SAND2015-9629C

SAND PENDING

Formulation of a New Complex Fleet Modernization Challenge for the Capability Portfolio Analysis Tool (CPAT)

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2015 INFORMS Annual Conference
Philadelphia, PA
November 4, 2015

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Purpose and Overview

CPAT (INFORMS Edelman Finalists 2015) was created to model the U.S. Army's Ground Combat Systems. It has since been adapted to model the U.S. Army's CS&CSS Tactical Wheeled Vehicle Fleet.

- **Introduction to CS&CSS CPAT** 

- **Unique modelling requirements for the CS&CSS TWV Fleet**
  - **Phases**
  - **Fleet Size**
    - **Memory issues**
  - **Vehicle Ages**
  - **Performance "ilities"**
  - **Components**
    - **Fielding Ratios**
- **Portfolio Analyses for CPAT-TWV**
- **Path Forward**

CS&CSS CPAT TWV

CPAT Tactical Wheeled Vehicle
Combat Support & Combat Service Support (CS&CSS)

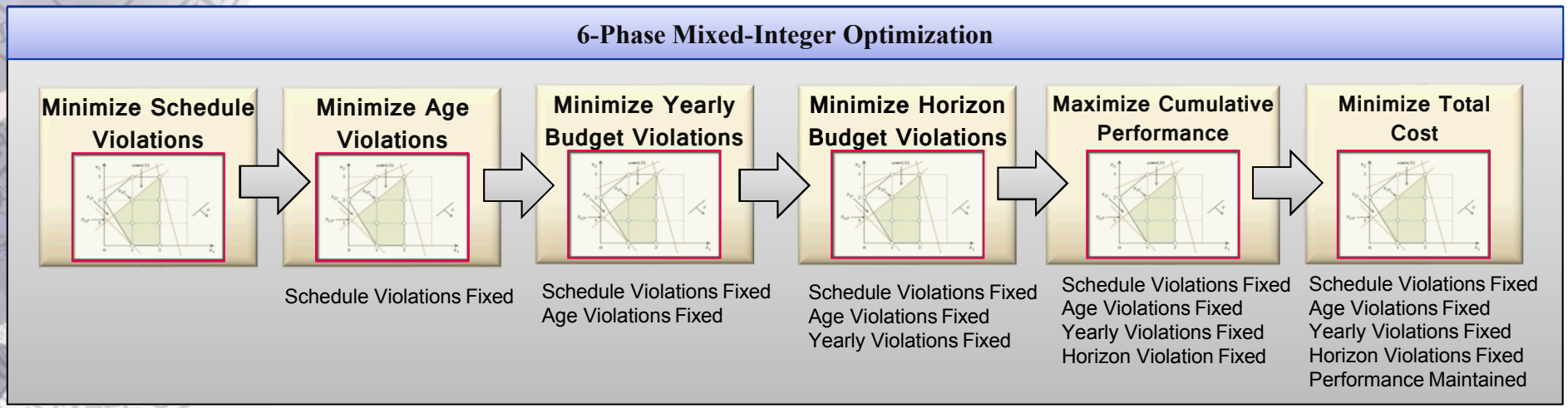
- **Work Sponsor: Shatiel Edwards**
  - Program Executive Officer Ground Combat Systems (PEO GCS)
- **Team:**
  - Sandia National Laboratories
  - Booz Allen Hamilton
- **Program executives face the fleet management challenge:**
  - The need to create optimal investment plans for fleet obsolescence, mitigation, and modernization.
  - Investment plans must be comprehensive, ensuring an optimal balance between performance, schedule, and cost.
- **Questions they want answered include:**
  - What fleet composition provides the highest performance?
  - What fleet composition meets schedule and budget constraints?
  - Is it possible to minimize cost while maintaining fleet performance?
  - How does fleet and vehicle age change through time?
  - How do we balance upgrading vehicles in the Active Army, Reserves, and National Guard at the same time?

CPAT Overview

- **CPAT model explores different areas of schedule, cost, and performance to develop and optimal fleet modernization plan**
- **Objectives**
  - Minimize schedule violations
  - Minimize age violations
  - Minimize budget violations
  - Maximize overall fleet performance
  - Minimize cost inefficiencies
- **Constraints**
  - Schedule constraints on vehicle retirement and replacement requirements
  - Budget restrictions on procurement, O&S, and RDT&E
  - Vehicle availability to particular missions via upgrades or purchases
- **Results**
  - Displays the optimal fleet performance over time broken out by vehicle, mission, family, or program
  - Displays optimal fleet modernization schedule indicating which vehicles to upgrade or purchase over all time periods
  - Gives costs of the modernization plan broken out by procurement, O&S, RDT&E, mission, family, program, etc.

CPAT TWV Phases

- **CPAT TWV is a 6-phase MILP**
  - **Schedule, Age, Yearly Budget, Horizon Budget, Cumulative Performance, Cost**
    - **Information from previous phase is fed forward to subsequent phases and not allowed to do any worse**



  - **Phase ordering is arbitrary**
    - **We could choose to minimize Age Violations before Schedule Violations**

Capability Portfolio Analysis Tool (CPAT)

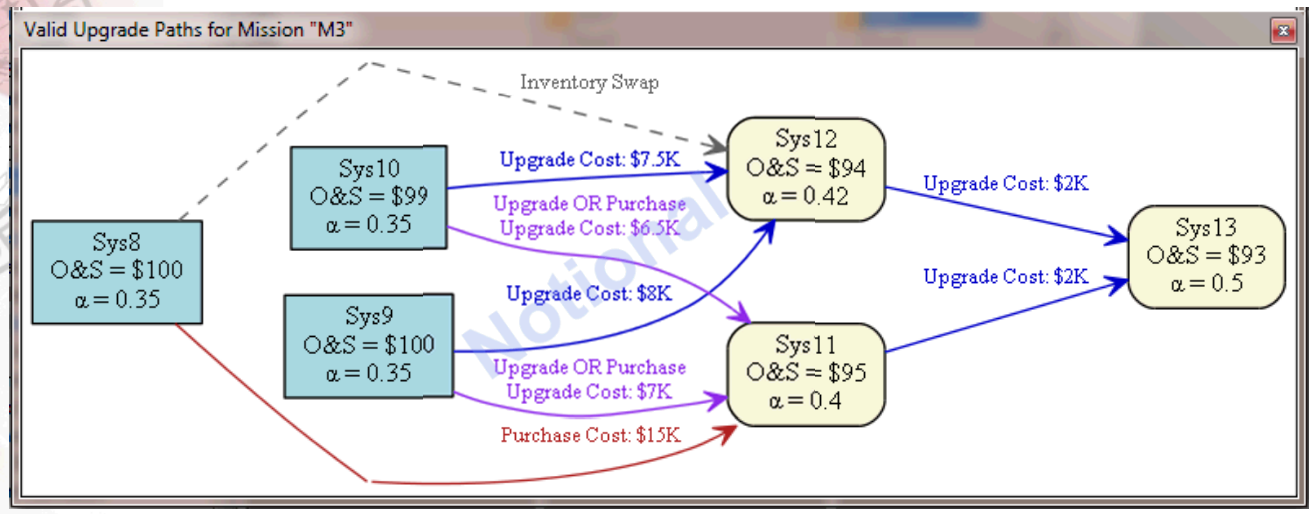
Introduction to CS&CSS CPAT

- **CPAT optimizes the mixture of vehicles within the entire fleet through time**

Current fleet

Future fleet

- **This is done via transitions for all missions**



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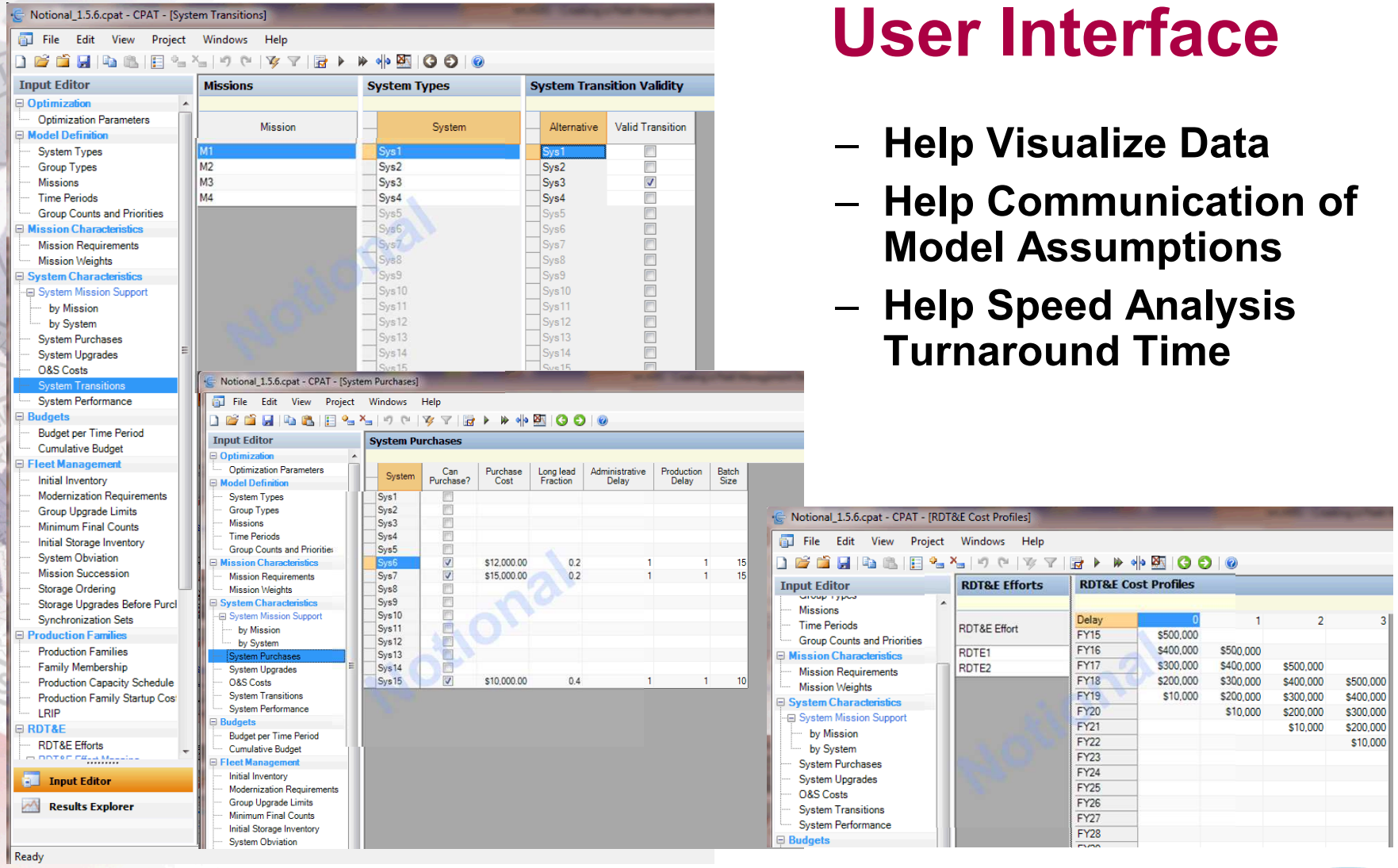
CPAT



User Interface

- Help Visualize Data
- Help Communication of Model Assumptions
- Help Speed Analysis Turnaround Time

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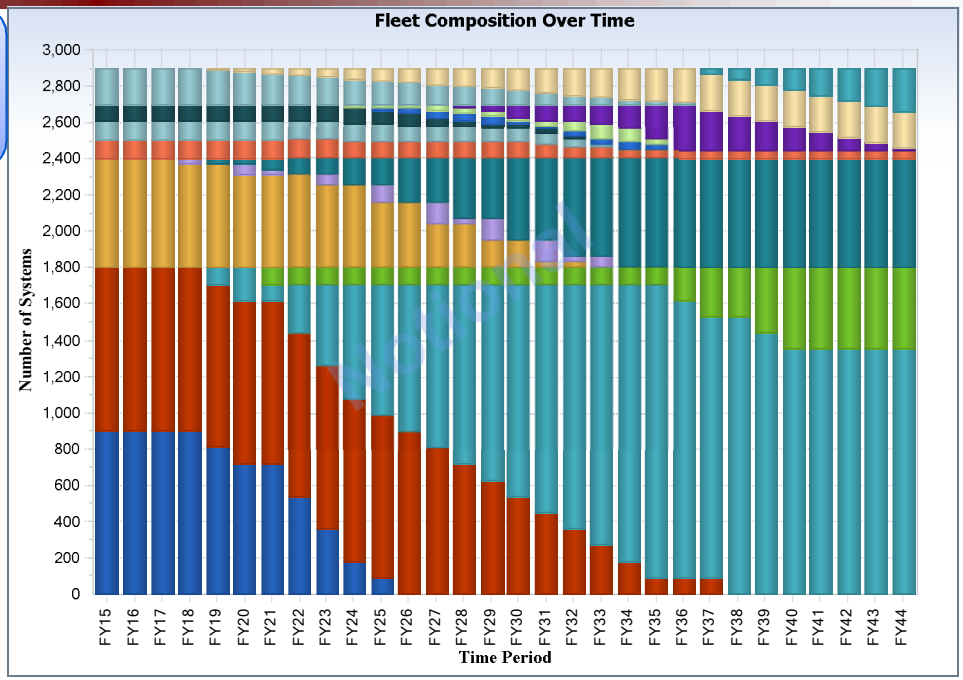
CPAT Outputs

High-level fleet changes over time



Detailed fleet transition schedule over time

Mission Population Schedule by Group Count

$49.656M			FY15	FY16	FY17	FY18	FY19	FY20	FY21	FY22	FY23	FY24	FY25	FY26	FY27	FY28	FY29	FY30	FY31	FY32	FY33	FY34	FY35	FY36	FY37	FY38	FY39	FY40	FY41	FY42	FY43	FY44
$21.879M	M1	Sys1	10	10	10	10	9	8	8	6	4	2	1																			
		Sys2	10	10	10	10	10	10	10	10	10	10	10	10	9	8	7	6	5	4	3	2	1	1	1							
		Sys3					1	2	1	3	5	7	8	9	10	11	12	13	14	15	16	17	18	17	16	17	16	15	15	15	15	15
		Sys4							1	1	1	1	1	1	1	1	1	1	1	1	1	1	2	3	3	4	5	5	5	5	5	5
$12.133M	M2	Sys5	20	20	20	19	19	17	17	17	15	15	12	12	8	8	5	5	1	1												
		Sys6				1		2	1		2		3		4	1	4		4	1	2											
		Sys7					1	1	2	3	3	5	5	8	8	11	11	15	15	18	18	20	20	20	20	20	20	20	20	20	20	20
$10.777M	M3	Sys8	7	7	7	7	7	7	7	7	7	6	6	6	6	6	6	6	5	4	4	3	3	3	3	3	3	3	3	3	3	3
		Sys9	7	7	7	7	7	7	7	7	7	7	7	6	6	6	5	5	4	3	1											
		Sys10	6	6	6	6	6	6	6	6	6	6	5	5	3	2	2	2	2	1												
		Sys12										1	1	1	2	2	2	1	2	4	6	5	2									
		Sys11											1	2	3	3	3	1	1	2	2	3	2									
		Sys13														1	2	5	6	6	7	9	13	17	15	13	11	9	7	5	3	1
		FSys4																							2	4	6	8	10	12	14	16
$4.866M	M4	Sys14	20	20	20	20	19	18	17	16	15	14	13	12	11	10	9	8	6	5	4	3	2	1								
		Sys15					1	2	3	4	5	6	7	8	9	10	11	12	14	15	16	17	18	19	20	20	20	20	20	20	20	20

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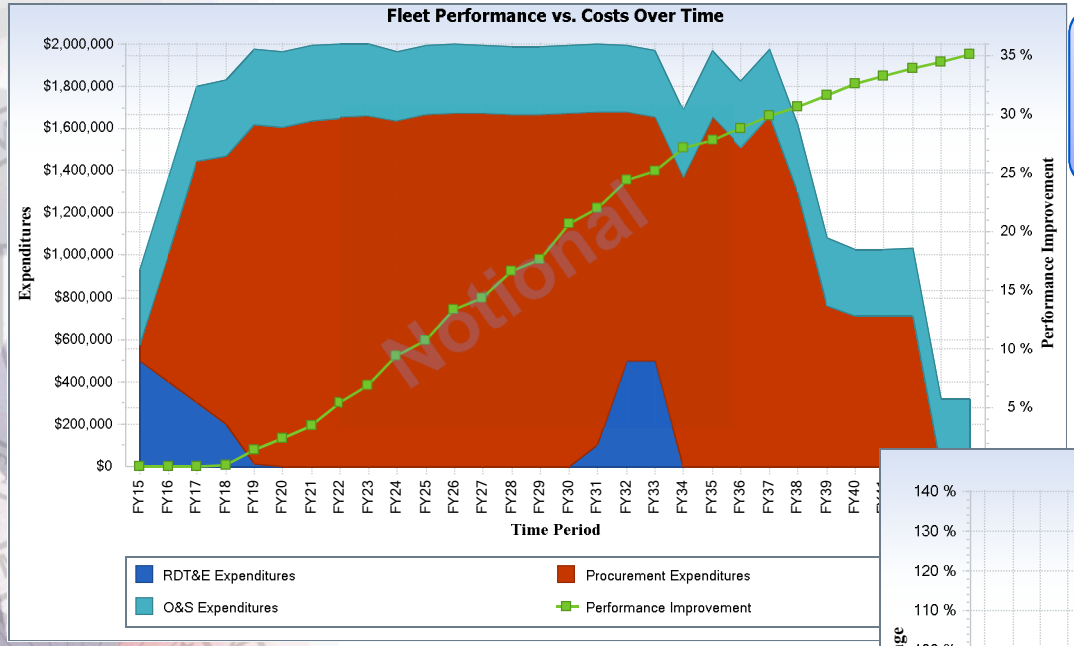
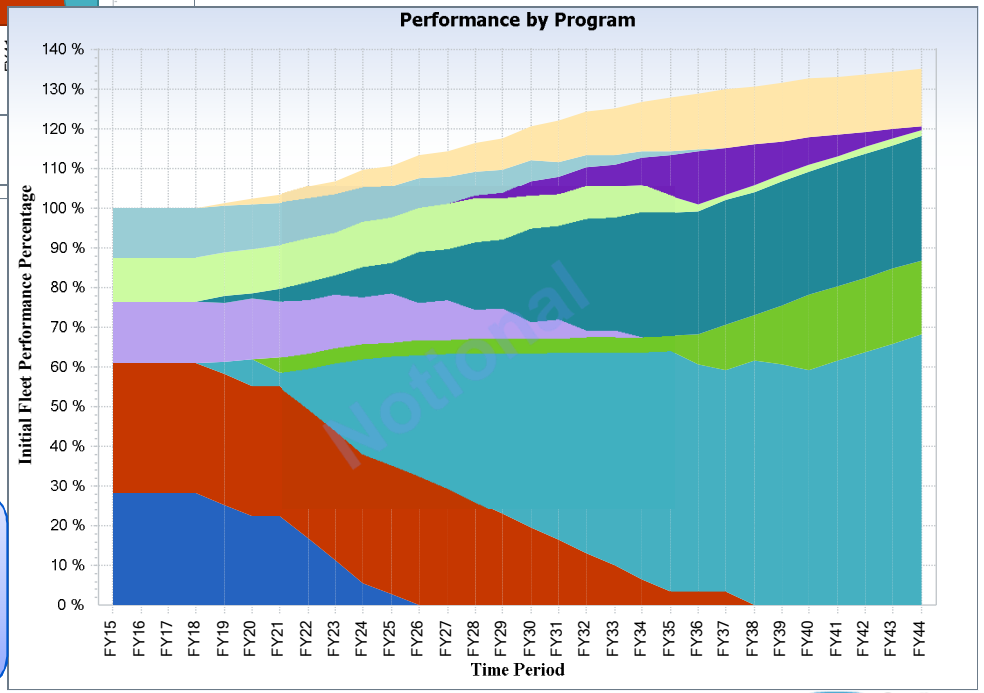
CPAT Outputs



Breakout of performance versus procurement, O&S, and RDT&E over time



Breakout of performance by groups of vehicles over time

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CPAT TWV Size

- **The CS&CSS fleet of tactical wheeled vehicles is much larger than the GCS fleet**
  - **GCS Fleet**
    - ~ 20,000 vehicles
    - ~ 70,000 variables
    - ~ 20,000 constraints
  - **CS&CSS Fleet**
    - ~ 200,000 vehicles
    - ~ 170,000 variables
    - ~ 170,000 constraints
    - Requires strategic modelling fidelity to even attempt to solve the problem
      - Not tractable to allow the optimization to make choices at the individual vehicle level.
      - Decisions made at the brigade (set of vehicles) level

CPAT TWV Software Structure

- **CPAT is solver agnostic**
  - **Created a modeling language in VB.NET**

```
' Number of batches of vehicles purchased
Private Property iNumBatchesPurchased As New IndexedSet(Of Integer, Integer, Integer, DecisionVariable)

Me.AddVars(iNumBatchesPurchased, "iNumBatchesPurchased", DecisionDomain.Int,
          (From c In _data.setComponentsID, v In _data.setPurchasableVehicles, t In _data.setTimePeriodID))

Me.AddConstraints(From c In _data.setComponentsID, _data.setTimePeriodID
                  Select Sum(From pair In _data.setSupportedStorageUpgrades, v2 In _data.setPurchasableVehicles
                             Where t + _data.ProductionDelay(pair.v_to) <= _data.maxTimePeriodID _
                             Select iNumBatchesPurchased(c, v2, t + _data.ProductionDelay(pair.v_to))) _
                                 <=
                                 _data.TotalVehiclePopulation)
```

- **CS&CSS CPAT Memory Issues**
  - **CPAT is a 32-bit application**
    - **Model in CPAT was over 3GB which resulted in out-of-memory statuses**
  - **CPAT calls 64-bit solver**
    - **Model in CPAT around 2GB while solver can get as large as necessary**

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CPAT TWV Age

- **Fleet and vehicle age is very important to decisions makers in CS&CSS**
  - **Age for each brigade is tracked through time**
    - **Constraints can enforce brigades to be upgraded based on the average age of the brigades not exceeding their Economic Useful Life**
    - **This prevents vehicles in the fleet from becoming too old**
  - **The age of the vehicles in the fleet do not affect performance or O&S costs**
    - **In real-life this is generally not the case**
    - **It is possible to model performance and O&S costs that change as the age of the vehicle increases should the data for these parameters become available**
      - **This will require some substantial changes to the model and the formulation**

CPAT TWV Age

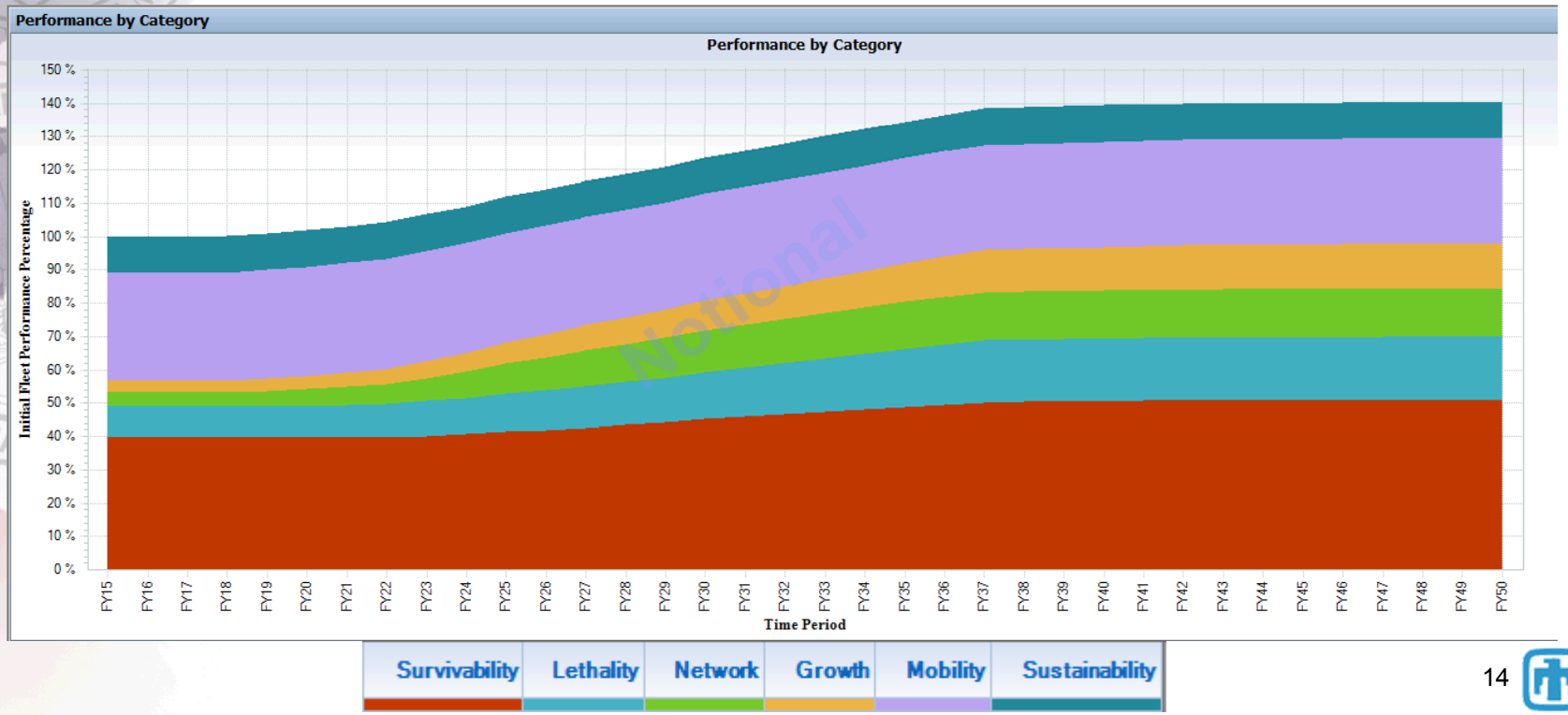
Average Age by Mission

Average Age		Initial	FY15	FY16	FY17	FY18	FY19	FY20	FY21	FY22	FY23	FY24	FY25	FY26	FY27	FY28	FY29	FY30	FY31	FY32	FY33	FY34	FY35
M1	Sys1	10	11	12	13	14	15	16	17	18													
	Sys2	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24							
	Sys3								1	1.5	2	2.5	3	3.5	4	4.5	5.2	6.2	7.2	8.2	9.2	10.2	11.2
M4	Sys23	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26
	Sys25	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26
	Sys26	5	6	7	8	9	10	11	12	13	14												
	Sys27						1	1.5	2	2.5	3	3.7	4.7	5.7	6.7	7.7	8.7	9.7	10.7	11.7	12.7	13.7	14.5
	Sys65																		1	1.5	2	2.5	3
M5	Sys32	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26
	Sys33	5	6	7	8	9	10	11	12	13	14												
	Sys34						1	1.5	2	2.5	3	3.7	4.7	5.7	6.7	7.7	8.7	9.7	10.7	11.7	12.7	13.7	14.5
	Sys36																						1
	Sys37																		1	1.5	2	2.5	3.5
M6	Sys41	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50						
	Sys42										1	1.5	1.9	2.4	2.8	3.4	4					8.8	9.8
M7	Sys43	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50						
	Sys44										1	1.5	1.9	2.4	2.8	3.4	4	4.8	5.8	6.8	7.		9.8
M12	Sys38	20	21	22	23	24	25	26	27	28	29	30	31	32									
	Sys39				1	1.5	1.8	2	2.4	2.8	3.5	4.1	4.6	5.4	6.1	6.3	6.5	6.7	6.6	6			
	Sys40												1	1.5	1.8	1.9	2.3	2.7	3.2	3.6	4.5		6.5
M13	Sys52	10	11	12	13	14	15	16	17	18	19	20	21										
	Sys53									1	1.5	2	2.5	3	4	5	6	7	8	9	9.5		10.5
	Sys69																				1		2
M14	Sys54	10	11	12	13	14	15	16	17	18	19	20	21										
	Sys55						1	1.5	2	2.5	3	3.5	4	4.5	5.5	6.5	7.5	8	8.5	9	9.5		10.5
	Sys70																	1	1.5	2	2.5		3.5

Forced retirements of Sys41 and Sys43 when they reach 50

CPAT TWV Performance "ilities"

- **Performance is now measured at the "ility" level**
  - **Survivability, Lethality, Network, Growth, Mobility, and Sustainability**
    - **Helpful to understand the lower level performance metrics that lead to overall performance increases**
    - **Constraints can be added to require changes to different "ilities" over the study horizon**



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CPAT TWV

- **CPAT TWV models components explicitly**
  - **Active Army, Reserves, National Guard**
    - **Brigade composition may not be identical across components**
      - **Active Army, Reserves, and National Guard all have different number of brigades per mission**
    - **There can exist component specific budgets**
      - **Money must be spent to modernize vehicles in that specific component**
    - **There is a prioritization among components**
      - **Implemented fielding ratios. For every three Active Army brigades upgraded at least one National Guard brigade must be upgraded**
      - **This prioritization can be implemented each year or over a specific number of years**

Path Forward

- **Current Analysis Work**
  - **Initial brief provided to CS&CSS Oct. 30th**
    - What modernization plan provided the best performing fleet under budget and age considerations
    - Compared performance and modernization of the fleet with and without age considerations
    - Second and third order effects of budget, scheduling, and age requirements
    - Performance vs. costs trade-offs
    - Which vehicles provide the best performance for their cost
- **Current Development Work**
  - **Refine CS&CSS TWV fleet data**
  - **Vehicle Age Considerations**
    - Age affects performance and O&S costs
  - **Modeling Improvements**
    - Reduce the model size via strategic formulation decision