Grabbing the Air Force by the Tail:
Applying Strategic Cost Analytics to Understand and Manage Indirect Costs

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Alan W. Johnson (Advisor)

Air Force Institute of Technology
Department of Operational Sciences

August 4, 2015

Committee Members

Committee Members:

- Dr. Alan Johnson (Chair)
- Dr. Edward White (AFIT/ENC)
- Dr. Jeffery Weir (AFIT/ENS)
- Dr. Mark Gallagher (AF/A9)

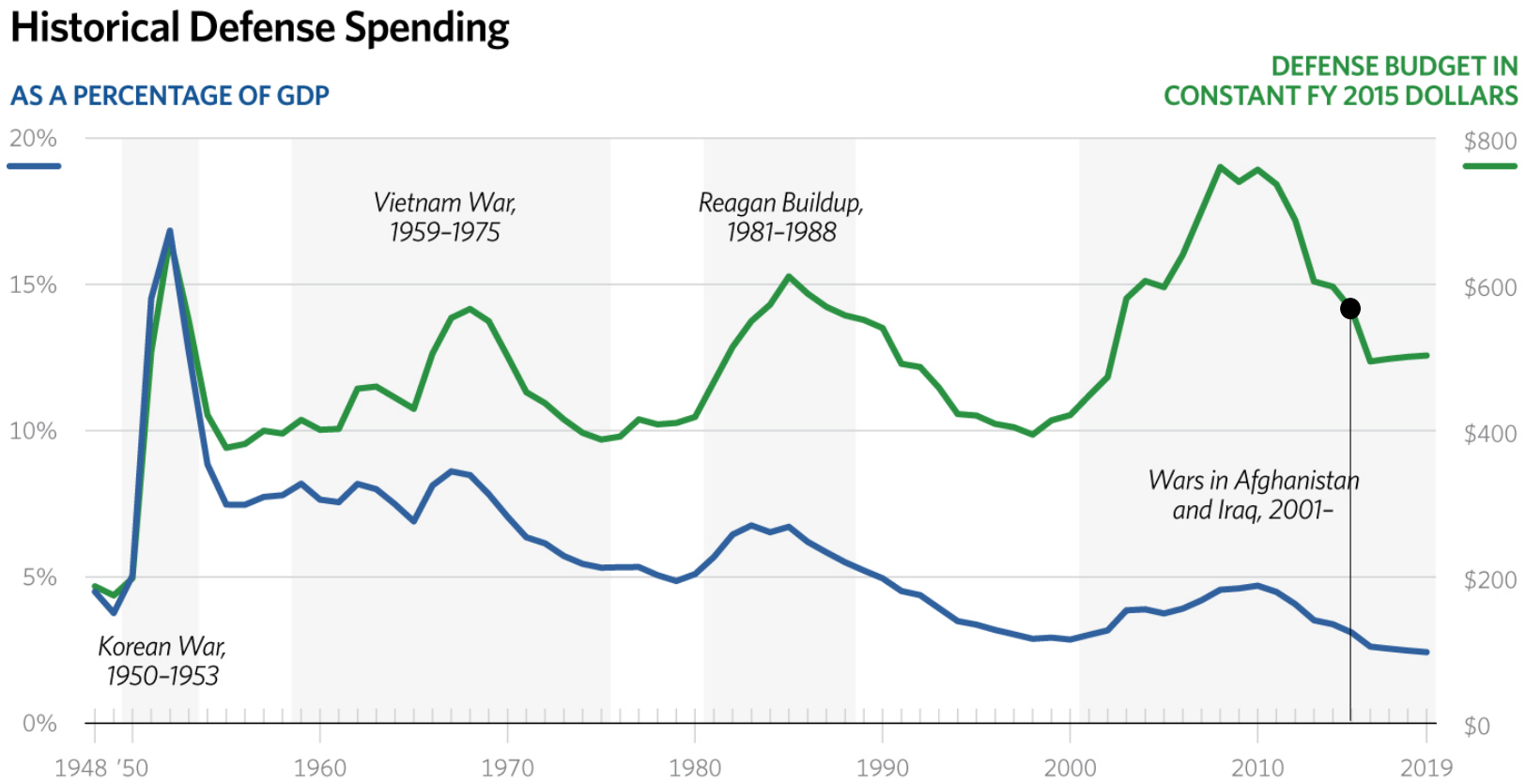
Dean's Representative:

- LtCol J. Daniel Ritschel, Ph.D

Agenda

Background

The DoD finds itself in an economically challenging situation:



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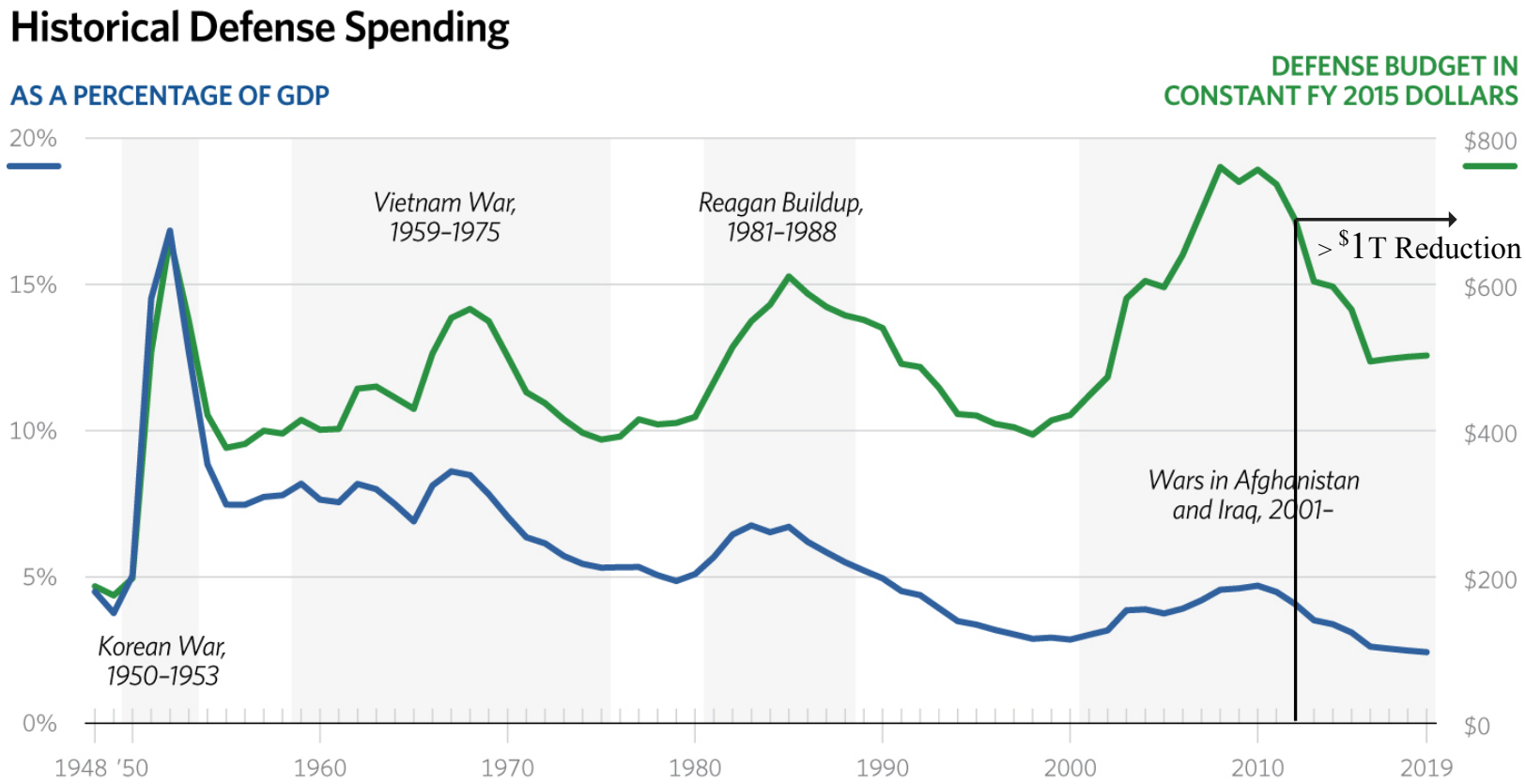

Background

Cost reduction strategies often focus on front-line mission resources (aka *"Tooth"*)

Estimated Impacts of Sequestration-Level Funding – FY 2015 Defense Budget

At sequestration-level funding, major reductions from the FY 2015-2019 President's Budget request would include:

- Reducing one squadron of F-35 aircraft (cutting acquisition of 15 aircraft would prevent fielding the squadron)
- Eliminating the fleet of KC-10 tankers
- Cutting operational surface combatant ships by 7 in FY 2019
- Cutting procurement of 8 ships across the FYDP
- Divesting the Global Hawk Block 40 fleet
- Divesting the Predator fleet beginning in FY 2016
- Eliminating planned purchases of Reaper aircraft in FY 2018 and FY 2019

Background

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AIR, CONGRESS, LAND, SEA

JLTV, EELV, A-10, F-35 All On Line At SASC

By COLIN CLARK
on March 17, 2015 at 9:32 PM

US Will Cut Air Force Nuke Missile Force by 50

27 31 comments

Associated Press | Apr 08, 2014 | by Robert Burns

DoD News

NEWS ARTICLE E-MAIL A COPY | PRINTER

James: New Acquisition Initiative Aims to Cut Costs

By Jim Garamone
DoD News, Defense Media Activity

Pentagon Reconsidering Total F-35 Buy, Dunford Says

JULY 9, 2015 BY MARCUS WEISGERBER

2/18/2015

Air Force to Divest U-2, Global Hawk Block 40 Should Sequestration Return

By Sarah Sicard

Air Force May Scrap KC-10 Tanker Fleet: General

By Brendan McGarry | Tuesday, September 17th, 2013 4:46 pm
Posted in Air, Policy

Background

Cost reduction strategies often focus on front-line mission resources (aka *"Tooth"*)

An underemphasized contributing source of costs are mission support activities (aka *"Tail"*)

Problem

Lack of research focusing on the advancement of knowledge behind the economics of, and analytic techniques applied to, tail activities for cost management purposes.

- Horowitz & Borga (1999)
- Campbell & Velasco (2002)
- McGrath (2007)
- Defense Business Board (2008)
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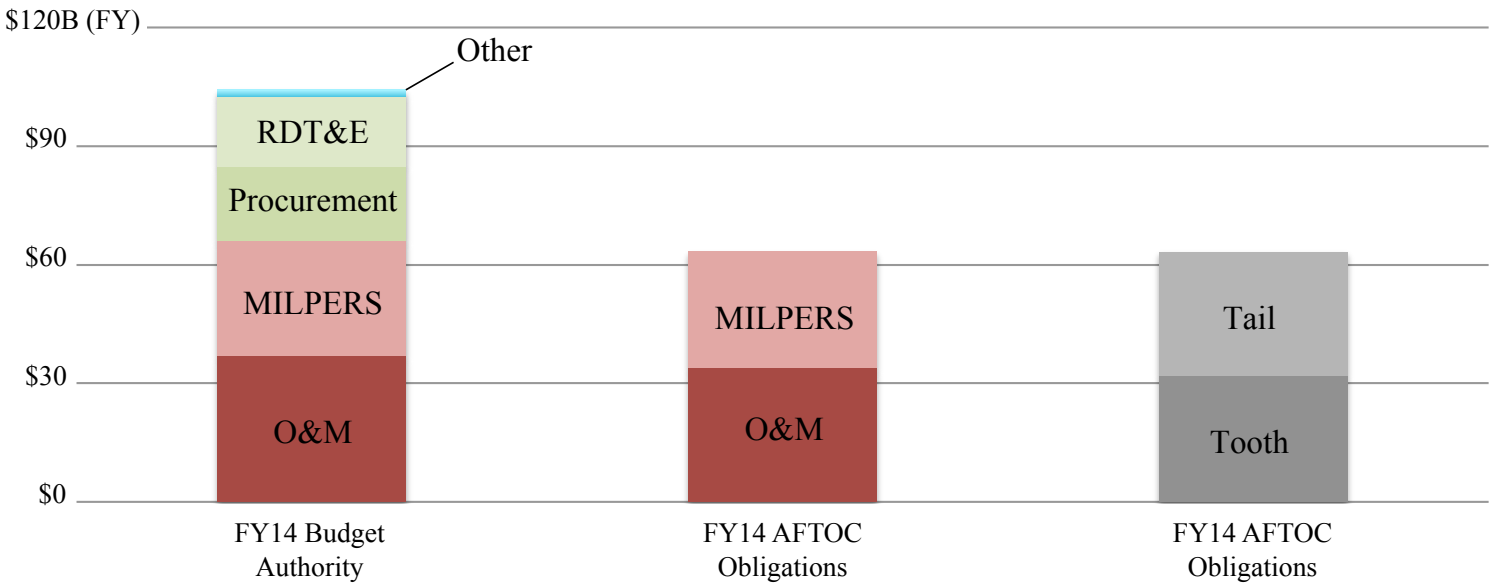
Why do we care?

- Annual DoD *Tail* $\approx$ 40% of TOA [1, 2]
- Annual AF *Tail* $\approx$ 50-60% of sustainment TOA [3]



Source: Author's assessment of FY14 AF Budget Overview prepared by SAF/FMB and 2014 AFTOC data. Costs categorized as *"Tooth"* or *"Tail"* are categorized as Direct or Indirect within AFTOC.

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Strategically managing tail costs offers opportunities for substantial cost savings

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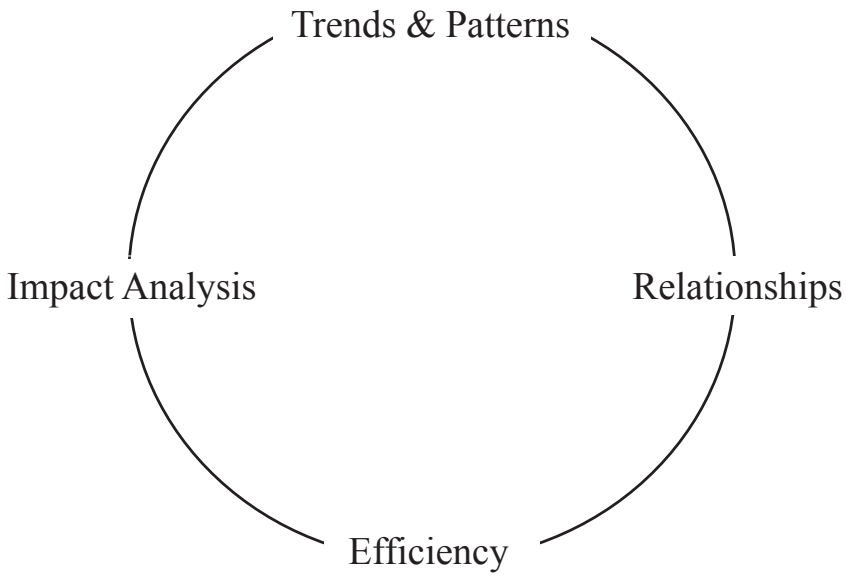
Strategically managing tail costs offers opportunities for substantial cost savings; however, this requires fundamental understanding of the underlying cost behavior and relationships...which requires the application of analytical rigor.

Research Objectives

Establish a foundation for applying analytical rigor to advance the knowledge and management of Air Force *tail* costs.



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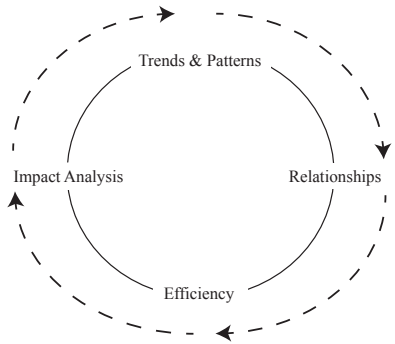
1. Provide a comprehensive understanding of strategic analytic practices for cost management purposes
2. Identify *tail* cost trends across the enterprise
3. Distinguish historical relationships between the *tooth* and *tail*
4. Measure the relative efficiency of *tail* activities
5. Establish a decision support tool for *tooth-to-tail* impact analysis



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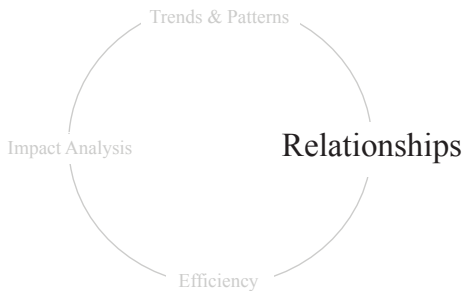

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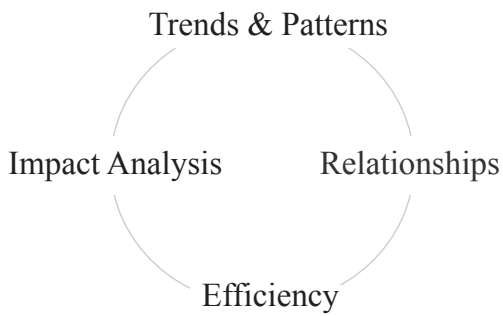

Motivation

Different approaches and conceptual frameworks for understanding strategic analytics for cost management purposes are found in operations research, economics, strategy, and accounting literature.

- Strategic cost management [24]
- Activity-based costing [25]
- Product cost estimating [26]
- Cost of quality [27]
- Supply chain perspective [28]

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- Supply chain perspective [28]

How are strategic analytics currently used for cost management purposes?

Objective

Create a framework for how advanced analytics are currently being applied across an organization's value chain[1] *for cost management purposes.*

1. Identify analytic techniques being applied
2. Identify the types of data used
3. Reconcile under the theory of *Competitive Advantage* [4]

[1] In this research we use the terms value chain and supply chain interchangeably.

Methodology

Data

- AFIT's 360 Literature Search Tool
- 278 papers from 88 journals spanning 10 fields
- 1990-2012

Analytic Approach

- Review of literature

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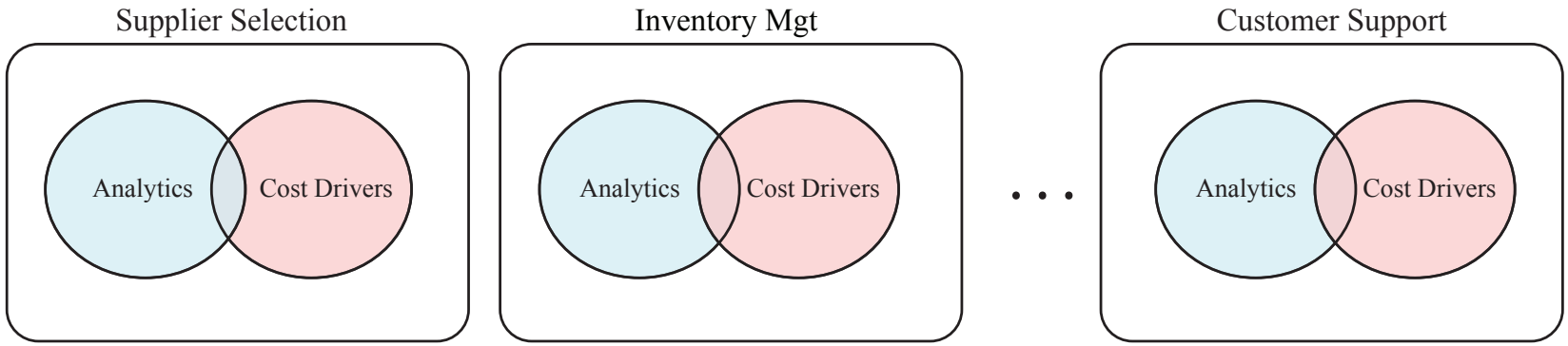

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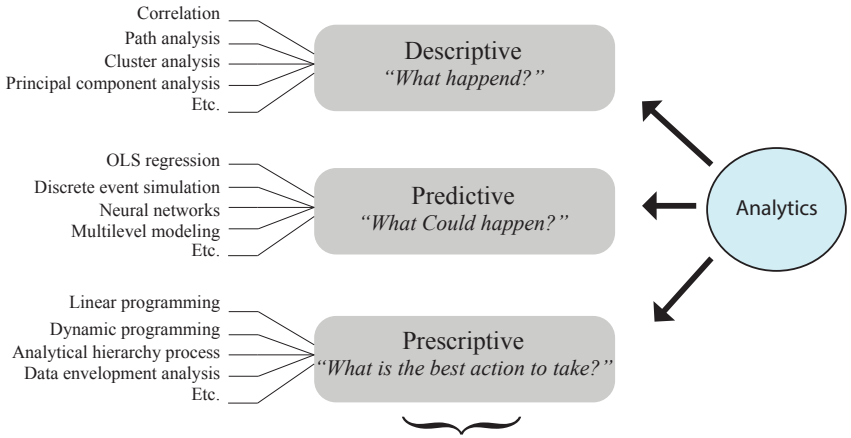
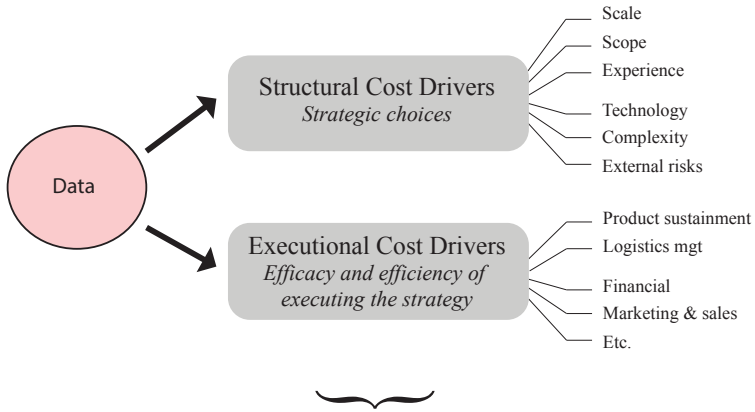


Expanded onto INFORMS analytic categorization



Combined and reconciled current cost driver taxonomies

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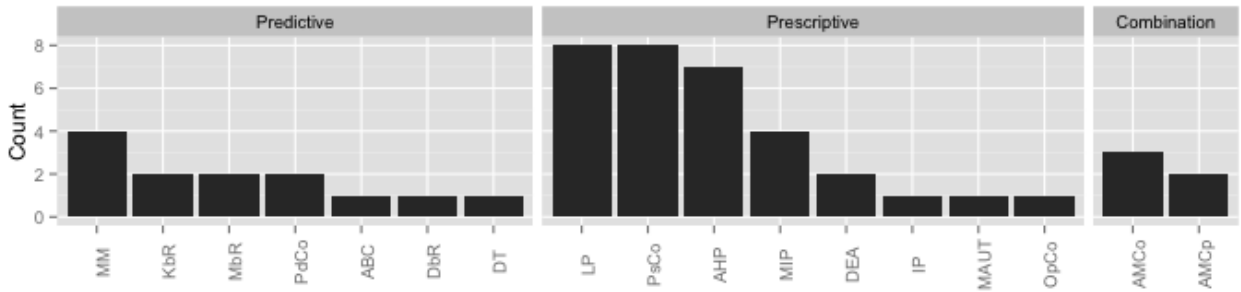

Supplier Selection: Analytic Techniques Employed

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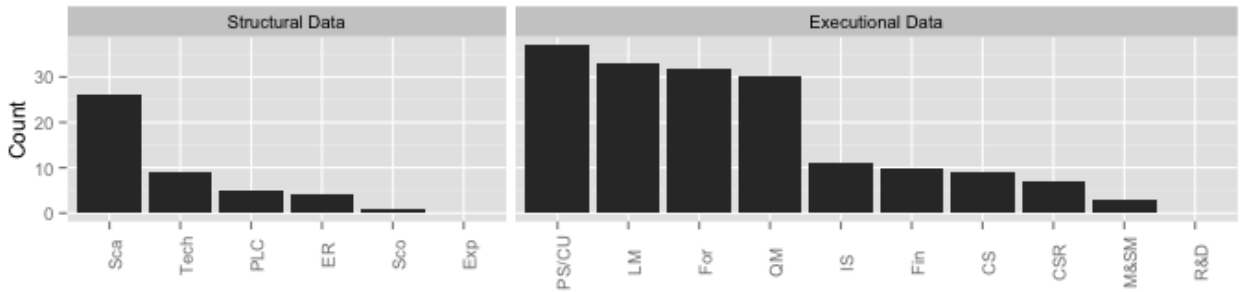

Supplier Selection: Data used as Cost Drivers

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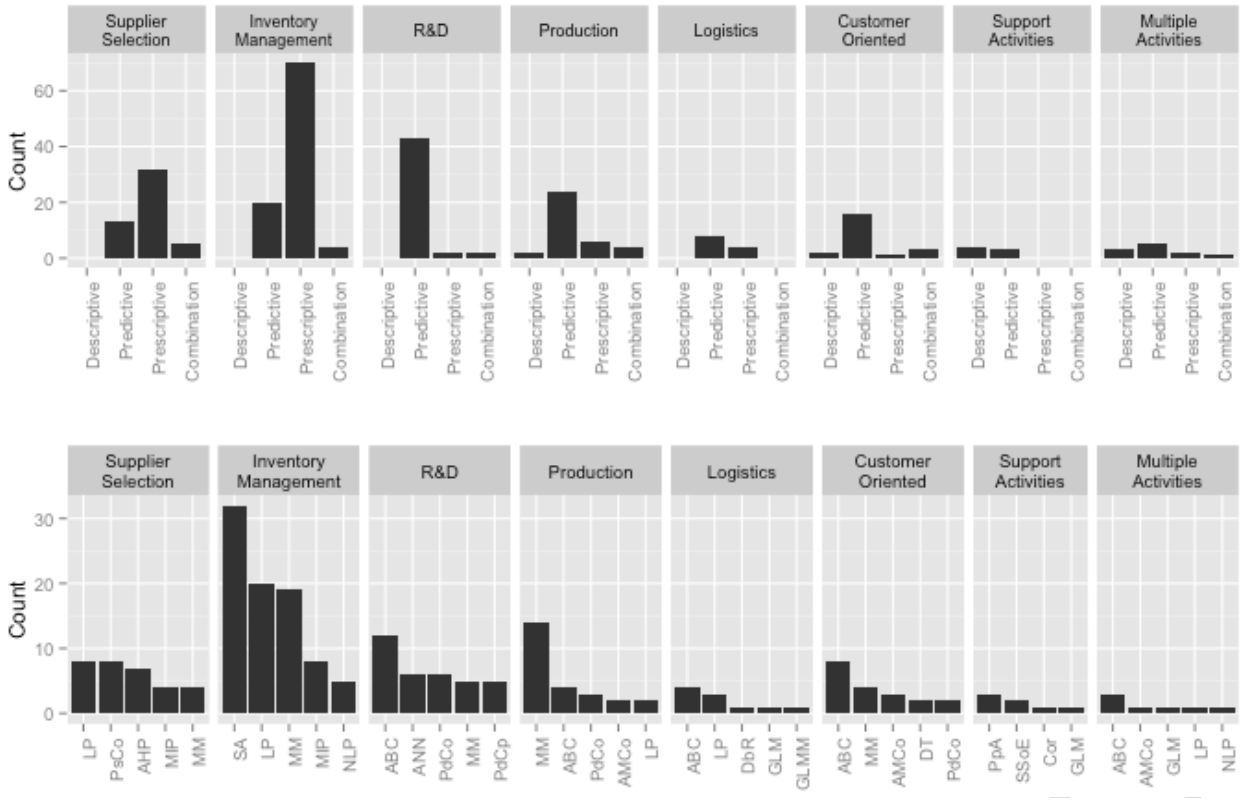
Analytic Approach

- Review of literature

	Analytic Approach			Structural Data						Executional Data									
Reference	Analytic Methodology	Analytic Classification	Analytic Technique	Scale	Scope	Experience	Technology	Product Line Complexity	External Risks	R&D Specific	Quality Management	Product Sustainment / Capacity Utilization	Logistics Management	Forecasting	Financial	Marketing & Sales Management	Customer Sustaining	Infrastructure Sustaining	Corporate Social Responsibility
Berger & Zeng (2006)	Pd	Cf	DT	X					X			X		X	X				
Dogan & Sahin (2003)	Pd	Co	PdCo								X	X	X					X	
Weber et al. (2010)	Pd	Co	PdCo								X		X					X	
Humphreys et al. (2003)	Pd	DSS	DbR				X					X							X
Micheli (2008)	Pd	DSS	KbR						X			X			X				
Micheli (2009)	Pd	DSS	KbR						X			X			X				
Akinc (1993)	Pd	DSS	MbR	X							X	X							
Sadrian & Yoon (1994)	Pd	DSS	MbR	X				X				X		X					
Roodhooft & Konings (1997)	Pd	Pm	ABC								X	X	X	X					
Ganeshan et al. (1999)	Pd	Pm	MM	X									X	X					
Piplani & Viswanathan (2003)	Pd	Pm	MM		X								X	X				X	
Laaksonen et al. (2009)	Pd	Pm	MM	X								X		X				X	
Vanteddu et al. (2011)	Pd	Pm	MM	X								X		X					
Ghodsypour & O'Brien (1998)	Ps	Co	PsCo								X	X	X	X			X		
Hammami et al. (2003)	Ps	Co	PsCo								X	X		X					
Wang et al. (2004)	Ps	Co	PsCo	X								X	X	X	X				
Wadhwa & Ravindran (2007)	Ps	Co	PsCo	X							X	X		X					
Kull & Talluri (2008)	Ps	Co	PsCo	X							X	X	X	X					
Demirtas & Ustun (2009)	Ps	Co	PsCo	X							X	X	X	X	X				

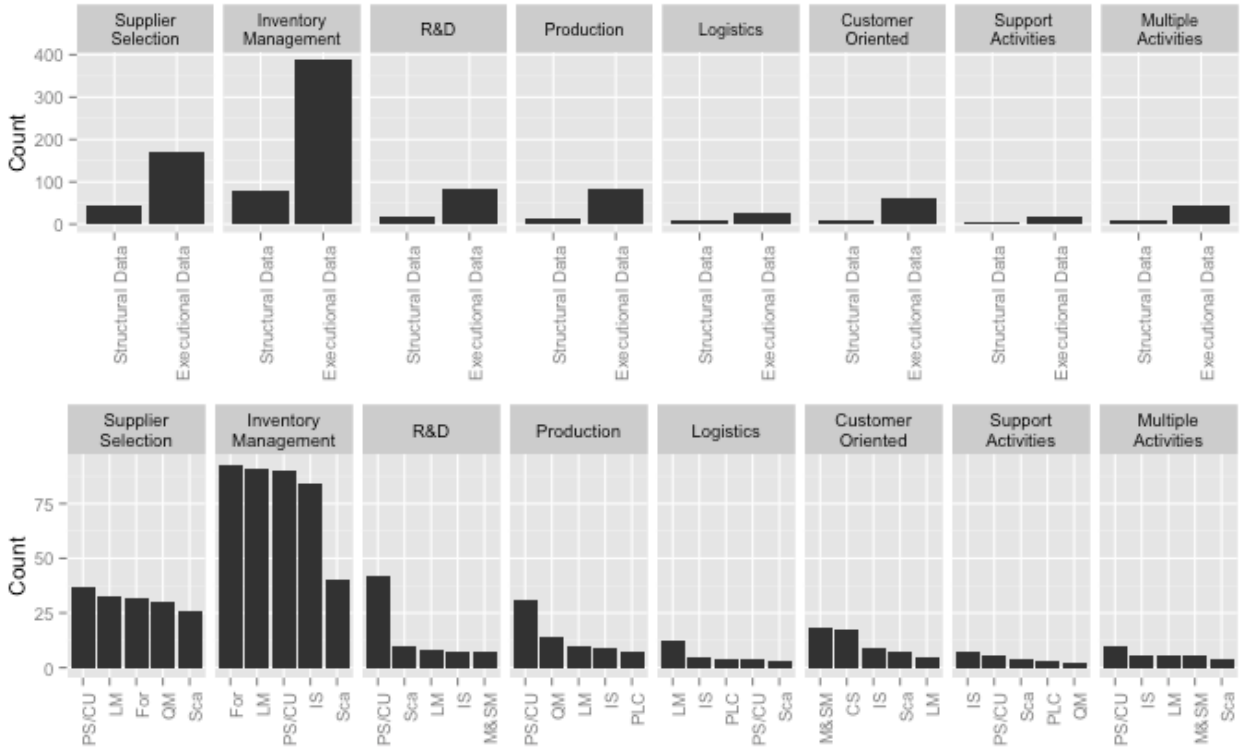
Results

Figure: Overall results for analytic methodologies (*top*) and Top 5 analytic techniques (*bottom*) applied across the supply chain



Results

Figure: Overall results for strategic cost drivers (*top*) and Top 5 types of data (*bottom*) used across the supply chain



Contribution

The results provide:

- Practical advancements:
  - Illustrate technical expertise and data leveraged for strategic cost analytics across the supply chain
  - Provides the big picture of how and where analytics and data are used across an enterprise
- Theoretical advancements:
  - Organizes the broad literature base under the concept of *Strategic Cost Analytics*
  - Establishes a common framework to stratify analytics and data across multiple domains
  - Identifies how and where analytics and data application can improve across an enterprise

Original Contribution

Creates a framework for how strategic cost analytics are currently being applied across an organization's value chain.

Presentation Boehmke, B.C. & Johnson, A.W. (2014). "Understanding Strategic Cost Analytics Across the Supply Chain." Institute of Industrial Engineering Annual Conference, Montreal, Canada.

Publication Boehmke, B.C., Johnson, A.W., Weir, J.D., White, E.D. & Gallagher, M.A. (2015). "Understanding Strategic Cost Analytics Across the Supply Chain." *Proceedings of the INFORMS: Cincinnati-Dayton 2014 Fall Technical Symposium, (Proposed Submission).*

Motivation

Bending the Cost Curve becoming the popular jargon for policy-makers:

- Health care [5, 6, 7, 8, 9, 10, 11, 12]
- Housing development [13]
- Climate change [14]
- Air Force [15]

"Which curve? Several cost trends are of interest to policymakers, and even though they are related, proposals might not have the same effects on each one." - Douglas Elmendorf, CBO Director

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Conventional growth modeling approaches give a single average growth estimate for a sample of individual growth trajectories [20]

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Often resorts to analyzing individual cost trends

Objective

Establish an approach to identify underlying cost curve behavior, and the pervasiveness of the behavior, across an enterprise.

1. Identify the existence of homogenous base-level cost curves[2]
2. Identify the bases affiliated with these cost curves
3. Identify the magnitude of these cost curves

[2] For illustrative purposes this research focuses on AF support costs.

Methodology

Data

- Data source: AF Total Ownership Cost (AFTOC) database & AF/A7C
- Cost categories: Manpower, Facility (sustainment & utilities), Discretionary
- Bases assessed: 58 U.S.-based active duty bases assessed
- Time period assessed: 1996-2014
- OCO costs removed and inflation adjusted (BY14 $)

Analytic Approach

- Non-parametric k-means clustering algorithm for longitudinal data

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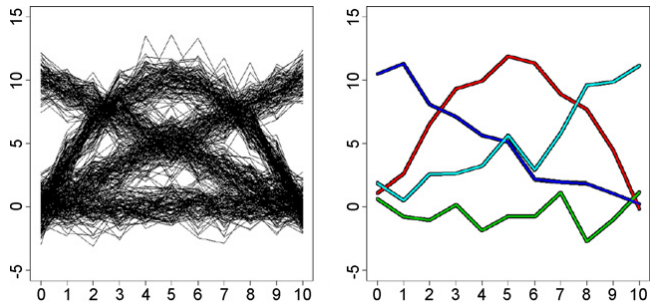


Analytic Approach

Distance measure:

$$Dist^E(y_i, y_m) = \sqrt{\sum_{j=1}^{t}(y_{ij} - y_{mj})^2} \tag{1}$$

- For subject i, the sequence of cost observations noted as $y_{i1}, y_{i2}, \ldots, y_{it}$ is called its cost trajectory
- We run the algorithm for $k = 2, 3, 4, 5$ and 6 clusters and, for each k cluster, we perform 20 iterations each time varying the initial seed to minimize the chance of converging to a local maximum

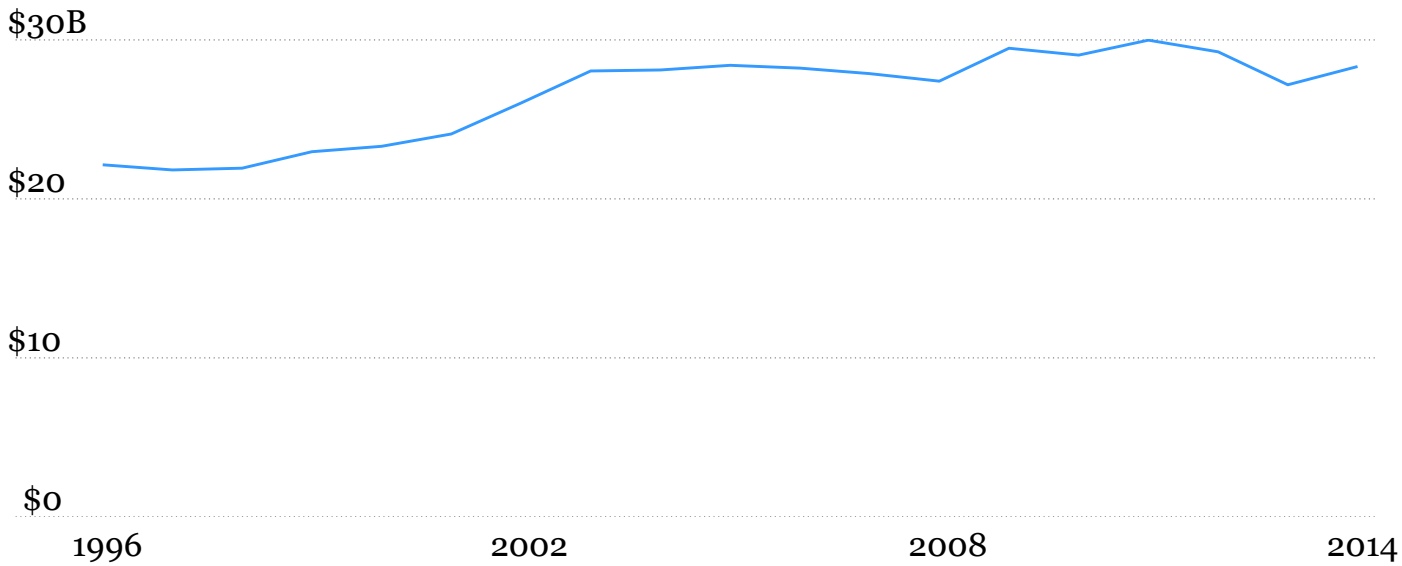
Validity measure:

$$C(k) = \frac{SS_B}{SS_W} \times \frac{(N-k)}{(k-1)} \tag{2}$$

- Primary criterion used is the Caliński & Harabatz criterion $C(k)$ [21]
- Two other criterions (Ray & Turi [22] and Davies & Bouldin [23]) along with visual assessment validated results

Total Assessed Support Costs

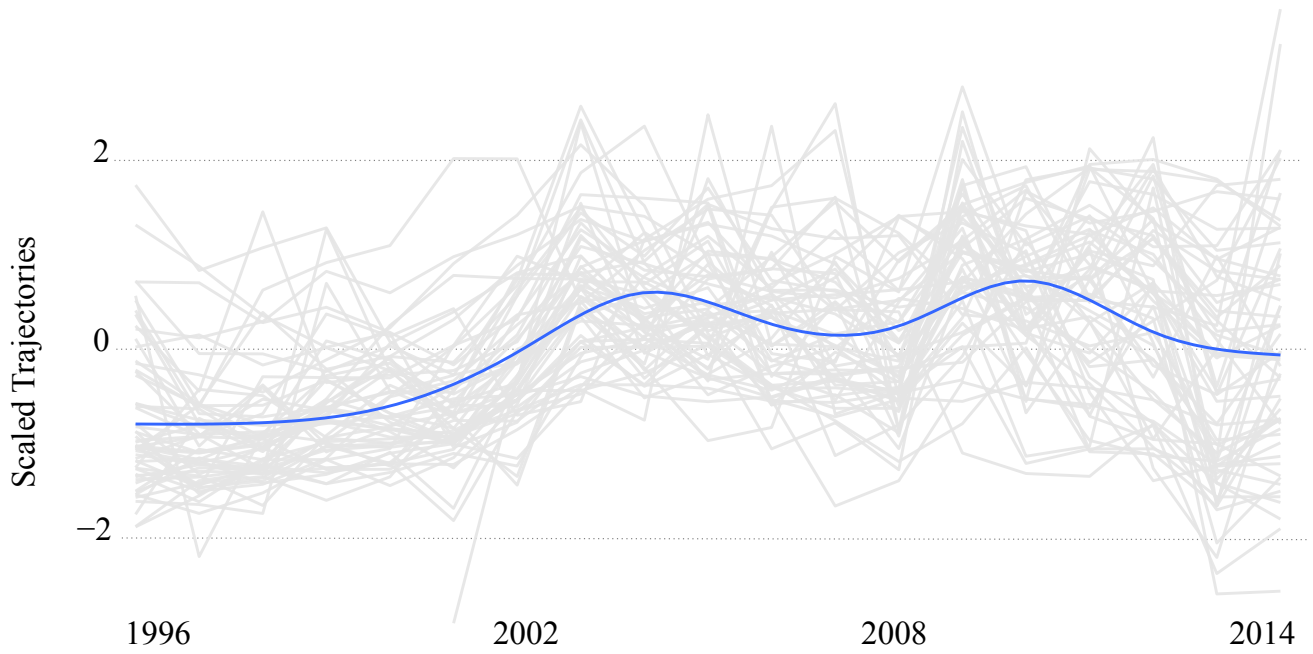
Figure: Total Aggregate Support Costs Assessed Across 58 Bases



- 1996: \$22.1B → 2014: \$28.3B
- 28% cost growth

Total Assessed Support Costs

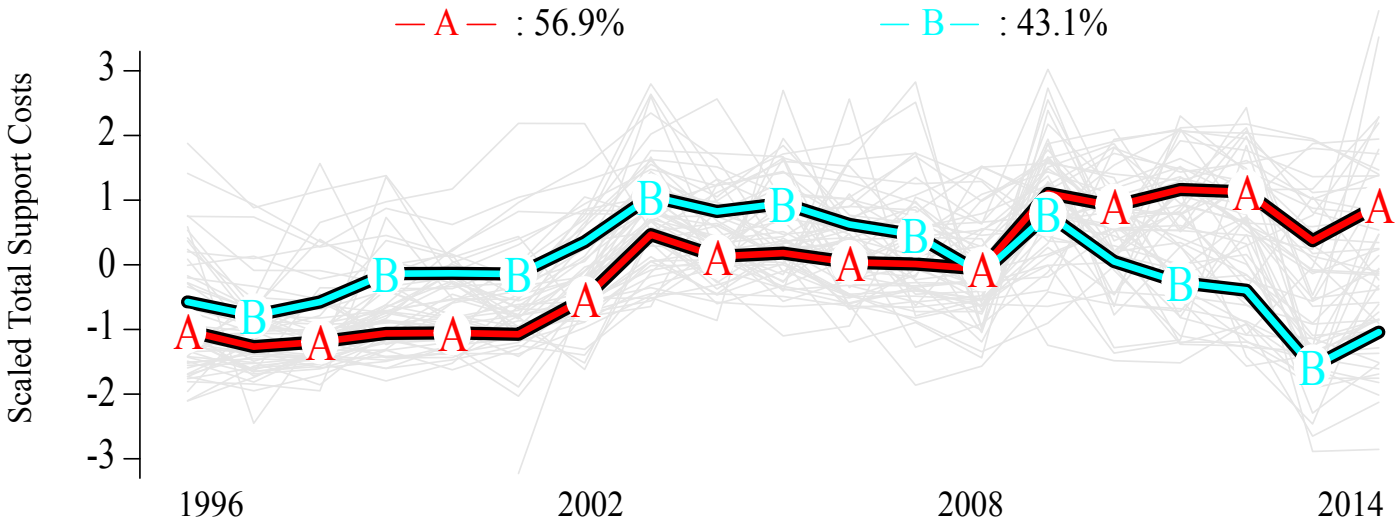
Figure: Historical Base-level Trajectories of Total Support Costs *(scaled)*



- Avg per base: 1996: \$388.5M → 2014: \$488.4M
- 26% cost growth

Total Assessed Support Costs

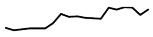
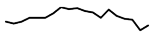
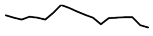
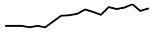
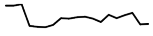
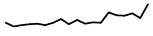
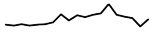
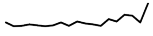
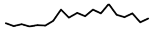
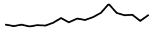
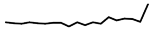
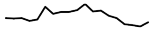
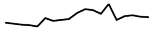
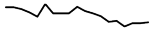
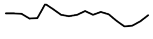
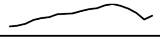
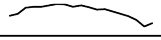
Figure: Optimal Clustered for Base-level Total Support Cost Curves *(scaled)*



- Cluster A: 48% cost growth since 1996
- Cluster B: 3% cost *contraction* since 1996

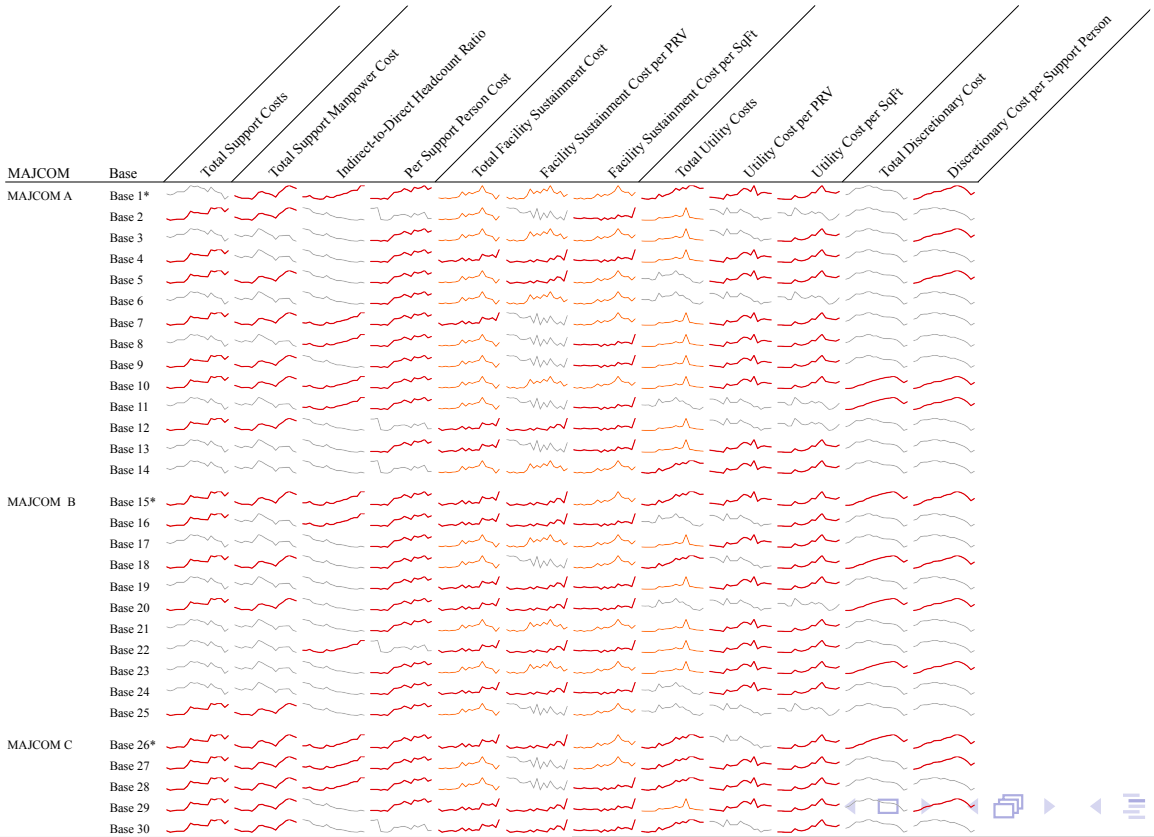
Enterprise View

Table: Summary of Cost Trends Across the AF Enterprise

	Increasing Cost Curves			Decreasing Cost Curves		
Metric	Percent of Bases	Cost Curve	Percent Growth	Percent of Bases	Cost Curve	Percent Growth
Total Support Costs	57%		48%	43%		-3%
Total Manpower Costs	62%		30%	38%		-15%
Indirect-to-Direct Headcount Ratio	52%		129%	48%		-58%
Per Support Person Costs	62%		15%	38%		-13%
Total Facility Sustainment Costs	38%		182%			
	62%		36%			
Facility Sustainment Cost per PRV	29%		144%	26%		-42%
	45%		29%			
Facility Sustainment Cost per SqFt	62%		70%			
	38%		162%			
Total Utility Costs	38%		123%	31%		-26%
	31%		11%			
Utility Cost per PRV	60%		75%	40%		-71%
Utility Cost per SqFt	76%		105%	24%		-16%
Total Discretionary Costs	28%		137%	72%		-35%
Discretionary Cost per Support Person	36%		100%	64%		-44%

Enterprise View

Table: Installation-level Cost Trends Across the AF Enterprise



Contribution

Results provide:

- Practical advancements:
  - Illustrates to decision-maker that micro-level growth curves can greatly vary from aggregate cost curves
  - Directs decision-makers' focus, proposals, and policy actions towards specific growth curves needing to be *"bent"*
- Theoretical advancements:
  - Introduces a new descriptive analytic technique for cost growth curve modeling

Original Contribution

Develops a novel approach to identify underlying cost curve behavior across an enterprise.

Publication Boehmke, B.C., Johnson, A.W., White, E.D., Weir, J.D., & Gallagher, M.A. (2015). "Bending the cost curve: Moving the focus from macro-level to micro-level cost trends with cluster analysis." *Journal of Cost Analysis and Parametrics* (DOI: 10.1080/1941658X.2015.1064046).

Presentation Boehmke, B.C. (2015). "Identifying Underlying Cost Trends." Air Force Institute of Technology: Enterprise Logistics Executive Capstone Course, WPAFB, OH.

Motivation

Lack of research exists to identify and understand relationships between force structure variables and *tail* costs

Conjecture 1: Total direct cost, or the "tooth", is the front-line mission force structure variable that provides the strongest link to indirect costs.

Conjecture 2: Relationships between front-line mission force structure variables and indirect costs are consistent across the multiple levels of the enterprise.

Objective

Establish an approach that identifies how indirect costs change in response to adjustments made to force structure variables.

1. Identify the force structure variables that provide the strongest link to *tail* costs
2. Identify the consistency in the tooth-to-tail relationships

Methodology

Data

- Focus on indirect personnel costs
- Data source: AFTOC
- Bases assessed: 57 U.S.-based active duty bases assessed
- Time period assessed: 1996-2014
- All cost variables were adjusted for inflation; represent BY14 $

Analytic Approach

- Multilevel Modeling

Methodology

Data

- Focus on indirect personnel costs
- Data source: AFTOC
- Bases assessed: 57 U.S.-based active duty bases assessed
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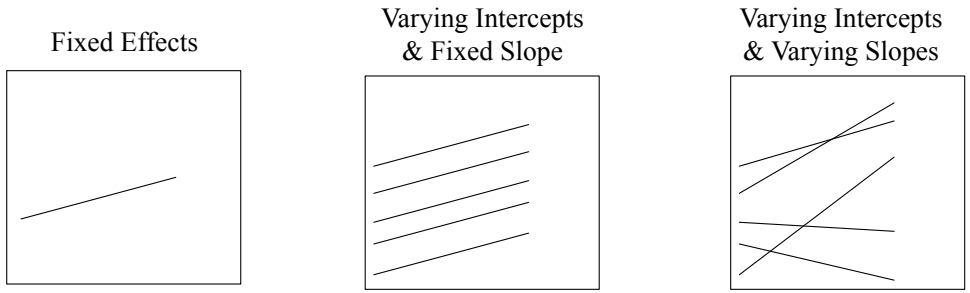

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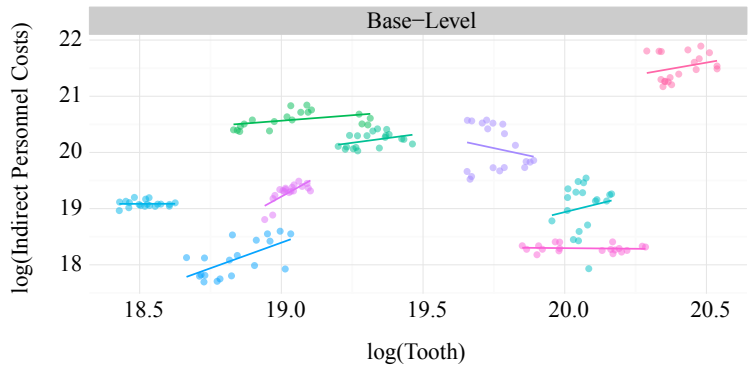
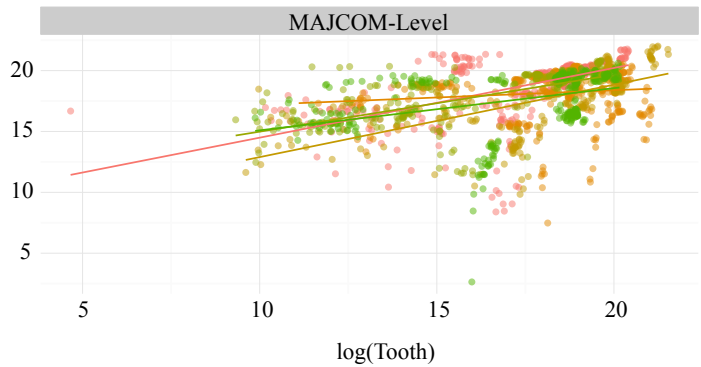




Methodology

Table: Organizational Variables Analyzed

Variable of Interest	Abbreviation	Description
Dependent Variables		
Civilian Personnel Costs	$CivPers^{ind}$	All civilian employees providing supporting roles located at AF installations
Military Personnel Costs	$MilPers^{ind}$	All military employees providing supporting roles located at AF installations
.....	.....	.....
Predictor Variables		
Tooth	*"Tooth"*	All direct operations and sustainment expenditures related to personnel, consumables, goods and services, and investments associated with the peacetime operations of weapon systems and programs.
Total Active Inventory	TAI	Total number of major weapon systems (i.e. aircraft, ICBMs, etc) in inventory
Flying Hours	FH	Number of hours that weapon systems are flown
End Strength	ES	Total headcount of direct personnel
Civilian End Strength	ES^{civ}	Total headcount of direct civilian personnel
Military End Strength	ES^{mil}	Total headcount of direct military personnel
Direct Personnel Costs	$Pers^{dir}$	Total cost of direct personnel
Direct Civilian Personnel Costs	$CivPers^{dir}$	Total cost of direct civilian personnel
Direct Military Personnel Costs	$MilPers^{dir}$	Total cost of direct military personnel

Table: Multilevel Model Building Process

Model	Multilevel Model Equation	Components
Null	$Y_{ij} = \gamma_{00} + u_{0j} + \epsilon_{ij}$	L1 fixed intercept (γ_{00}) L2 random intercept (u_{0j})
(1)	$Y_{ij} = \gamma_{00} + u_{0j} + \gamma_{10}X_{ij} + \epsilon_{ij}$	L1 fixed intercept (γ_{00}) L2 random intercept (u_{0j}) L1 fixed slope (γ_{10})
(2)	$Y_{ij} = \gamma_{00} + u_{0j} + (\gamma_{10} + u_{1j})X_{ij} + \epsilon_{ij}$	L1 fixed intercept (γ_{00}) L2 random intercept (u_{0j}) L1 fixed slope (γ_{10}) L2 random slope (u_{1j})
(3)	$Y_{ijk} = \delta_{000} + v_{00k} + u_{0jk} + (\delta_{100} + v_{10k} + u_{1jk})X_{ijk} + \epsilon_{ijk}$	L1 fixed intercept (δ_{000}) L2 random intercept (u_{0jk}) L3 random intercept (v_{00k}) L1 fixed slope (δ_{100}) L2 random slope (u_{1jk}) L3 random slope (v_{10k})

L1 represent the fixed and random components modeled at level 1 (*individual observation level*)
L2 represent the fixed and random components modeled at level 2 (*installation level*)
L3 represent the fixed and random components modeled at level 3 (*MAJCOM level*)

Table: Multilevel Model Building Process

Model	Multilevel Model Equation	Components
(4)	$Y_{ijk} = \delta_{000} + v_{00k} + u_{0jk} +$ $(\delta_{100} + v_{10k} + u_{1jk})X_{ijk} +$ $(\delta_{200} + v_{20k} + u_{2jk})T_{ijk} + \epsilon_{ijk}$	L1 fixed intercept (δ_{000}) L2 random intercept (u_{0jk}) L3 random intercept (v_{00k}) L1 fixed slope (δ_{100}) L2 random slope (u_{1jk}) L3 random slope (v_{10k}) L1 fixed growth rate (δ_{200}) L2 random growth rate (u_{2jk}) L3 random growth rate (v_{20k})

L1 represent the fixed and random components modeled at level 1 (*individual observation level*)
L2 represent the fixed and random components modeled at level 2 (*installation level*)
L3 represent the fixed and random components modeled at level 3 (*MAJCOM level*)

- Applied a log-log transformation to minimize heteroskedasticity
- Applied group-mean centering to minimize correlation between random effects [29]

Interpretation: $log\left(CivPers_{ij}^{ind}\right) = \gamma_{00} + \gamma_{10} log\left(FH_{ij}\right) + u_{0j} + \epsilon_i$

Results

- Assuming fixed slopes biases tooth-to-tail relationships
- Allowing for random slopes at base *and* MAJCOM levels improves model performance
  - Slope variability is greater between bases than between MAJCOMs
  - Variability exists between bases *within* MAJCOMs

Table: Slope Parameters and Model Fit for Model 4

Panel A: $CivPers^{ind}$

	Force Structure Fixed Effect		Growth Rate Fixed Effect		Force Structure Random Effects		Growth Rate Random Effects				
Predictor	δ_{100}	$se\ (\delta_{100})$	δ_{200}	$se\ (\delta_{200})$	τ_2^3	τ_2^2	τ_3^3	τ_3^2	σ^2	*AIC*	*BIC*
"Tooth"	-	-	-	-	-	-	-	-	-	-	-
TAI	-	-	-	-	-	-	-	-	-	-	-
FH	-	-	-	-	-	-	-	-	-	-	-
ES	-	-	-	-	-	-	-	-	-	-	-
ES^{civ}	0.08*	0.038	0.01**	0.003	0.003	0.023	0.000	0.000	0.116	-1471	-1386
ES^{mil}	-	-	-	-	-	-	-	-	-	-	-
$Pers^{dir}$	0.20**	0.068	0.01**	0.003	0.018	0.060	0.000	0.000	0.135	-1471	-1386
$CivPers^{dir}$	0.09	0.060	0.01**	0.004	0.025	0.023	0.000	0.000	0.155	-1415	-1331
$MilPers^{dir}$	0.12*	0.048	0.01**	0.004	0.006	0.035	0.000	0.000	0.097	-1483	-1398

Panel B: $MilPers^{ind}$

	Force Structure Fixed Effect		Growth Rate Fixed Effect		Force Structure Random Effects		Growth Rate Random Effects				
Predictor	δ_{100}	$se\ (\delta_{100})$	δ_{200}	$se\ (\delta_{200})$	τ_2^3	τ_2^2	τ_3^3	τ_3^2	σ^2	*AIC*	*BIC*
"Tooth"	-	-	-	-	-	-	-	-	-	-	-
TAI	-	-	-	-	-	-	-	-	-	-	-
FH	-	-	-	-	-	-	-	-	-	-	-
ES	-	-	-	-	-	-	-	-	-	-	-
ES^{civ}	-	-	-	-	-	-	-	-	-	-	-
ES^{mil}	-	-	-	-	-	-	-	-	-	-	-
$Pers^{dir}$	0.14**	0.034	0.00	0.004	0.013	0.023	0.000	0.000	0.027	-2121	-2036
$CivPers^{dir}$	-	-	-	-	-	-	-	-	-	-	-
$MilPers^{dir}$	0.15**	0.036	0.00	0.004	0.012	0.036	0.000	0.000	0.031	-2147	-2062

[1] *p-value:* < 0.001***, < 0.01**, <0.05*

Results

Conjecture 1: *Total direct costs, or the "tooth", is the front-line mission force structure variable that provides the strongest link to indirect personnel costs.*

- False
- $CivPers^{ind} \Leftrightarrow [ES^{civ}, Pers^{dir}, MilPers^{dir}]$
- $MilPers^{ind} \Leftrightarrow [Pers^{dir}, MilPers^{dir}]$
- Low elasticity relationships
- $CivPers^{ind}$ influenced by a 0.01% growth rate ($52M per yr)

Results

Conjecture 2: *Relationships between front-line mission force structure variables and indirect personnel costs are consistent across the multiple levels of the enterprise.*

- False
- Random effects at the base-level and MAJCOM-level significantly improves model performance
- Relationships vary more between bases than between MAJCOMs

Contribution

Results provide:

- Practical advancements:
  - Identifies relationships that consistently exist across the enterprise
  - Identifies the variability in these relationships
- Theoretical advancements:
  - Illustrates the potential biases in cost driver relationships that can result from an enterprise's nested nature
  - Introduces an analytic technique which has not been used to assess support cost relationships

Original Contribution

Establishes a methodology to analyze *Tooth-to-Tail* relationships across an enterprise and advances the understanding of *Tooth-to-Tail* relationships within the Air Force.

Publication Boehmke, B.C., Johnson, A.W., White, E.D., Weir, J.D. & Gallagher, M.A. (2015). "A multilevel understanding of Tooth-to-Tail." *Proceedings of the IIE Industrial and Systems Engineering Research Conference.*

Publication Boehmke, B.C., Johnson, A.W., White, E.D., Weir, J.D. & Gallagher, M.A. (2015). "The influence of operational resources and activities on indirect personnel costs: A multilevel modeling approach." *Under Review - The Engineering Economist.*

Presentation Boehmke, B.C. (2015). "A Multilevel Understanding of Tooth-to-Tail." Institute of Industrial Engineering Annual Conference, Nashville, Tennessee.

Presentation Boehmke, B.C. (2015). "The Influence of Front-line Activities on Indirect Costs: A Multilevel Modeling Approach." 83rd Military Operations Research Symposium, Washington D.C.

Motivation

The current performance assessment process for installation support activities emphasizes *effectiveness*

Motivation

The current performance assessment process for installation support activities emphasizes *effectiveness*

AF COLS MAJCOM Dashboard

Page: 1 of 1 Pages (3 Total Rows)

Functional Area	AF COLS Level	Mid-FY15 Fully Meets	Mid-FY15 Partially Meets	Mid-FY15 Not Met	Mid-FY15 N/A	Mid-FY15 Blank
facility						
Facility Demolition	Level 4	6 67%	0 0%	3 33%	0 0%	0 0%
Facility Recapitalization	Level 4	9 100%	0 0%	0 0%	0 0%	0 0%
Facility Sustainment	Level 4	25 46%	11 20%	15 28%	3 6%	0 0%

Motivation

The current performance assessment process for installation support activities emphasizes *effectiveness*

AF COLS Base Reporting Dashboard

Page: 1 of 1 Pages (6 Total Rows)

Metric ID	Base (wright)	Metric	AF COLS Level	Target Threshold	Minimum Threshold	Mid-FY15 Value	Mid-FY15 KPI
FS 1.1	Wright-Patterson	% of the Sustainment Funding Distributed	Level 4	100	98	96.7	◆
FS 2.2	Wright-Patterson	% of Emergency Work Orders Responded to and Mitigated within 24 Hours	Level 4	100	98	94.2	◆
FS 5.1	Wright-Patterson	% of PM Completed	Level 4	95	85	50	◆
FS 8.1	Wright-Patterson	% of Sustainment Funding Spent on Enhancement	Level 4	0	3	3.3	◆
FS 7.1	Wright-Patterson	Scheduled Low Sustainment - % of Work Tasks are Completed	Level 4	60	45	72.8	●
FS 6.1	Wright-Patterson	Scheduled High/Medium Sustainment - % of Work Tasks are Completed	Level 4	75	60	65.4	▲

Motivation

The current performance assessment process for installation support activities emphasizes *effectiveness*...fails to consider the *efficiency* of changing resource inputs into performance outputs.

Objective

Improve the performance assessment process of installation support activities by measuring and comparing the relative efficiency of transforming resource inputs to performance outputs.

1. Benchmark performance
2. Identify potential cost savings
3. Identify potential performance improvements

Methodology

Data

- Focus on Facility Sustainment
  - Inputs: labor, contract services, M&R, supply costs
  - Outputs: unscheduled, scheduled high/med, scheduled low, preventative mx
- Data source: AFTOC, COLS, & AF/A4/7
- Bases assessed: 35 U.S.-based Air Force bases assessed
- Time period assessed: 2014

Analytic Approach

- Data Envelopment Analysis

Methodology

Data

- Focus on Facility Sustainment metrics
- Data source: AFTOC, COLS, & AF/A4/7
- Bases assessed: 35 U.S.-based active duty bases assessed
- Time period assessed: 2014

Analytic Approach

- Data Envelopment Analysis

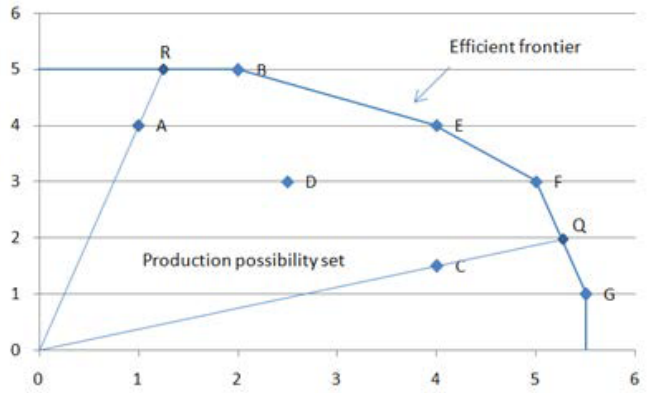


Table: DEA Fractional Input Models

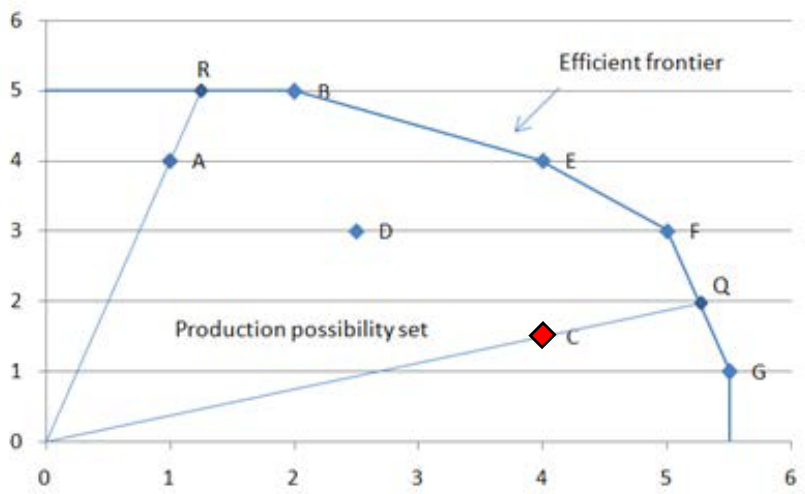
Radial Models (CRS & VRS)	Non-radial Model[1] (SBM)
Maximize:	Maximize:
$h_o = \frac{\sum_{r=1}^{s} u_r y_{ro} + \mu_o}{\sum_{i=1}^{m} v_i x_{io}}$	$h_o = \frac{1 - (\frac{1}{m}) \sum_{i=1}^{m} \frac{\bar{s_i}}{x_{io}}}{1 + (\frac{1}{s}) \sum_{r=1}^{s} \frac{\bar{s_r}}{y_{ro}}}$
Subject to:	Subject to:
$\frac{\sum_{r=1}^{s} u_r y_{rj} + \mu_o}{\sum_{i=1}^{m} v_i x_{ij}} \leq 1; \quad j = 1, \ldots, n$	$\sum_{j=1}^{n} \lambda_j x_{ij} + \bar{s_i} = x_{io}; \quad i = 1, \ldots, m$
$u_r \geq \epsilon; \quad r = 1, \ldots, s$	$\sum_{j=1}^{n} \lambda_j y_{rj} - s_i^{+} = y_{ro}; \quad r = 1, \ldots, s$
$v_i \geq \epsilon; \quad i = 1, \ldots, m$	$\sum_{j=1}^{n} \lambda_j y_{rj} - s_i^{+} = y_{ro}; \quad r = 1, \ldots, s$
for CRS: $\mu_0 = 0$	$\sum_{j=1}^{n} \lambda_j = 1$
for VRS: μ_0 is free	$\lambda_j, \bar{s_i}, s_r^{+} \geq 0; \quad \forall j, i, r$

[1] Based on a VRS frontier type

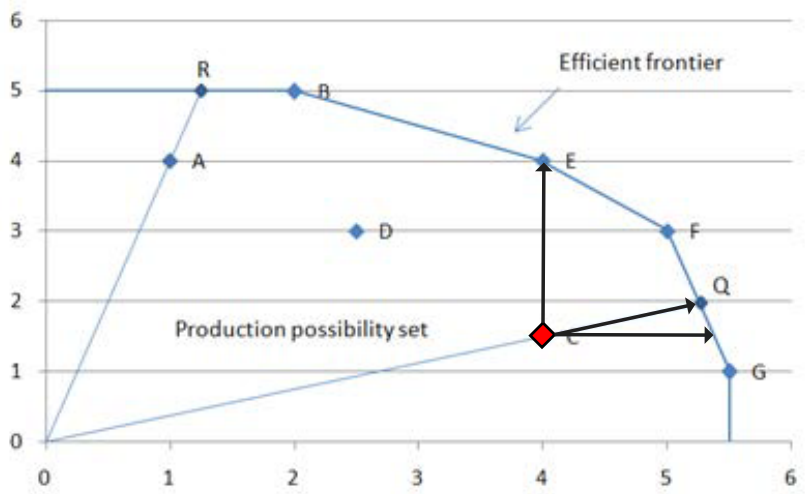
where

h_o = efficiency rating for the base under investigation noted as $base_o$
y_{rj} = facility sustainment performance output r for base j
x_{ij} = facility sustainment resource input i for base j
$\bar{s_i}$ = input excesses
s_r^{+} = output shortfalls

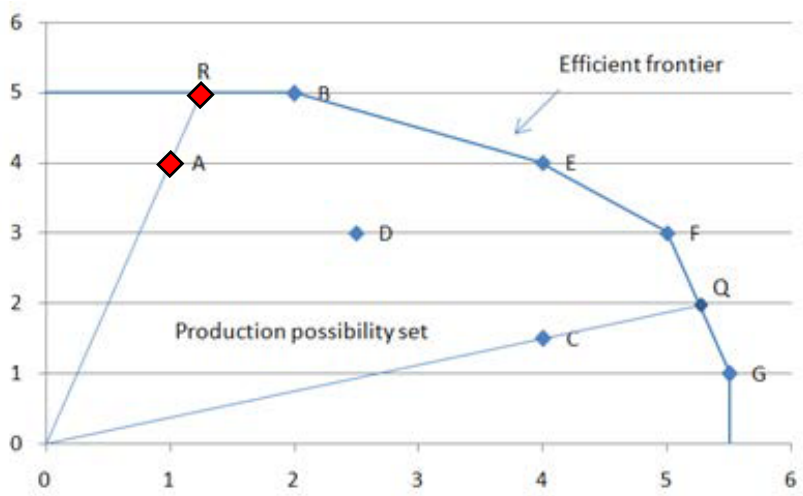
Radial vs. Non-radial Projections



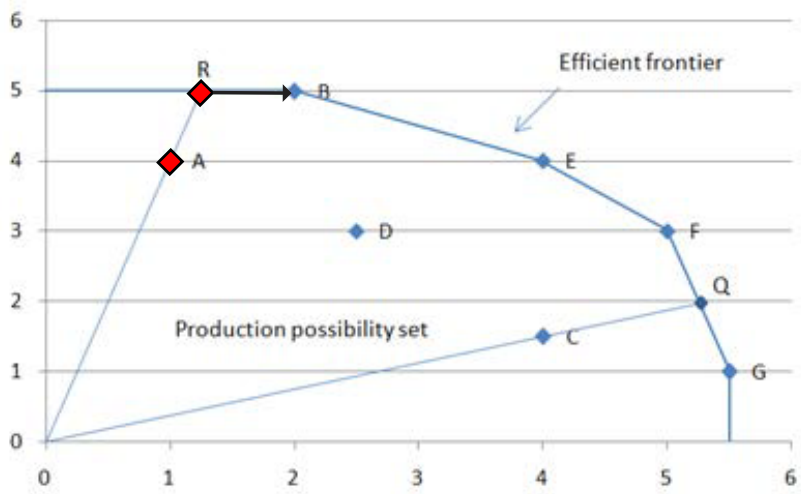
Radial vs. Non-radial Projections



Radial vs. Non-radial Projections



Radial vs. Non-radial Projections



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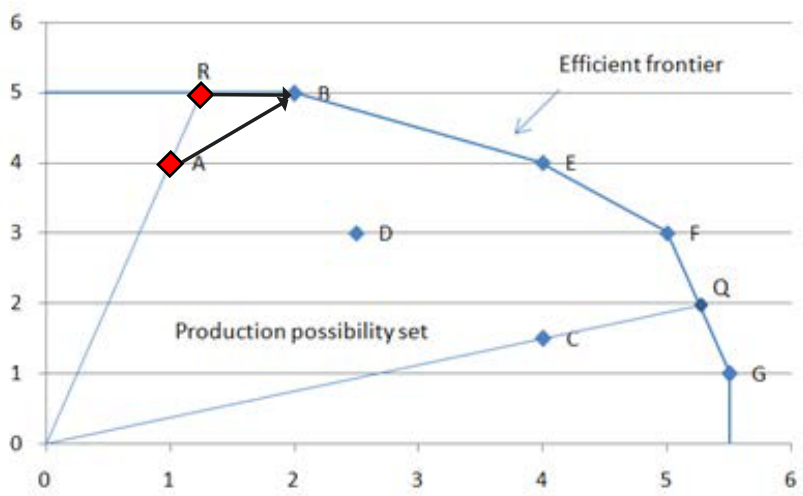


Results

Table: FY14 Input Resource Slacks ($M) for Bases Considered *"Ineffective"*

Performance	SBM	CRS	VRS	Potential Slack Range	
Installations achieving a "Green" risk rating:					
S^-_{Labor}	$18.83	$1.03	$0.48	$0.48-18.83	(1-8%)
S^-_{CS}	$7.65	$4.42	$0.00	$0.00-7.65	(0-5%)
$S^-_{M\&R}$	$26.38	$8.54	$4.04	$4.04-26.38	(1-3%)
S^-_{Supply}	$10.04	$1.98	$1.85	$1.85-10.01	(2-12%)
Total	$62.90	$15.97	$6.37	$6.37-62.90	(1-5%)
minus M&R	$36.52	$7.43	$2.33	$2.33-36.52	(1-7%)
Installations achieving a "Green" or "Yellow" risk rating:					
S^-_{Labor}	$52.59	$5.00	$3.65	$3.65-52.59	(1-21%)
S^-_{CS}	$18.44	$4.42	$0.00	$0.00-18.44	(0-11%)
$S^-_{M\&R}$	$131.21	$42.10	$33.45	$33.45-131.21	(4-16%)
S^-_{Supply}	$19.45	$3.43	$3.32	$3.32-19.45	(4-23%)
Total	$221.68	$54.95	$40.42	$40.42-221.68	(3-17%)
minus M&R	$90.47	$12.85	$6.97	$6.97-90.47	(2-18%)

*Percents listed represent percent of total enterprise-wide costs for that respective resource category.

Results

Table: Adjusted Performance Outputs for Bases Considered *"Ineffective"*

Performance	SBM	CRS	VRS	Efficient Performance Range
Installations achieving a "Yellow" risk rating:				
S^+_{EM}	99% (+6pp)	108% (+16pp)	99% (+6pp)	99-100% (+6-7pp)
S^+_{HP}	88% (+8pp)	96% (+17pp)	87% (+7pp)	87-96% (+8-17pp)
S^+_{LP}	78% (+5pp)	79% (+6pp)	79% (+6pp)	78-79% (+5-6pp)
S^+_{PM}	91% (+9pp)	95% (+12pp)	90% (+7pp)	90-95% (+7-12pp)
Installations achieving a "Red" or "Yellow" risk rating:				
S^+_{EM}	98% (+9pp)	102% (+12pp)	98% (+9pp)	98-100% (+9-12pp)
S^+_{HP}	85% (+10pp)	89% (+14pp)	84% (+9pp)	84-89% (+9-14pp)
S^+_{LP}	80% (+7pp)	81% (+9pp)	81% (+8pp)	80-81% (+7-9pp)
S^+_{PM}	86% (+7pp)	92% (+14pp)	85% (+6pp)	85-92% (+6-14pp)

*pp values listed represent the percentage point(s) increase gained if the installations would have operated efficiently.

Results

Table: Installation Level Results: McConnell AFB

	Subject Base	Benchmark Bases	
	McConnell AFB	Travis AFB	USAF Academy
Efficiency:	0.43	1.00	1.00
Weights:		0.64	0.36
Inputs*:			
x_{Labor}	0.0050	0.0031	0.0004
x_{CS}	0.0025	0.0008	0.0016
$x_{M\&R}$	0.0313	0.0055	0.0125
x_{Supply}	0.0043	0.0010	0.0001
Outputs:			
y_{EM}	100%	100%	100%
y_{HP}	100%	100%	100%
y_{LP}	91%	87%	100%
y_{PM}	95%	97%	100%
Slacks:			
$S^-_{M\&R}$	\$4.04M		
S^-_{Supply}	\$0.83M		

*Inputs are presented as cost per plant replacement value
*Slacks are presented in FY14 \$M

Results

Table: Installation Level Results: Fairchild AFB

	Subject Base	Benchmark Bases		
	Fairchild AFB	Beale AFB	Travis AFB	Arnold AFB
Efficiency:	0.49	1.00	1.00	1.00
Weights:		0.45	0.38	0.17
Inputs*:				
x_{Labor}	0.0050	0.0028	0.0031	0.0000
x_{CS}	0.0013	0.0004	0.0008	0.0009
$x_{M\&R}$	0.0133	0.0015	0.0055	0.0058
x_{Supply}	0.0016	0.0008	0.0010	$<$ 0.0001
Outputs:				
y_{EM}	93%	94%	100%	100%
y_{HP}	78%	83%	100%	60%
y_{LP}	62%	89%	87%	48%
y_{PM}	93%	90%	97%	92%
Slacks:				
S^+_{EM}	+4pp			
S^+_{LP}	+8pp			
S^+_{PM}	+7pp			

*Inputs are presented as cost per plant replacement value

Contribution

Results provide:

- Practical advancements:
  - Provides decision-makers with input-output tradespace
  - Provides more actionable information for resource allocation decisions
- Theoretical advancements:
  - Establishes a performance assessment based on both *effectiveness* and *efficiency* measures

Original Contribution

Improves performance assessments of Tail activities to guide resource allocation decisions.

Publication Boehmke, B.C., Jackson, R.A., Johnson, A.W., White, E.D., Weir, J.D. & Gallagher, M.A. (2015). "Effectiveness myopia: Improving the Air Force's 'visual acuity' of performance for installation support activities through the evaluative prism of data envelopment analysis." *Under Review - Military Operations Research.*

Presentation Boehmke, B.C. (2015). "Managing Performance and Resources for Air Force Installation Support Activities: A DEA Approach." INFORMS: Cincinnati-Dayton 2014 Fall Technical Symposium.

Motivation

An adequate decision support tool has yet to be explored to aid decision-makers when considering force reduction policies and their implications to support costs.

Objective

Introduce a systematic approach to perform tooth-to-tail policy impact analysis

1. Visual illustration of cause-and-effect impacts
2. Ability to model uncertainty in the decision environment
3. Ability to perform multi-directional reasoning

Methodology - Stage 1

Data

- Focus on limited subset of Tail activities and group into two cost pools:
  - Personnel support costs
  - Discretionary support costs
- Data source: AFTOC
- Bases assessed: 36 U.S.-based active duty bases assessed
- Time period assessed: 1996-2014
- All cost variables were adjusted for inflation; represent BY14 $

Analytic Approach

- Multiple regression

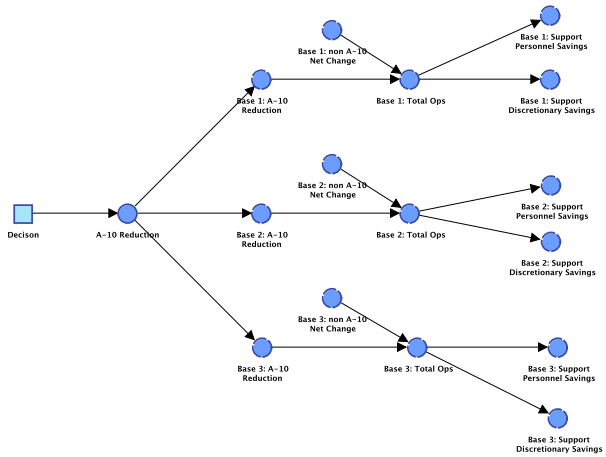
Methodology - Stage 2

Data

- Leverage results from stage 1
- Add additional variables to capture uncertainty in the decision environment
- Monte Carlo simulation to develop variable distributions
- Illustrate with potential reductions for A-10 fleet

Analytic Approach

- Bayesian network



Methodology - Stage 2

Data

- Leverage results from stage 1
- Add additional variables to capture uncertainty in the decision environment
- Monte Carlo simulation to develop variable distributions
- Illustrate with potential reductions for A-10 fleet

Analytic Approach

- Bayesian network

Joint probability distribution $\Rightarrow$ $P(T) = \prod_{i=1}^{n} P(\tau_i | pa(\tau_i))$

Posterior joint probability in light of new evidence $\Rightarrow$ $P(T, \mathbf{e}) = \prod_{\tau \in T}^{n} P(\tau_i | pa(\tau_i)) \cdot \prod_{i=1}^{m} \mathbf{e_i}$

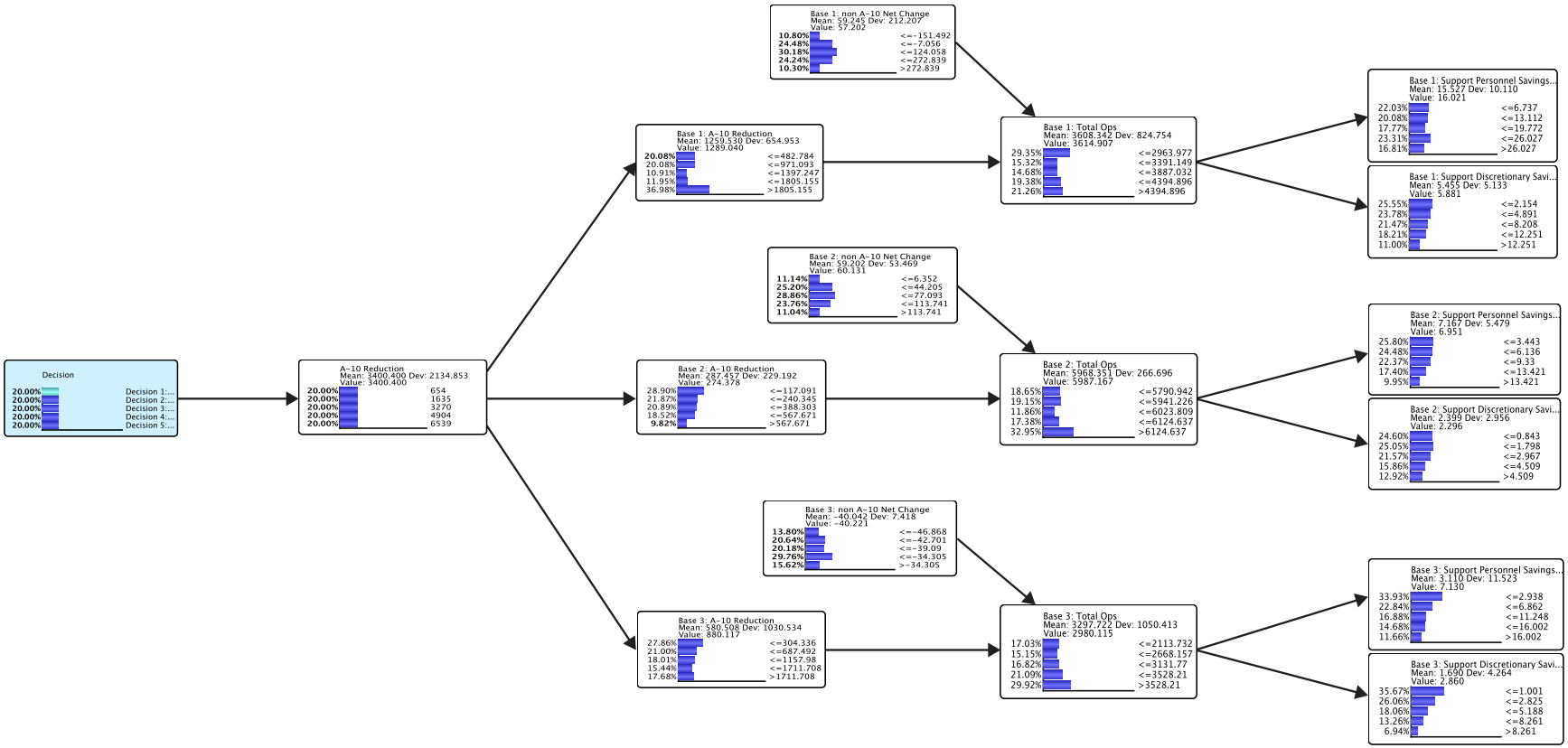
Posterior probability for individual variables $\Rightarrow$ $P(\tau_i \mid \mathbf{e}) = \frac{\sum_{T \setminus \{\tau_i\}} P(T, \mathbf{e})}{P(\mathbf{e})}$

Results - Stage 1

Results (slide 82):

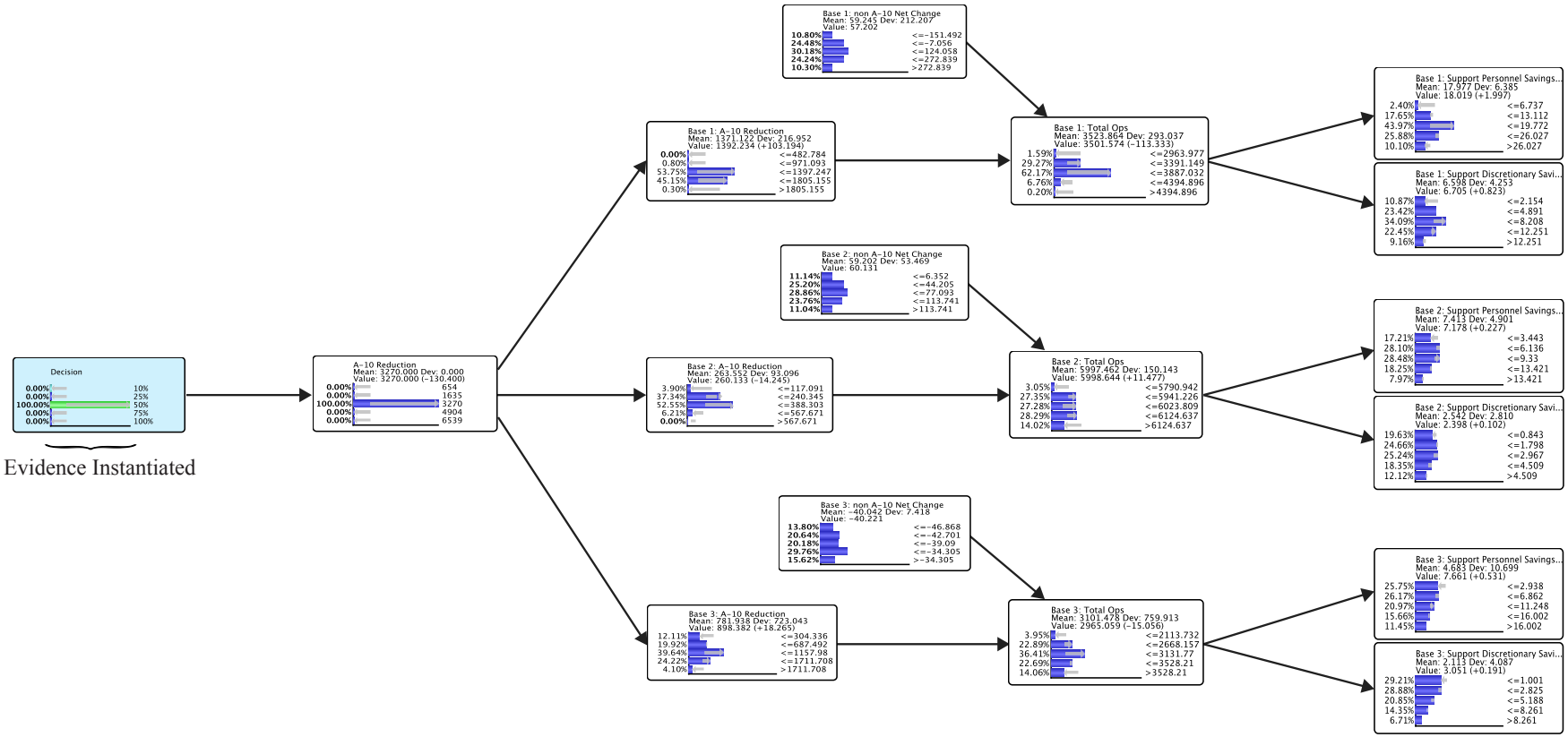
- Confirm that operational personnel population provides strongest link to support costs
- Identifies fixed costs
  - Personnel Support Costs: $132.9M
  - Discretionary Support costs: $68.8M
- Identifies variable costs
  - 10% $\downarrow$ ES $\approx$ \$3.2M $\downarrow$ Personnel Support Costs
  - 10% $\downarrow$ ES $\approx$ \$1.3M $\downarrow$ Discretionary Support costs

Results - Stage 2



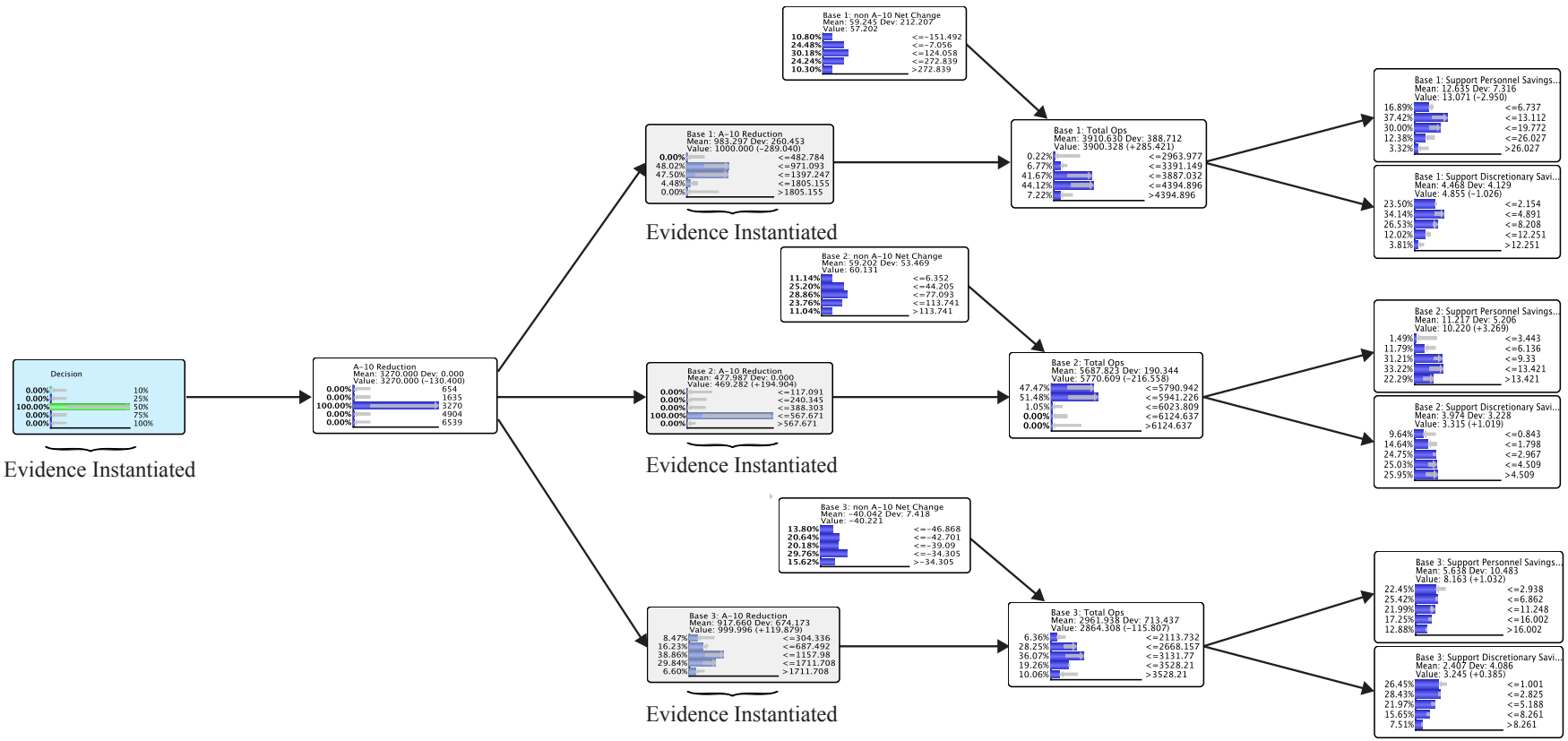
Results - Stage 2

Predictive Reasoning $\Longrightarrow$



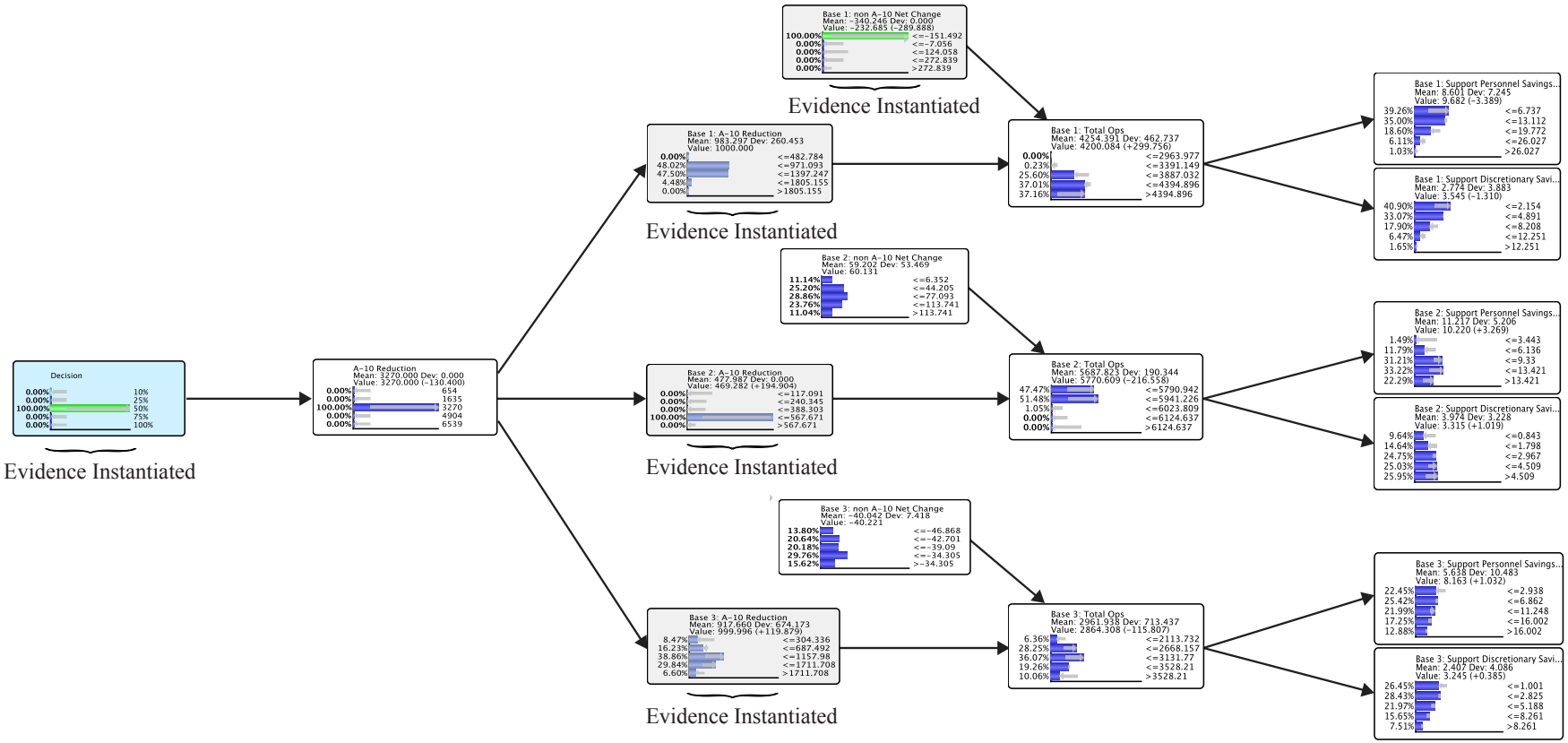
Results - Stage 2

Predictive Reasoning $\Longrightarrow$

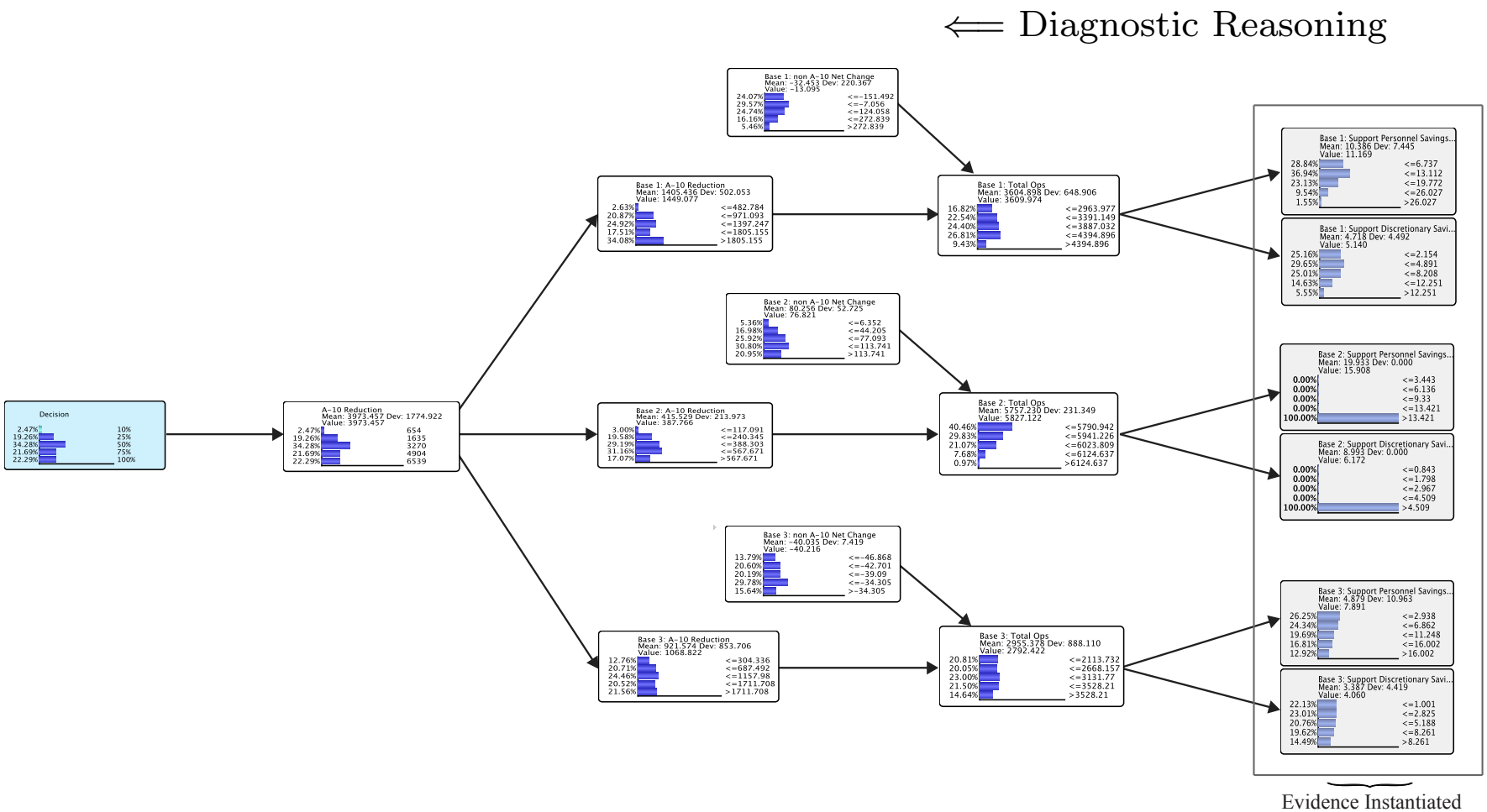


Results - Stage 2

Predictive Reasoning ==========⟹

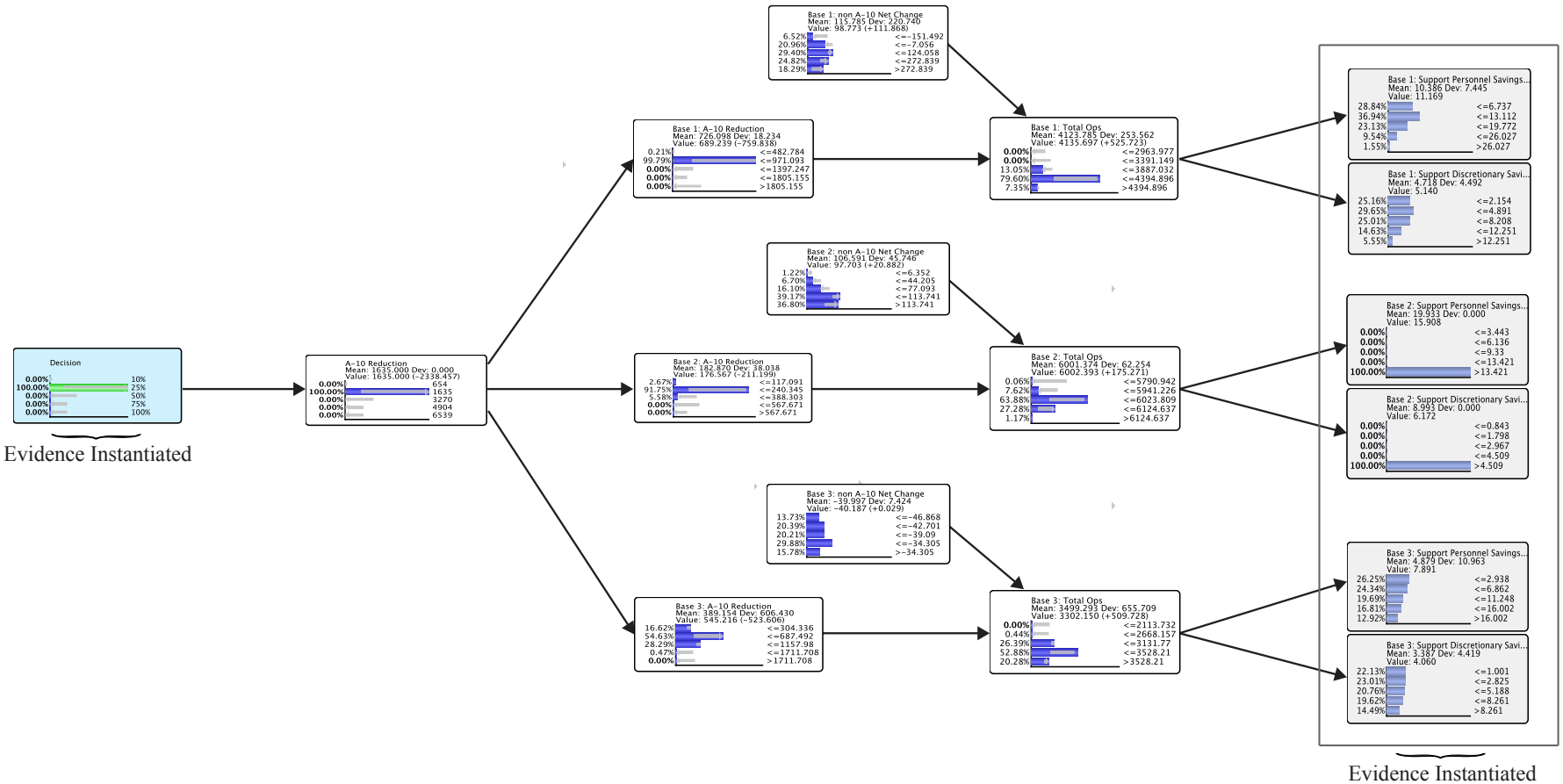


Results - Stage 2



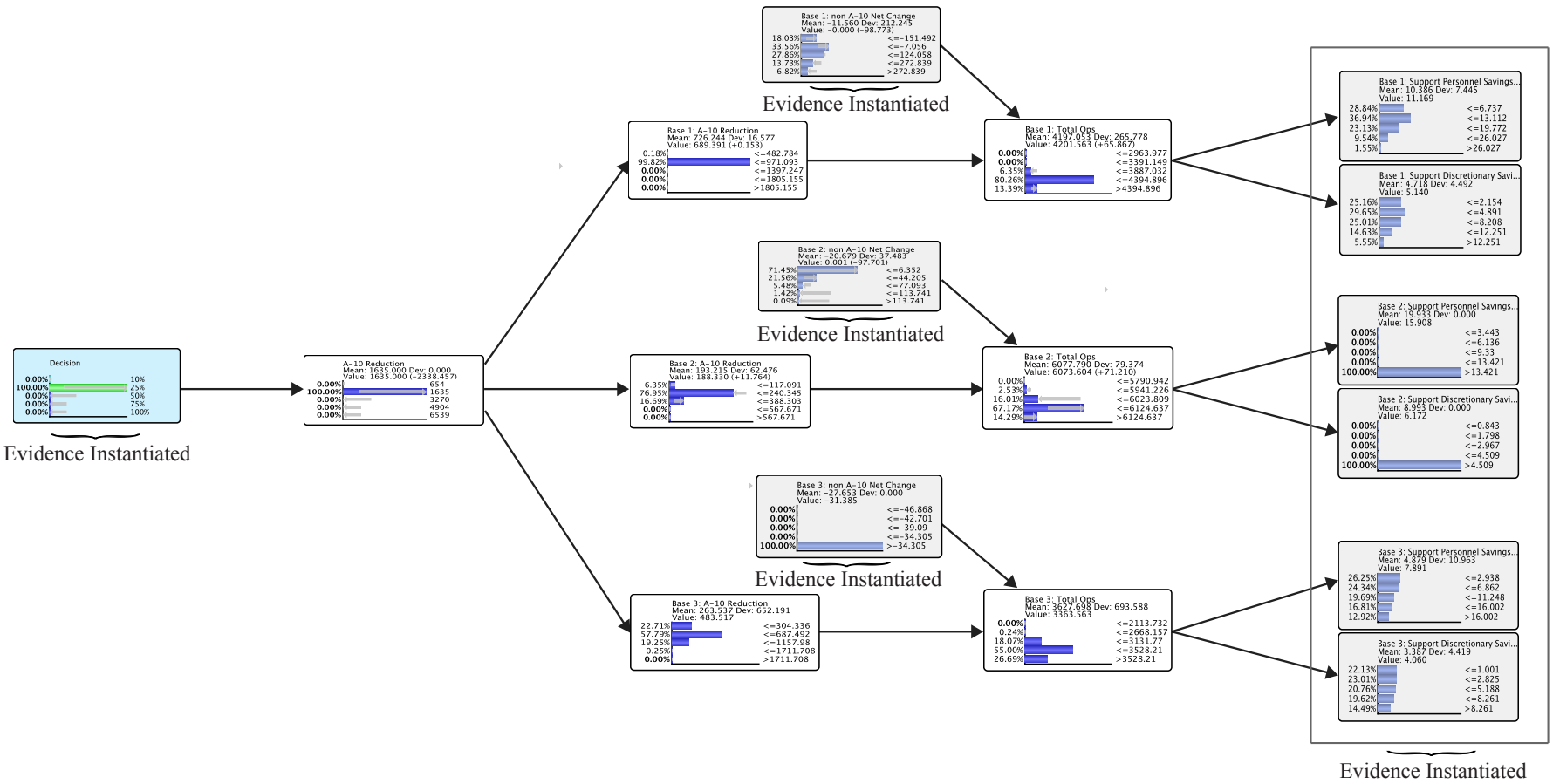
Results - Stage 2

Predictive Reasoning $\Longrightarrow$ $\Longleftarrow$ Diagnostic Reasoning



Results - Stage 2

Predictive Reasoning ⟹⟹⟹⟹⟹ ⟸⟸⟸⟸⟸ Diagnostic Reasoning



Contribution

Results provide:

- Practical advancements:
  - Provides AF leaderships with dynamic tooth-to-tail modeling capabilities
- Theoretical advancements:
  - Applies a decision support tool to model indirect cost impact analysis
  - Applies a Bayesian network approach to model indirect costs

Original Contribution

Introduces an actionable decision support tool to model tooth-to-tail cost consequences

Publication Boehmke, B.C., Jackson, R.A., Johnson, A.W., White, E.D., Weir, J.D. & Gallagher, M.A. (2015). "Tooth-to-Tail impact analysis: Combining econometric modeling and Bayesian networks to assess support cost consequences due to changes in force structure." *Under Review - Journal of Cost Analysis and Parametrics.*

Contributions

This dissertation provided five unique contributions:

Contribution 1	Created a framework for how strategic cost analytics are currently being applied across an organization's value chain
Contribution 2	Developed a novel approach to identify underlying cost curve behavior across an enterprise
Contribution 3	Establishes a methodology to analyze tooth-to-tail relationships across an enterprise
Contribution 4	Improves performance assessments of tail activities to guide resource allocation decisions
Contribution 5	Incorporates a decision support tool for tooth-to-tail impact analysis

Publications

Contribution 2 **Boehmke, B.C.**, Johnson, A.W., Weir, J.D., White, E.D. & Gallagher, M.A. (2015). "Bending the cost curve: Moving the focus from macro-level to micro-level cost trends with cluster analysis." *Journal of Cost Analysis and Parametrics.*

Contribution 3 **Boehmke, B.C.**, Johnson, A.W., Weir, J.D., White, E.D. & Gallagher, M.A. (2015). "A multilevel understanding of Tooth-to-Tail." *Proceedings of the IIE Industrial and Systems Engineering Research Conference.*

Contribution 3 **Boehmke, B.C.**, Johnson, A.W., Weir, J.D., White, E.D. & Gallagher, M.A. (2015). "The influence of operational resources and activities on indirect personnel costs: A multilevel modeling approach." *Under Review - The Engineering Economist.*

Contribution 4 **Boehmke, B.C.**, Jackson, R.A., Johnson, A.W., Weir, J.D., White, E.D. & Gallagher, M.A. (2015). "Effectiveness myopia: Improving the Air Force's "visual acuity" of performance for installation support activities through the evaluative prism of data envelopment analysis." *Under Review - Military Operations Research.*

Contribution 5 **Boehmke, B.C.**, Johnson, A.W., Weir, J.D., White, E.D. & Gallagher, M.A. (2015). "Tooth-to-Tail impact analysis: Combining econometric modeling and Bayesian networks to assess support cost consequences due to changes in force structure." *Under Review - Journal of Cost Analysis and Parametrics.*

Presentations

Prospectus Prep — Boehmke, B.C. (2013). "Tooth-to-Tail: Linking Air Force's Force Structure to Infrastructure Resource Demands." Military Operations Research Symposium QDR Workshop, Washington, D.C.

Contribution 1 — Boehmke, B.C. & Johnson, A.W. (2014). "Understanding Strategic Cost Analytics Across the Supply Chain." Institute of Industrial Engineering Annual Conference, Montreal, Canada.

Contribution 2 — Boehmke, B.C. (2015). "Identifying Underlying Cost Trends." Air Force Institute of Technology: Enterprise Logistics Executive Capstone Course, WPAFB, OH.

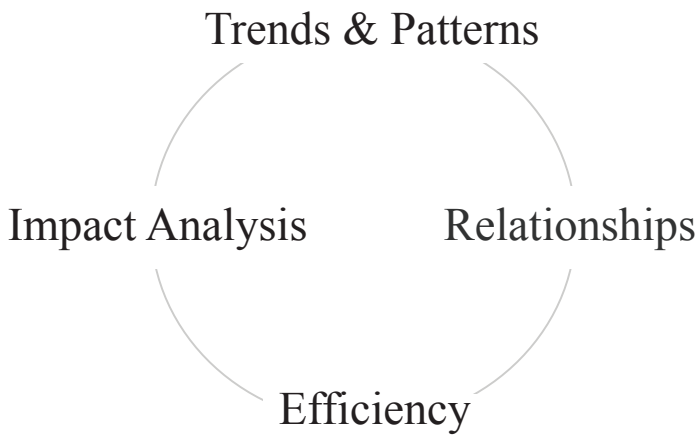
Contribution 3 — Boehmke, B.C. (2015). "A Multilevel Understanding of Tooth-to-Tail." Institute of Industrial Engineering Annual Conference, Nashville, Tennessee.

Contribution 3 — Boehmke, B.C. (2015). "The Influence of Front-line Activities on Indirect Costs: A Multilevel Modeling Approach." 83rd Military Operations Research Symposium, Washington D.C.

Contribution 4 — Boehmke, B.C. (2015). "Managing Performance and Resources for Air Force Installation Support Activities: A DEA Approach." INFORMS: Cincinnati-Dayton 2015 Fall Technical Symposium.

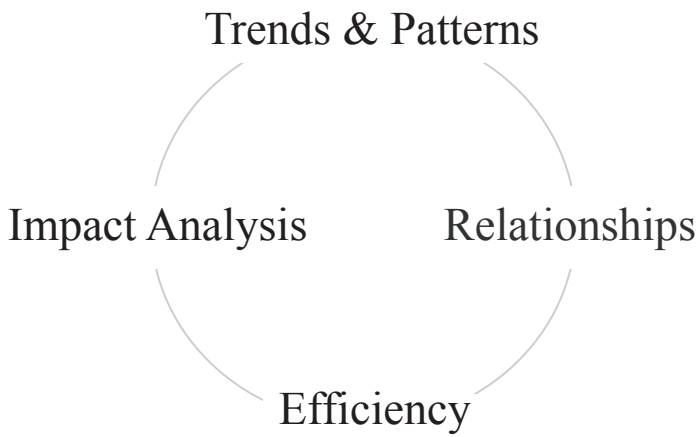
Summary

This research helps to lay the foundation for applying analytical rigor to the Air Force *tail* domain:



Summary

This research helps to lay the foundation for applying analytical rigor to the Air Force *tail* domain:



Moves the Air Force towards strategically managing $30B in *tail* costs

Future Work

Applied:

- Direct support to MG Carter AFIMSC/CC

Extensions:

- Paper 2: Compare the performance of other distance measures to the Euclidean measure
- Paper 3: Identify relationships for the many other support cost categories
- Paper 4: As more data is collected apply a longitudinal DEA assessment
- Paper 5: Map a larger set of bases and weapon systems into the BN decision tool

Numerous opportunities to inject new forms of analysis into the *tail* domain

Questions?

Thank You

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Paper #2 Cost Categories

For purposes of this research we focused on three support cost categories

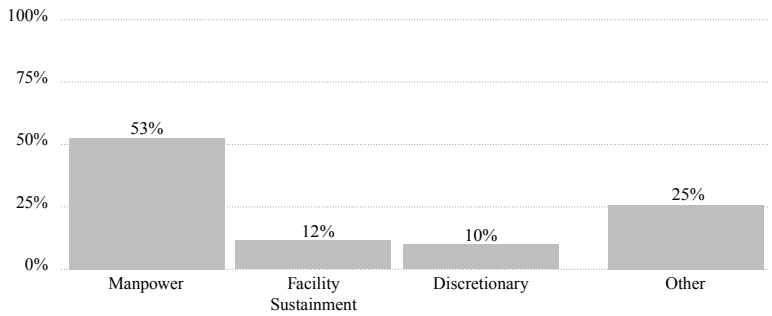
Manpower: Captures pay, benefits, and allowances for military and civilian personnel providing support services.

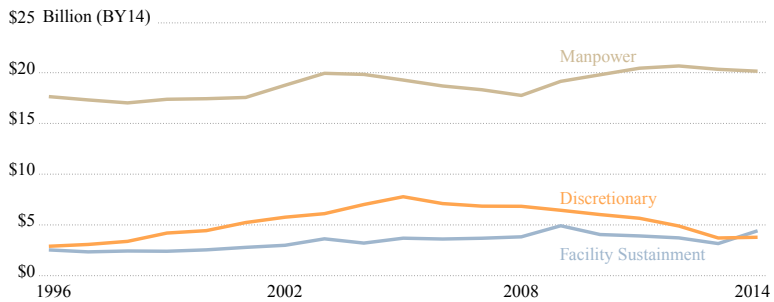
Facility: Captures the cost of sustainment activities such as civil engineering, maintenance, repair, minor renovation, and utilities.

Discretionary: Captures the cost of supplies (office, chaplain, welfare & morale, etc supplies), traveling costs (air fare, lodging, per diem) for support personnel, local transportation of people (vehicle rental and bus services), professional advancement (continuing ed, membership & credential fees), printing (advertisements), and technology & software (IT training, database hosting, off-the-shelf software, software licenses).

Paper #2 Cost Categories

Figure: Aggregate-level Descriptors of Selected Cost Categories





Metrics Assessed

Indirect Headcount per Direct Headcount: Captures the number of support personnel required to aid each front-line mission person at a base.

Indirect Manpower Cost per Indirect Manpower Headcount: Captures the average cost of each support person at a base.

Facility Sustainment Cost per Plant Replacement Value: Captures the cost curve of operating, maintaining and repairing a facility relative to its PRV.

Facility Sustainment Cost per Square Foot: Captures the cost curve of operating, maintaining and repairing each square foot at a base.

Utility Cost per Plant Replacement Value: Captures the cost curve of energy requirements per plant replacement dollar.

Utility Cost per Square Foot: Captures the cost curve of energy requirements per square foot at a base.

Discretionary Cost per Person: Captures the cost curve of providing all discretionary resources per support person at a base.

Paper #2 Data

- Data source: Cost data obtained from AF Total Ownership Cost (AFTOC) database
- EEICs represented are provided in back-up (slide 80)
- Bases assessed: 58 U.S.-based active duty bases assessed
- Time period assessed: 1996-2014
- Overseas Contingency Operations (OCO) costs removed
- Facility data provided by AF Civil Engineering office (HAF/A7C)

TABLE: Element of Expense & Investment Codes Used in Analysis

Category	EEIC	Description
Manpower	1*	All Civilian compensation EEICs starting with 1*.
	201*	All Military compensation EEICs starting with 201*.
Facility Sustainment	52* & 56*	All facility maintenance, repair and minor construction EEICs starting with 52* and 56*
	480*,513*,600* & 642*	All utility EEICs
	570*	Contracted facility operations & maintenance costs
	532* & 533*	Facility/civil engineering & architecture costs
	531*	Facility custodial service costs
Discretionary Spending	618* & 619*	Non-DWCF clothing & supply purchases
	409*	TDY expenses for mission support travel
	431*,432*,433*, 434*&435*435*	Base bus service, limousine service, passenger vehicle rental (commercial & GSA)
	501*,502*,503* &504*	Printing, binding, coping, publications, & paid advertisements
	558*,559*&592*	Continuing education, professional memberships, credential fees, certification fees, short-term clerical support, and morale & welfare services (award & trophy engravings, conferences, counter-drug program, etc)
	439*,567*, 568*,637*,701*, 702*	IT purchases services (application & database hosting), leased computer equipment, AF-owned IT equipment (purchase, repair, maintenance), off-the-shelf software & licenses, and government development & maintenance of software

Paper #3 Data

- All data obtained from AFTOC
- 57 U.S.-based AF installations
- 1996-2014
- All cost variables were adjusted for inflation; represent BY14 $
- Our sample represents 70% of AF indirect personnel costs ($20.2B in FY14)

Paper #6 Stage 1 Results

Panel A: Results for Personnel Support Cost Model

Term	Estimate	Std Error	Lower 95%	Upper 95%	p-value
β_0	18.705	0.025	18.655	18.754	$p < 0.0001$
β_1	5.346e-5	7.959e-6	3.783e-5	6.910e-5	$p < 0.0001$

Fit Summary: adj. $R^2 = 0.94$; RMSE $= 0.087$; F Ratio $= 477.82$ (< 0.0001)

Panel B: Results for Discretionary Support Cost Model

Term	Estimate	Std Error	Lower 95%	Upper 95%	p-value
β_0	18.046	0.0659	17.916	18.176	$p < 0.0001$
β_1	4.255e-5	2.100e-5	1.493e-6	8.361e-5	$p = 0.0423$

Fit Summary: adj. $R^2 = 0.85$; RMSE $= 0.229$; F Ratio $= 84.63$ (< 0.0001)