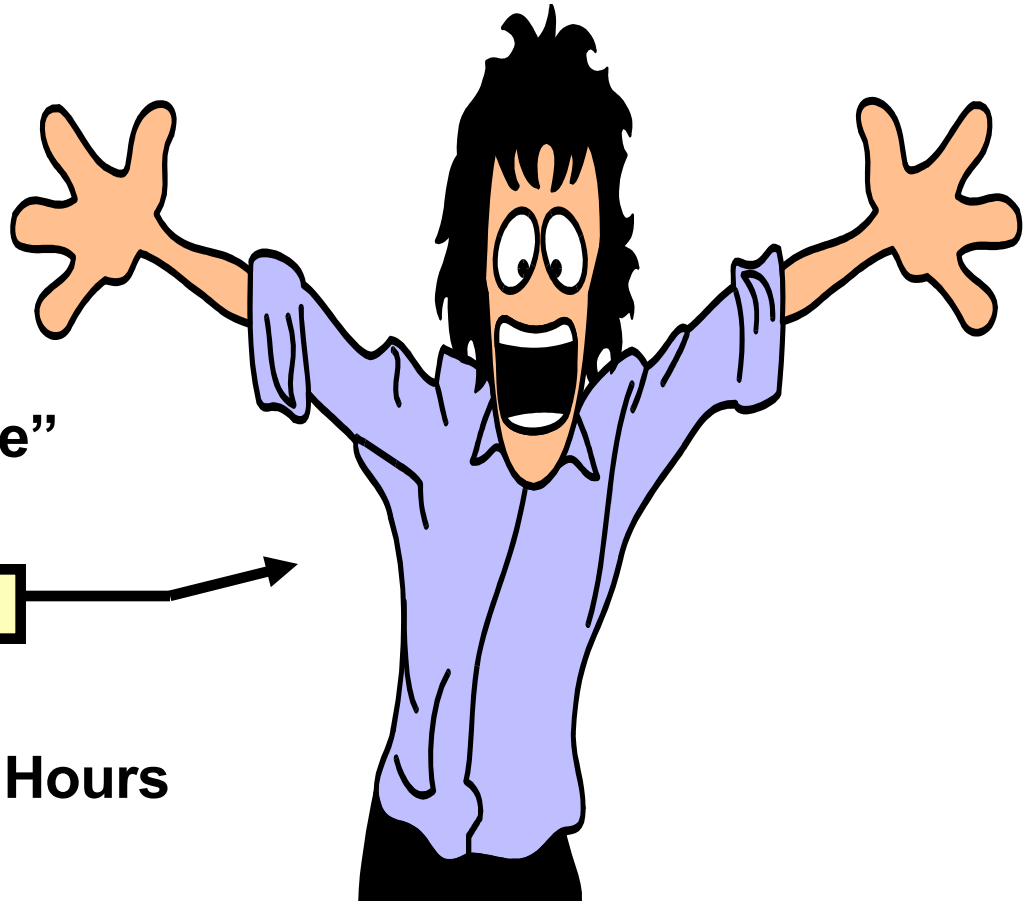


# Customer Input

**Objective**: Change the Oil

**Inputs**:

- Spend Only a "Reasonable" Amount of Money
- **Unskilled Labor Available**
- Buy Off-the-Shelf Parts
- Don't Spend More Than 4 Hours



# Systems Engineering Process

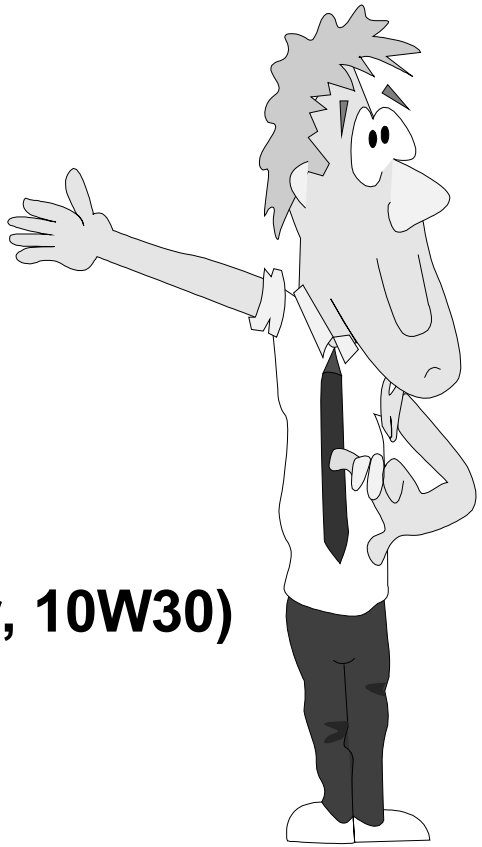
## Define/Refine The Problem?

**Identify Constraints**

- Take No More Than 4 Hours
- Use Only a "Reasonable" Amount of $$
- Use COTS

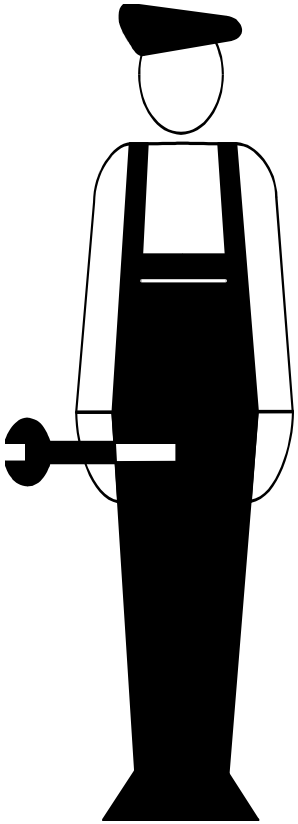
**Identify Top Level Actions**

- Acquire Materials
  - What Materials? (Define Them)
    - Oil
      - What Amount? (4 Quarts)
      - What Kind? Season? (Winter, 10W30)
    - New Filter? (Yes)
- Remove Old Oil
- Put In New Oil



# Systems Engineering Process

## Break Down Top-Level Actions



***Acquire Materials***

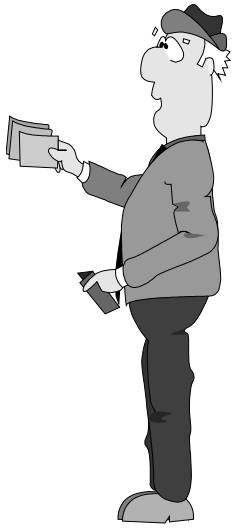
- Buy Oil and Filter

***Remove Old Oil***

- Remove Oil Filter
- Remove Drain Bolt

***Put In New Oil***

- Put On New Oil Filter
- Insert Drain Bolt
- Remove Oil Cap
- Add Oil
- Replace Oil Cap



"Turning Big Ones Into Little Ones"

# Spread "How Well" - Check Completeness

**Assign Performance (Time/Cost) to the Actions and See How We Are Satisfying the Problem.**

- **Buy Oil and Filter** ⟷ ***Nearest APC parts store - 45 min round trip***

- **Remove Oil Filter** ⟷
- **Remove Drain Bolt**
- **Put On New Oil Filter**
- **Insert Drain Bolt**

***80% of oil drains 0.5 sec after removing oil filter. Drains 1 quart per 30 sec from oil pan drain.***

- **Remove Oil Cap**
- **Add Oil** ⟷ ***5 min***
- **Replace Oil Cap**

# Systems Engineering Process

## Spread "How Well" - Sum "How Well's"

***time ; cost***

| | |
|---|---|
| Buy Oil and Filter..... | 45 min; $10 |
| Remove Oil Filter ..... | ? sec |
| Remove Drain Bolt ..... | ? sec |
| • Oil Drain Time ..... | 10 min |
| Put On New Oil Filter ..... | ? sec |
| Insert Drain Bolt ..... | ? sec |
| Remove Oil Cap ..... | ? sec |
| Add Oil ..... | 5 min |
| Replace Oil Cap ..... | ? sec |
| Clean-Up Oil Spill ..... | 2.5 hrs |
| Shower with Lava ..... | 1 hr |

**To Date:**

**Total Time - 4.5 hr**
**Total Cost: $10.00**

# Systems Engineering Process

## Is It Doable?

### "Deconflict & Balance Requirements"

- "Clean-Ups Take Too Long
- Potential Environmental Problems
  - "New" Requirement - Disposal
    - New & Revised Actions
      - Catch the Oil in a Container
      - Remove Drain Plug & Oil, Then Remove Filter

"Broke" Constraint:
4.5 hr > 4 hr

**Refine Problem and Actions:**

Obtain 5 Quart Catch Pan (Catch Oil)

Empty Gallon Milk Carton (Dispose of Oil)

Plastic Bag (Dispose of Oil Filter)

# Spread "How Well"

- Buy Oil, Filter, Pan (New) ...45 min, $10.00
- Remove Drain Bolt ..... ? sec [reorder sequence]
  - Oil Drain Time ..... 10 min [reorder sequence]
- Remove Oil Filter ..... ? sec [reorder sequence]
- Put On New Oil Filter ..... ? sec
- Insert Drain Bolt ..... ? sec
- Remove Oil Cap ..... ? sec
- Add Oil ..... 5 min
- Replace Oil Cap ..... ? sec
- Clean-Ups ..... 1 hour [revised]

**To Date:**
**Total Time - 2 hours**
**Total Cost - $10.00**

# How Can It Be Done ?

## Develop Solution (s)

**Design-to-Time Available ~ 2 hour**

**Analysis**

- Remove Drain Bolt: Bolt Design - 3/4” Hex Nut (Wrench Adequate, Cost = $4, R&R Time = 4 min)
- Remove Oil Filter: Special Tool Required (Oil Filter Wrench, Cost = $10, R&R Time = 10 min)
- Remove Oil Cap: Hand Tighten (3” Wrench to remove, Cost = $4, R&R Time = 1 min)

**Note: An adjustable wrench could work for both the drain bolt and the oil cap (Cost = $5, Savings = $3)**

# How Can It Be Done ?

## Develop Solution (s)

**Problem:**

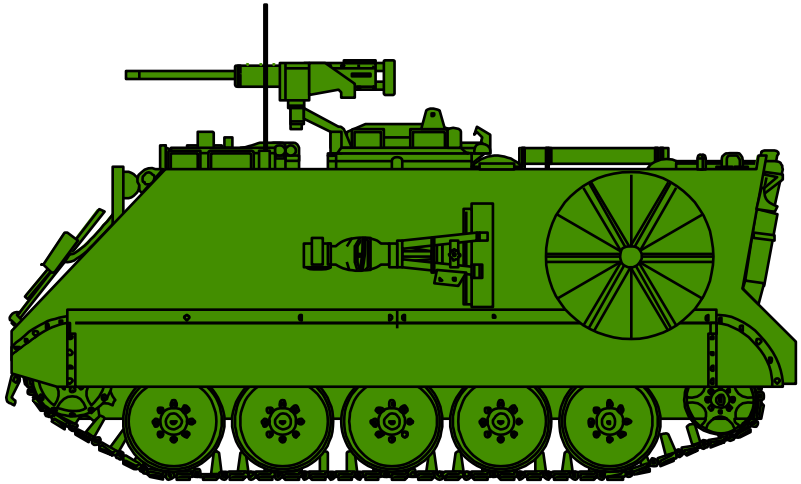
- Mechanic doesn't fit under APC, and can't reach drain bolt & oil filter from the side.

**Alternatives:**

- Get Mechanic with Longer Arms
- Lower the Ground Underneath Oil Pan Area
- Raise the APC
  - Park APC with Front Wheels on the Curb
  - Use Fork Lift Truck to Raise Front End ($25, 10 min)
  - Obtain APC Ramps ($50, 30 min Set-Up Time)
- Take APC to Dealership ($20, Leave APC All Day)

# Systems Engineering Process

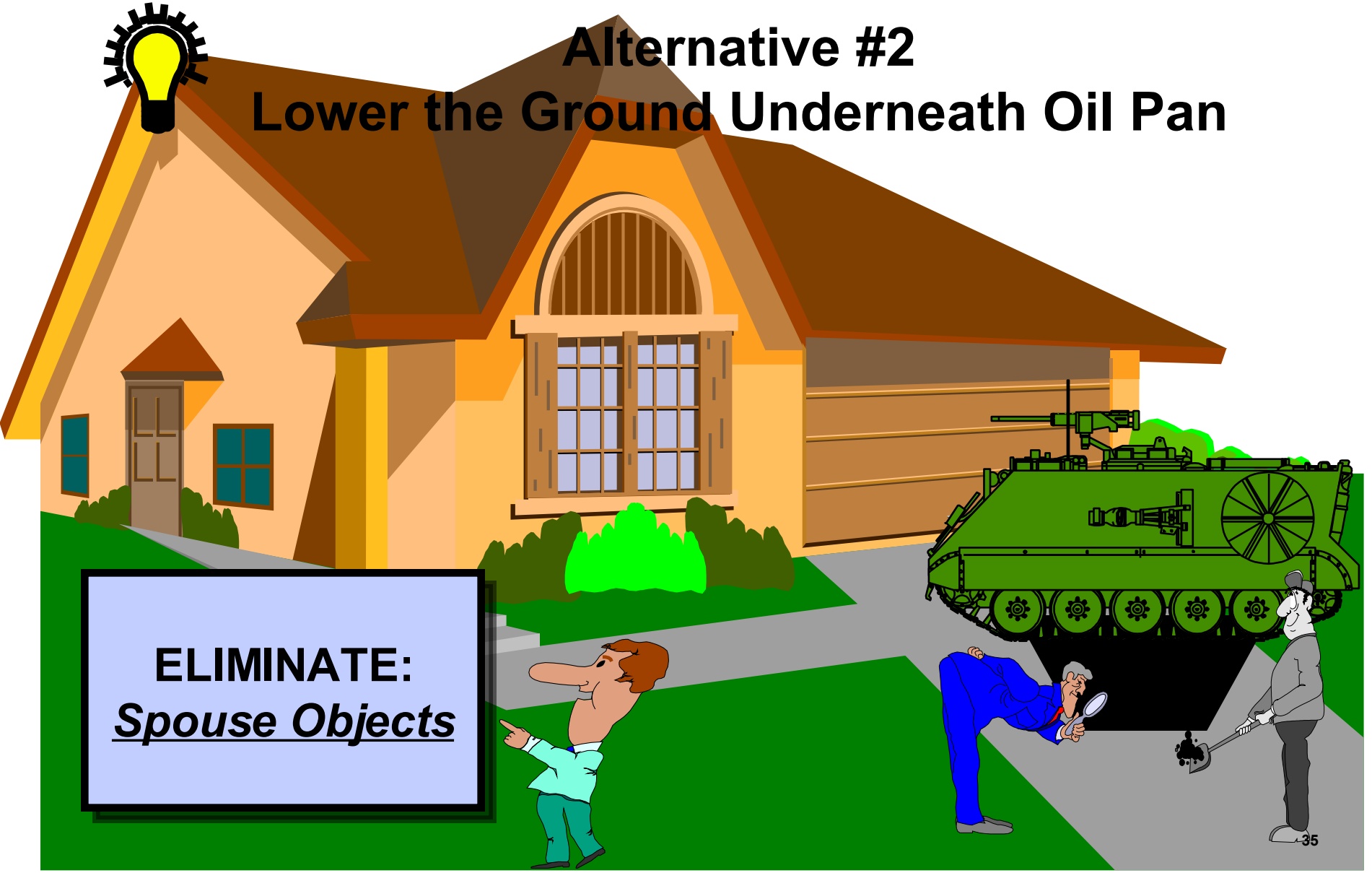
## Alternative #1
## Get Mechanic With Longer Arms



**ELIMINATE:**
***Overqualified for Job***

# Systems Engineering Process

## Alternative #2
## Lower the Ground Underneath Oil Pan



**ELIMINATE:**
***Spouse Objects***

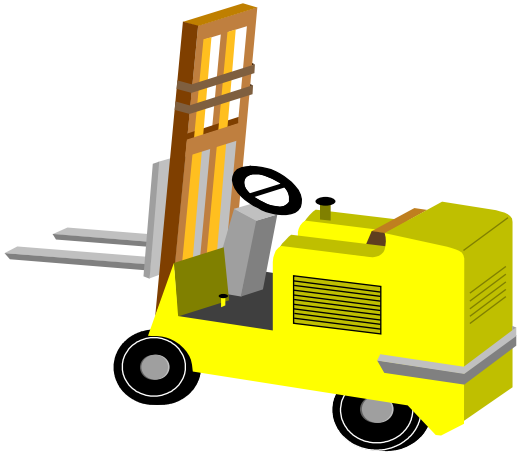
# Systems Engineering Process

## Alternative #3
## Park APC with Front Wheels on the Curb

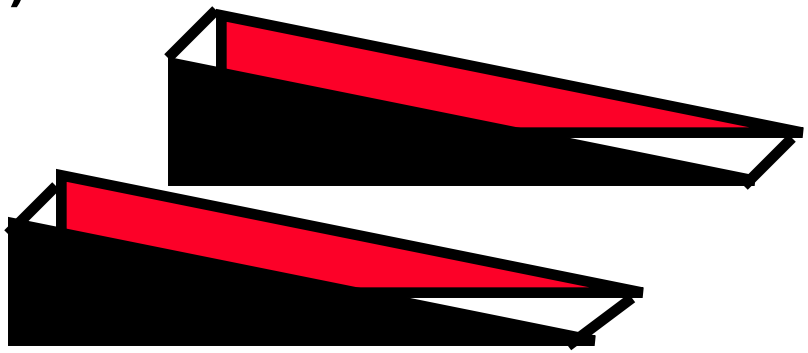
**ELIMINATE:**
***Safety Hazard***

# Candidate Alternatives

- Use Fork-Lift Truck to Raise Front End ($25, 10 min)



- Obtain APC Ramps ($50, 30 min Set-Up Time)



# Systems Engineering Process

## Are Alternatives Doable?

| Tasks | Lift Truck | Ramps | Dealer |
|---|---|---|---|
| • Buy oil, filter | $10, 45 min | $10, 45 min | |
| • Buy pan, wrenches* | $20, 45 min | $20, 45 min | |
| • Lift front end | $25, 10 min | $50, 30 min | |
| • Remove/replace drain bolt | 4 min | 4 min | |
| • Drain oil | 10 min | 10 min | |
| • Remove/replace oil filter | 10 min | 10 min | |
| • Remove/replace oil cap | 1 min | 1 min | |
| • Add oil | 5 min | 5 min | |
| • Clean-ups | 1 hour | 1 hour | |
| Total Time | 3 hr 10 min | 3 hr, 40 min | 1 Day |
| Total Cost | $55 | $80 | $20 |

* One Time Cost

RETAIN *DEALER*: TOO LONG, BUT LEAST COST

# Observations

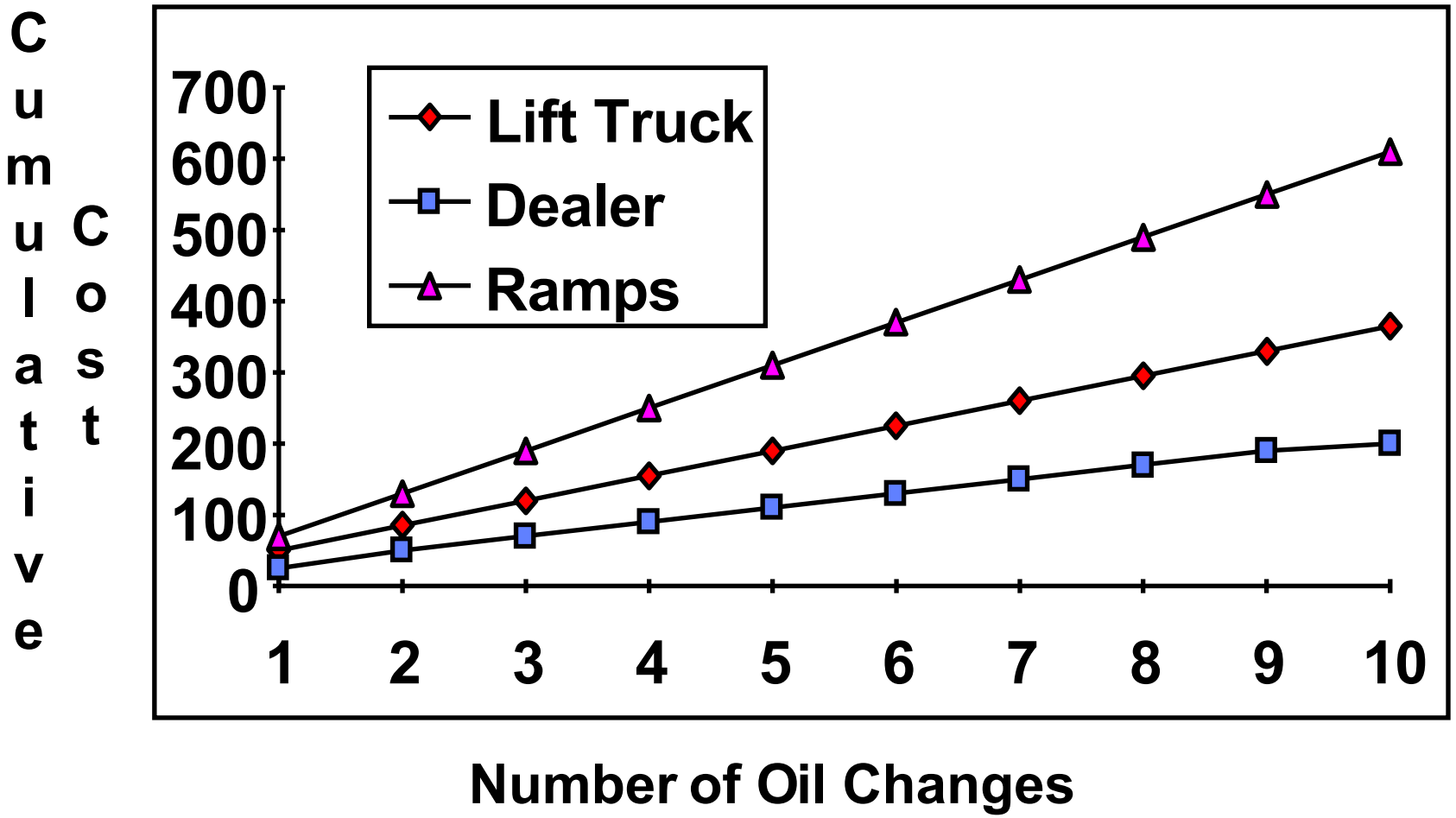
- Lift Truck Best Cost and Performance that Meets Requirement
- Dealer option Doesn't Meet Time Requirement, but Offers Significantly Less Cost

# Life Cycle Considerations

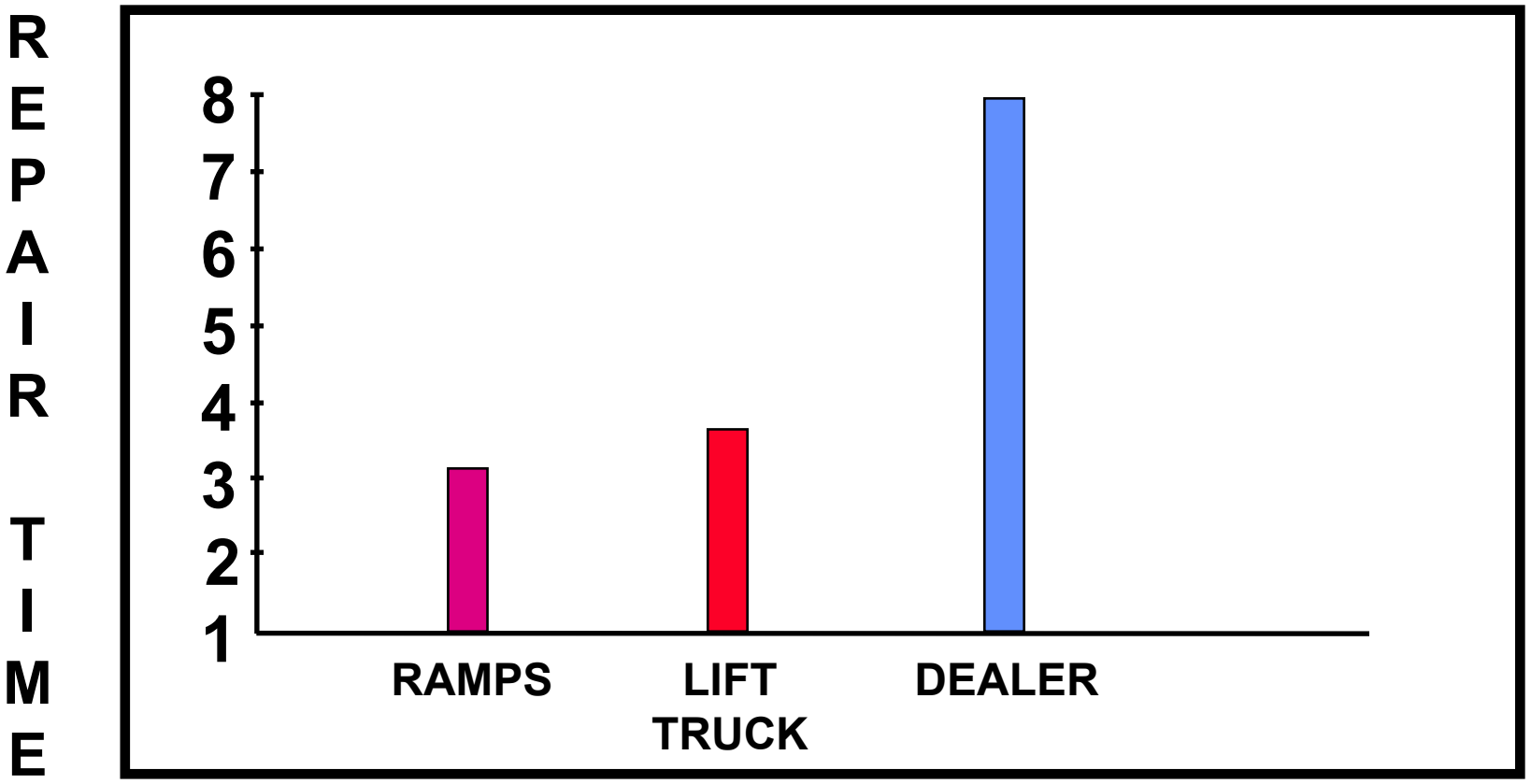
## (But How Many Times Will the Oil Be Changed?)

| | Lift Truck | Ramps | Dealer |
|---|---|---|---|
| One-Time Purchases (Pan and wrenches) | $20 | $20 | $ 0 |
| One-Time Delay (Buying materials) | 45 min | 45 min | 0 min |
| Recurring Costs | $35 | $60 | $20 |
| Recurring Time Delay | 2 hr, 25 min | 2 hr, 55 min | 1 day |

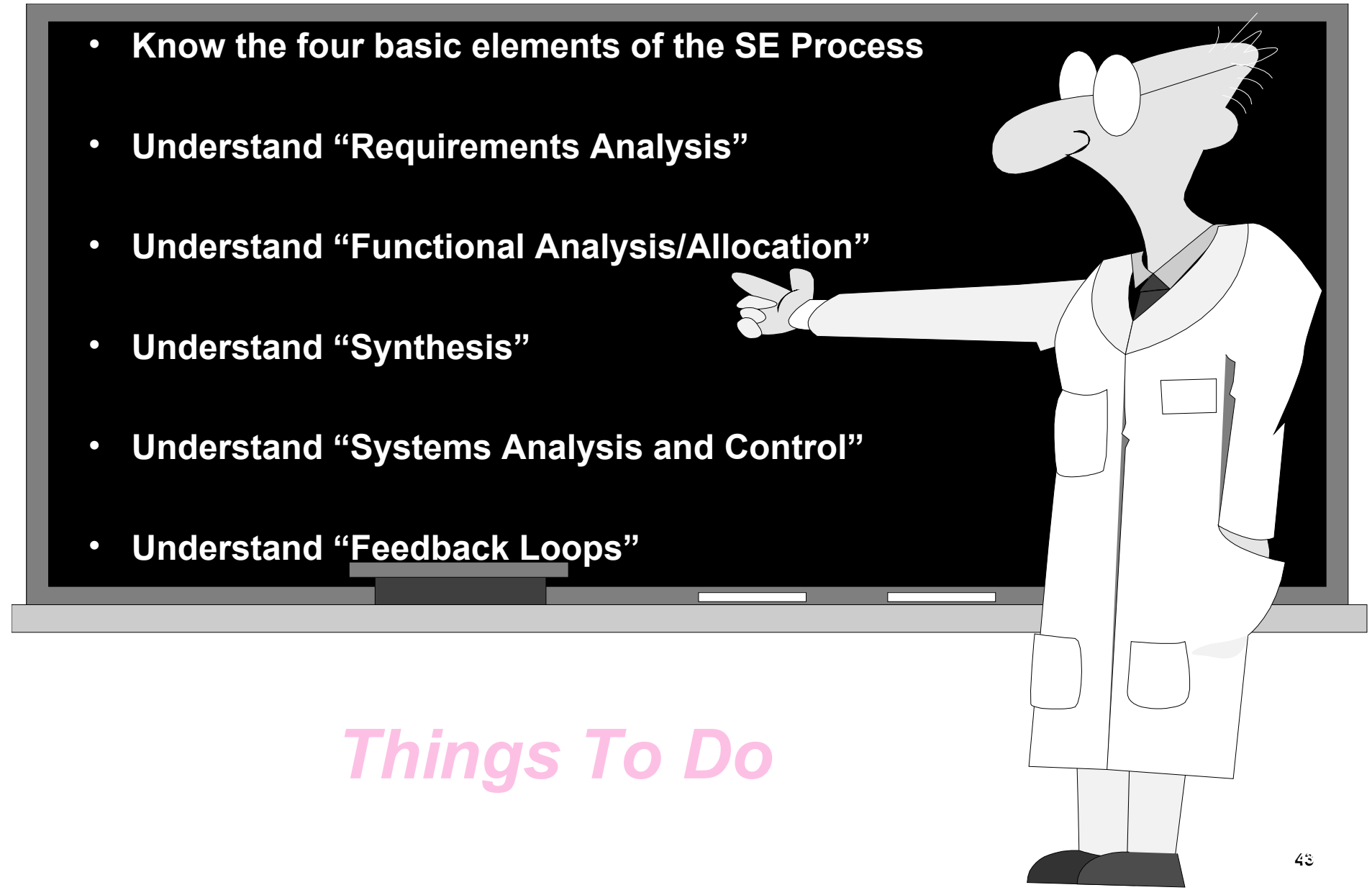
# Life Cycle Assessment



# Repair Time Assessment



# Systems Engineering Process



- Know the four basic elements of the SE Process
- Understand “Requirements Analysis”
- Understand “Functional Analysis/Allocation”
- Understand “Synthesis”
- Understand “Systems Analysis and Control”
- Understand “Feedback Loops”

*Things To Do*