A Decision Analytic Approach for Measuring the Value of Counter-IED Solutions at the Joint Improvised Explosive Device Defeat Organization

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Overall Problem Statement

- During peacetime, defense organizations conduct deliberate planning against an envisioned set of future threats.
- Defense investments are made based on an annual budgetary cycle.
  - *Knapsack Problem*
- Short conflicts are fought with the peacetime inventory.
- During longer conflicts, the defense establishment can seek to improve its inventory.
- The battlefield presents a co-evolving landscape.
- Opportunities to improve the inventory arrive irregularly over time.
- Good solutions not exploited as quickly as possible lead to lost opportunities.
- But poor solutions rob resources from good solutions that arrive later.
- How to maximize the effectiveness of the defense portfolio when decisions must be made sequentially?
  - *Dynamic Stochastic Knapsack*

Case Study: JIEDDO

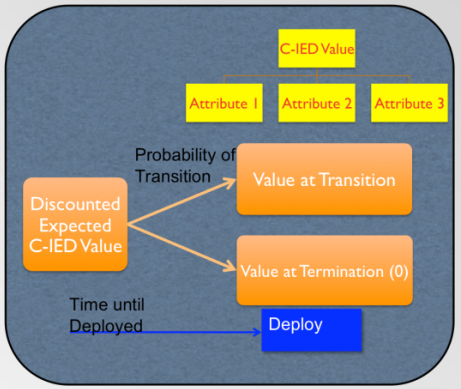
- With an average annual budget of $2.4B, JIEDDO funds a great variety of possible counter-IED solutions: initiatives that range from intelligence centers to sensors to training programs.
- JIEDDO faces increasing scrutiny of its investment decisions from oversight organizations (Congress, GAO, OSD-CAPE) while its budget is anticipated to decline.
- To enhance its responsiveness to the war effort, JIEDDO considers solutions sequentially.
- With funding diminishing, JIEDDO will have to become more selective.
- JIEDDO lacks quantitative methods to support its decisions and defend these against scrutiny.

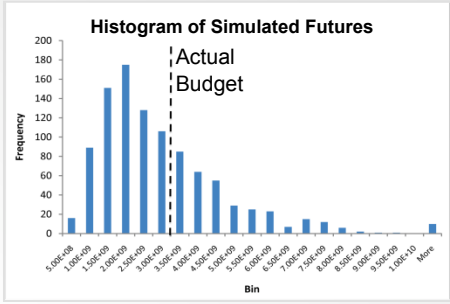
JIEDDO Case Study Objectives

- Three objectives:
  - **How to measure the quantitative value of its C-IED initiatives in the context of portfolio selection decisions**;
  - How to generate statistical forecast of future quantities, costs, and values of arriving C-IED initiatives in a given funding period at a level that will support enterprise-level resourcing and planning;
  - How to select randomly arriving initiatives for inclusion in a portfolio of C-IED solutions in order to maximize overall portfolio value.
- In the end-state, it is desired that the research support transition of technologies that can run on JIEDDO computers and be employed by JIEDDO personnel.

Bottom Line up Front

- Measuring the Value of C-IED Solutions
  - Developing a decision analytic prototype
  - Uses a multi-attribute utility approach to measure Potential C-IED Value (*PCV*)
  - Calculates Discounted Expected PCV (*DE-PCV*) using likelihood of transition, discounting for time until deployed.
- Future Initiative Stream Simulation (*FISS*)
  - Modeled sequence of initiatives as a random arrival process w/ jointly distributed initiative cost, value
  - Generates futures via Monte Carlo simulation using parameters from analysis of initiative history
- C-IED Portfolio Optimizer (*CIPO*)
  - Given cost and value of a set *S* of initiatives and an estimate of cost and value of future arrivals, which subset of *S* maximizes expected portfolio value?
  - Have solved as 2-stage stochastic integer program
  - Developing approximate dynamic programming version.





Maximize

$$\sum_i Value_i Buy_i + \sum_j P_j \sum_k^{K_j} futValue_{jk} futBuy_{jk}$$

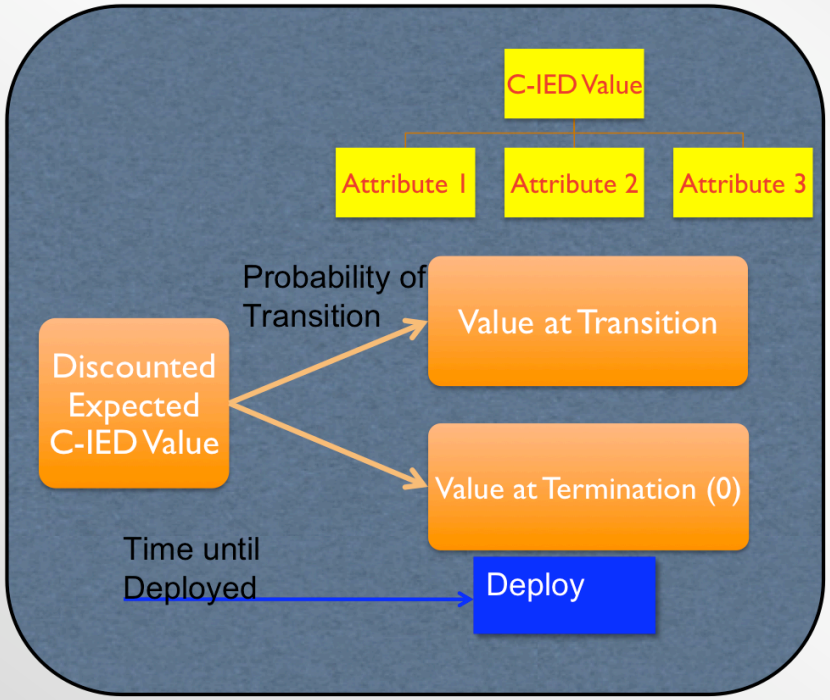
Stay within Budget

$$\sum_i Cost_i Buy_i + \sum_k^{K_f} futCost_{fk} futBuy_{fk} \le Budget, \forall f$$

Measuring Initiative Valued: Desired Endstate

- Every initiative is evaluated for its overall value based on how well it addresses overall C-IED needs, its likelihood of transition, and the time until it can deploy.
- Overtime, this measure is updated for subsequent decisions as new information becomes available.

C-IED Initiative ➔ *i*



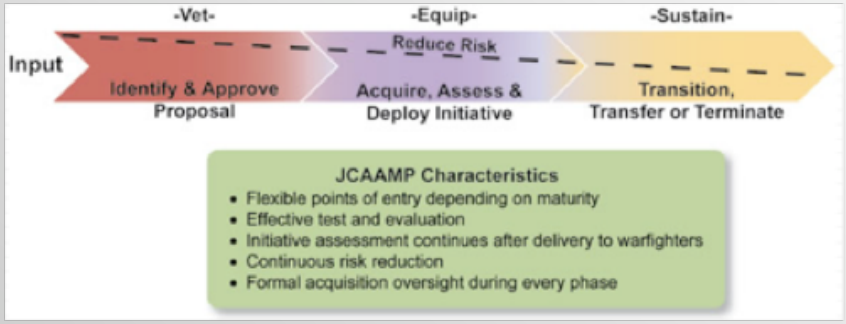
➔ Quantitative Measure of the Value of Initiative *i*

Counter-IED Lines of Operations

- JIEDDO partitions its counter-IED efforts into *Lines of Operation* (LOO):
  - Attack the Network (AtN) - preventing IEDs from reaching their intended time and place of employment.
  - Defeat the Device (DtD) - preventing IEDs that have reached their intended place of employment from achieving their intended effects.
  - Train the Force (TtF) - enhancing the counter-IED training of individuals and units.

JCAAMP

- Joint Improvised Explosive Device Defeat Capability Approval and Acquisition Management Process (JCAAMP)
- Sequential funding steps
- 2 years of sustainment once deployed after which must transition to Title 10 organization (usually a Military Service)
- Process conducted within each LOO but integrated at the Vice Director level for actual funding.



- Increasing desire for decisions to be done across the LOOs (source: J-8 Comptroller).
- Primary cause for selecting an initiative for funding is whether it aligns with a stated need - usually a Joint Urgent Operational Needs (JUONS).
- Choosing an initiative is easier when the initiative x to JUONS y mapping is one-to-one.
- Harder when multiple initiatives map to the same JUONS - or when there is no JUONS for the initiative.

Some Literature

- Brown, G. G., R. F. Dell, A. G. Loerch, A. M. Newman. "Optimizing Capital Planning." In *Methods for Conducting Military Operational Analysis*, edited by A. G. Loerch and L. B. Rainey, Washington: Military Operations Research Society, 2007.
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Approach

- Employed a combination of Parnell's Silver and Gold standards:
  - Silver standard: model based upon interactions with an organization's mid-level decision makers.
  - Gold standard: model based upon an organization's strategy and vision literature.
- Used a year's worth of observation of JCAAMP decisions to develop the prototype.
- Used brainstorming and affinity exercise to develop a set of concepts that defined value, which we grouped into a hierarchy.
- Mathematically, we evolved from an additive model to a hybrid additive-multiplicative model.

JIEDDO Strategic Objectives

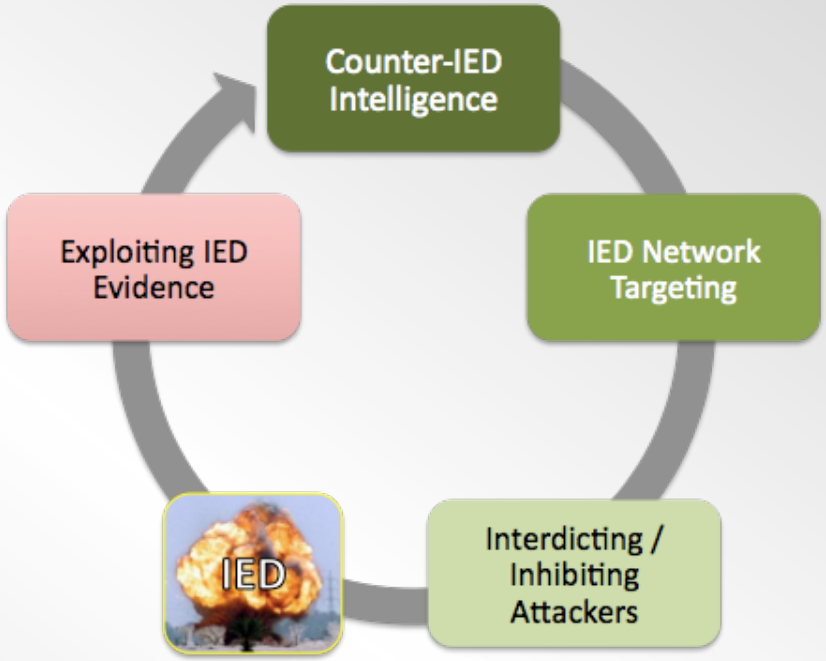
- From interviews with key personnel and our review of JIEDDO Strategy, we identified three JIEDDO strategic objectives to fulfill when selecting initiatives for funding.
  - SO 1: Reduce the impact of IED incidents
  - SO 2: Respond to the Warfighter's needs quickly
  - SO 3: Transition funded initiatives to the Services

SO1: Reduce the Impact of IEDs

- For this strategic objective, we identified three goals, which map naturally aligned to the LOOs
  - Goal 1: Decrease the number IEDs reaching intended time and place of employment (AtN)
  - Goal 2: Decrease the effects of the IEDs that have reached their intended time and place of employment (DtD)
  - Goal 3: Improve effectiveness of counter-IED training for individuals and units (TtF) to make these better at Goal 1 and Goal 2.
- Challenge: how to decompose these goals into sub-goals that bring us closer to something measurable.

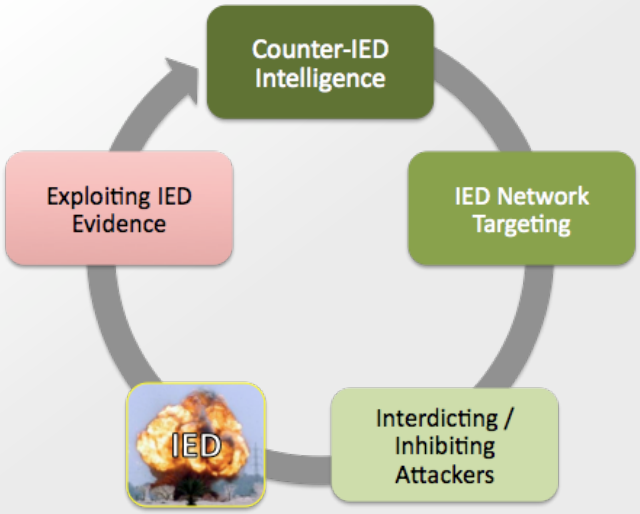
Goal 1: Decrease Number of IEDs that Reach their Intended Place of Employment

- AtN has two current *Tenets*:
  - Predict and Prevent
  - Detect (Air)
- This was not helpful for developing a means to bin AtN initiatives.
- We examined the nature and function of AtN initiatives and developed a cyclical concept of AtN that provided more bins and a more intuitive decomposition.



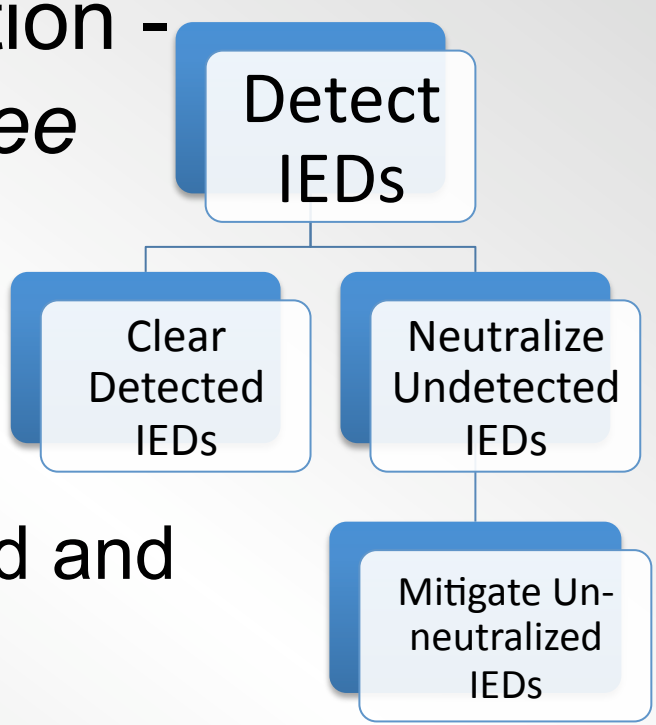
Goal 1 Examples

- Counter IED Intel:
  - Software
  - Websites
  - Products
  - Productivity tools
  - Sources
- IED Network Targeting:
  - Signals
  - Cueing Fusion
  - Social Network Analysis
  - Signatures
  - Biometric
- Interdicting / Inhibiting:
  - Airborne Surveillance
  - Culvert Denial
  - Route sanitation
  - Sniper systems
- Exploiting IED Evidence:
  - Unit level analysis
  - CEXC
  - FBI Labs



Goal 2: Decreasing effects of IED at the Intended Place of Employment

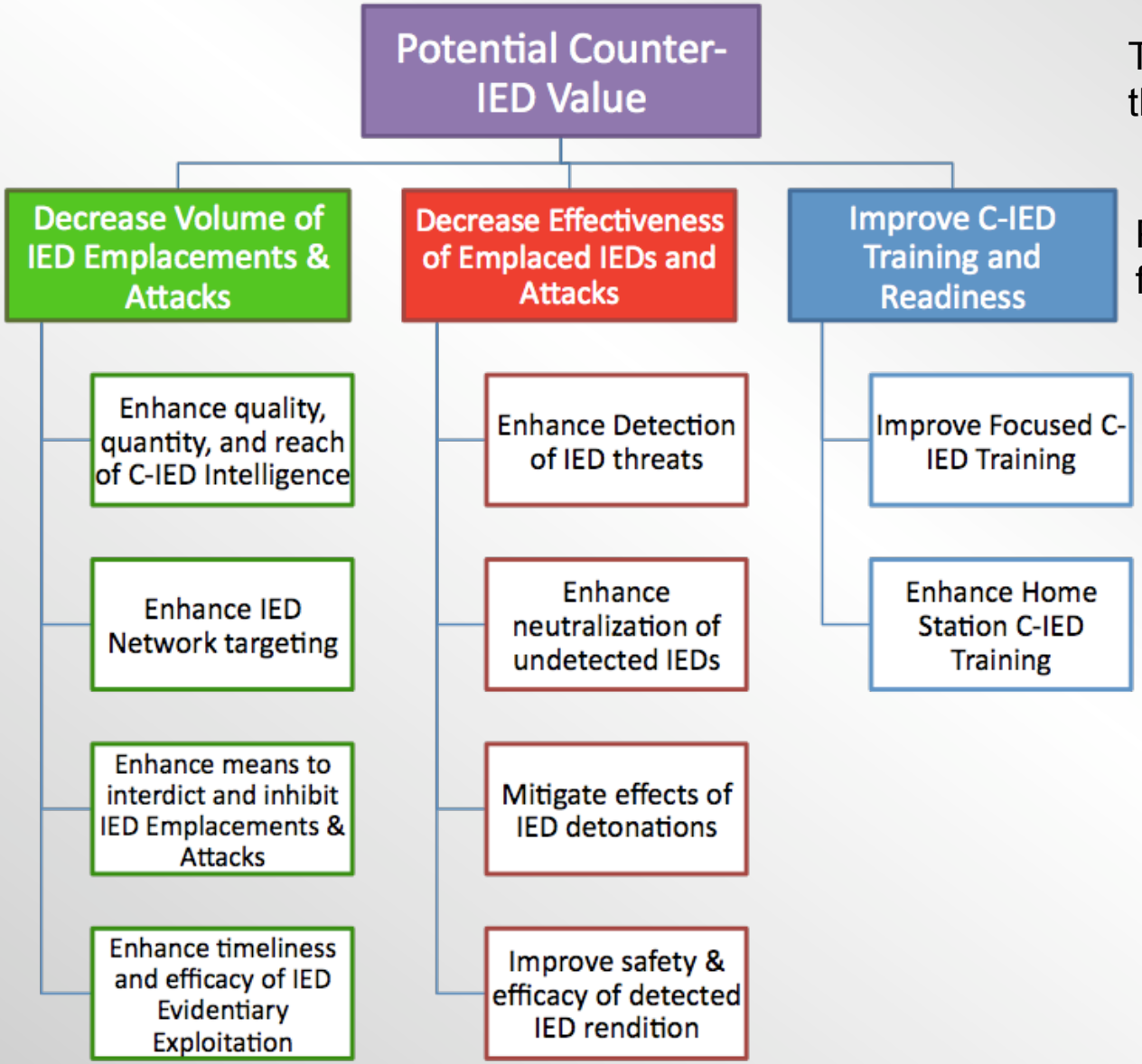
- JIEDDO has a taxonomy of *Tenets* that - with modification - provided a natural *event tree* structure:
  - Detect IEDs
  - Neutralize undetected IEDs
  - Mitigate effects of undetected and un-neutralized IEDs
  - Clear detected IEDs



Goal 3: Enhance Counter-IED Training

- Two major areas:
  - Improve Home-station training
    - Units and individuals
  - Improve Focused Training
    - Schools - individuals
    - Training Centers - units

Potential Counter-IED (PCV) Value Tree



The value tree summarizes the goals and subgoals.

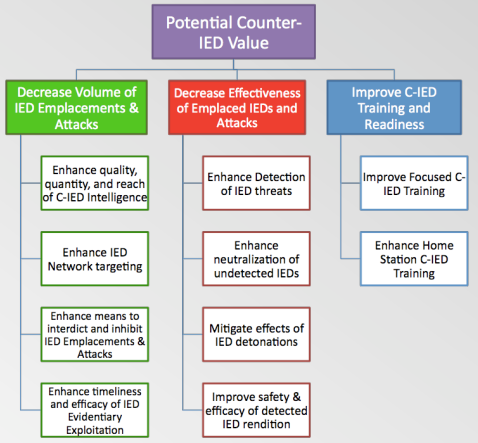
Provides a ready structure for a gap analysis.

Measuring Goal Fulfillment

- An Evaluative Measure (EM) is intended to measure degree of goal fulfillment.
- EM's may be direct or proxy, and their units can be real or constructed.
- Because JIEDDO's initiatives contribute to an overall set of capabilities, measures must focus on identifying net contribution of an initiative.
- We have developed a candidate set of measures (making no particular claim as to their efficacy).

Postulated EM Set

Goal	Model	Measure
Enhance Quantity, Quality, & Reach (QQR) of C-IED Intelligence	QQR := Intel Volume (TB) * Readership / Avg Product Age (days)	% Improvement in QQR
Enhance IED Cell Targeting	Target Service Rates Vector (TSRV) := $\{V_f: f$ is the set of IED cell functions$\}$	Sum of Estimated % Improvements in TSRV
Enhance Means to Interdict & Inhibit	High Threat Attack Rates Vector (HTARV) := $\{Ar_i: i$ is the set of high threat IEDs$\}$	Sum of Estimated % Decrease in HTARV
Enhance IED Evidentiary Exploitation	Exploitation Volume Rate (EVR) := Incident Intel Volume (TB) / Weighted Processing Time (days)	% Improvement in EVR
Enhance Means of IED Detection	Found & Cleared Rate Vector (FCRV) := $\{FCr_i: i$ is the set of high threat IEDs$\}$	Sum of Estimated % Improvements in FCRV
Enhance Means of IED Neutralization	Probability of Neutralization Vector (PNV) := $\{PN_i: i$ is the set of high threat IEDs$\}$	Sum of Estimated % Improvements in PNV
Enhance Mitigation of IED Effects	IED Casualties Rate Vector (ICRV) := $\{Cr_i: i$ is the set of high threat IEDs$\}$	Sum of Estimated % Improvements in ICRV
Improve Means of IED Reduction	IED Reduction Rate Vector (IRRV) := $\{Rr_i: i$ is the set of high threat IEDs$\}$	Sum of Estimated % Improvements in IRRV
Improve Focused C-IED Training	Quantity Quality Volume := Hours * Throughput / Class Size / Content Age	Estimated % Improvement
Improve Home Station Training	Quantity Quality Volume := Hours * Throughput / Class Size / Content Age	Estimated % Improvement



- The EMs align with the subgoals.
- This set provides an integrated approach to identify gaps in capability.

Postulated EM Set

Goal	Model	Measure
Enhance Quantity, Quality, & Reach (QQR) of C-IED Intelligence	QQR := Intel Volume (TB) * Readership / Avg Product Age (days)	% Improvement in QQR
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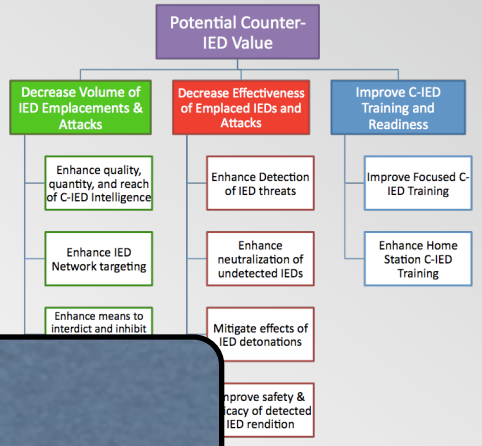
Enhance Means to Interdict & In	High Threat Attack Rates Vector	Sum of Estimated %
Enhance IED Evidentiary Exploitation		
Enhance Mea IED Detectio		
Enhance Mea IED Neutralizatio		
Enhance Mitigation of Effects		
Improve Mea IED Reductio		
Improve Focused C-IED Training	Quantity Quality Volume := Hours * Throughput / Class Size / Content Age	Estimated % Improvement
Improve Home Station Training	Quantity Quality Volume := Hours * Throughput / Class Size / Content Age	Estimated % Improvement



- Each of these metrics is still at a high level of aggregation.
- It may prove more fruitful to create another layer of goals.

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Measuring PCV

- We have a hierarchy of goals and associated evaluative measures.
- For each evaluative measures we need a value function to translate a point on the measure scale to a point on the normalized value scale; e.g., [0,100], or [0,1.0].
  - If x_{mi} is the measured level of i^{th} alternative on the m^{th} evaluative measure, then the corresponding value level is obtained from the value function $v_m(x_{mi})$
  - A simple approach is to identify minimal and maximal acceptable levels, min_m and max_m, and use a linear transformation.
  - Then $v_m(x_{mi}) = (x_{mi} - min_m) / (max_m - min_m)$, for x_{mi} on $[min_m, max_m]$
  - If $x_{mi} < min_m$, $v_m(x_{mi}) = 0$, and If $x_{mi} > max_m$, $v_m(x_{mi}) = 1$
- To obtain the overall value of an initiative, we need to obtain a weighted average of the value scores.

$$PCV(i) = \sum_m w_m v_m(x_{m,i})$$

$$\sum_m w_m = 1$$

Obtaining Weights

- *Swing Weights* are preferred in much of the Decision Analytic literature.
  - Measures change in overall value that results when the evaluative measure *swings* from least acceptable value to highest acceptable value.
  - Incorporates both the importance of the attribute and its feasible measure range.
  - Require *elicitation* from decision makers
  - Many techniques to do this.
- Example: among the 5 cars that Greg likes most, the most important attribute of the many he is considering is color. But he discovers that all 5 cars are available in hot pink, his favorite. How much weight should he assign this attribute?

POSREP

- Where are we…
  - Measuring Value of C-IED Initiatives
  - SO1: Reducing the impact of IED incidents
- Up Next:
  - SO 2: Respond to the Warfighter's needs quickly
  - SO 3: Transition funded initiatives to the Services

SO 2: Respond to the Warfighter's Needs Quickly

- This objective seeks to deliver capability to the warfighter as quickly as possible.
- When shown two items of equal counter-IED potential, how much more valuable is the item that can deploy sooner?
  - *Discounting* is the standard process when comparing cash flow over time - this is the basis for measuring Net Present Value.
    - If DF is the discount factor ($0 < DF < 1$), and t is the amount of time we will wait to get value x, then the value of x today is $DF^t x$
  - For cash flows, we use a standard lending rate. How much to discount IED initiatives?

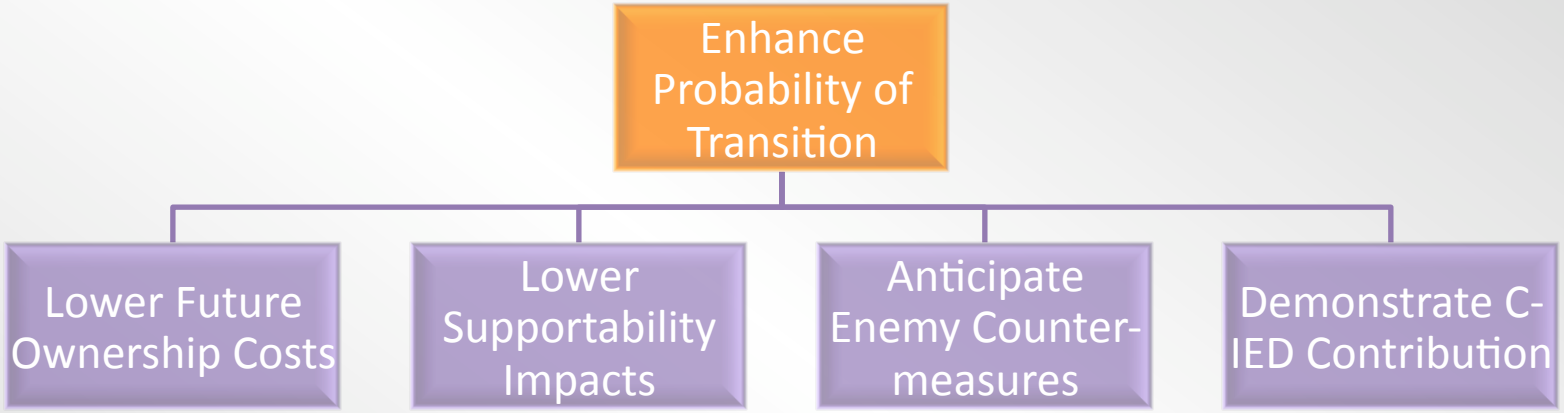
Factors to Consider when Discounting Counter-IED Initiatives

- Only one discount rate needed if there are no factors to consider.
- However, there maybe other considerations that differentiate the willingness of the warfighter to wait for otherwise equally valuable items.
- Main factor we have identified is the urgency of the requirement:
  - An active JUONS would have highest discount factor.
  - Other requirement documentation such as service-specific requirement documents and technology roadmaps might have a lower discount factor.
  - No requirement document would have the lowest.

SO 3: Transition Initiatives to a Service

- Clearly higher potential is correlated with higher likelihood to transition.
- What might differentiate the likelihood of transitioning for items with equal potential?
- We have identified four issues:
  - Future Total Ownership Cost – the cost for JIEDDO may be a different issue than the service's costs of adoption
  - Supportability – how hard is it for a service to adopt – DOTMLPF issues
  - Defeat-ability – the ease with which the enemy might counter the initiative over time
  - Demonstrated performance – what evidence exists that the potential might be achieved

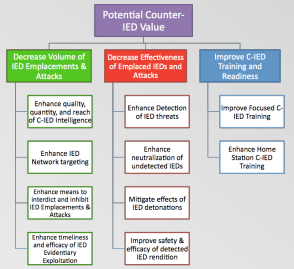
Factors Affecting Probability of Transition - P_T

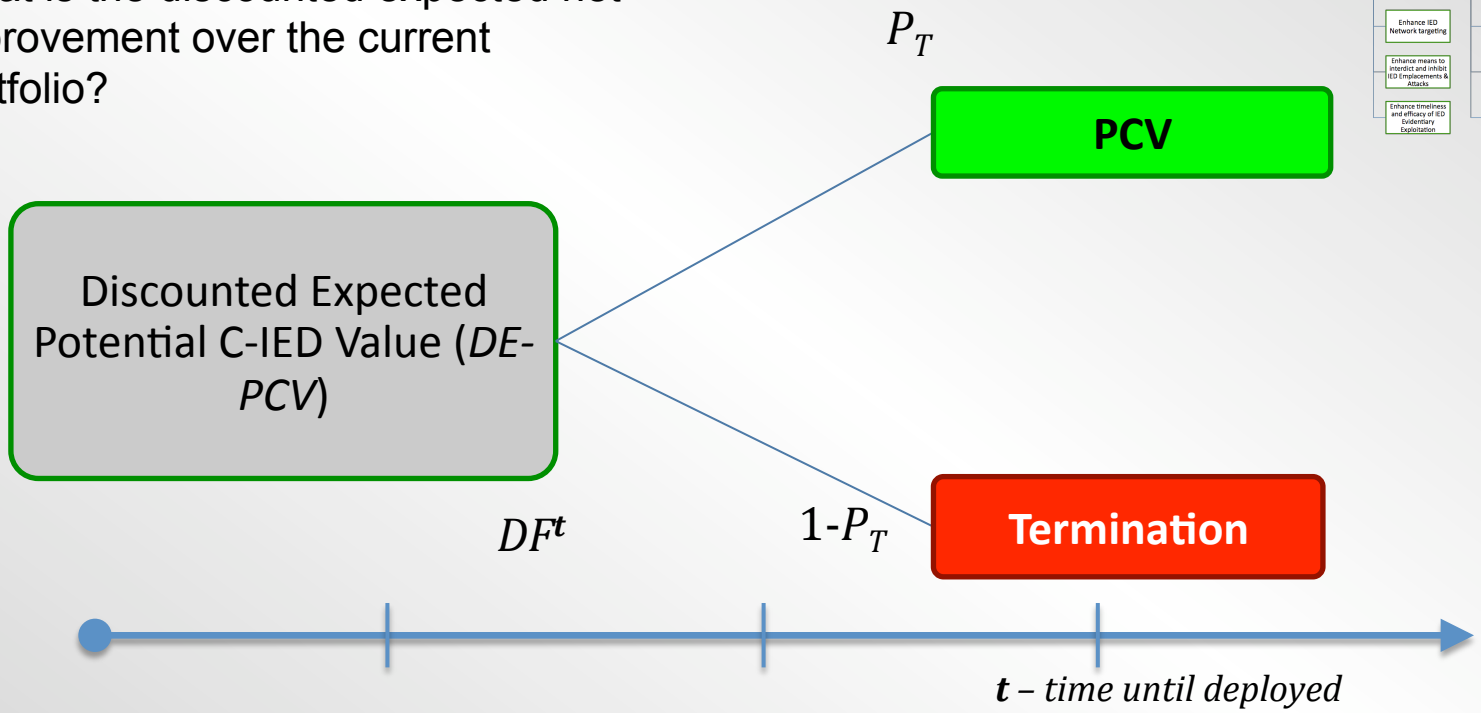


- These factors are restated as goals.
- This structure represents a *hypothesis* - we need to conduct an analysis of those that transitioned vs those that did not to better inform the method for assessing this probability.

Discounted Expected Potential C-IED Value

What is the discounted expected net improvement over the current portfolio?



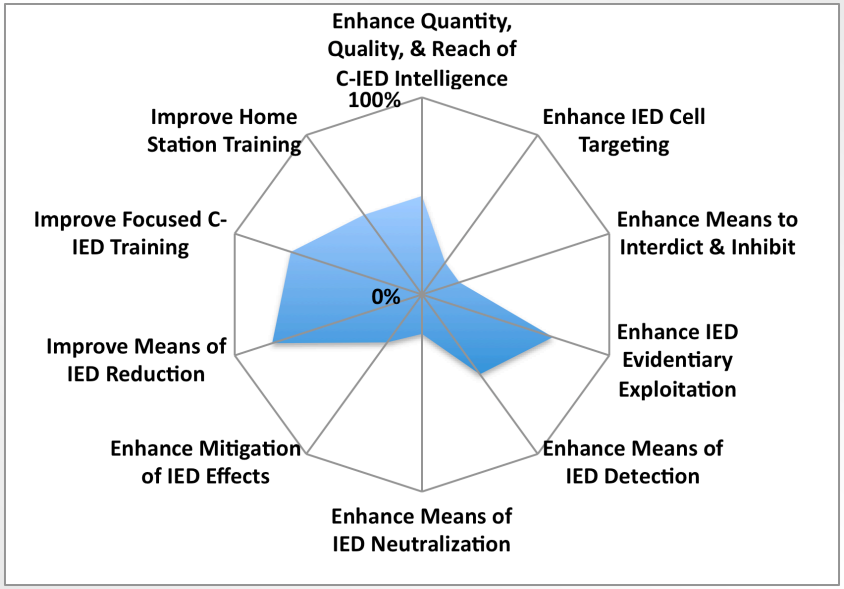


$$DE-PCV(i)=\sum_m w_m v_m((1+P_T DF^t x_{m,i})y_m))-\sum_m w_m v_m(y_m)$$

An Example: Setting the Stage

- JIEDDO has incorporated the approach advocated here.
- They use the Planning Board for Development (PB4D) to score the initiatives.
- They hold periodic off-sites to assess the overall capability set as % of the envisioned ideal by attribute, and to reassess the swing weights based upon their understanding of theater priorities and threat trends.
- The latest off-site resulted in the following assessment of capability levels and the resulting set of weights.

Evaluative Measure	Current Level (% of Max Preferred)	Rank	Raw Swing Wt	Normalized Swing Wt
C-IED Intelligence	50%	5	40	0.115
IED Cell Targeting	20%	1	60	0.172
Interdict & Inhibit	20%	2	50	0.143
Evidentiary Exploitation	70%	7	30	0.086
IED Detection	40%	3	45	0.129
IED Neutralization	20%	4	41	0.117
IED Effect Mitigation	30%	6	35	0.100
IED Reduction	80%	10	10	0.029
Focused Training	70%	9	15	0.043
Home Station Training	50%	8	23	0.066



An Example: At PB4D Today

- The PB4D must consider three new initiatives:
  - Ground Sensor A: improves detection of a particularly lethal class of IEDs.
  - Intelligence Analyst Software B: improves analyst productivity.
  - Training System C: improves home station throughput and training content currency.

Ground Sensor A

- Potential Counter-IED Value evidence
  - Detects a lethal class of IEDs 60% of the time.
  - 300% improvement over U.S. forces current ability (20% detection rate).
  - This class of IEDs causes 40% of all IED casualties.
  - Sensor A has the potential to cut these casualties in half.
  - In terms of coalition forces' total ability to detect all types of IEDs, as weighted by IED-casualties, Ground Sensor A improves overall detection capability by 20%.
- Probability of transition factors
  - System has been successfully employed in similar conflicts by a close ally.
  - Requires minimal levels of sustainment.
  - The Service reps find that its overall costs are affordable.
  - Thus, its probability of transition is set at the highest level – 0.9.
- Discount Factor - addressed by a JUON ➔ assigned highest DF of 0.99. Can be deployed in the next quarter (***t*** = 1).

Intelligence Analyst Software B

- Potential Counter-IED Value evidence
  - Based on preliminary tests, will significantly increase the productivity of a large portion of the workforce.
  - In terms of QQR ➔ 33.3% improvement.
- Probability of transition factors
  - Very expensive to buy and sustain.
  - Immature – many kinks and bugs.
  - PB4D has many concerns so probability of transition is set at 0.7.
- Discount Factor
  - No JUON ➔ assigned DF of 0.9.
  - Earliest it can begin employment is 9 months (***t*** = 3).

Training System C

- Potential Counter-IED Value evidence
  - 10% improvement in home station throughput.
  - Radically reduces the lag time to get latest TTPs from the battlefield.
  - In terms of QQV ➔ 50% improvement.
- Probability of transition factors
  - Not very expensive.
  - However, major environmental factors at many potential sites.
  - PB4D has strong concerns so probability of transition is set at 0.5.
- Discount Factor
  - Addressed by training technology roadmap ➔ assigned DF of 0.9.
  - Earliest it can begin employment is 12 months (***t*** = 4).

DE-PCV Results

$x_{i,m}$

Evaluative Measure	Sys A	Sys B	Sys C
C-IED Intelligence	0%	**33%**	0%
IED Cell Targeting	0%	0%	0%
Interdict & Inhibit	0%	0%	0%
Evidentiary Exploitation	0%	0%	0%
IED Detection	**25%**	0%	0%
IED Neutralization	0%	0%	0%
IED Effect Mitigation	0%	0%	0%
IED Reduction	0%	0%	0%
Focused Training	0%	0%	0%
Home Station Training	0%	0%	50%
t - Time to Deploy (qtrs)	**1**	**3**	**4**
DF	**0.99**	**0.90**	**0.95**
DF^t	**0.99**	**0.73**	**0.81**
P_T	**0.90**	**0.70**	**0.50**

$P_T DF^t x_{i,m}$

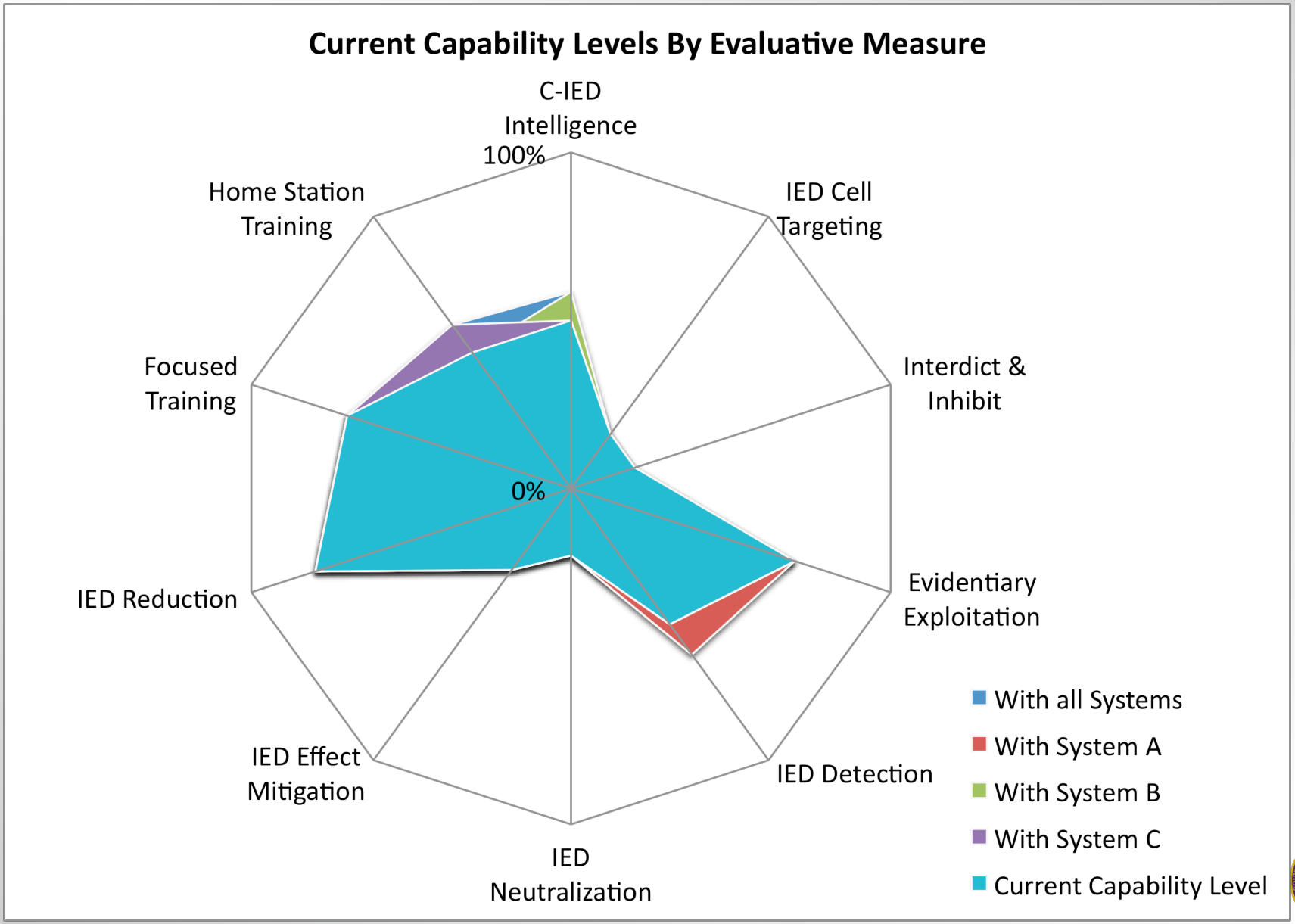
Evaluative Measure	Sys A	Sys B	Sys C
C-IED Intelligence	0%	**17%**	0%
IED Cell Targeting	0%	0%	0%
Interdict & Inhibit	0%	0%	0%
Evidentiary Exploitation	0%	0%	0%
IED Detection	**22%**	0%	0%
IED Neutralization	0%	0%	0%
IED Effect Mitigation	0%	0%	0%
IED Reduction	0%	0%	0%
Focused Training	0%	0%	0%
Home Station Training	0%	0%	**20%**

$$DE-PCV(i) = \sum_m w_m v_m((1 + P_T DF^t x_{m,i})y_m)) - \sum_m w_m v_m(y_m)$$

Evaluative Measure	Current Capability Level	With System A	With System B	With System C
C-IED Intelligence	50%	50%	**58%**	50%
IED Cell Targeting	20%	20%	20%	20%
Interdict & Inhibit	20%	20%	20%	20%
Evidentiary Exploitation	70%	70%	70%	70%
IED Detection	40%	**49%**	40%	40%
IED Neutralization	20%	20%	20%	20%
IED Effect Mitigation	30%	30%	30%	30%
IED Reduction	80%	80%	80%	80%
Focused Training	70%	70%	70%	70%
Home Station Training	50%	50%	50%	**60%**
Overall Value	**37.2%**	**38.3%**	**38.1%**	**37.8%**
DE-PCV(i)	**na**	**3.1%**	**2.6%**	**1.8%**

- Ground Sensor A scored highest, but in large part because its maturity, high likelihood of transition and readiness to be deployed.
- Computing the discounted expectation reversed rank ordering of the initiatives.
- Resolving issues – getting the theater commander to provide a JUON for System B, resolving environmental issues with System C – could have dramatic effects on their scores.

How would the Portfolio change with these Initiatives – using *DE-PCV*?



A good decision involves a socio-technical process*

- The conversation is only as good as the people participating
  - Model structure (terms of the conversation) and
  - Numbers (what is being said about the topics of the conversation)
- We have to design the process as well as the model
  - Right people (broad and deep knowledge of the problem)
  - Right data and information
  - Right forum (conducive to discussion and interaction)
  - Right balance of modeling and challenging the model with intuition
  - Right duration (meet needed deadlines but enable information gathering and socializing the results)
- A well executed decision analysis emphasizes insight, not just numbers

From Dr. Greg Parnell's "Portfolio Decision Analysis". Presentation to WINFORMS, 2 April 2010.

Next Steps

- *DE-PCV*:
  - **Conduct spiral development with JIEDDO decision making bodies (CAC, J-8)**
- *Future Initiative Stream Simulation*:
  - Confirming recent indications that arrival process may be better modeled via a “Poisson with random delay” distribution of arrivals.
- *Counter-IED Portfolio Optimizer*:
  - Develop approximate dynamic approximation approach (ADP) (embeds the Monte Carlo simulation)
  - Compare ADP approach to the stochastic integer programming approach