An Analysis of TRL-Based Cost and Schedule Models

Bernard El-Khoury and Bob Kenley
Massachusetts Institute of Technology
17 May 2012

Overview

- **Introduction**
- **Theoretical Framework and Currently Available Models**
- **A New Framework for Cost and Schedule Joint Modeling**

Introduction

- **Technology Development under high uncertainty, with increasing cost/schedule/maturity constraints.**
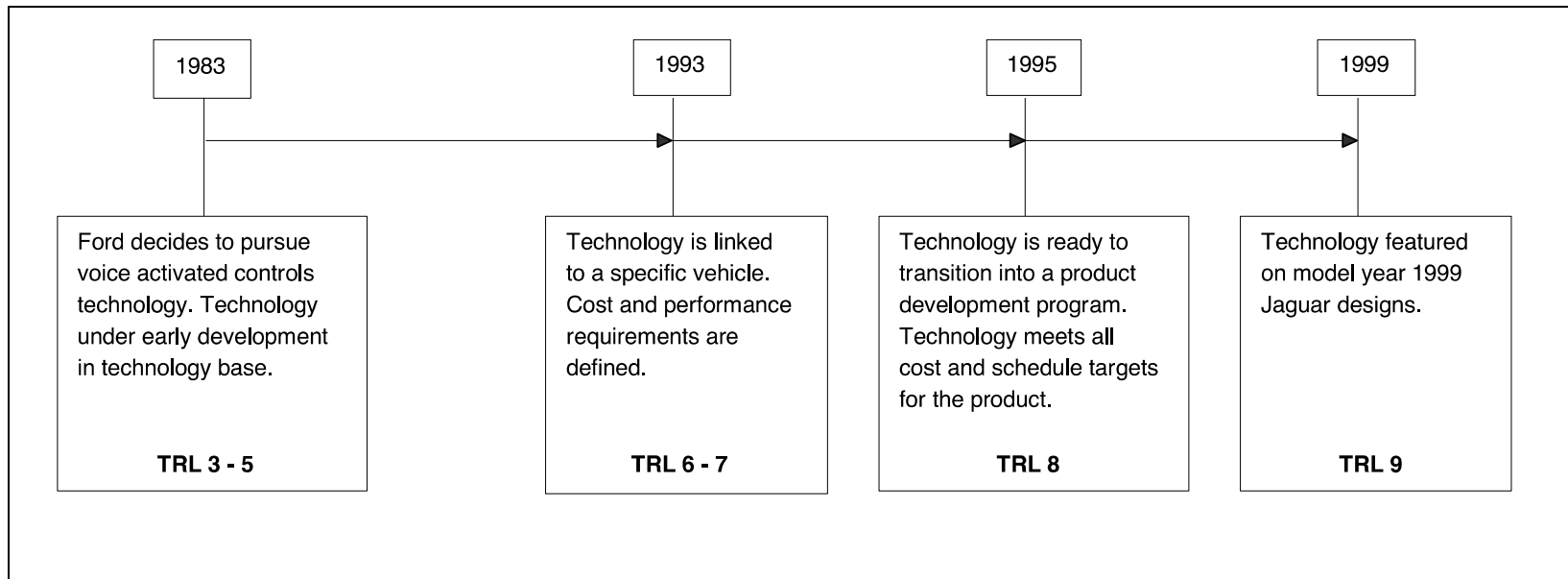- **Even more challenging for government agencies:**

htt

Technology Readiness Level Progression Example from GPS

US DoD R&D Budget Activity	TRL	Event Indicating Achievement of TRL	Cumulative Time to Reach TRL (yr)*
6.6 Operational Systems Development	9	Actual application "mission proven" through successful operations: GPS achieves full operational capability with full constellation of 24 Block II and Block IIA satellites.	22.7
6.4 Engineering and Manufacturing Development	8	Actual application completed and "mission qualified" through test and demonstration in an operational environment: DoD and Department of Transportation determines GPS system achieved the required assets available on orbit for initial operational capability.	21.4
6.4 Engineering and Manufacturing Development	7	Prototype demonstration in high-fidelity environment (parallel or shadow mode operation): Three GPS Block II satellites (required for triangulation) operational and tested with user equipment.	19.6
6.3b Demonstration and Validation	6	Prototype demonstration in a relevant end-to-end environment: GPS Block I satellite launched and tested with user equipment.	16.3
6.3a Advanced Technology Development	5	Module validation in relevant environment: Tests of GPS user equipment on simulated satellites.	14.1
6.2 Applied Research	4	Module validation in laboratory environment: successful research, development, and testing of initial Air Force and Navy satellites.	12.1
	3	Analytical and experimental critical function and/or characteristic proof-of-concept: TIMATION, the first three-dimensional space-based navigation system.	11.0
6.1 Basic Research	2	Technology concept and/or application formulated: TRANSIT, the first space-based navigation system.	6.0
	1	Basic principles observed and reported: Researchers at APL discovered that measurements of Doppler shift as Sputnik passed by were adequate to determine the entire satellite orbit. Frank McClure noted conversely, if the satellite orbit were known, position on the earth could be determined using these same Doppler measurements.	N/A

*Based on Smoker, R. and Smith, S. "Approach to Use of Selected Acquisition Reports for Measurement of TRLs and Associated System Cost Growth" 2008

Figure 2.3: Time Line for Ford's Development of Voice Activated Controls Technology

1983	1993	1995	1999
Ford decides to pursue voice activated controls technology. Technology under early development in technology base.	Technology is linked to a specific vehicle. Cost and performance requirements are defined.	Technology is ready to transition into a product development program. Technology meets all cost and schedule targets for the product.	Technology featured on model year 1999 Jaguar designs.
TRL 3 - 5	**TRL 6 - 7**	**TRL 8**	**TRL 9**

Between 1993 and 1994, based on discussions with customers, Ford developed cost and performance requirements for the technology. Ford has
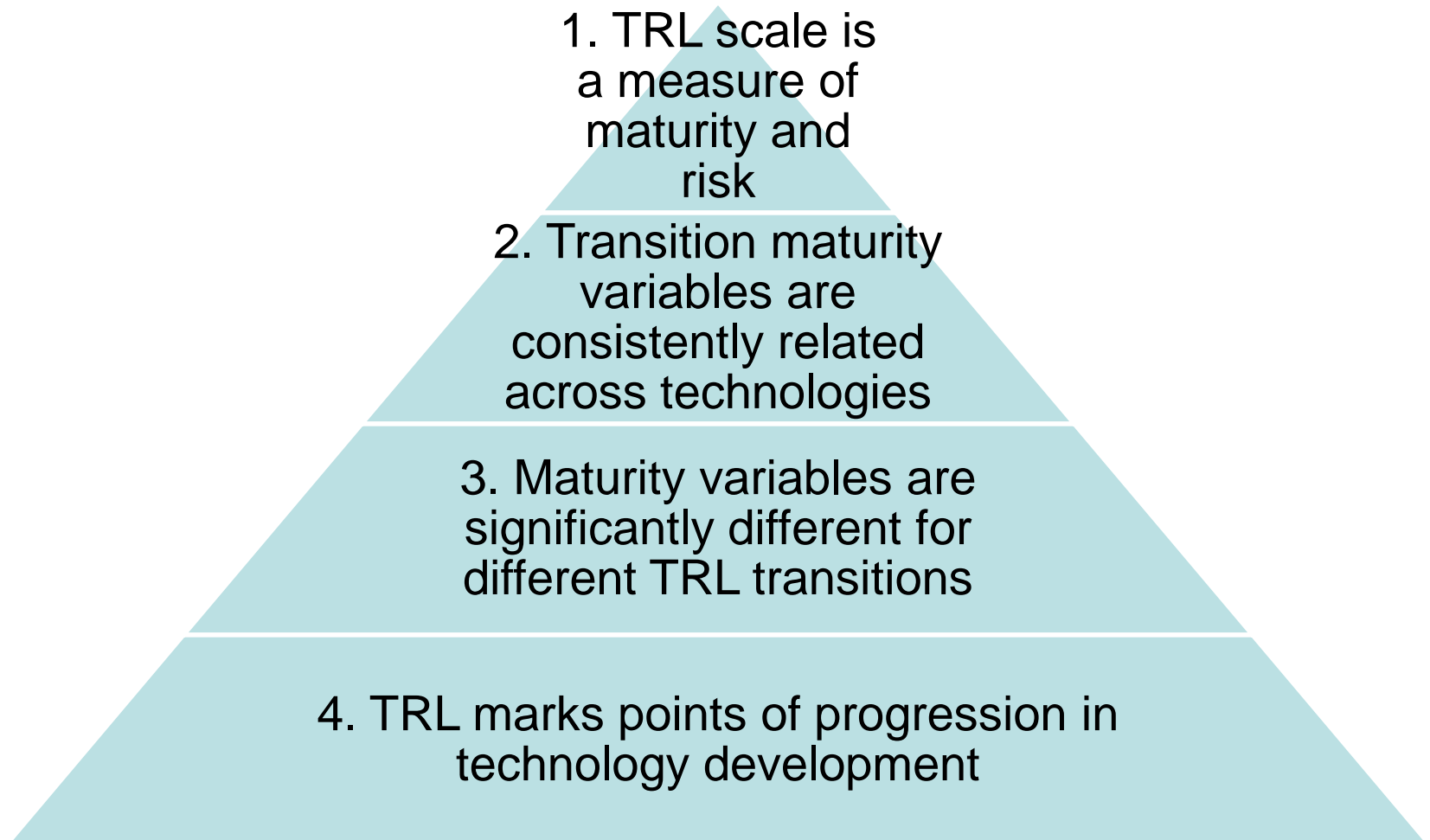
Page 28   GAO/NSIAD-99-162 Best Practices

16 years from TRL 3 to 9 comparable to 11.7 years for GPS

- **Using historical data, is it feasible to use TRL for technology development cost/schedule models?**

- **If yes, can we use TRLs to develop a dynamic programming or real options approach to managing technology?**

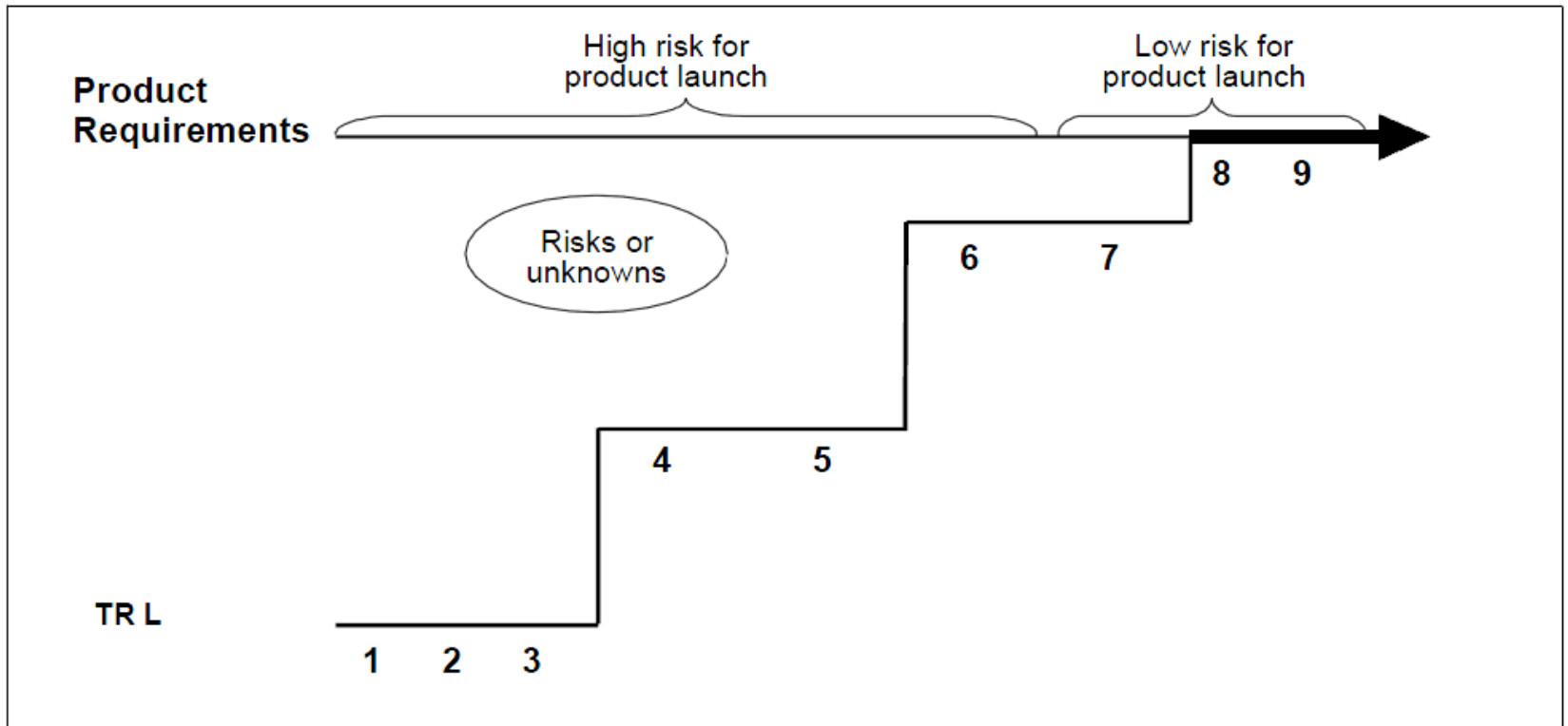# Theoretical Framework and Currently Available Models

Assumption Levels for the Framework

1. TRL scale is a measure of maturity and risk

2. Transition maturity variables are consistently related across technologies

3. Maturity variables are significantly different for different TRL transitions

4. TRL marks points of progression in technology development

Level 1 Assumption

TRL marks points of progression in technology development

High risk for product launch

Low risk for product launch

Product Requirements

Risks or unknowns

8   9

6   7

4   5

TR L

1   2   3

GAO, 1999, p.24

Level 2 Assumption

Maturity variables are significantly different for different TRL transitions
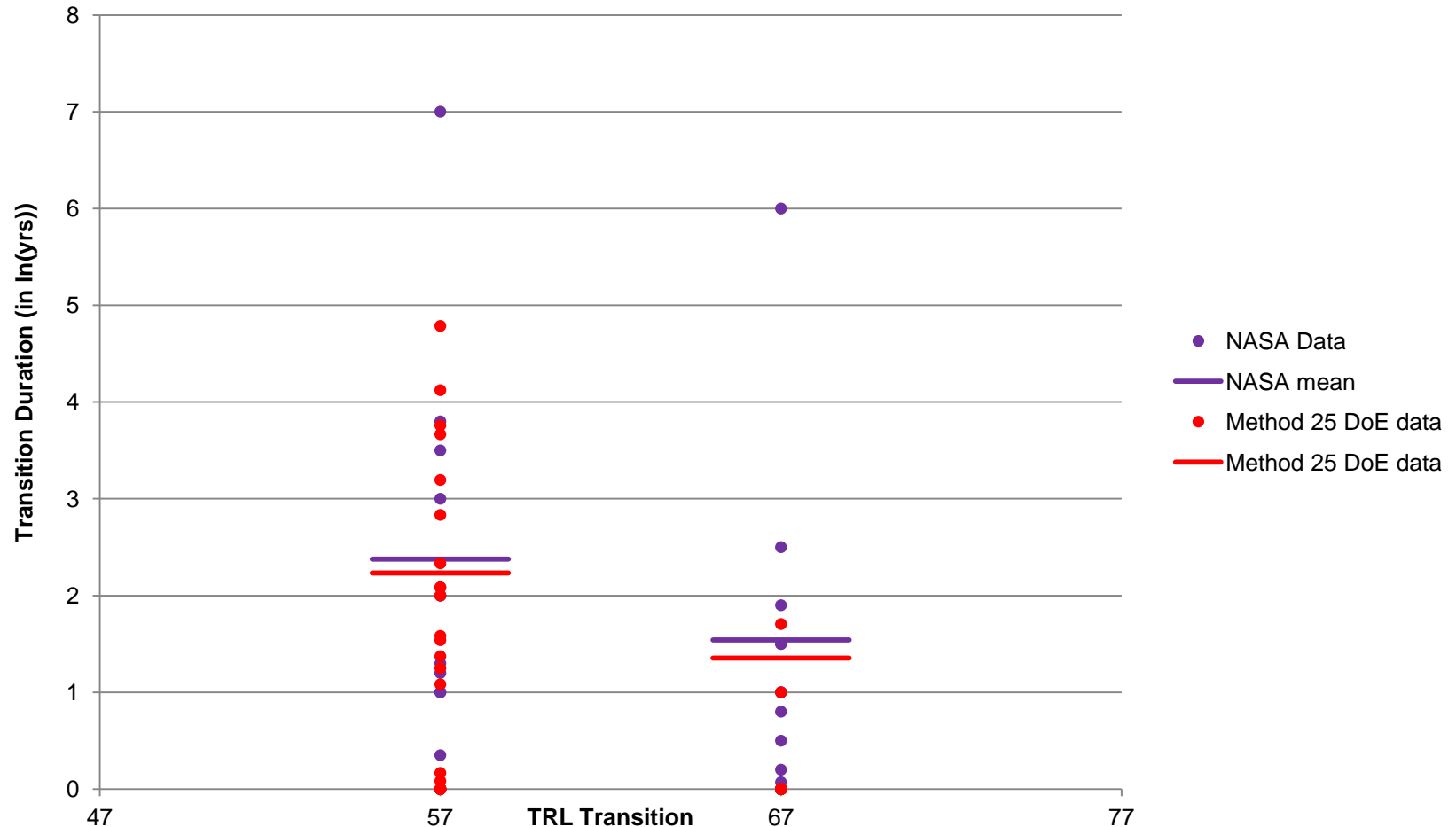
Transition	Carbon-6 Thermal Barrier	Direct To	Fiber Preform Seal	Low Emissions combustors	Nondestructive Evaluation	Tailless Fighter	Thrust Vectoring Nozzle	Electro Expulsive DeIcing	Engine Monitoring Systems	Flow Visualization	Fly-by-Light	GA Wing	Graphite Fiber Stator Vane Bushings (Tribology)	Particulate Imaging Velocimetry	Propfan development	Runway Grooves	Surface Movement Advisor	Supercritical Wing	Tiltrotor Technology
12	0.4	0.2	1	1	0.5	3	0.3	0.5	0.5	5	2.5	0.5	1.9	2	2.5	0.7	0.8	1.5	3
23	0.4	0.1	1.5	1	1	1	0.3	0.5	0.5	1	5	0.5	1.9	4	1	0.2	0.3	1	1
34	0.4	0.1	1.5	1	1	1	0.4	1	0.5	3.5	7.5	0.5	1.9	2.5	1.5	0.2	0.3	1	1
45	0.5	1.1	1.5	2	1	1	2	1	0.5	1	4	3	1.9	3	2.5	0.2	0.35	1	1
56	0.2	0.1	6	4	1	2	2	1	1	0.5	1.5	0.5	1.9	0.5	1	0.2	0.35	1	22
67								6	0	0.5	1.5	1.5	1.9	0.8	2.5	1	0	1	8
78								0.5	5	0.5	1.5	3	1.9	0.3	6	1	1.2	12	0
89								5.5	0	0.5	1.5	4	1.9	0.3	1	1	0.1	1	11
Criteria A	4	3	4	4	1	2	2	2	2	2	2	1	4	4	4	3	3	1	2
Criteria B	1	0	1	1	0	1	1	1	0	1	1	1	0	1	1	1	1	0	1
Criteria C	2	3	3	3	2	6	6	3	2	3	1	3	3	3	1	2	1	3	3
Criteria D	0	0	1	1	1	1	1	0	0	0	1	0	0	0	1	0	1	0	1
Criteria E	0	0	0	1	1	1	1	1	0	1	0	1	0	1	1	1	0	1	1
Criteria F	0	0	0	0	1	0	1	0	1	1	1	1	0	1	1	1	1	1	1

Bootstrapping Used to Generate Median

- **Iterated smoothed bootstrapping**

- ***Iterated*: to eliminate bias**
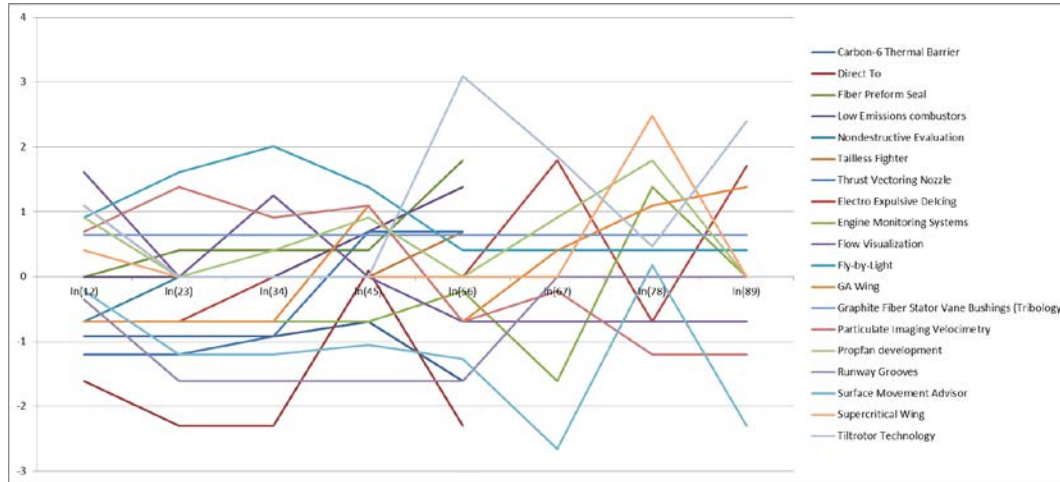
- ***Smoothed*: to look nice for the program managers**

Excel function

Level 3 Assumption

Transition maturity variables are consistently related across technologies

Correlation Analysis of the NASA Dataset (log)

Correlation Table	ln(12) log data	ln(23) log data	ln(34) log data	ln(45) log data	ln(56) log data	ln(67) log data	ln(78) log data	ln(89) log data
ln(12)	1.000	0.660	0.752	0.312	0.149	-0.074	-0.135	-0.606
ln(23)	0.660	1.000	0.905	0.673	0.385	0.043	-0.170	-0.350
ln(34)	0.752	0.905	1.000	0.639	0.351	0.113	-0.256	-0.265
ln(45)	0.312	0.673	0.639	1.000	0.490	0.344	0.006	0.073
ln(56)	0.149	0.385	0.351	0.490	1.000	0.325	0.331	0.307
ln(67)	-0.074	0.043	0.113	0.344	0.325	1.000	-0.092	0.633
ln(78)	-0.135	-0.170	-0.256	0.006	0.331	-0.092	1.000	0.180
ln(89)	-0.606	-0.350	-0.265	0.073	0.307	0.633	0.180	1.000

Forecasting Methods

- **Fixed Estimates**
  - **Mean**
  - **Median**
  - **Regression**
- **Influence Diagrams**
  - **ID (full)**
  - **ID (frag 4-3)**
  - **ID (frag 5-2)**
  - **ID bounded**

- **Extrapolation**
  - **Moving average**
  - **Exponential smoothing**
  - **Exponential smoothing with trend**
- **Regression**
  - **Full autoregression**
  - **Full autoregression (bounded)**
- **Other**
  - **Closest neighbor**

Objective Forecasting Error Function
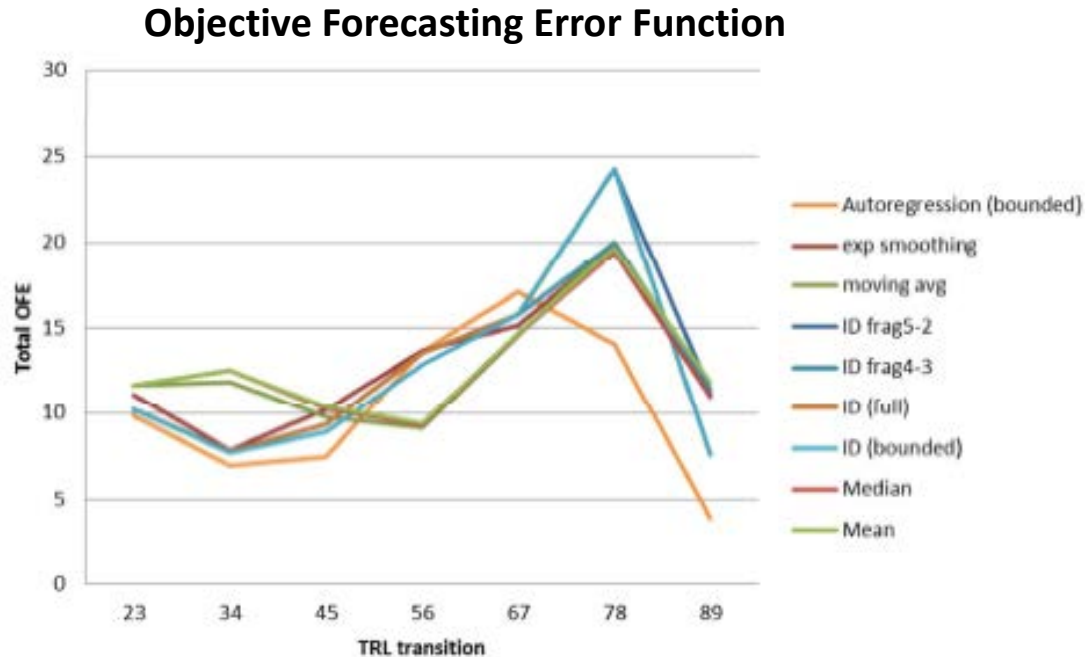
- **Some "smart" methods performed better than fixed estimates both in total error and in robustness**
- **Smart models might have "overlearned" this particular dataset**
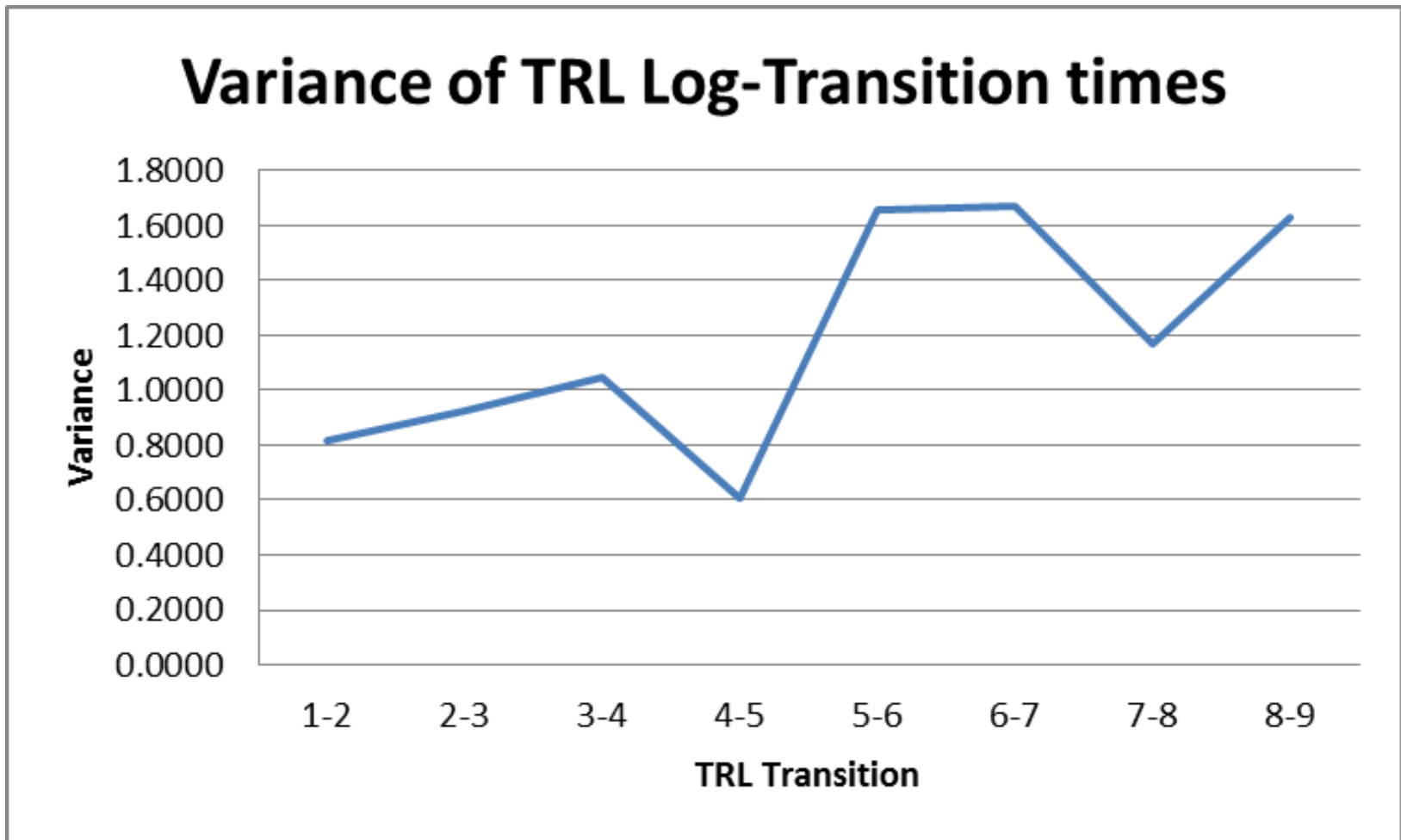
Level 4 Assumption

TRL scale is a measure of maturity and risk

Cost modeling comparison
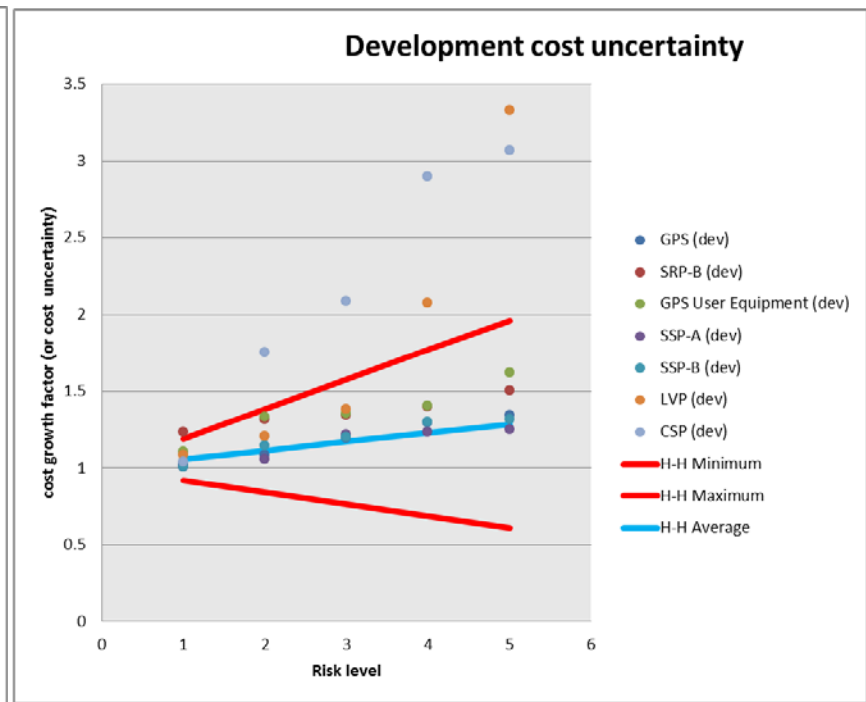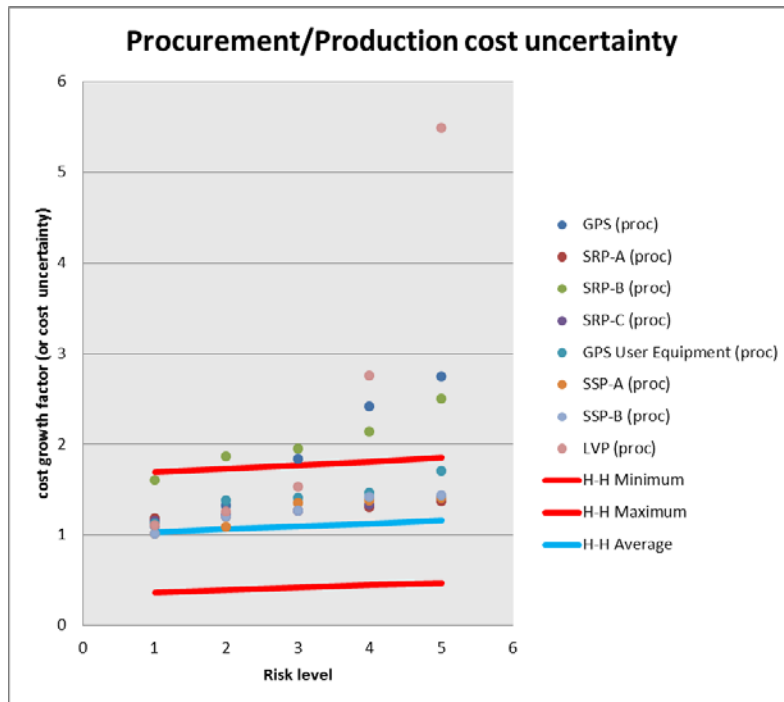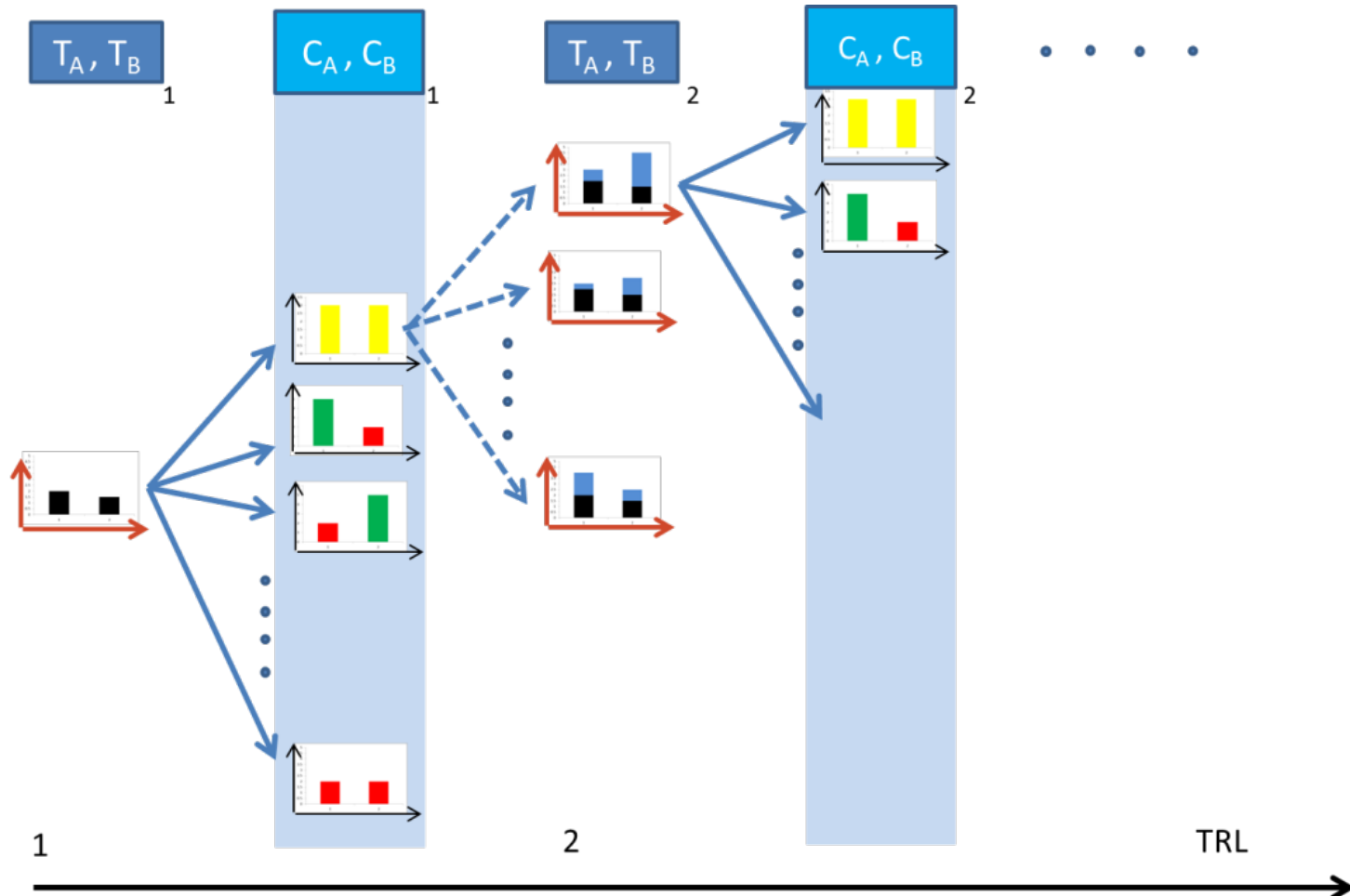
A New Framework for Cost and Schedule Joint Modeling

- **Classic multivariate distributions do not work**
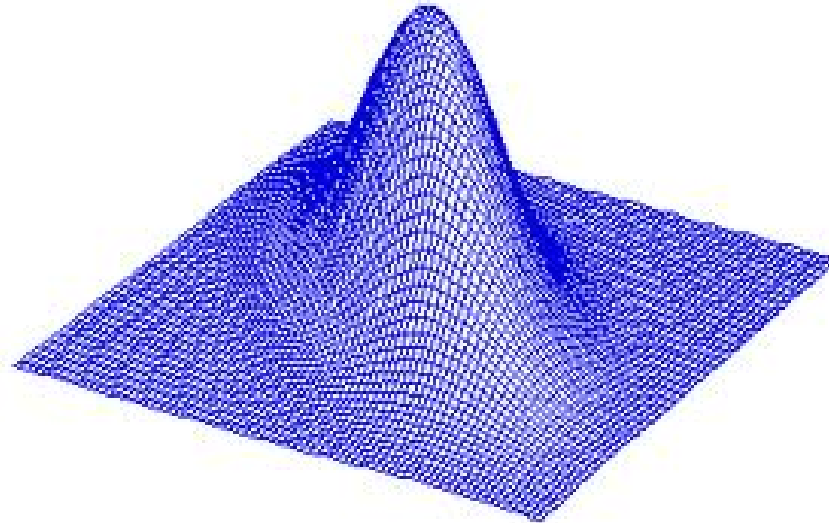
- **We need to include decision**
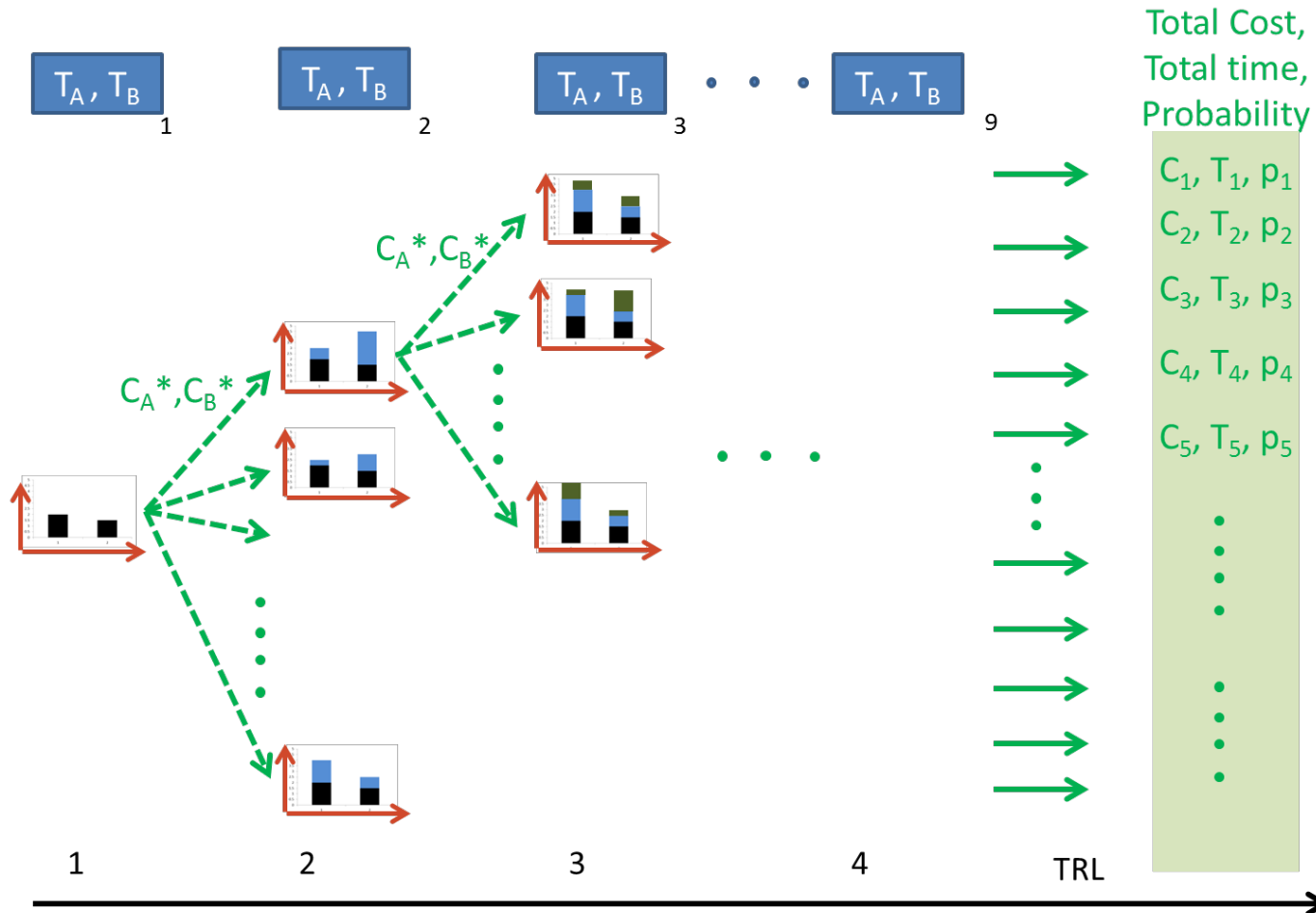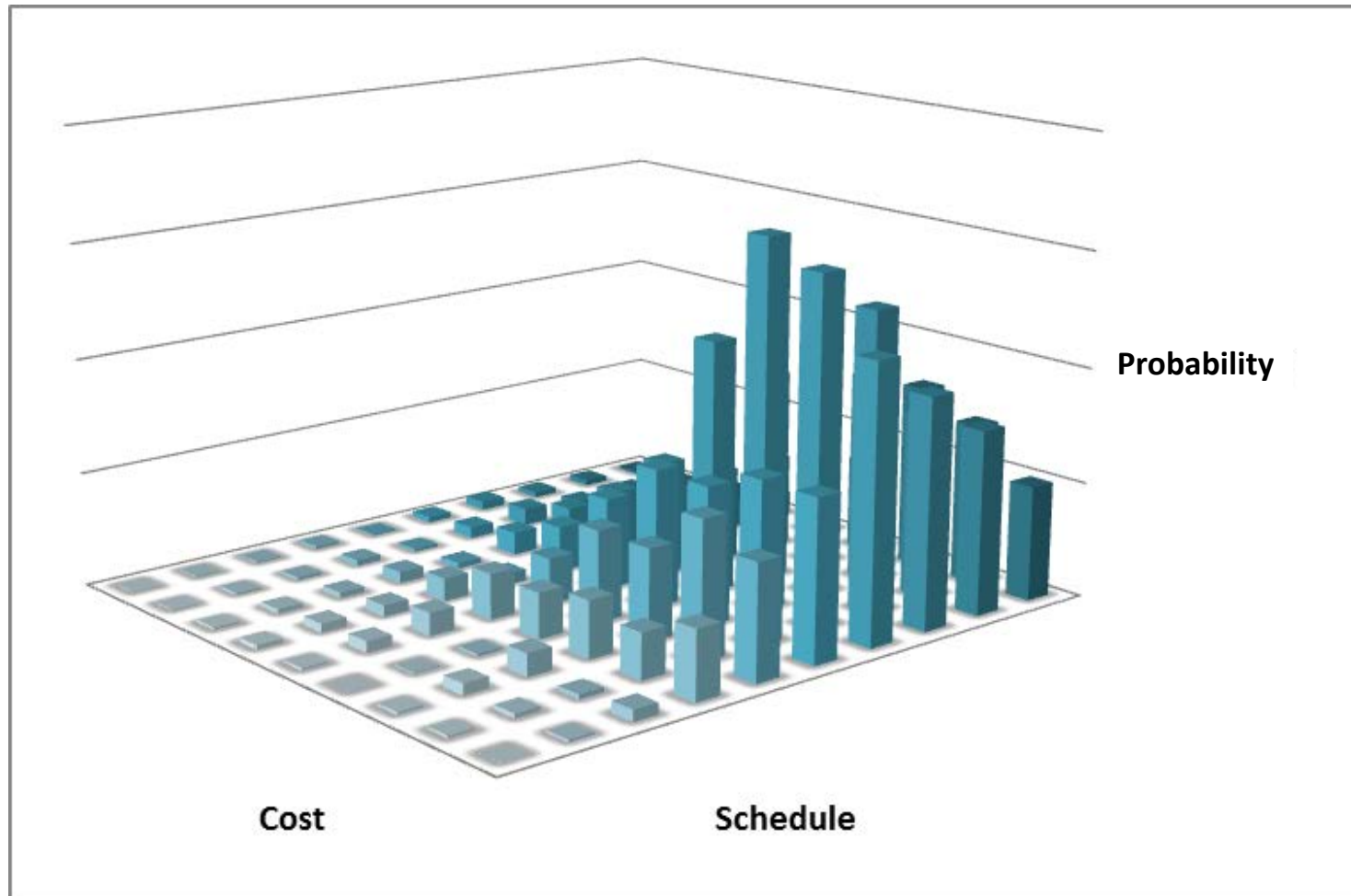
T_A, T_B 1 T_A, T_B 2 T_A, T_B 3 $\cdots$ T_A, T_B 9

C_A*, C_B*

C_A*, C_B*

Total Cost, Total time, Probability

C_1, T_1, p_1

C_2, T_2, p_2

C_3, T_3, p_3

C_4, T_4, p_4

C_5, T_5, p_5

1   2   3   4   TRL

Dynamic Programming Approach with Time as Period Variable

- **Questions ?**