Optimizing Test Confidence Based on Life Cycle Cost

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Army Proven
Battle Ready

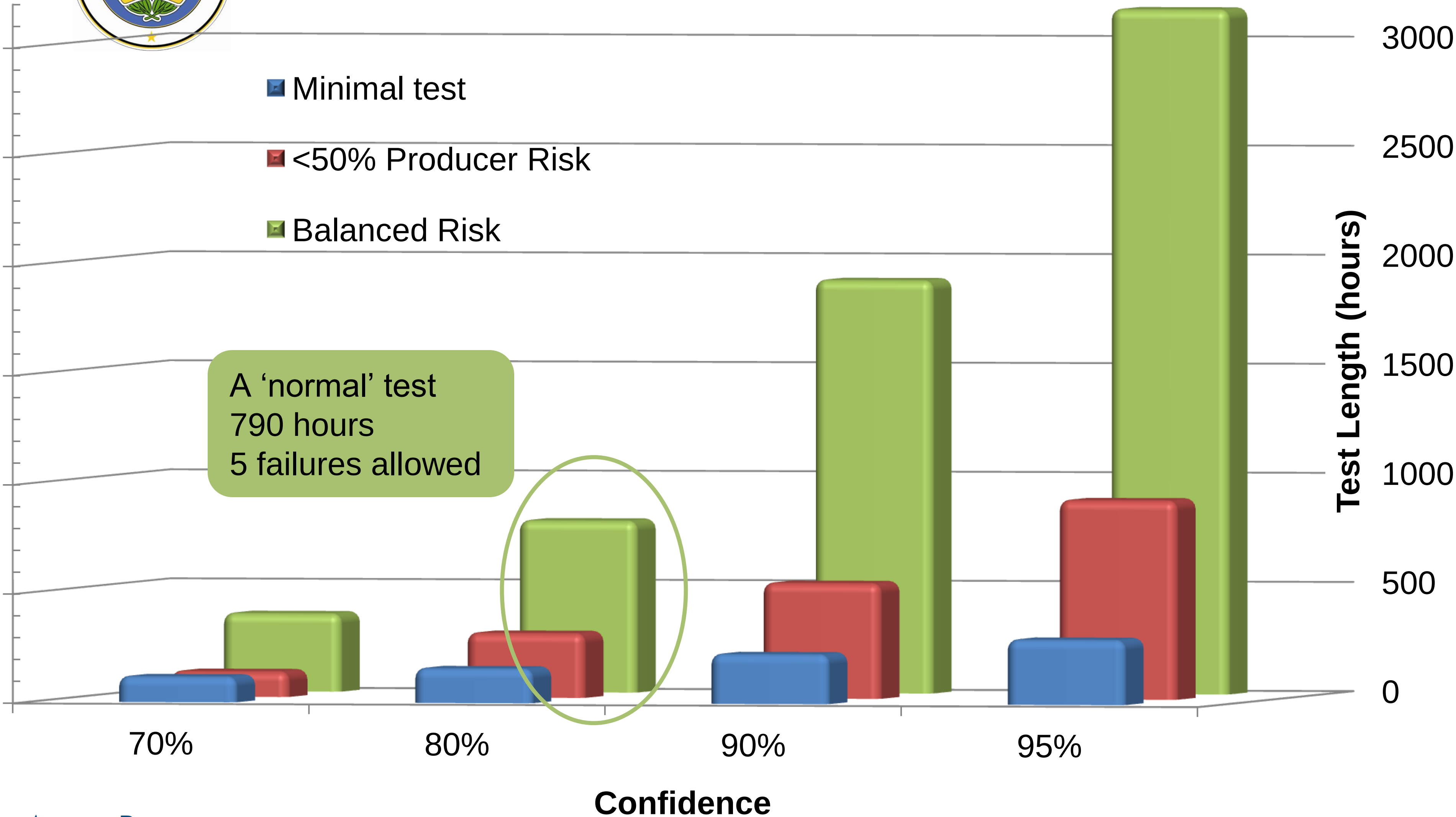
Outline

- Background on confidence, and its impact on test scope
  - Confidence, Risk, and Discrimination Ratio (DR)
- The calculation and some simple examples
- Three system examples
  - Expensive, Low fielding density
  - Expensive, Medium fielding density
  - Inexpensive, High density
- Conclusions

What Confidence Level is Appropriate?

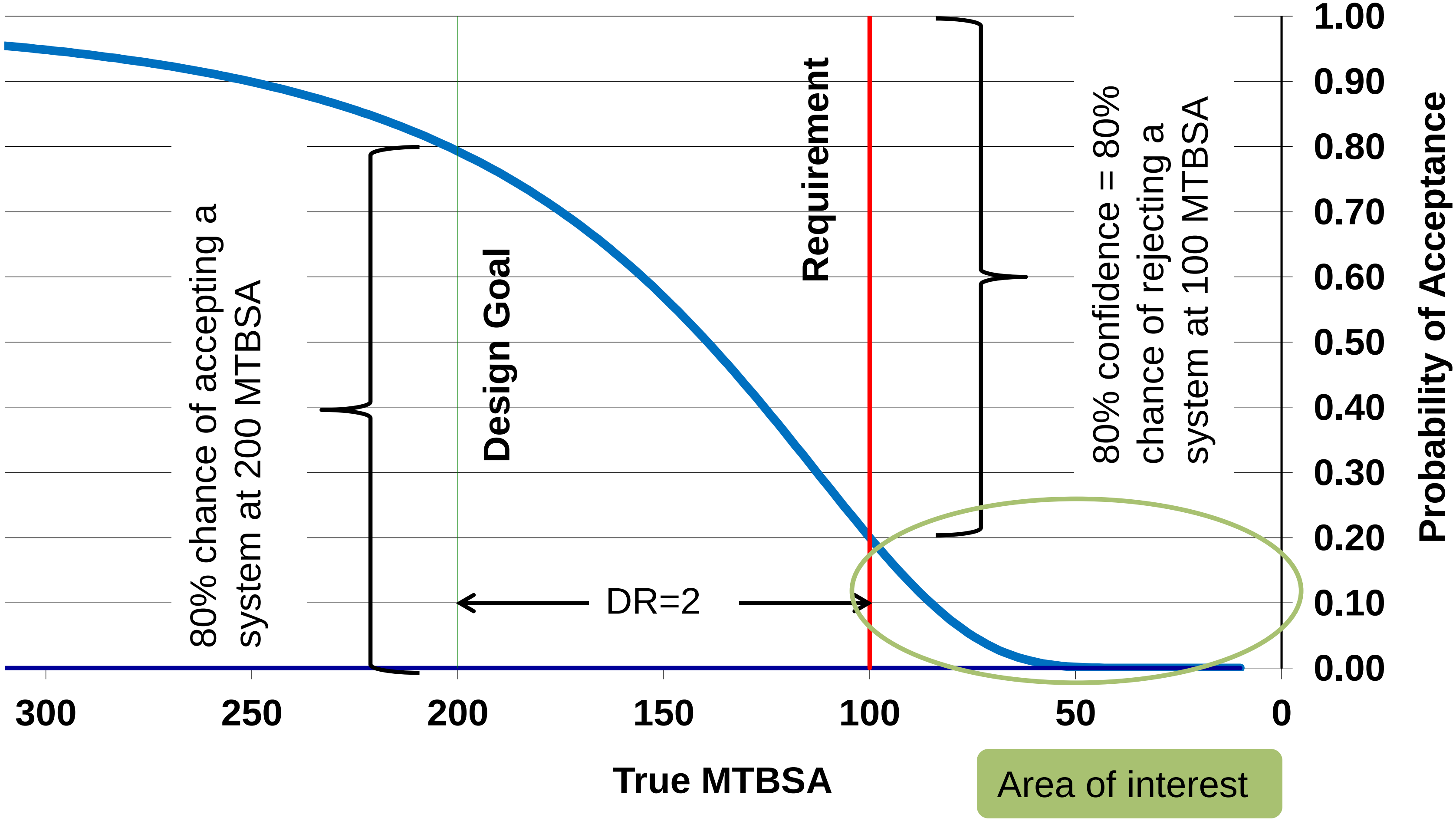
- Sometimes explicitly stated in the requirement
- Frequently left to the test community
  - Army guidance is to demonstrate reliability with ‘high confidence’
  - Frequently this is interpreted as 80%
    - For small arms it is often 90%
    - For ammunition or safety critical items it can be even higher.
  - Regardless of requirement, confidence has a major impact on test length and probability of successfully demonstrating a requirement.

Confidence Impact on Test Length
(100 hour requirement, DR = 2)



Sample OC Curve

Operational Characteristic curve for the 790 hour 5 failure test



Confidence Impact on LCC Calculation

$$\sum_{x=1}^{\text{rel rqmt}} \text{Cost}(x) \times \text{Probability}_{\text{conf}}(x)$$

1. Determine the life cycle cost for each reliability level
2. Multiply by the likelihood of accepting that reliability level (do this for each level of confidence)
3. Calculate the area under the (likelihood x cost) curve (do this for each level of confidence)

   The area under the curve is the average cost risk

   (for each confidence level)

A simple example calculation

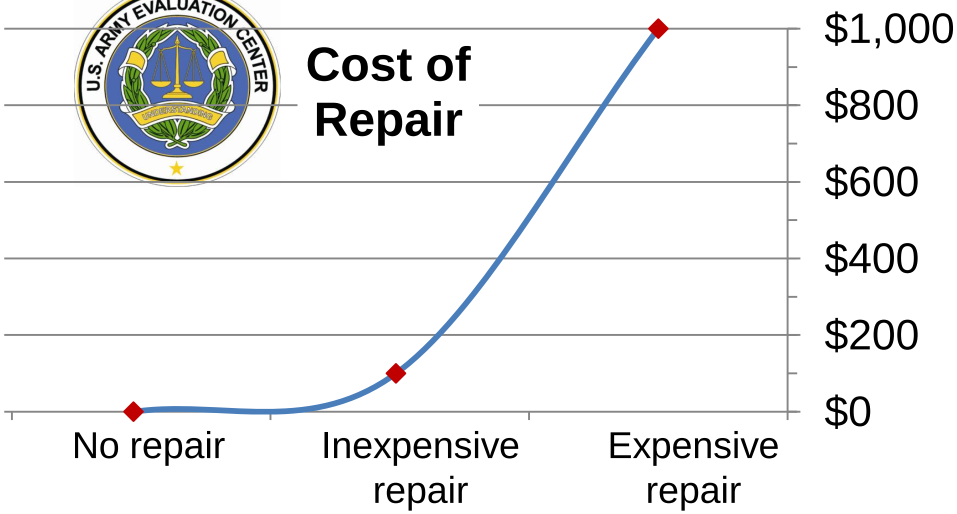
- You think your car has a problem
- You call two mechanics (Dave and Rick) to get estimates
- Based on your description, they guess the likelihood and cost of the problem

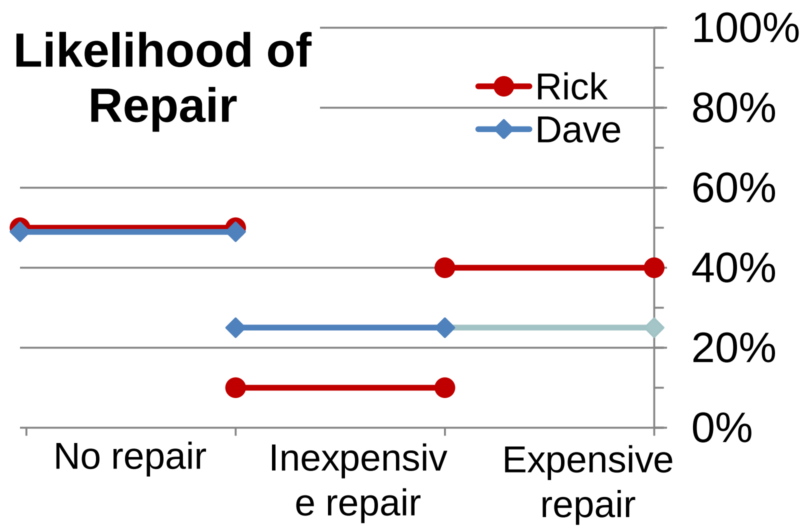
Repair Cost	Probability of Repair		Cost x Probability	
	Dave	Rick	Dave	Rick
$0	50%	50%	$0	$0
$100	25%	10%	$25	$10
$1,000	25%	40%	$250	$400
Average cost			$275	$410
Cost difference			**$135**	

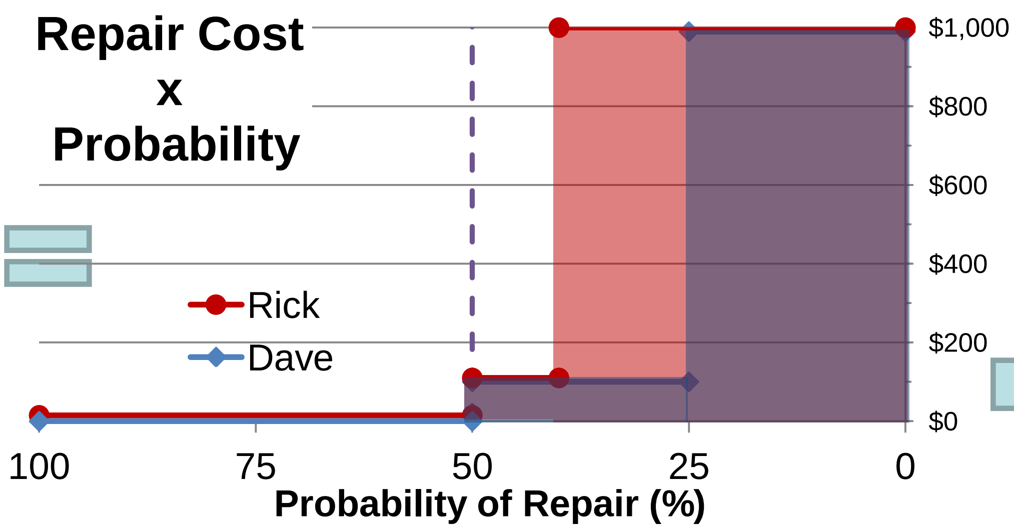
- If we asked instead for average repair cost ***only*** when something is wrong, we would get a slightly different answer (scaled by a factor of 2).

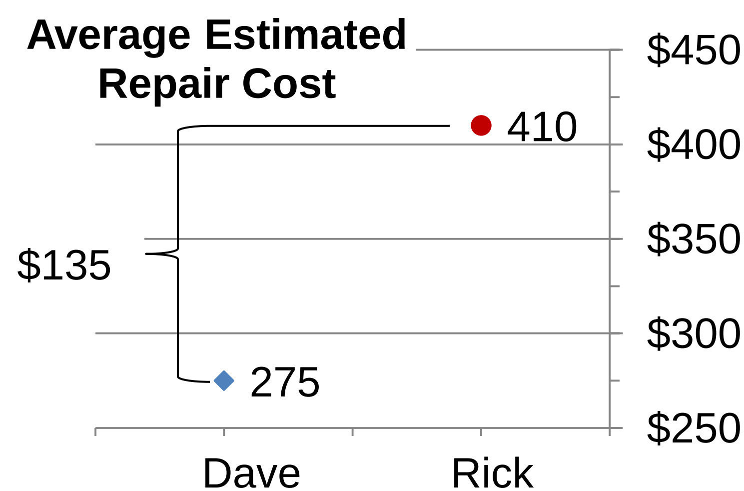
Repair Cost	Probability of Repair		Cost x Probability	
	Dave	Rick	Dave	Rick
$100	50%	20%	$50	$20
$1,000	50%	80%	$500	$800
Average cost			$550	$820
Cost difference			**$270**	

Visual for Example Calculation









The area under the Repair cost x probability curve is the average cost for each mechanic

Why coverage should not be scaled

- Again imagine you have a car that you suspect has a problem, and you call two mechanics:

Repair Cost	Probability of Repair		Cost x Probability	
	Dave	Rick	Dave	Rick
$0	80%	60%	$0	$0
$100	10%	20%	$10	$20
$1,000	10%	20%	$100	$200
Average cost			$110	$220
Cost difference			**$110**	

- But what if we adjust them so that the coverage is equal again
  (i.e. we are only considering average cost of repair when there is a problem.)

Repair Cost	Probability of Repair		Cost x Probability	
	Dave	Rick	Dave	Rick
$100	50%	50%	$50	$50
$1,000	50%	50%	$500	$500
Average cost			$550	$550
Cost difference			**$0**	

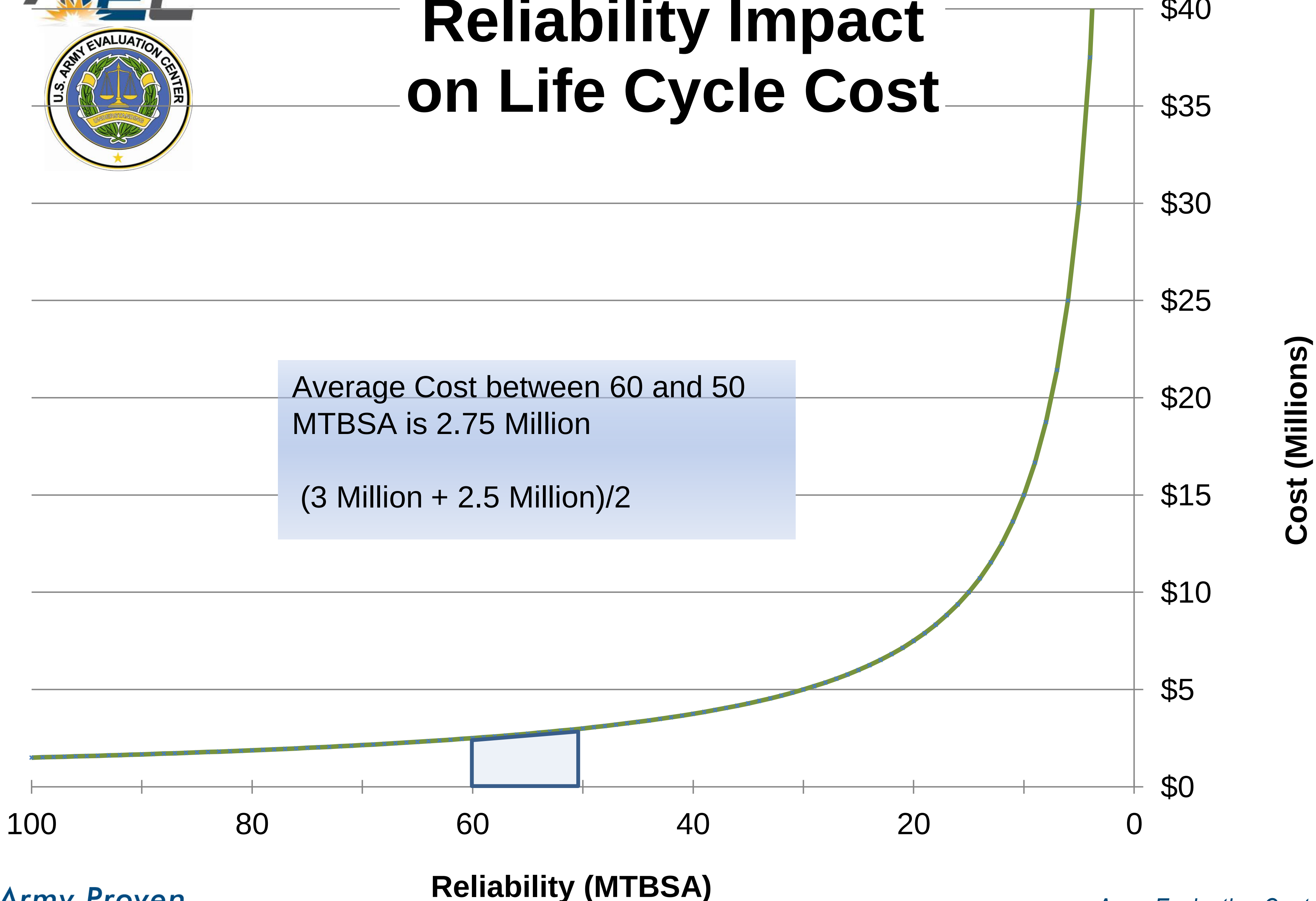
- Not surprisingly the repair costs are now identical, but this is misleading for which approach would on average cost more (assuming both had correct probabilities)
- We don't scale the cost x confidence sums for the same reason

Example: Expensive Low Density System

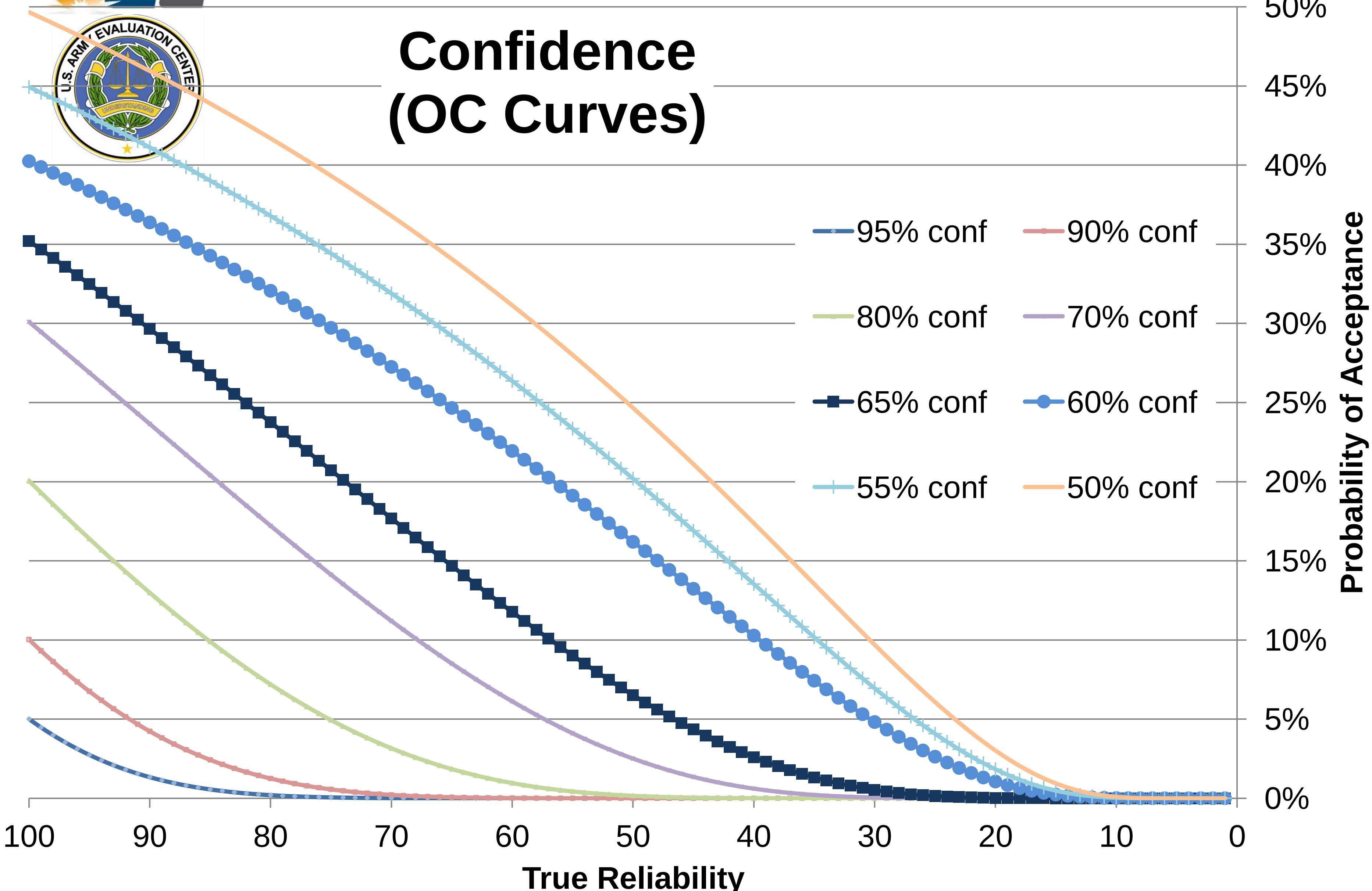
Total systems	5
System life (years)	10
Requirement MTBSA (hours)	100
Utilization (hours per year)	3000
Repair cost per SA ($)	1000
Test cost per hour ($)	5000

Test cost is high to account for high prototype costs

Reliability Impact on Life Cycle Cost



Confidence (OC Curves)

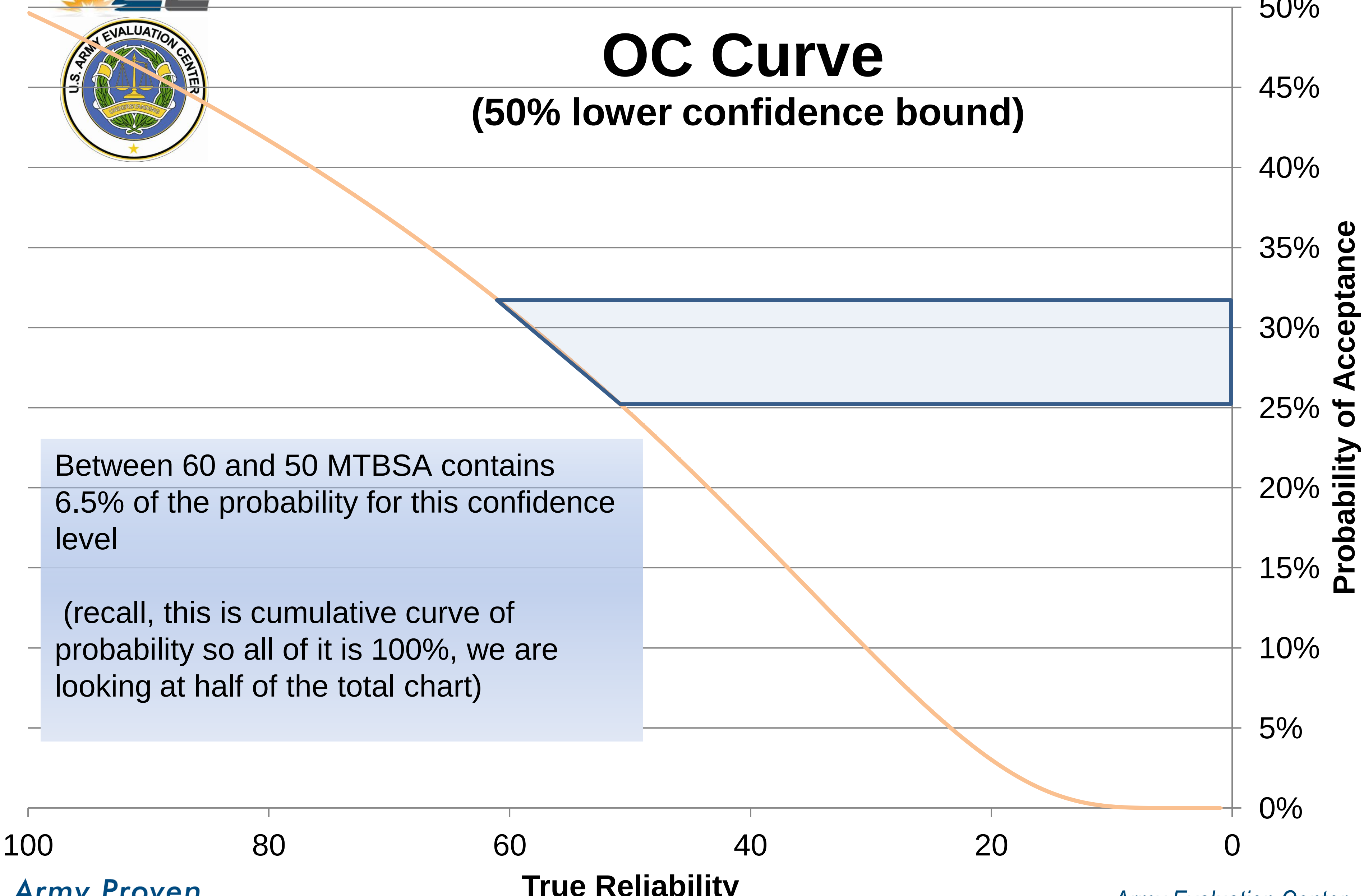


OC Curve

(50% lower confidence bound)

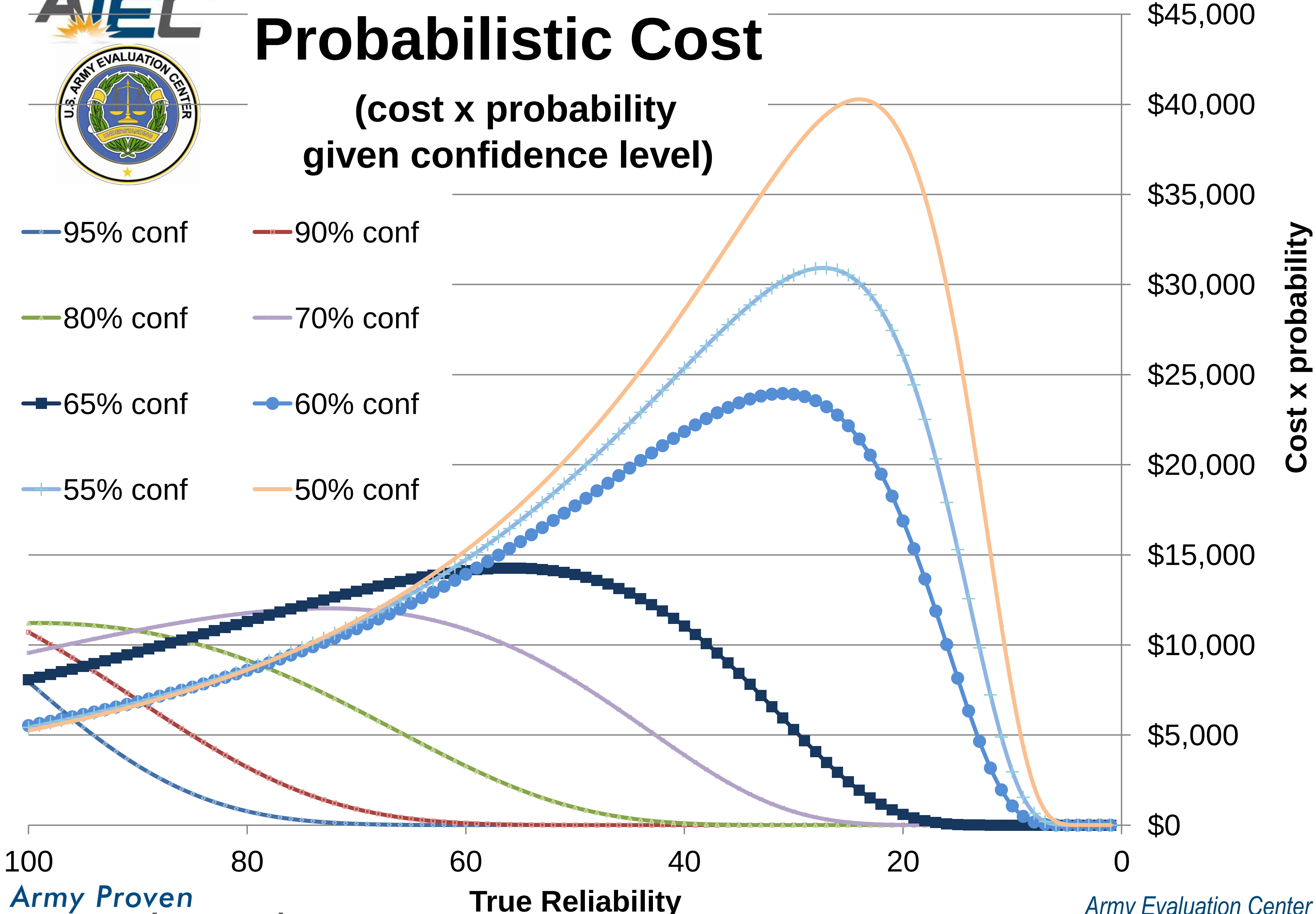
Between 60 and 50 MTBSA contains 6.5% of the probability for this confidence level

(recall, this is cumulative curve of probability so all of it is 100%, we are looking at half of the total chart)



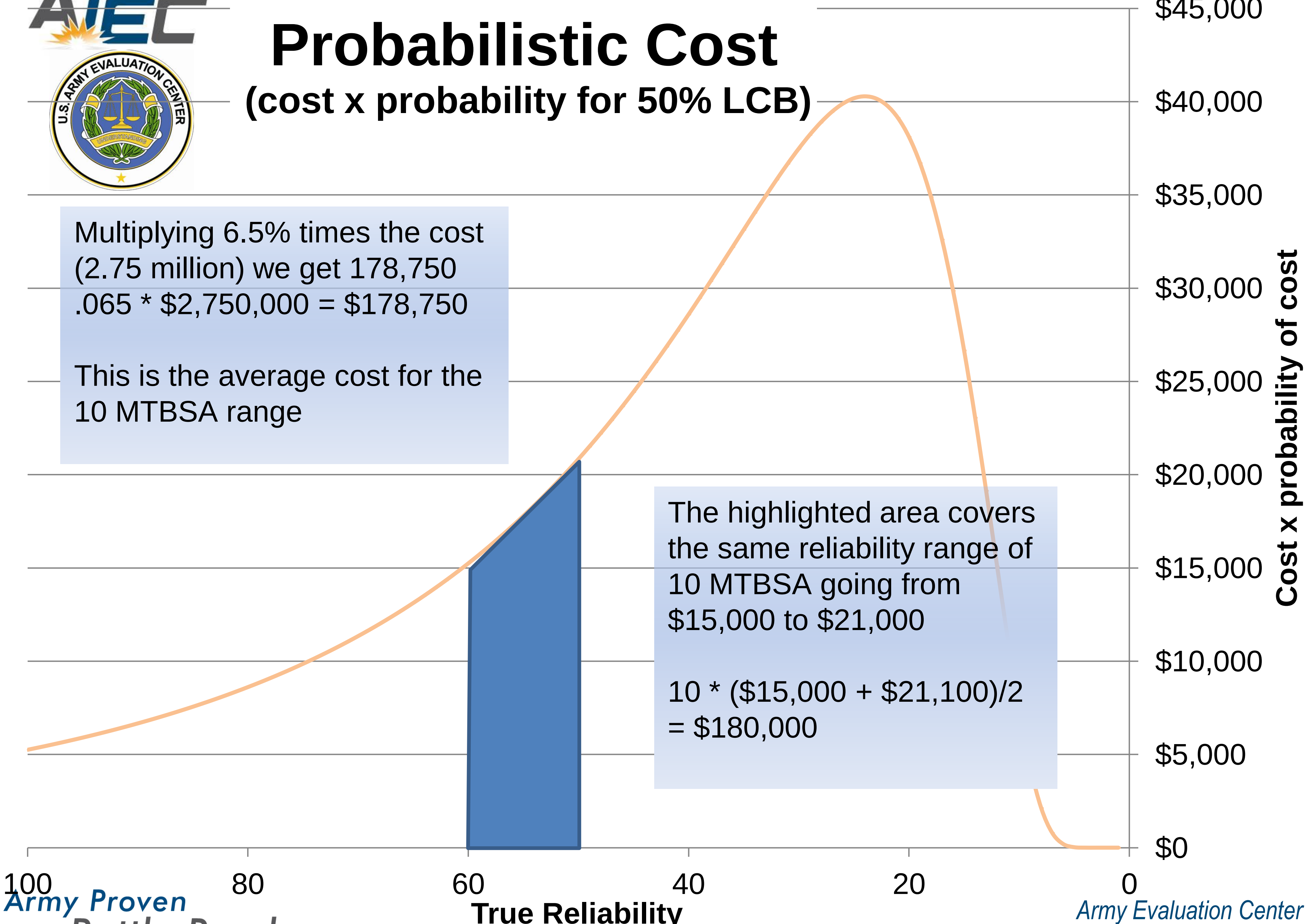
Probabilistic Cost

(cost x probability given confidence level)



Probabilistic Cost

(cost x probability for 50% LCB)



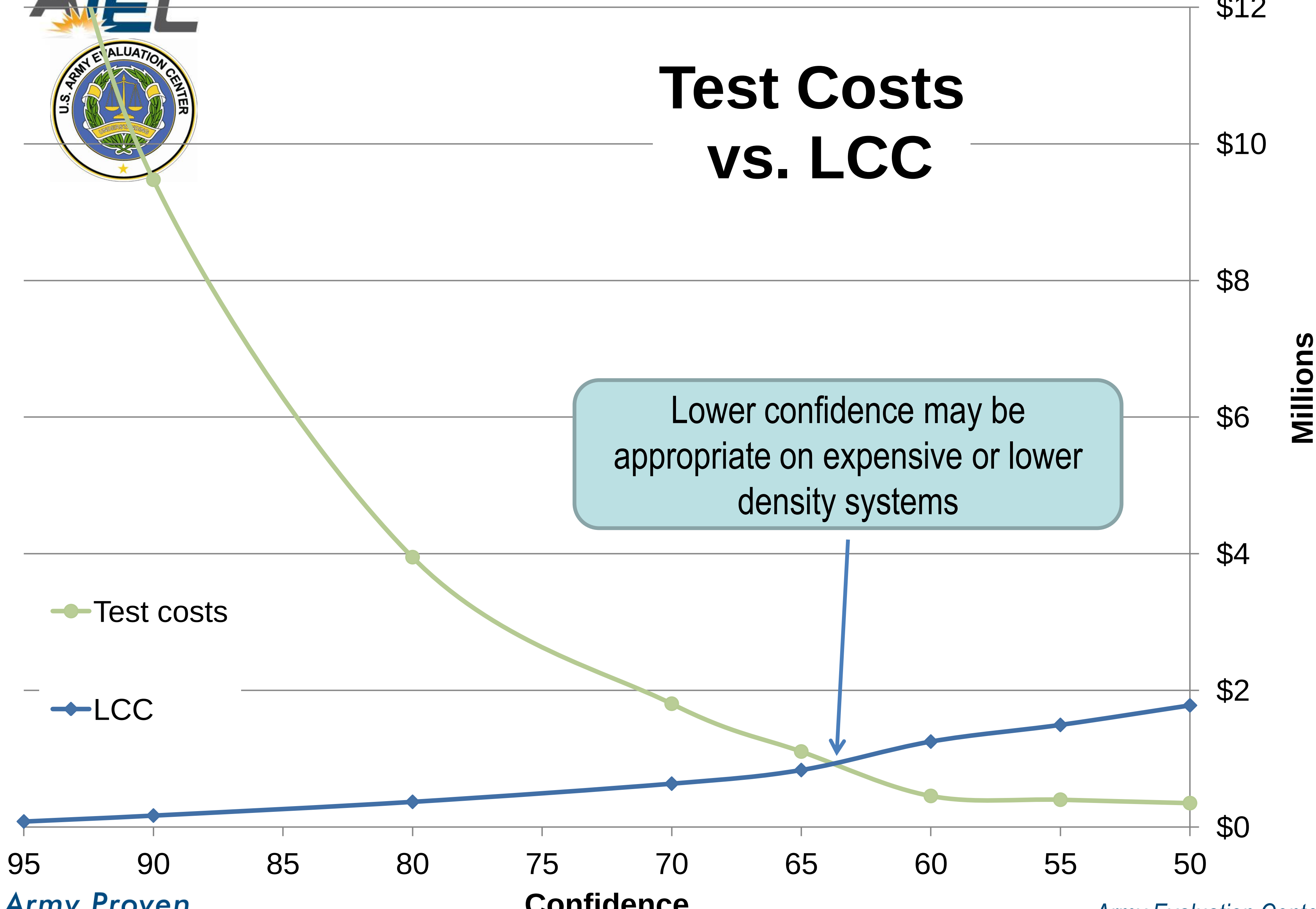
Multiplying 6.5% times the cost (2.75 million) we get 178,750
.065 * $2,750,000 = $178,750

This is the average cost for the 10 MTBSA range

The highlighted area covers the same reliability range of 10 MTBSA going from $15,000 to $21,000

10 * ($15,000 + $21,100)/2 = $180,000

Test Costs vs. LCC



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Army Evaluation Center

Example: Expensive Medium Density System

Total systems	500
System life (years)	20
Requirement MTBSA (hours)	60
Life Cycle Cost	COHORT
System Cost	10 million
Test Cost	20 million per 1x test

COHORT

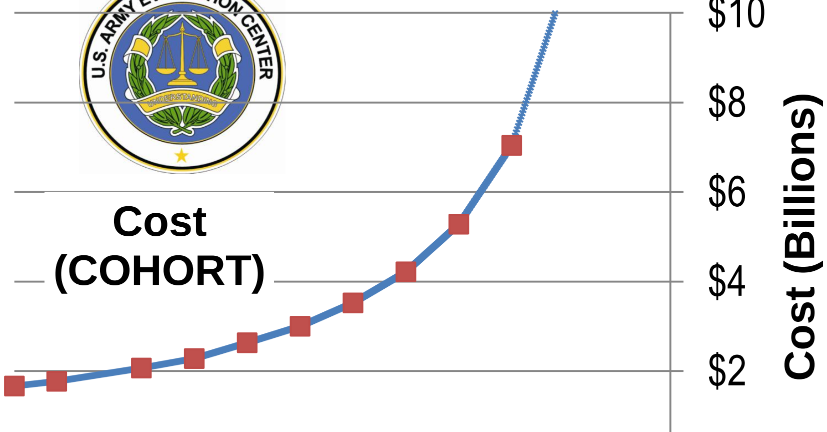
COnsumption **HO**lding **R**epair & **T**ransport model

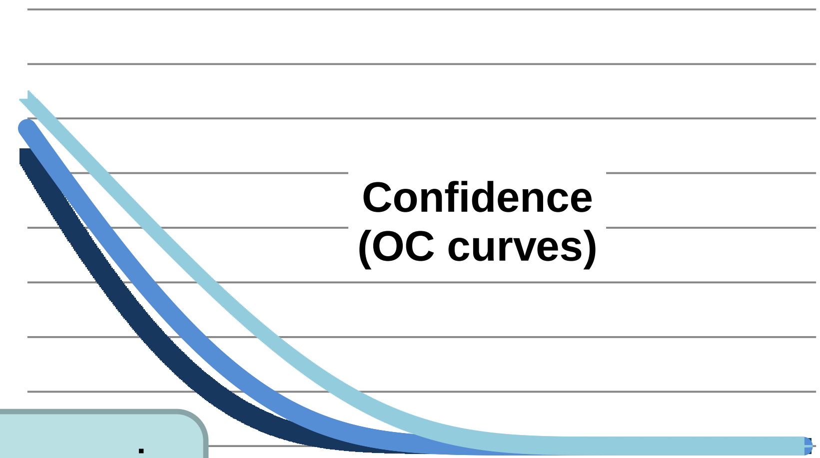
- **COHORT** is an AMSAA model that uses **SESAME's*** initial issue stock lists, unit and end item production schedules, and input part reliability and maintenance data to determine both the discounted and non-discounted expected life cycle costs for:
  - initial issue spares and repair parts;
  - the replacement of consumed spares and repair parts;
  - the repair of reparable items;
  - the transportation of serviceable items among the supply echelons;
  - the costs to retrograde unserviceable reparable items to the echelon of repair or condemnation.

Captures all Significant O&S Costs that are Reliability driven

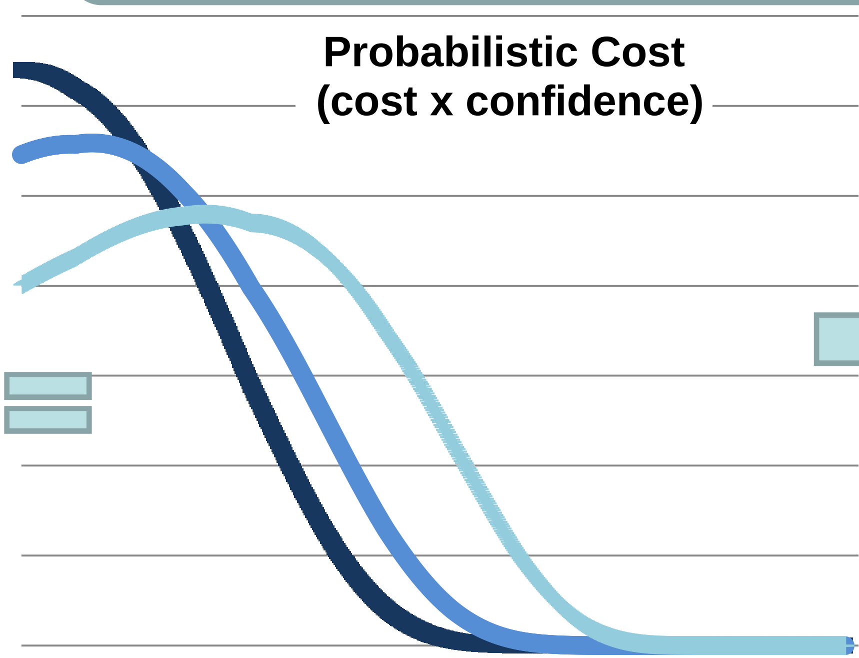
* SESAME – Selected Essential-Item Stock for Availability Method

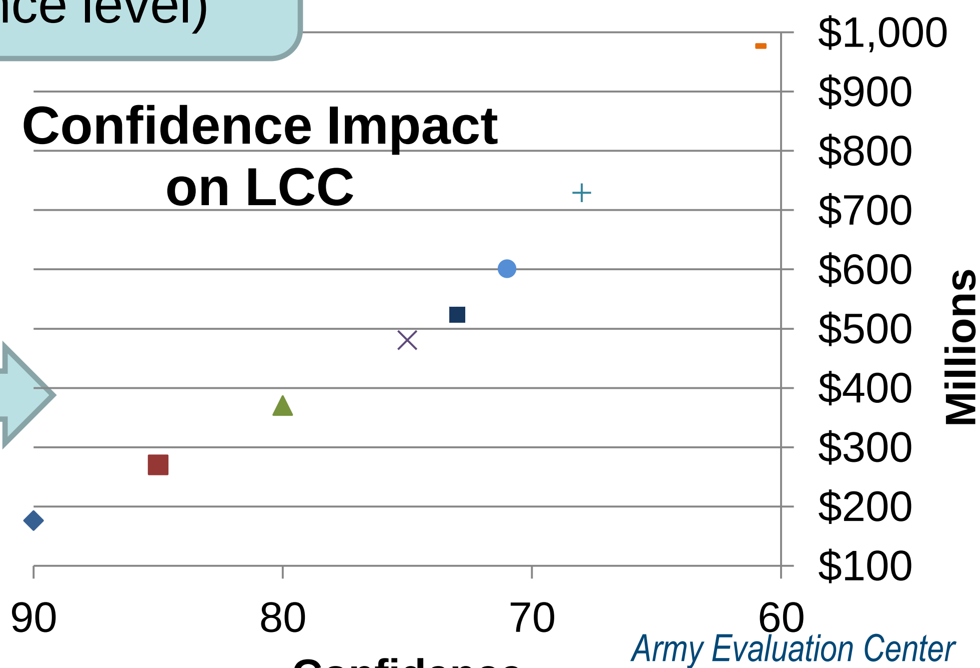
Visual for Calculation



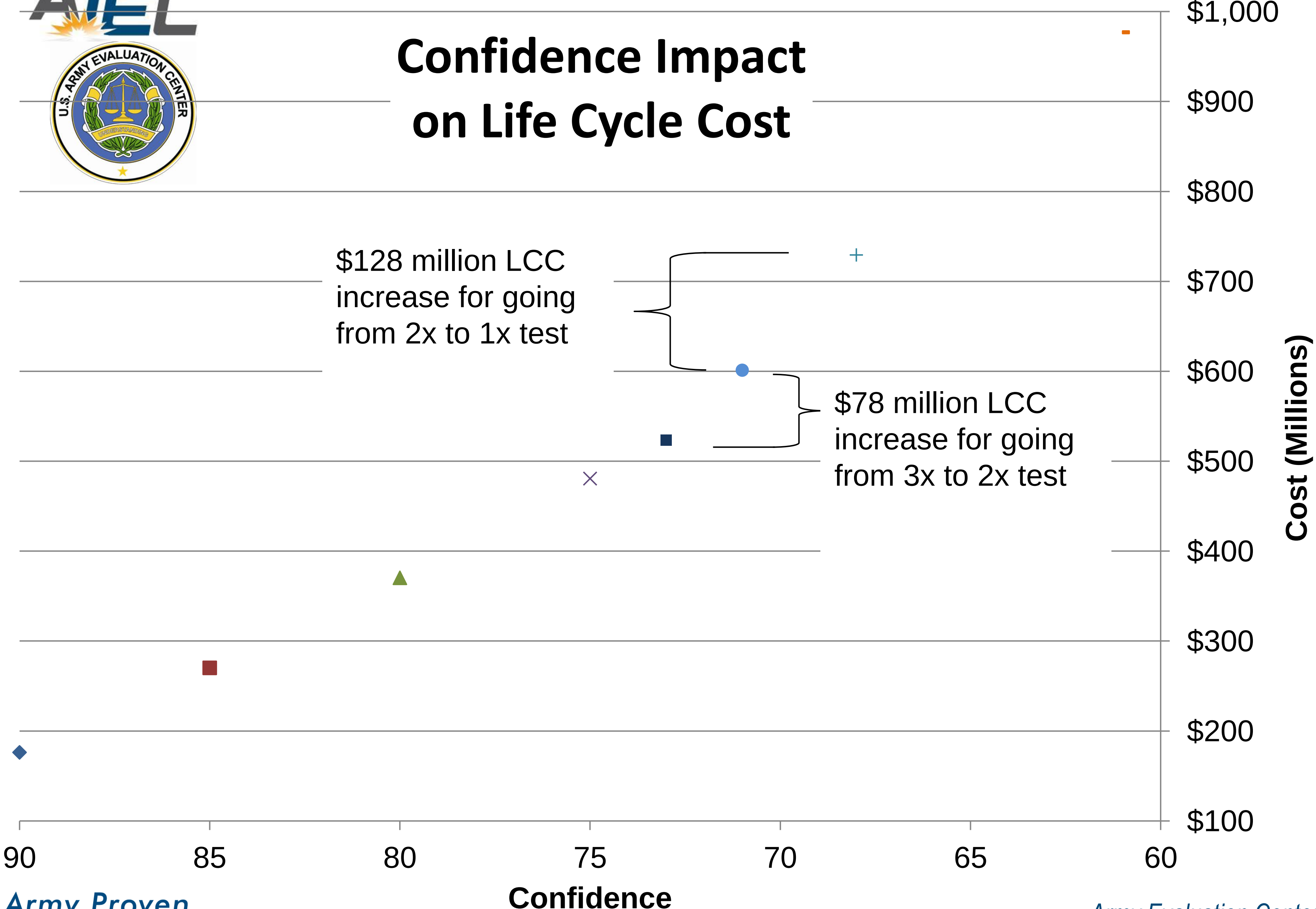


The area under the cost x confidence curve, is the average cost (for each confidence level)





Confidence Impact on Life Cycle Cost

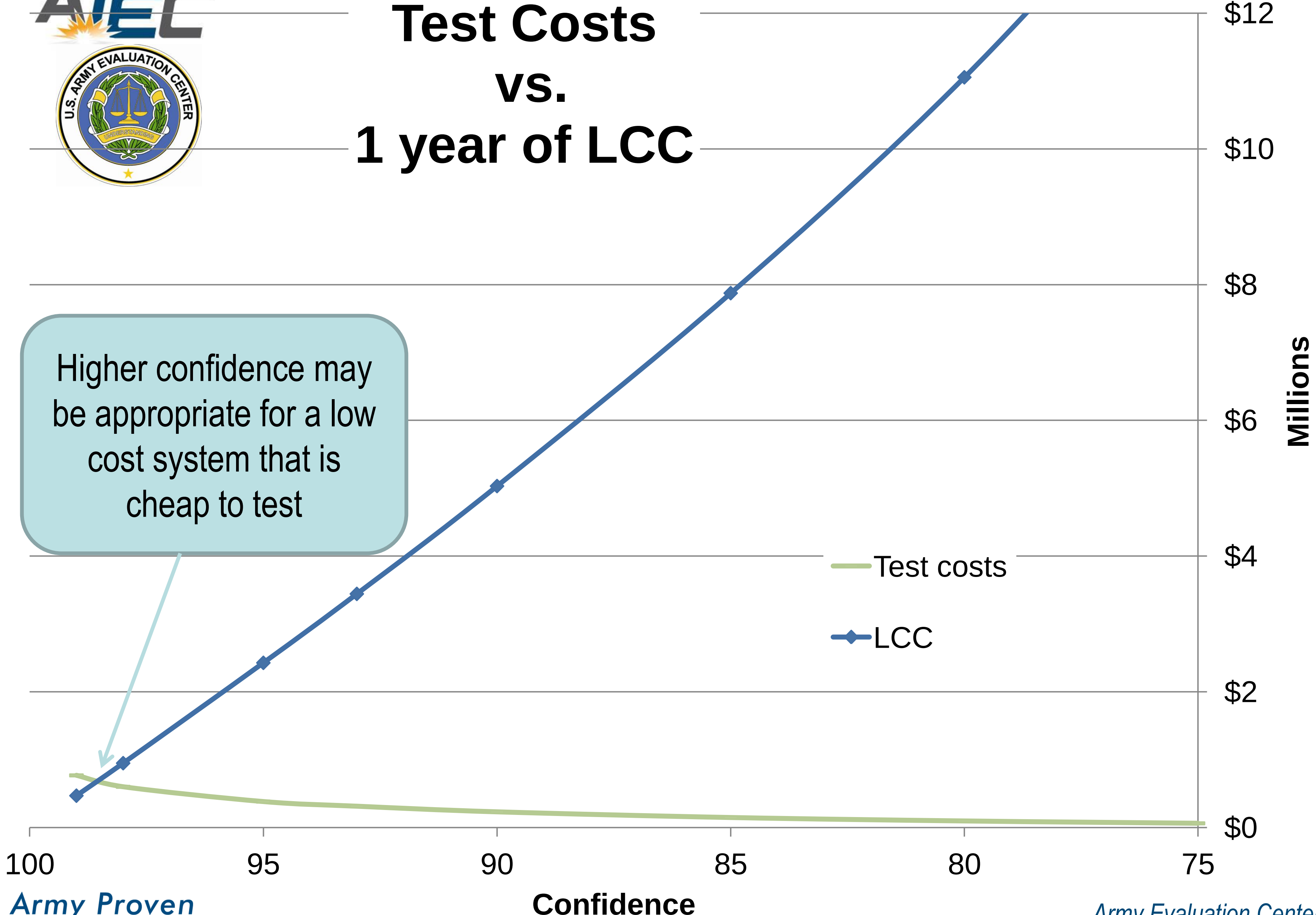


Example: Inexpensive High Density System

Total systems	500,000
System life (year)	* 1
Requirement MRBSA (rounds)	6078
Utilization (rounds per year)	5483
Repair cost per SA ($)	100
Test cost per round ($)	2

* One year system life to ease comparison

Test Costs vs. 1 year of LCC



Conclusions

- Confidence plays a large role in test costs and durations
- There is an optimal confidence level
  - Might not be based on LCC
  - Competing factors like durability, Soldier safety, mission criticality, etc.
- Similar to Risk (likelihood x consequence)
- Method offers incomplete coverage
- Focuses on increase above what the government planned to pay
- This is an overall cost risk prior to having the information
- Can mitigate future costs, but redesigns are costly too
- Method addresses only government risk
- Confidence analysis would be useful early in the requirements process

Questions?

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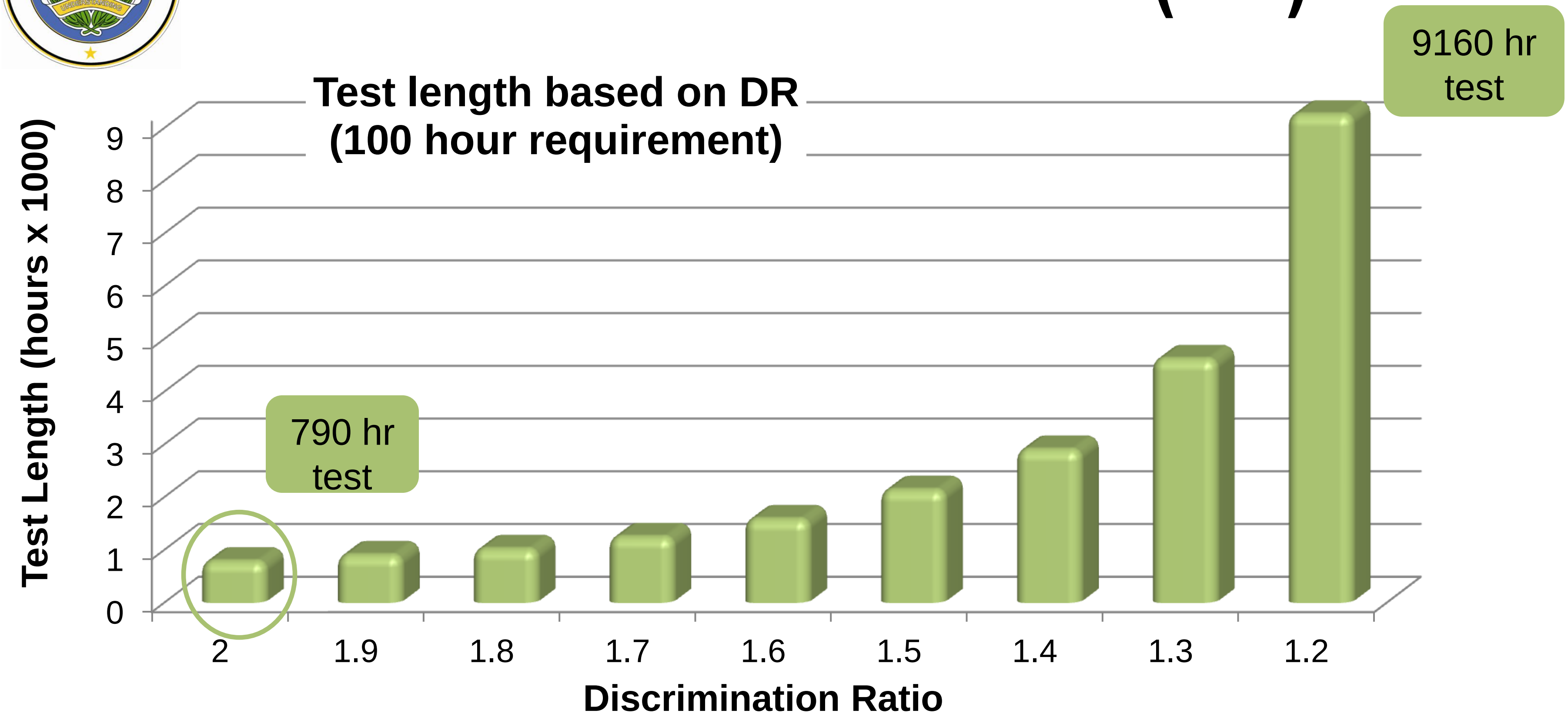
Backups

Impact of Discrimination Ratio (DR)



The best way to succeed quickly is design well above the requirement!

Input options

- Confidence options
  - Calculated with Poisson
  - Other distributions as appropriate (single shot systems for instance.)
- Cost (options)
  - Estimated repair costs (surrogated)
  - **Co**nsumption **Ho**lding **R**epair & **T**ransport (COHORT) model
  - Actual costs
    - manpower, force structure, parts, and locations
    - Requires very detailed data and complex modeling

Cost of Confidence Calculation

$$F_{\text{ProbabilisticCost}}(x, confidence) = \int_0^x F_{\text{Cost}}(x) \times F_{\text{OCcurve(confidence)}}(x)$$

$$F_{\text{ProbabilisticCost}}(x, t, f) = \sum_1^x F_{\text{COHORT}}(x) \times F_{\text{Poisson}(t,f)}(x)$$

COHORT is an AMSAA model that returns Life Cycle Cost based on fielding plan (density, spares, allocations, etc.), maintainability data, and reliability data. The model is designed to maintain the desired A_o, and changes the previous parameters to achieve this. COHORT has been vetted with DASA-CE and OSD CAPE, and they agree with the methodology.

The OC curve is based on the Poisson function (see next slide), which (in this case) provides the cumulative probability of seeing *f* or fewer failures in time *t* given a reliability of *x.*

In practice, this summation was done as a spreadsheet multiplying the probability of landing in a certain slice under the OC curve (Poisson) by the cost of falling in that slice (linear interpolation from COHORT results). A simple sensitivity analysis was performed to ensure the step size was suitable: the variation based on an order of magnitude step size refinement was less the 1%.

Assumptions and Notes

- The costs between discreet cohort runs were done with a simple linear interpolation (although a power curve fits the data very well, it does not hit the points exactly)
- OC curves were estimated based on the Poisson distribution
- While balanced tests are the goal, due to the fixed DT goal and discreet test lengths, the percentages are not exact.

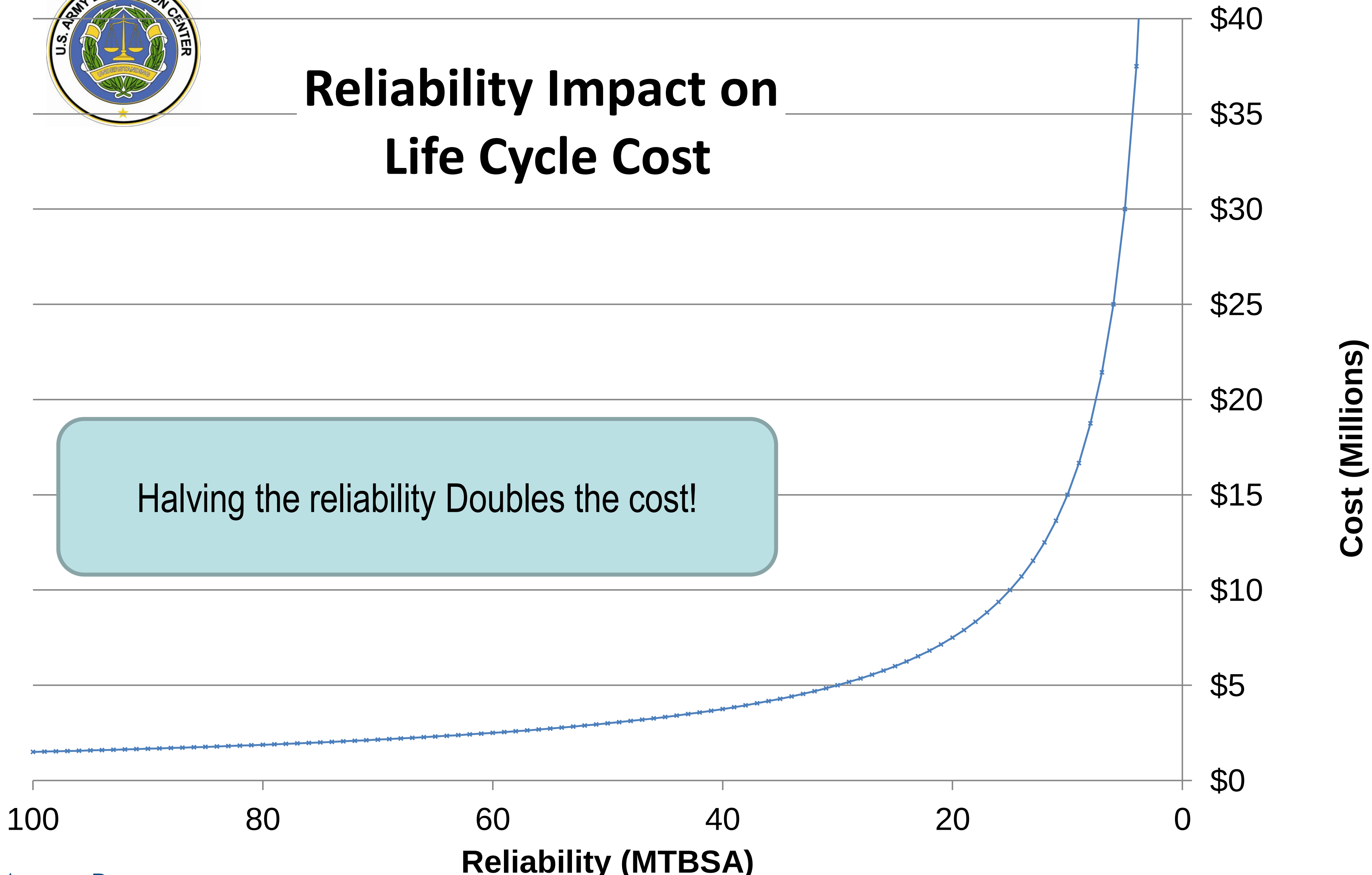
Example: Expensive Low Density System

Total systems	5
System life (years)	10
Requirement MTBSA (hours)	100
Utilization (hours per year)	3000
Repair cost per SA ($)	1000
Test cost per hour ($)	5000

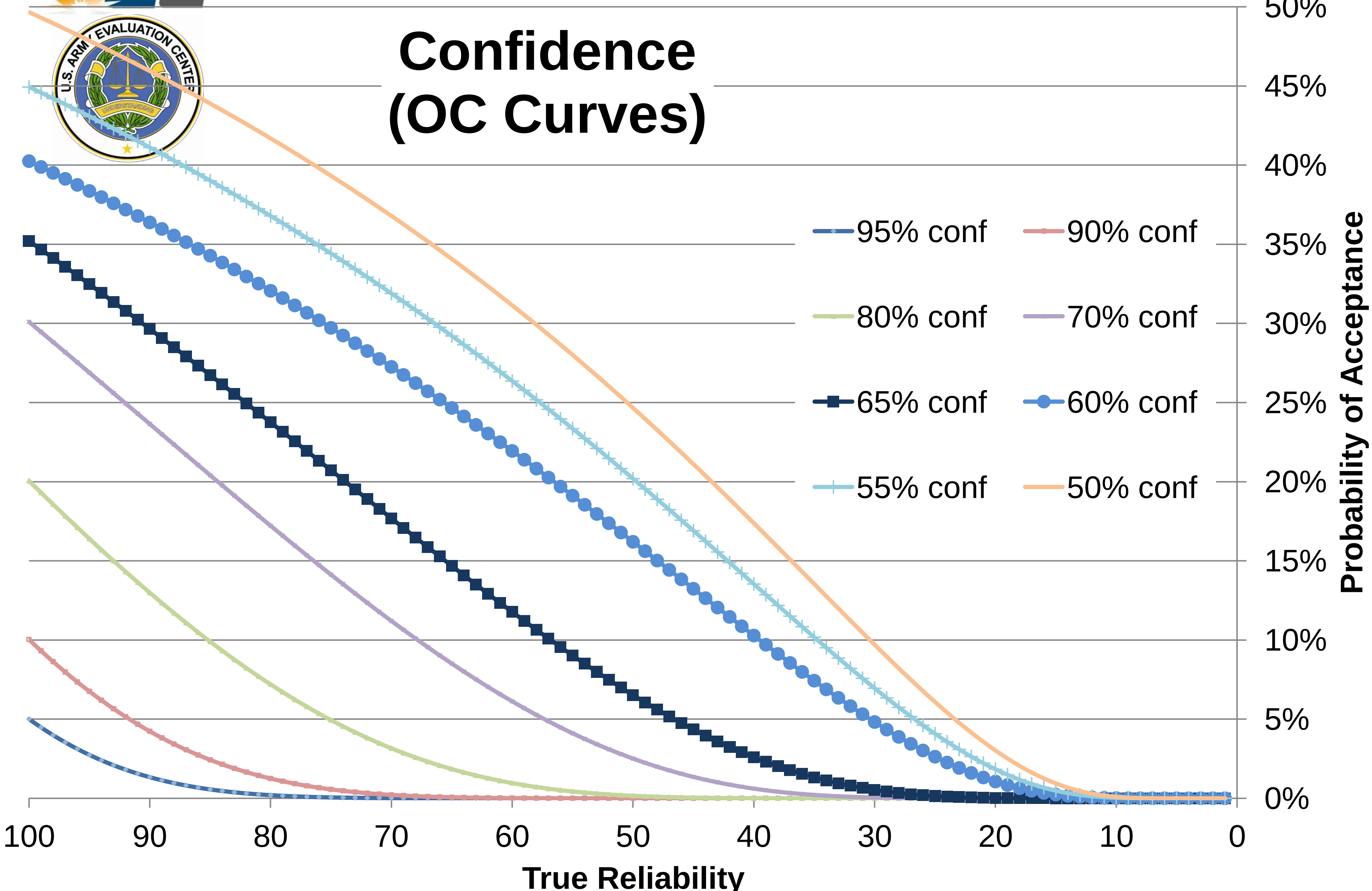
Test cost is high to account for high prototype costs

Reliability Impact on Life Cycle Cost

Halving the reliability Doubles the cost!

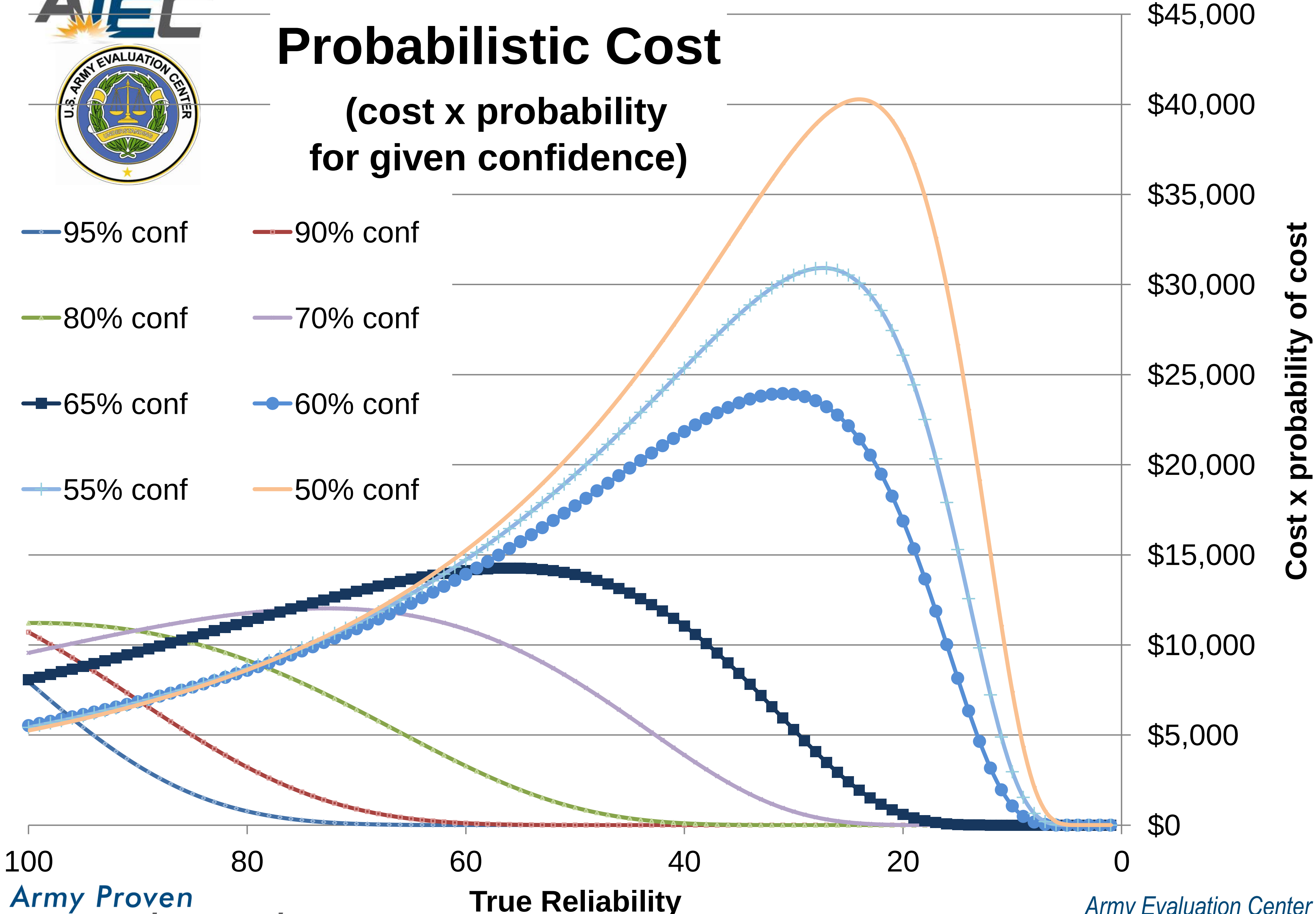


Confidence (OC Curves)

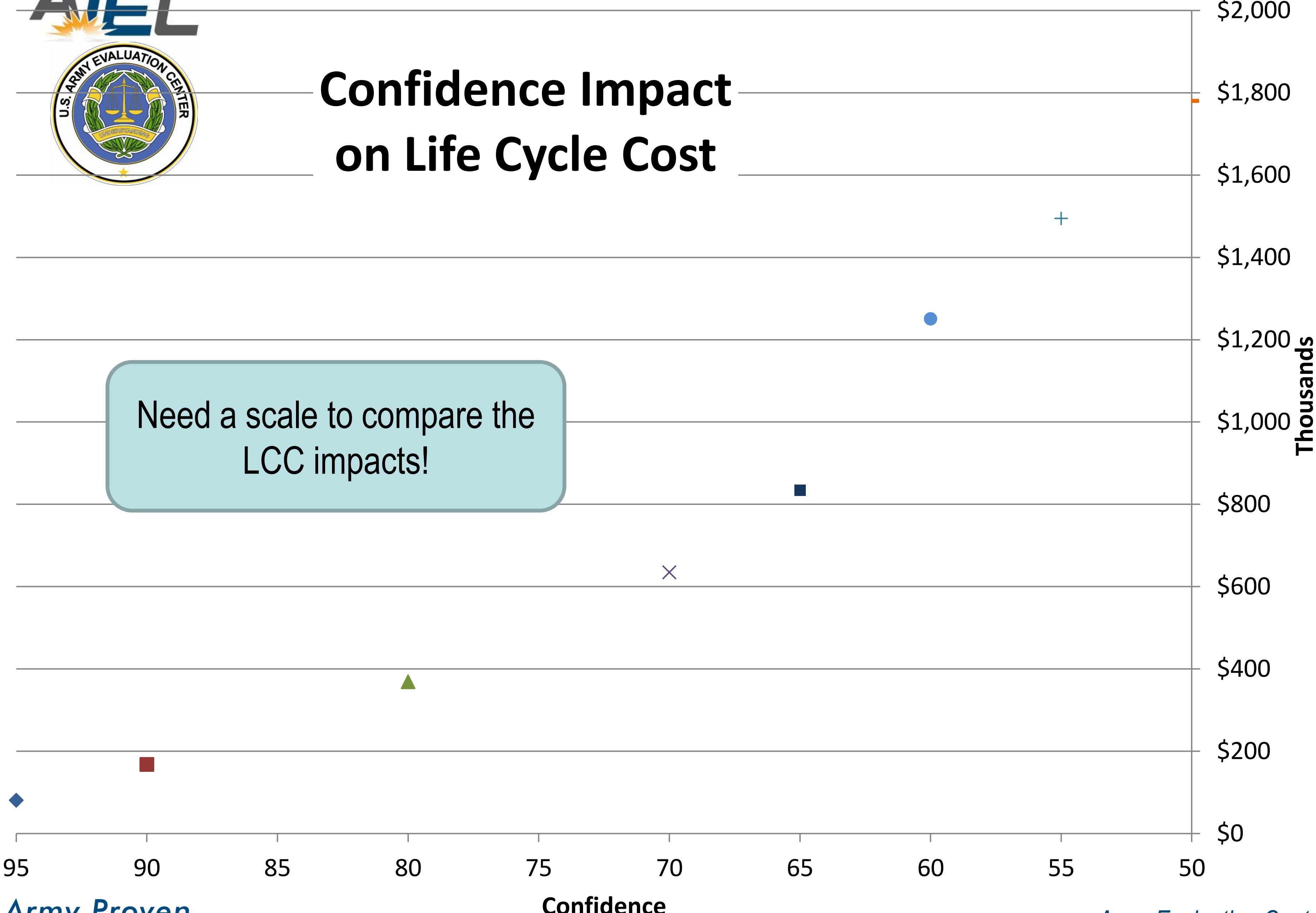


Probabilistic Cost

(cost x probability for given confidence)



Confidence Impact on Life Cycle Cost



Need a scale to compare the LCC impacts!

Example: Expensive Medium Density System

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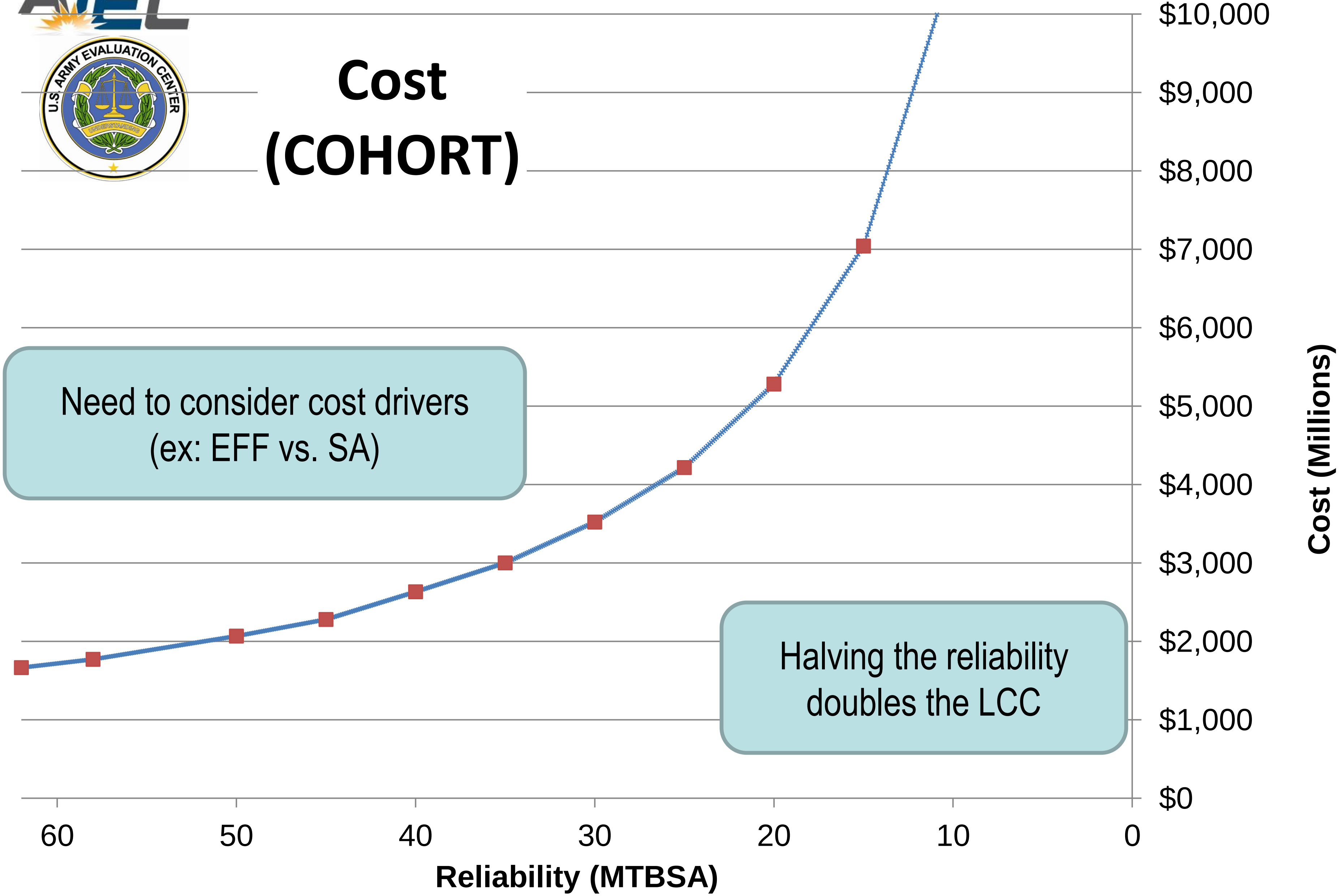
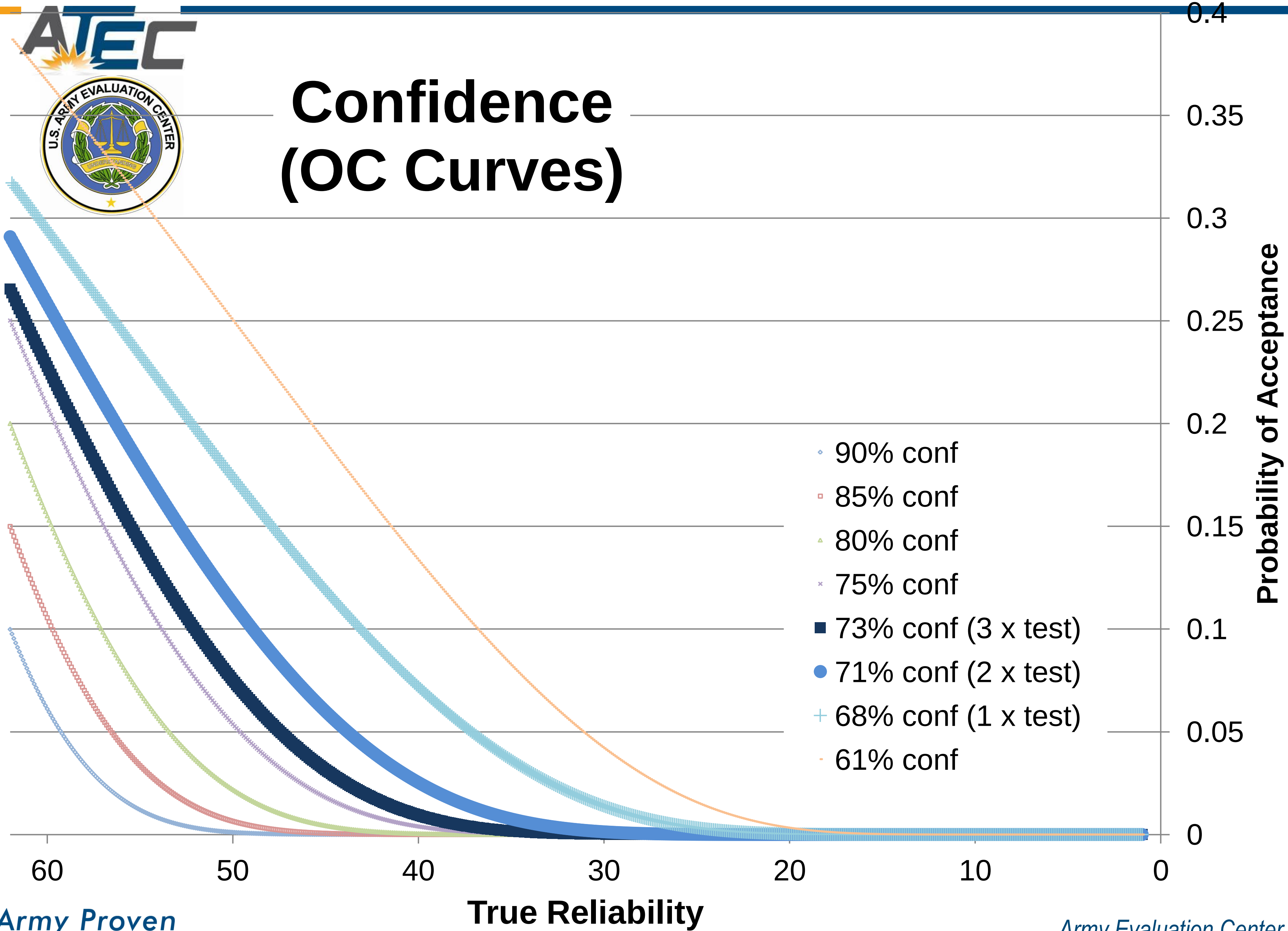
System Cost	10 million
Test Cost	20 million per 1x test

Cost (COHORT)



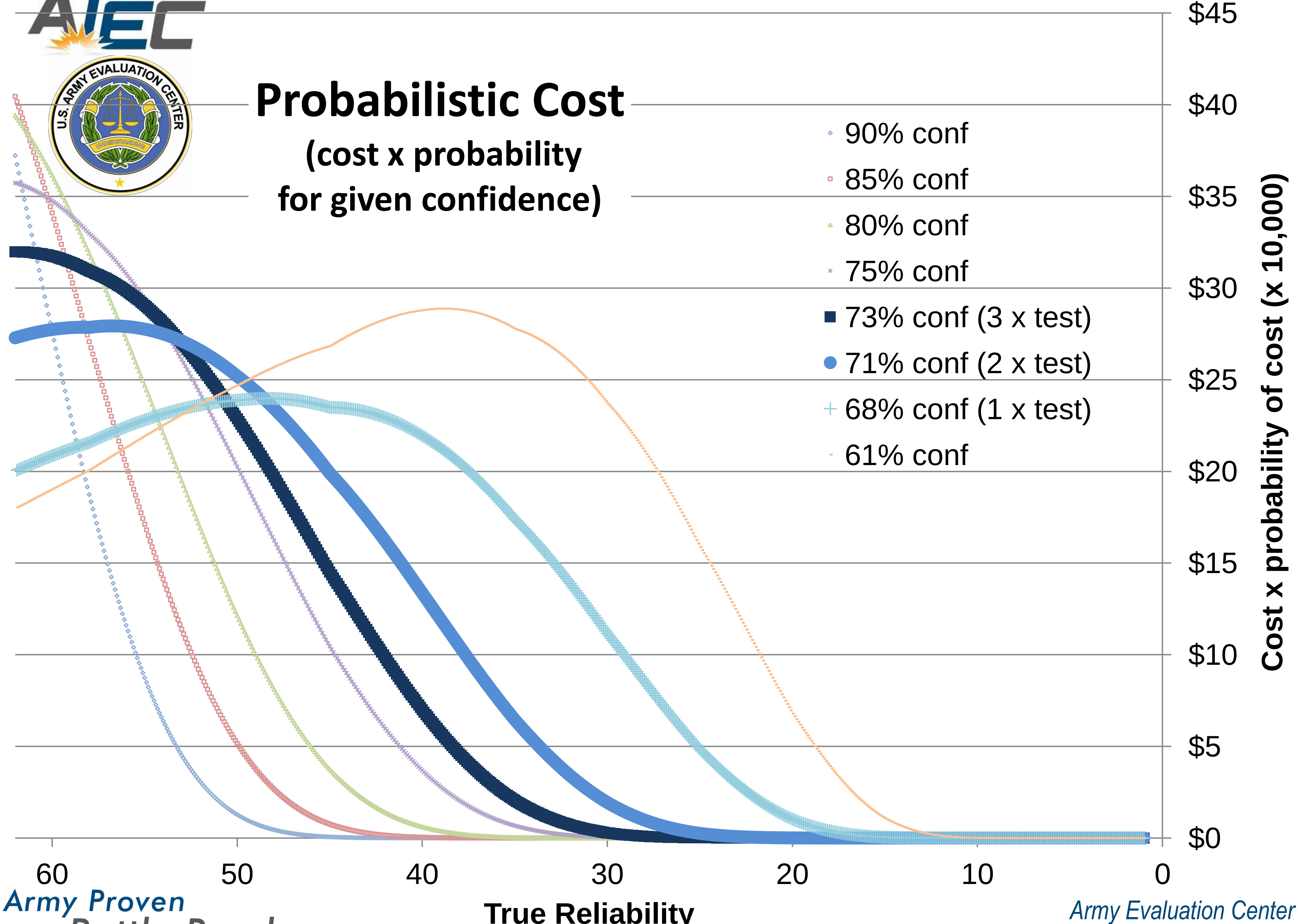
$10,000
$9,000
$8,000
$7,000
$6,000
$5,000
$4,000
$3,000
$2,000
$1,000
$0
Cost (Millions)
60
50
40
30
20
10
0
Reliability (MTBSA)
Need to consider cost drivers (ex: EFF vs. SA)
Halving the reliability doubles the LCC

Confidence (OC Curves)



Probabilistic Cost

(cost x probability for given confidence)



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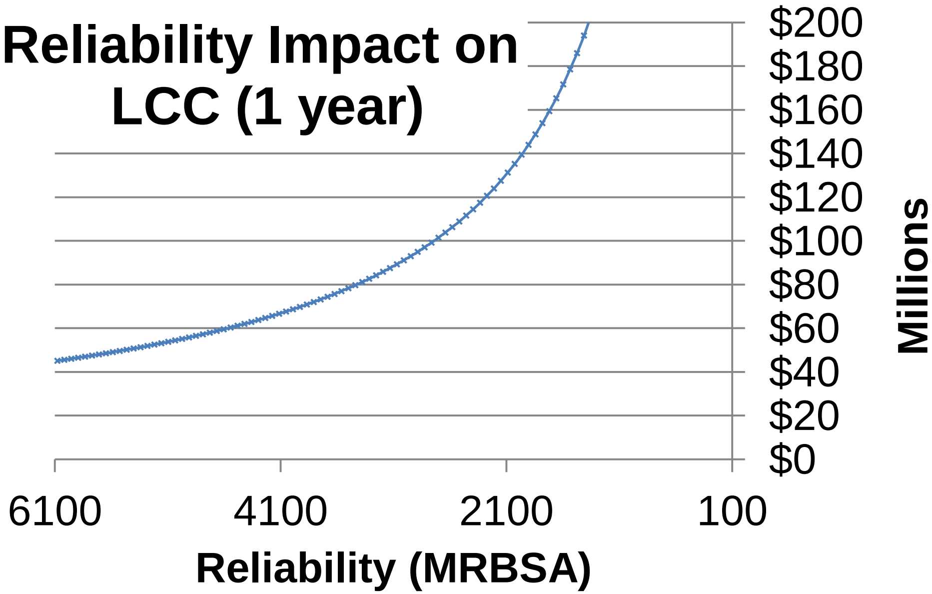
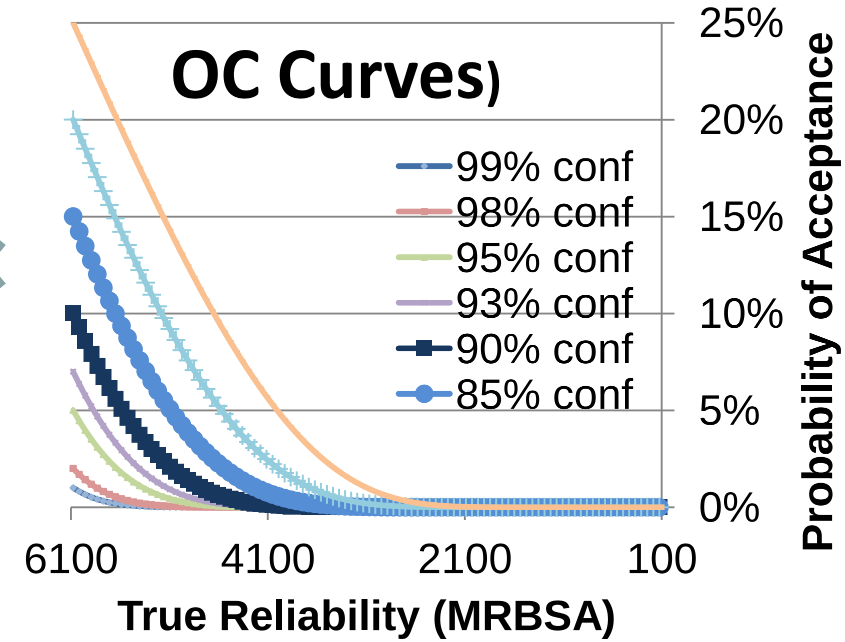
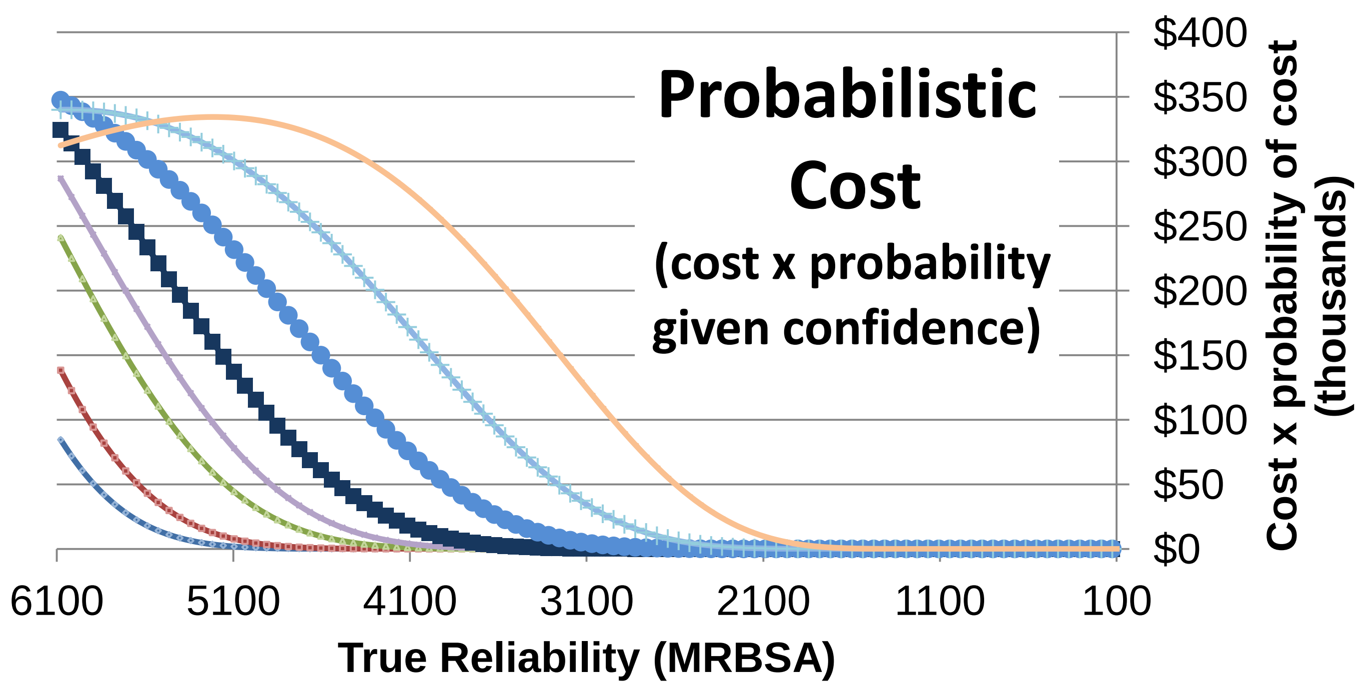


Reliability Impact on LCC (1 year)
$200
$180
$160
$140
$120
$100
$80
$60
$40
$20
$0
Millions
6100
4100
2100
100
Reliability (MRBSA)



OC Curves)
99% conf
98% conf
95% conf
93% conf
90% conf
85% conf
25%
20%
15%
10%
5%
0%
Probability of Acceptance
6100
4100
2100
100
True Reliability (MRBSA)



Probabilistic Cost
(cost x probability given confidence)
$400
$350
$300
$250
$200
$150
$100
$50
$0
Cost x probability of cost (thousands)
6100
5100
4100
3100
2100
1100
100
True Reliability (MRBSA)