Chapter 11

War-Gaming Applications for Achieving Optimum Acquisition of Future Space Systems

Tien M. Nguyen, Andy T. Guillen,
Sumner S. Matsunaga, Hien T. Tran and Tung X. Bui

Additional information is available at the end of the chapter

http://dx.doi.org/10.5772/intechopen.71044

Abstract

This chapter describes an innovative modeling and simulation approach using newly proposed Advanced Game-based Mathematical Framework (AGMF), Unified Game-based Acquisition Framework (UGAF) and a set of War-Gaming Engines (WGEs) to address future space systems acquisition challenges. Its objective is to assist the DoD Acquisition Authority (DAA) to understand the contractor's perspective and to seek optimum Program-and-Technical-Baseline (PTB) solution and corresponding acquisition strategy under both the perspectives of the government and the contractors. The proposed approach calls for an interdisciplinary research that involves game theory, probability and statistics, and non-linear programming. The goal of this chapter is to apply the proposed war-gaming frameworks to develop and evaluate PTB solutions and associated acquisition strategies in the context of acquisition of future space systems. Our simulation results suggest that our optimization problem for the acquisition of future space systems meets the affordability and innovative requirements with minimum acquisition risk.

Keywords: game theory, probability and statistics, non-linear programming, mathematical modeling, simulation, Program and Technical Baseline, acquisition strategy, space systems

1. Introduction

The U.S. Department of Defense (DoD) has recently released the Defense Innovation Initiative (DII) with the goal to "reinvigorate war-gaming" and to make DoD (best) practices more innovative [1]. In addition, DoD and U.S. Air Force have generated new acquisition regulations and initiatives to promote "Owning the Technical Baseline" (OTB) and "modular open system approach (MOSA)" as enablers for affordability [2, 3]. The Aerospace Corporation has been investigating and developing war-gaming techniques to improve the DoD acquisition

efficiency and productivity by using AGMF-UGAF to generate optimum PTB solutions and associated optimum acquisition strategies for future space systems [4–9]. The goal is to provide a set of decision support tools that can be used by the DoD Acquisition Authority (DAA) to make joined acquisition-and-programmatic decisions that will avoid acquiring the "mission area stovepipe" space systems in the future. Although the focus of this chapter is on the future space systems, but the models presented in this chapter can be adapted and used for general civil and commercial systems with minor modifications.

The UGAF-AGMF [4, 7] describes two levels of War-Gaming Engines (WGEs) or game models, namely, one representing the government's "Acquisition" perspective, and the other representing the contractor's "Bidding" perspective. The multivariate optimization involves the government objective to maximize performance and minimize cost for "affordability," and the contractor objective to maximize performance and maximize profits. The framework establishes government models (DAA-WGE) and contractor models (KTR-WGE). Each of these WGEs is further subdivided into PTB (P) solution models and corresponding Acquisition (A)/Bidding (B) strategy models; government models are abbreviated as DAA-PWGE and DAA-AWGE; contractor models are KTR-PWGE and KTR-BWGE. These proposed frameworks and associated game models address technical baseline, contract type, associated incentives, source selection criteria described in Sections L & M of a Request for Proposal (RFP) [10].

The chapter discusses AGMF that utilizes static and dynamic games and associated WGEs that employ Bayesian cooperative and non-cooperative games with both complete and incomplete information scenarios, and the use of UGAF for employing appropriate WGEs and solving conflicting system and acquisition requirements. In addition, this chapter also presents and discusses simulation results obtained from the proposed DAA-PWGE, DAA-AWGE, KTR-PWGE and KTR-BWGE. The Chapter is organized as follow:

- Section 2 presents the "Acquisition War-Gaming Concept" and discusses the "Art versus Science" for the development of the AGMF and UGAF frameworks;
- Section 3 provides a detailed description of AGMF; Section 4 discusses the UGAF;
- Section 5 describes the PTB-WGEs or PWGEs including DAA-PWGE and KTR-PWGE;
- Section 6 describes and discusses the government "Acquisition" DAA-AWGEs and contractor "Bidding" KTR-AWGE for commonly used contract types, including Firmed-Fixed Price (FFP), Fixed Price Incentive Firm (FPIF), and Cost Plus Incentive Firm (CPIF);
- Section 7 presents the MATLAB models[1] and simulation results obtained from the DAA-PWGE, DAA-AWGE, KTR-PWGE and KTR-BWGE models for commonly used contract types discussed above.
- Section 8 provides a brief discussion on the integration of PWGEs and AWGEs. Note that the optimum PTB solution will be selected by integrating the DAA-PWGE and KTR-PWGE,

[1]The MATLAB models presented in this chapter were implemented by a Nationally-Diverse Student Team (NDST) under the support of the National Science Foundation (NSF), Grant Number DMS-1461148, through the NCSU Industrial and Applied Mathematics Research Experience for Undergraduates (REU) Project. Note that the NDST is also referred to as the REU team.

while the optimum acquisition strategy is selected by integrating the DAA-AWGE and KTR-AWGE.

- Finally, Section 9 presents the conclusion and discusses way-forward.

2. Acquisition War-Gaming Concept: Art versus Science

Our proposed "Acquisition War-Gaming" frameworks leverage existing war-gaming concept, which is defined as a step-by-step process of action, reaction, and counteraction for visualizing the execution of each friendly Course-Of-Action (COA) in relation to an enemy's COA and reactions. In the war-gaming process, planners determine how to apply combat multipliers to the COA to improve the possibility of mission success and minimize risks to soldiers. "Acquisition War-Gaming" employs "Game Theory" in the "war-gaming" concept to optimize (i) the Program and Technical Baseline (PTB) solution for a set of warfighter requirements, and (ii) associated acquisition strategy and contract incentives for acquiring the "PTB solution." The optimization games require "Payoff and Cost Functions" or PCFs and associated "Objective Function." The readers can find detailed description of PTB and its components in Refs. [4–6].

As discussed in Ref. [7], we envision two categories of War-Gaming Engines (WGE[2]), namely, DAA War-Gaming Engine (DAA-WGE) and Contractor-WGE (KTR-WGE). **Figure 1** depicts our vision for the two categories of war-gaming applications [7]. DAA-WGE is to be played by DAA and its stakeholders (see **Figure 1**(**a**)). KTR-WGE is to be played by potential contractors (or organizations posing as contractors), with game rules dictated by DAA and its stakeholders (see **Figure 1**(**b**)). The DAA-WGE and KTR-WGE will be developed and integrated such that DAA and its stakeholders can use them for the development and generation of optimum PTB solutions and associated acquisition strategy, respectively. Note that the optimum acquisition strategy addresses contract type, associated incentives, and RFP and source selection criteria. To achieve this goal, we define and develop the following four types of game models:

- DAA-PWGE: government plays the game to select optimum PTB solutions. Past acquisition data and market survey data are used to characterize each contractor's bidding behavior. A PTB solution is selected based on minimum program execution risk and cost.
- DAA-AWGE: government plays the game to select an optimum acquisition strategy associated with a PTB solution. Past acquisition data and market survey data are used to characterize each contractor's bidding behavior. An acquisition strategy is selected based on minimum program execution risk and cost.
- KTR-PWGE: in this game, we simulate the contractors as players and the goal is to select optimum contractors' PTB solutions. Past acquisition data and market survey data are used to characterize each contractor's bidding behavior. A PTB solution is selected for each contractor based on minimum program execution risk and maximum contractor profit.

[2]WGE is defined a set of Algorithms, characterizing the Program and Technical Baseline (PTB), technology enablers, architectural solutions, contracting parameters, and industry bidding position, implemented in MATLAB statistical optimization models.

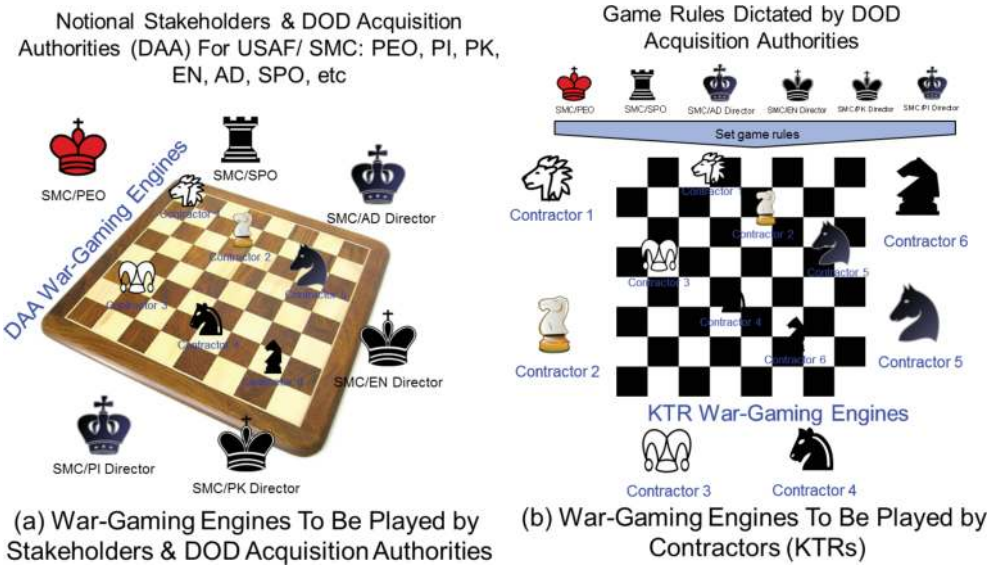

Figure 1. Our vision for war-gaming applications [7].

- KTR-BWGE: this game also is referred to as KTR-AWGE because the contractor's bidding strategy will be derived based on the acquisition strategy specified by the government or DAA-AWGE. The KTR-AWGE game simulates the contractors as players and the goal is to select the optimum bidding strategy associated with each contractor's selected PTB solution. Past acquisition data and market survey data are used to characterize each contractor's bidding behavior. A bidding strategy is selected based on minimum program execution risk and maximum contractor profit.

To integrate these War-Gaming Engines together, we need a unified framework that can achieve the vision shown in **Figure 1**. The proposed unified framework described in Ref. [7] consists of two frameworks, namely, AGMF and UGAF. The development of AGMF framework to apply war-gaming concept for "Acquisition" is a "Science." The AGMF is a framework for selecting optimum game structure and game type depending on the information available for PTB Action Space (PAS) and Acquisition Action Space (AAS). On the other hand, the development of UGAF for "Exercising" AGMF is an "Art." UGAF is used for the exercising of the AGMF to generate optimum PTB solutions and optimum acquisition strategies. The overview of these unified frameworks will be provided in the following sections.

3. Advanced Game-based Mathematical Framework (AGMF)

Figure 2 describes the framework where it captures the Bayesian game structures and seven game types (game selection from #1 through #7) for DAA-PWGE, DAA-AWGE, KTR-PWGE

http://dx.doi.org/10.5772/intechopen.71044

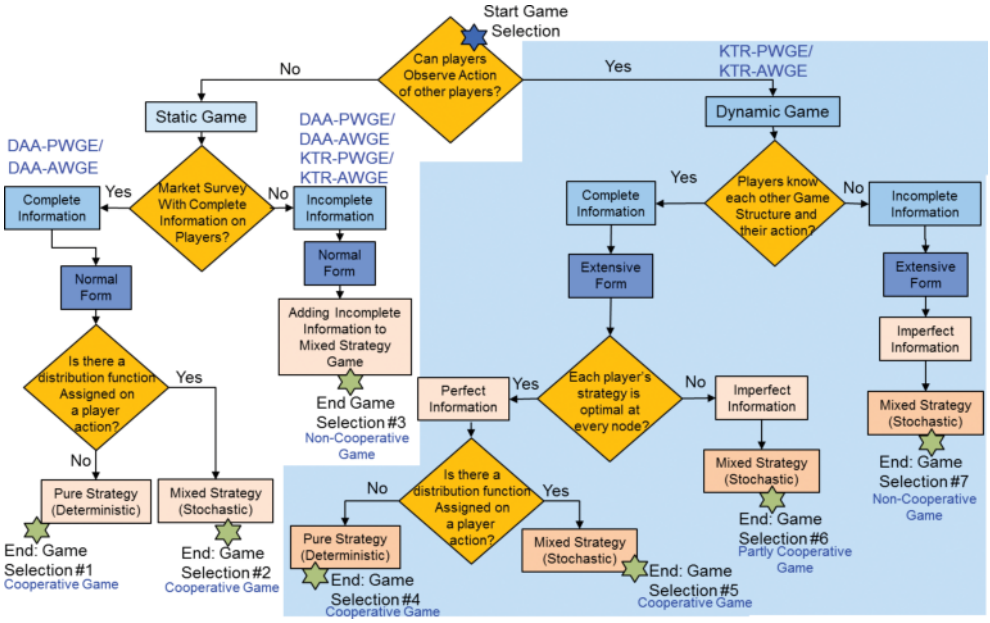

Figure 2. AGMF: selection of optimum war-gaming structure and type [7].

and KTR-AWGE depending on the information available for PAS and AAS [7]. As shown in **Figure 2**, the framework starts the game selection by answering a question concerning the player's ability to observe other player action. As depicted in **Figure 2**, the DAA-PWGE and DAA-AWGE always have the static game structure since all the games will be played by the DAA and its stakeholders, with contractors as players in each game. On the other hand, the KTR-PWGE and KTR-AWGE can have either static game or dynamic game structure. The KTR-PWGE and KTR-AWGE can have a dynamic game structure when the DAA and its stakeholders assume that the one contractor can observe other contractor's action when the games are played. For dynamic game structure, the players make move based on the information released from the RFP and the players' ability (or contractor's ability) to observe other players' action through the "intelligent" information gathered on the competitors. A detailed discussion of AGMF is provided in Ref. [7].

4. Unified Game-based Acquisition Framework (UGAF)

The goal for UAGF is two-fold, namely, (i) play games to determine optimum PTB solution for a specified set of warfighter needs, and (ii) play games to determine the corresponding optimum acquisition strategy for a specified optimum PTB solution [7]. The optimum PTB solution

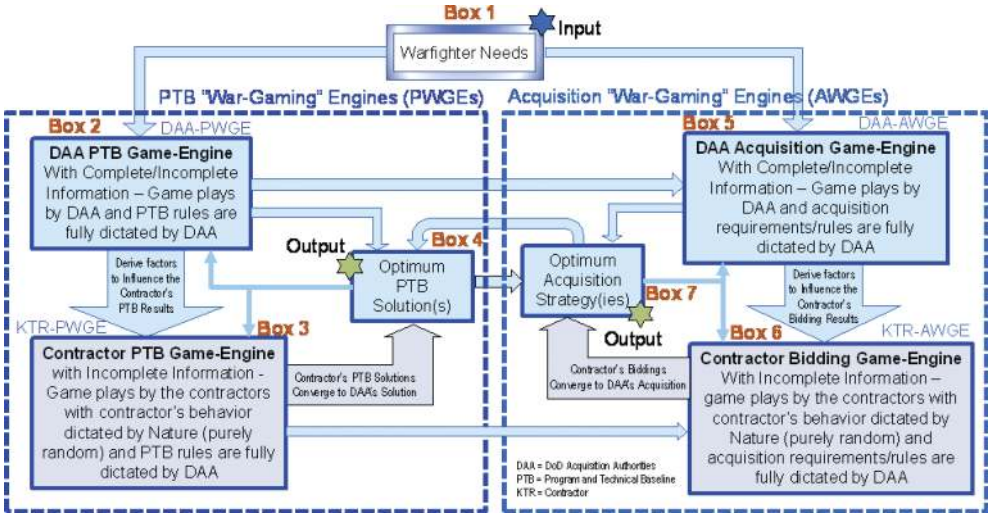

Figure 3. UGAF: a unified approach for exercising AGMF [7].

is defined as the "Architecture Solution[3]" (ARCS) for the required warfighter needs that meets the affordability and innovative requirements with minimum acquisition risk. **Figure 3** describes our proposed unified framework to exercise the AGMF. It describes the processing flow for the DAA-PWGE, DAA-AWGE, KTR-PWGE and KTR-AWGE to generate optimum PTB solutions and associated optimum acquisition strategies. **Figure 3** also shows seven processing boxes, in the order of execution. Detailed descriptions of Boxes #1 through #7 are described in Ref. [7].

5. PTB War-Gaming Engines (PWGEs)

This section provides an overview of DAA-PWGE and KTR-PWGE models. The approach presented in this section follows [8]. It focuses on static Bayesian game models with "Pure" and "Mixed" games depending on the outcomes of the market survey results. For a pure game with complete and perfect information, the contractors are "surer" of their risk assessments on the selected TEs. The risk is either "Good" or "Bad" with probability of 1 and the "Belief" and/or "Weighting" functions for this game type are not needed. For mixed games with complete and imperfect information, the contractors are "more uncertain" of their risk assessments on TEs and the "Belief" and/or "Weighting" functions are needed for assessing TE risks. In this case, the TEs are weighted based on their priorities and using a probability density function with either uniform or triangular distribution depending on the TE's uncertainty.

[3]Architecture solution or ARCS is descried in terms of a set of selected "Technology Enablers" (TEs) that can provide the required system capabilities, which meet the warfighter needs. TE is a specific technology solution that meets a "capability" alone or in combination with other TEs, e.g. a telemetry communications system.

The TE's uncertainties are expressed in terms technology and market uncertainties. The definition for the system requirement types and associated PTB solution framework for classifying a PTB Solution are described in **Figure 4** [8]. As an example, a Type 1 Requirement is mapped into a "Less Innovative & Conservative PTB Solution" where the "Market Uncertainty" and "Technology Uncertainty" are "Low" and "Low," respectively. Since each "Requirement Type" is associated with specific measure of technology and market uncertainties, the proposed PTB solution framework allows us to select the appropriate acquisition strategy for each "Requirement Type" and assess the technology and cost risk for each "PTB Solution Type." **Figure 5** provides a PTB mapping framework to identify the "Acquisition Strategy" and risks associated with each "Requirement Type" and "PTB Solution."

A detailed description of PTB System Engineering (SE) frameworks, the analytical and simulation modeling approaches for developing optimum PTB solutions can be found in Ref. [8].

5.1. Analytical and simulation modeling approach for government PTB games

This section provides an overview description of the analytical and simulation modeling approaches for PTB cooperative Bayesian games for complete information with pure and mixed strategies [8].

5.1.1. DAA-PWGE cooperative Bayesian games set-up for complete information with pure and mixed strategies

The DAA plays static Bayesian cooperative games with either complete and perfect information (pure game) or complete and imperfect information (mixed game) using normal-form

System Requirements Type

Requirement Type	Requirement Type Description
Type 1	Firmed and fixed requirements with known Technology Enablers and known market
Type 2	Well-defined requirements with some uncertainties on technology enabler and market. Note that firm Requirements with unknown market is classified as this Type 2
Type 3	Requirements are somewhat known with some market uncertainty but can not identify the exact technology enablers
Type 4	Requirements are somewhat known with some technology uncertainty but can not identify the exact company (or companies) to provide the technology enabler
Type 5	Unknown Requirements with unkhown technology enable and market

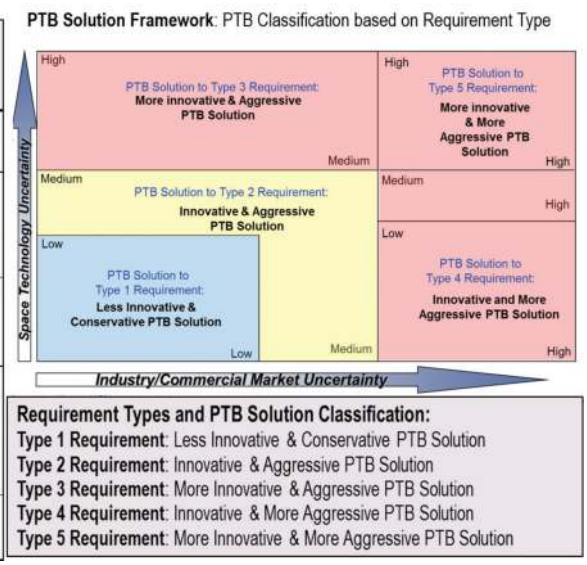

Figure 4. PTB framework for classifying PTB solution according to requirement uncertainties.

Requirements Classifications, Advanced Acquisition Strategy Mapping, PTB Solution Classification and PTB Risk Assessment							
Requirement Type	Requirement Type Description	Market Uncertainty	Technology Uncertainty	Advanced Acquisition Strategy Mapping	PTB Solution Type Classification	PTB Risk Assessment	
						Technical & Performance Risks	Cost & Schedule Risks
Type 1	Firmed and fixed requirements with known Technology Enablers	Low	Low	Enhancement Launch: FFP, FPEPA	PTB Type 1 Solution: Conservative	Low	Low
Type 2	Well-defined requirements with some uncertainties on technology enabler and market	Low	Medium	Platform Launch: FPIF, FPAF	PTB Type 2 Solution: Innovative	Low	Medium
		Medium	Low			Medium	Low
		Medium	Medium			Medium	Medium
Type 3	Requirements are somewhat known with some market uncertainty but can not identify the exact technology enablers	Medium	High	Positioning Option: CPIF	PTB Type 3 Solution: More Innovative	High	Medium
Type 4	Requirements are somewhat known with some technology uncertainty but can not identify the exact company (or companies) to provide the technology enabler	High	Medium	Scouting Option: CPAF, CPIF	PTB Type 4 Solution: Less Conservative	Medium	High
Type 5	Unknown Requirements with unkhown technology enable and market	High	High	Stepping Stone Option: CPAF, CPFF	PTB Type 5 Solution: Most Innovative	High	High

Figure 5. PTB mapping framework: requirement type-acquisition strategy mapping [7].

representation of the Bayesian games [8]. Our game models assume "N" suppliers (or contractors (KTRs)) participating in the bidding games and the availability of market survey data for which Government's "request for information" (RFI) is used to collect the required data from each contractor for assessing potential TEs identified by DAA. The contractor set is defined mathematically as

$$KTR = \{KTR_n, n = 1, 2, \ldots, N\} \tag{1}$$

The DAA defines PTB strategies involving potential architecture solutions and make them available to each supplier through RFI. The DAA estimates payoff received by each supplier for each combination of PTB strategies that could be chosen by the suppliers. The potential "I" architecture solutions set or ARCS is defined mathematically as

$$ARCS = \{ARCS_i, n = 1, 2, \ldots, I\} \tag{2}$$

The DAA plays complete-Bayesian game with a "Pure" or "Mixed" strategy, depending on the market survey data, to select the optimum PTB solution that can achieve "Nash" equilibrium. "Pure" game will be played if the market survey data show "complete and perfect information" for TEs. On the other hand, "Mixed" game will be played when the data show "complete and imperfect information." A "Pure" strategy, $\boldsymbol{S_{Pure}}$, is a strategy for a contractor "k" to map an architecture solution "i" to a PTB solution "j" defined as

$$S_{Pure} = \left\{ S^k_{i,j} : ARCS^k_i \rightarrow PTB^k_j; i = 1, 2, \ldots I; j = 1, 2, 3, 4, 5; k = 1, 2, \ldots, N \right\} \tag{3}$$

A "Mixed" strategy, $\boldsymbol{S_{Mixed}}$, is a strategy for a contractor "k" to map an architecture solution "i" to a PTB solution "j" with a "Belief" function $\boldsymbol{P^k_{i,j}}$ defined as

$$\boldsymbol{S_{Mixed}} = \left\{ \boldsymbol{S_{i,j}^k} : \boldsymbol{ARCS_i^k} \overset{\boldsymbol{P_{i,j}^k}}{\rightarrow} \boldsymbol{PTB_j^k}; \boldsymbol{i} = 1,2,\ldots \boldsymbol{I}; \boldsymbol{j} = 1,2,3,4,5; \boldsymbol{k} = 1,2,\ldots,\boldsymbol{N} \right\} \tag{4}$$

The "Belief" function set or "Conditional" probability set P is defined as "the probability of selecting a PTB solution type "*j*" given an architecture solution "*i*""

$$P = \left\{ P_{i,j}^k; i = 1,2,\ldots I; j = 1,2,3,4,5; k = 1,2,\ldots,N \right\} \tag{5}$$

The "Belief" function $\boldsymbol{P_{i,j}^k}$ must satisfy the following conditions

$$0 \le P_{i,j}^k \le 1 \text{ and } \sum_{i=1}^{I} P_{i,j}^k = 1 \tag{6}$$

Note that the ARCS-PTB mapping rules are based on the "Requirement Type" that is given in **Figure 5**. The PTB "Utility" set for a "Pure Strategy," U_{Pure}, is defined as the Payoff and Cost Function (PCF) for selecting a pure strategy $S_{i,}^k$ for each contractor "*k*," which can be expressed mathematically as:

$$U_{Pure} = \left\{ U_{i,j}^k : S_{i,j}^k \rightarrow PCF_{i,j}^k; i = 1,2,\ldots I; j = 1,2,3,4,5; k = 1,2,\ldots,N \right\} \tag{7}$$

Similarly, the PTB "Utility" set for a "Mixed" strategy, U_{Mixed}, is defined as the PCF for selecting a mixed strategy $S_{i,j}^k$ for each contractor "*k*" with a "Belief" function $P_{i,j}^k$ is defined as follow:

$$U_{Mixed} = \left\{ U_{i,j}^k : S_{i,j}^k \overset{P_{i,j}^k}{\rightarrow} PCF_{i,j}^k; i = 1,2,\ldots I; j = 1,2,3,4,5; k = 1,2,\ldots,N \right\} \tag{8}$$

A notional description of PCF, $PCF_{i,j}^k$, and PCF scoring[4] approach are provided in Ref. [8].

5.1.2. DAA-PWGE cooperative game with complete information and pure strategy

DAA plays the DAA-PWGE "**Pure Strategy**" games to "**Minimize**" the **Cost** and "**Maximize**" the **Payoff** (e.**g.**, performance) for the selected optimum strategy, $\boldsymbol{S_{Opt}}$. Mathematically, DAA plays the following DAA-PTB "**Pure**" strategy Bayesian games

[4]Ref. [9] describes the PCF scoring approach based on seven DOD initiatives including Initiative (i): "Proposed Technical Requirements and Associated TEs Incorporated Industry's Input"; Initiative (ii): "Should Cost Data Available for Each TE"; Initiative (iii): "Should Cost Data Available for Overall System"; Initiative (iv): "Leverage DOD IRAD to Lower Cost"; Initiative (v): "Leverage Contractor's IRAD to Lower Cost"; Initiative (vi): "Provide Incentives to Allow Contractor to Make IRAD an Allowable Cost"; and Initiative (vii): "Leverage MOSA for Architecture Design Solution." The higher the PCF score, the better PTB solution is.

$$Optimum\ PTB\ Solution \equiv S_{Opt} = \underset{\forall i,j,k}{MinMax} \left\{ U^k_{i,j} : S^k_{i,j} \rightarrow PCF^k_{i,j} \right\} \tag{9}$$

Where $S^k_{i,j}$ is defined as in Eq. (3) and $U^k_{i,j}$ is given by Eq. (7). This is the "MinMax" optimization problem to search for S_{Opt} such that, assuming that the $ARCS_i$ is the optimum solution with PTB Type 1 solution:

$$S_{Opt} = \left\{ U^k_{i,1} > U^k_{i,2} > U^k_{i,3} > U^k_{i,4} > U^k_{i,5}, for\ \forall i\ and\ \forall k \right\} \tag{10}$$

The above optimum solution is said to achieve the Nash equilibrium, which is a stable solution to this game theoretic problem in which no individual contractor can improve their payoff by a unilateral change in his bidding behavior. The DAA-PWGE pure game algorithm is shown in **Figure 6** with details provided in Ref. [8].

5.1.3. DAA-PWGE cooperative game with complete information and mixed strategy

Similar to the "Pure" strategy, DAA plays the DAA-PWGE "Mixed Strategy" games to "Minimize" the Cost and "Maximize" the Payoff. Mathematically, DAA plays the following DAA-PTB "Mixed" Strategy Bayesian games:

$$Optimum\ PTB\ Solution \equiv S_{Opt_{Mixed}} = \underset{\forall i,j,k}{MinMax} \left\{ U^k_{i,j} : S^k_{i,j} \overset{P^k_{i,j}}{\rightarrow} PCF^k_{i,j}; i = 1,..,I; j = 1,..5; k = 1,..,N \right\} \tag{11}$$

Where $S^k_{i,j}$ is defined as in Eq. (4), $U^k_{i,j}$ is given by Eq. (8) and the "Belief" function $P^k_{i,j}$ is given by Eq. (5). Again, this is the "MinMax" optimization problem that reaches the "Nash equilibrium"

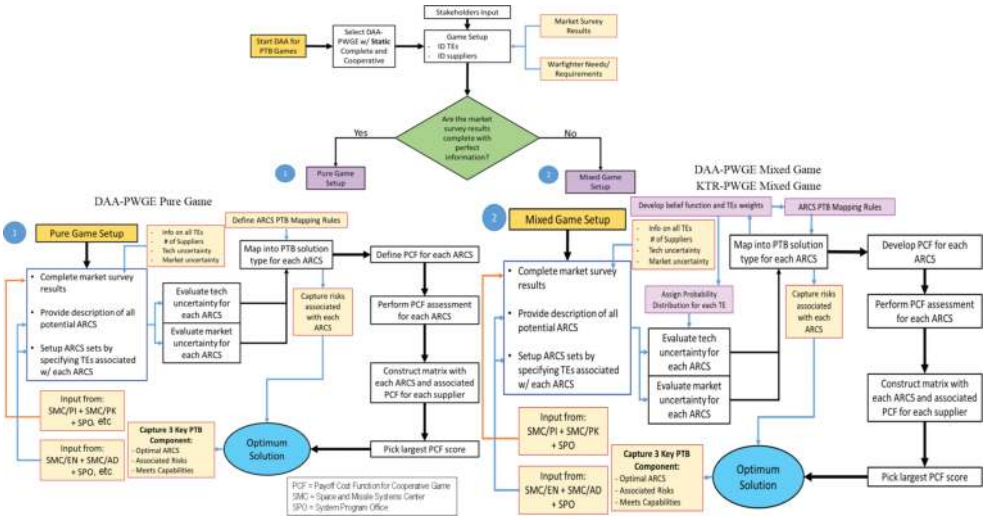

Figure 6. Description of DAA-PWGE and KTR-PWGE algorithms.

when $S_{Opt_{Mixed}}$ satisfies the following condition, assuming that $ARCS_i$ is the optimum solution with PTB Type 1 solution:

$$S_{Opt_{Mixed}} = \left\{ U_{i,1}^{k} > U_{i,2}^{k} > U_{i,3}^{k} > U_{i,4}^{k} > U_{i,5}^{k}, for\ \forall i\ and\ \forall k \right\} \tag{12}$$

The DAA Plays the DAA-PTB "Mixed Strategy" games to maximize the payoff for the selected optimum strategy $S_{Opt_{Mixed}}$ resulting from the optimally mapping an ARCS to a PTB Solution for a given set of "Belief Function $P_{i,j}^{k}$" defined in Eq. (5). The conditional probability that the k^{th} supplier/contractor (KTR) selects the l^{th} TE with a weighting factor of W_l for the i^{th} architecture solution, $ARCS_i$, given that the $ARCS_i$ is mapped to PTB Type "j" is defined as:

$$\Pr_{i,j,l}^{k} = W_l.PrTE_{i,j,l}^{k} \tag{13}$$

where

$$PrTE_{i,j,l}^{k} = \Pr\left\{ KTR\ "k"\ Selects\ TE_l^k\ for ARCS_i / KTR\ "k"\ maps\ ARCS_i\ to\ PTB\ Type\ "j" \right\} \tag{14}$$

The "Belief Function" set "P" for all architecture solutions, $i = 1, 2, \ldots, I$, can be calculated using the following equation:

$$P_{i,j}^{k} = \sum_{l=1}^{L} W_l.PrTE_{i,j,l}^{k} \tag{15}$$

Note that our team[5] has recently found that the above equation provides a better mathematical model than the one described in Ref. [8] for the belief function. Since each TE will have its own "Technology Risk" and "Market Risk",[6] Eq. (15) becomes:

$$\mathrm{P}_{1,\mathrm{j}}^{\mathrm{k\_Tech}} = \sum_{l=1}^{L} W_l.PrTE_{i,j,l}^{k\_Tech} \tag{16}$$

$$\mathrm{P}_{1,\mathrm{j}}^{\mathrm{k\_Market}} = \sum_{l=1}^{L} W_l.PrTE_{i,j,l}^{k\_Market} \tag{17}$$

$P_{i,j}^{k\_Tech}$ and $P_{i,j}^{k\_Market}$ must satisfy the following conditions:

$$0 \le \mathrm{P}_{\mathrm{i,j}}^{\mathrm{k\_Tech}} \le 1 \text{ and } \sum\nolimits_{\mathrm{i}=1}^{6} \mathrm{P}_{\mathrm{i,j}}^{\mathrm{k\_Tech}} = 1, \text{ for } \forall \mathrm{k} \tag{18}$$

$$0 \le \mathrm{P}_{\mathrm{i,j}}^{\mathrm{k\_Market}} \le 1 \text{ and } \sum\nolimits_{\mathrm{i}=1}^{6} \mathrm{P}_{\mathrm{i,j}}^{\mathrm{k_{Market}}} = 1, \text{ for } \forall \mathrm{k} \tag{19}$$

[5]Our team for the FY 2017 includes the REU team funded by NSF with the following selected undergraduate students: Brittany Dyer, Claire Goldhammer, Daniel Chertock and Scott Mahan. The 2017 REU team also includes Amanda Coons, a graduate assistant, and Prof. Hien Tran, a NCSU faculty advisor.

[6]Note that the terms "Technology Risk/Market Risk" and "Technology Uncertainty/Market Uncertainty" are used interchangeably in this chapter.

A detailed description of the calculation approach for the belief function is provided in Ref. [8]. The DAA-PWGE mixed game algorithm is shown in **Figure 6** with the details provided in Ref. [8]. The calculation approach described in Ref. [8] should be modified as shown in Eq. (15). The PTB tracking tool described in Ref. [6] will be used to capture the PTB solution captured by the DAA-PWGE.

5.2. Analytical and simulation modeling approach for contractor PTB games

For KTR-PWGE model, the DAA plays game on behalf of the contractors [8]. Similar to DAA-PWGE, the KTR, actually played by DAA, plays the static Bayesian "Non-Cooperative" (NC) games with complete and imperfect information or mixed game using normal-form representation of the game. The game is NC because it is assumed that the contractors do not share their bidding information. The KTR plays game to select optimum PTB solution that can maximize profits and reduce execution risks. The KTR is assumed to play games to search for an optimum PTB solution that can achieve the "Nash" equilibrium. The KTR game is set-up as follows:

- Step 1: contractor set: assume to have N contractors to play the game (see Eq. (1)).
- Step 2: contractor identifies a set of potential "*I*" architecture solution $ARCS_{NC}$ based on the requirements described in the release of RFI or RFP from a government agency:

$$ARCS_{NC} = \{ARCS_{NC\_i}, n = 1, 2, \ldots, I\} \tag{20}$$

- Step 3: each architecture solution selected by a KTR will be mapped into a unique PTB solution type defined by DAA.
- Step 4: the Non-Cooperative (NC) game with mixed strategy and incomplete information: The strategy for the kth contractor to map the ith architecture solution to the jth PTB solution type is performed using the following mathematical expression:

$$S_{Mixed\_Non\_Coop} = \left\{ S^k_{NC\_i,j} : ARCS^k_{NC\_i} \overset{P^k_{NC\_i,j}}{\rightarrow} PTB^k_{NC\_j}; i = 1, 2, \ldots I; j = 1, 2, 3, 4, 5; k = 1, 2, \ldots, N \right\} \tag{21}$$

- Step 5: The "Belief Function" set or conditional probability set "P" for NC games: For each contractor "k", the belief function "$P_{Non-Coop}$" is defined as the probability of selecting a PTB solution type "*j*" given the ith architecture solution:

$$P_{Non-Coop} = \left\{ P^k_{NC_i,j}; i = 1, 2, \ldots I; j = 1, 2, 3, 4, 5; k = 1, 2, \ldots, N \right\} \tag{22}$$

where $P^k_{NC_i,j}$ is defined as:

$$P^k_{NC_i,j} = \sum_{l=1}^{L} W_{NC_l}.PrTE^k_{NC_i,j,l} = \left\{ \begin{array}{l} P^{k_{Tech}}_{NC_i,j} = \sum_{l=1}^{L} W_{NC_l}.PrTE^{k_{Tech}}_{NC_i,j,l} \\ P^{k_{Market}}_{NC_i,j} = \sum_{l=1}^{L} W_{NC_l}.PrTE^{k_{Market}}_{NC_i,j,l} \end{array} \right\} \tag{23}$$

Similar to the DAA games, the above equation provides a better mathematical model than the one described in Ref. [8] for contractor games, and Eq. (22) must also satisfy the following condition:

$$0 \le P^k_{NC_{i,j}} \le 1 \text{ and } \sum_{i=1}^{I} P^k_{NC_{i,j}} = 1 \tag{24}$$

- Step 6: PTB Utility Set for a "NC Mixed Strategy" is defined as $U_{Mixed\_Non\_Coop}$. This is the PCF_{NC} for selecting a mixed strategy $S^k_{i,j}$ for the k^{th} contractor. Mathematical, it is given by the following equation:

$$U_{Mixed\_Non\_Coop} = \left\{ U^k_{NC\_i,j} : S^k_{NC\_i,j} \overset{P^k_{NC\_i,j}}{\rightarrow} PCF^k_{NC\_i,j}; i = 1,2,\ldots I; j = 1,2,3,4,5; k = 1,2,\ldots,N \right\} \tag{25}$$

- Step 7: The KTR plays the following mixed game to select the optimum PTB solution:

$$KTR\ Optimum\ PTB\ Solution = S_{Opt\_KTR} = \underset{\forall i,j,k}{\text{Max}} \left\{ U^k_{NC\_i,j} : S^k_{NC\_i,j} \overset{P^k_{NC\_i,j}}{\rightarrow} PCF^k_{NC\_i,j} \right\} \tag{26}$$

Similar to DAA-PWGE, the contractor plays KTR-PWGE to maximize his payoff or "Profit" for the selected optimum strategy $S_{Opt_{KTR}}$ resulting from optimally mapping an ARCS to a PTB Solution for a given set of belief function "$P_{Non-Coop}$." The detailed KTR-PWGE mixed game algorithm is shown in **Figure 6** with details provided in Ref. [8]. The PTB tracking tool described in Ref. [6] will be used to capture the PTB solution captured by the KTR-PWGE.

6. Acquisition-bidding War-Gaming Engines (AWGEs)

The approach for the development of Acquisition-bidding WGEs presented in this section follows Ref. [9]. An overview description of the government "Acquisition" DAA-AWGEs and contractor "Bidding" KTR-AWGE will be presented in this section for commonly used contract types, including Firmed-Fixed Price (FFP[7]) and Cost Plus Incentive Firm (CPIF). The Fixed Price Incentive Firm (FPIF) contract type can be found in Ref. [9].

6.1. Acquisition-bidding WGE set-up

The acquisition-bidding game model assumes that there are N contractors participating in the bidding of the space system with the contractor set given by Eq. (1). The following subsections describe the game setup from the government and contractor perspectives, namely, DAA-AWGE and KTR-AWGE, respectively.

[7] FFP is also referred to Fixed Price Seal Bid (FPSB).

6.1.1. DAA-AWGE game set-up

The KTRDAA-AWGE model simulates the government's acquisition games from the government perspective based on the "Contract Type" selected based on the PTB solution obtained from DAA-PWGE models described in Section 5. The DAA-AWGE strategy is to map the optimum "Type ith PTB Solution" (PTB_i), obtained from DAA-PWGE and KTR-PWGE games described in Section 5 above, to the optimum "Acquisition Strategy" and the associated "Type ith Contract" (CT_i). Denote the government strategy as S_{DAA}, mathematically S_{DAA} for Bayesian games with complete and imperfect information can be written as:

$$S_{DAA} = \left\{ S_{DAA_i} : PTB_i \overset{p_i^{DAA}}{\rightarrow} CT_i; i = 1, 2, \ldots N \right\} \tag{27}$$

where p_i^{DAA} is the government "Belief Function" describing the probability that the DAA will map PTB_i to CT_i. It is defined as follows:

$$\mathrm{P_{DAA}} = \left\{ \mathrm{p_i^{DAA}}; \mathrm{i} = 1, 2, \ldots \mathrm{N} \right\} \tag{28}$$

Each p_i^{DAA} must satisfy the following conditions:

$$0 \leq \mathrm{p_i^{DAA}} \leq 1 \text{ and } \sum_{\mathrm{i}=1}^{\mathrm{N}} \mathrm{p_i^{DAA}} = 1 \tag{29}$$

The DAA utility function U_{DAA} is defined as:

$$\mathrm{U_{DAA}} = \left\{ \mathrm{U_{DAA\_i}} : \mathrm{S_{DAA_i}} \overset{\mathrm{p_i^{DAA}}}{\rightarrow} \mathrm{PCF_{DAA_i}}; \mathrm{i} = 1, 2, \ldots \mathrm{N} \right\} \tag{30}$$

where PCF_{DAA_i} is the government "Payoff and Cost Function" (PCF) associated with the selection of the ith strategy S_{DAA_i}. If PCF is the government estimated "contractor cost" associated with the space system being acquired ($\mathrm{PCF_{DAA\_KTR_i}}$), the "Nash strategy" dictates that the optimum strategy for selecting the contract parameters is to minimize the PCF according to:

$$\mathrm{S_{DAA_{Opt}}} = \underset{\forall \mathrm{i}}{\mathrm{Min}} \left\{ PCF_{DAA\_KTR_i} \right\} = \underset{\forall \mathrm{i}}{\mathrm{Min}} \left\{ \mathrm{S_{DAA_i}} \overset{\mathrm{p_i^{DAA}}}{\rightarrow} \mathrm{PCF_{DAA\_KTR_i}}; \mathrm{i} = 1, 2, \ldots \mathrm{N} \right\} \tag{31}$$

If the government utility function $U_{DAA_{i=1}}$ represents the optimum government saving strategy expressed in Eq. (30), $S_{DAA_{Opt}}$, the following condition must be true according to Nash:

$$\mathrm{U_{DAA\_KTR_{i=1}}} = \left\{ \mathrm{S_{DAA_1}} \overset{\mathrm{p_1^{DAA}}}{\rightarrow} \mathrm{PCF_{DAA\_KTR_{i=1}}} \right\} < \mathrm{U_{DAA\_KTR_{i=2}}} < \mathrm{U_{DAA\_KTR_{i=3}}} < \ldots < \mathrm{U_{DAA\_KTR_{i=N}}} \tag{32}$$

If PCF is the government saving associated with the space system being acquired ($\mathrm{PCF_{DAA\_Saving_i}}$), "Nash strategy" dictates that the optimum contract parameters can be selected by maximizing the saving or PCF according to:

$$S_{DAA_{Opt}} = \underset{\forall i}{\text{Min}} \left\{ PCF_{DAA\_Saving_i} \right\} = \underset{\forall i}{\text{Max}} \left\{ S_{DAA_i} \overset{P_i^{DAA}}{\rightarrow} PCF_{DAA\_Saving_i}; i = 1, 2, \ldots N \right\} \tag{33}$$

If the government utility function $U_{DAA_{i=1}}$ represents the optimum government saving strategy expressed in Eq. (32), $S_{DAA_{Opt}}$, the following condition must be true according to Nash strategy:

$$U_{DAA\_Saving_{i=1}} = \left\{ S_{DAA_1} \overset{P_1^{DAA}}{\rightarrow} PCF_{DAA\_Saving_1} \right\} > U_{DAA\_Saving_{i=2}} > \ldots > U_{DAA\_Saving_{i=N}} \tag{34}$$

The DAA can play non-cooperative or cooperative games depending on the "Contract Type." For example, for the FFP contract type, the DAA plays non-cooperative games if the DAA provides a clear direction on the FFP contract that the lowest bidder will be selected and there is no negotiation between the government and the selected contractor. On the contrary, the FPIF contract type requires the cooperation between DAA and the selected contractor to agree on a set of sharing ratios, and perhaps on the Point of Total Assumption (PTA) [12] as well.

6.1.2. KTR-AWGE game set-up

The KTR-AWGE model simulates the contractor's bidding games from the contractor perspective based on the "Contract Type" and the associated contract parameters generated from the DAA-AWGE games. Let b_i be the bidding strategy for the i^{th} contractor, the contractor strategy set for Bayesian game with complete and imperfect information, S_{KTR}, is defined as:

$$S_{KTR} = \left\{ S_{KTR_i} : KTR_i \overset{p_i^{KTR}}{\rightarrow} b_i; i = 1, 2, \ldots N \right\} \tag{35}$$

where p_i^{KTR} is the conditional probability that the i^{th} contractor selects the i^{th} bidding strategy given by:

$$P_{KTR} = \left\{ p_i^{KTR}; i = 1, 2, \ldots n \right\} \tag{36}$$

$$\sum_{i=1}^{n} p_i^{KTR} = 1 \tag{37}$$

The contractor utility function U_{KTR} is defined as:

$$U_{KTR} = \left\{ U_{KTR_i} : S_{KTR_i} \overset{p_i^{KTR}}{\rightarrow} PCF_{KTR_i}; i = 1, 2, \ldots N \right\} \tag{38}$$

where PCF_{KTR_i} is the contractor "Payoff and Cost Function" associated with the i^{th} contractor, KTR_i, who selects the i^{th} bidding strategy S_{DAA_i}. Since the PCF_{KTR_i} is the contractor cost associated with the space system being acquired ($PCF_{DAA\_KTR_i}$), "Nash strategy" dictates that the optimum bidding parameters are selected by maximizing the contractor cost function according to:

$$S_{KTR_{Opt}} = \underset{\forall i}{\text{Max}} \{PCF_{KTR_i}\} = \underset{\forall i}{\text{Max}} \left\{ S_{KTR_i} \overset{p_i^{KTR}}{\rightarrow} PCF_{KTR_i}; i = 1, 2, \ldots N \right\} \tag{39}$$

If the contractor utility function $U_{KTR_{i=1}}$ represents the optimum contractor profit strategy expressed in Eq. (38), $S_{KTR_{Opt}}$, the following condition must be true according to Nash strategy:

$$U_{KTR_{i=1}} = \left\{ S_{KTR_1} \overset{p_1^{KTR}}{\rightarrow} PCF_{KTR_1} \right\} > U_{KTR_{i=2}} > U_{KTR_{i=3}} > \ldots > U_{KTR_{i=N}} \tag{40}$$

Note that the KTR-AWGE models always assume non-cooperative games since the contractors do not share their bidding strategies among themselves.

6.2. Analytical and simulation modeling approach for government acquisition games: DAA-AWGE

6.2.1. DAA-AWGE for FFP contract type

The DAA-AWGE game for FFP assumes that the PTB solution obtained from the DAA-PWGE game model described in Section 5 is the "Type 1 PTB Solution" and the corresponding optimum "Contract Type" is FFP (see **Figure 5**). The FFP game assumes that the contractor actual costs are unknown with a cost ranges of [C_{min}, C_{max}], and the actual cost has either an uniform distribution or a triangular distribution. For this game, from the government's perspective, the higher is the contractor's bid, the lower is the probability of winning the contract. For optimum acquisition strategy, the contractor needs to use the "Nash strategy" to maximize the expected profit taking into consideration both his bid and other contractors' 'expected bids. For non-optimum strategy, the contractor profit is selected by a random percentage over the target cost. The DAA strategy is to minimize contractor profits by searching for a bidding solution that will increase the number of bidders to at least two bidders for increased competition at the minimum possible price. To simplify the modeling effort, the government and the contractors are assumed to have the same risk.

For FFP, the DAA-AWGE game seeks the optimum contract parameters, including the optimum fixed price $P_{C_{opt}}$. Thus, for FFP, the ith contractor's profit function PF_{KTR_i} is defined as:

$$\text{PF}_{\text{KTR}_i} = \{\text{P}_c - \text{c}_i, \text{i} = 1, 2, \ldots, \text{N}\} \tag{41}$$

where P_C is the fixed price and c_i is the actual production cost of the ith contractor. The government payment is the fixed price P_C. The DAA-AWGE game is to minimize P_C. This section provides a war-gaming model for deriving the optimum fixed price $P_{C_{opt\_Gov}}$ from the government perspective. From Section 5, the optimum strategy for selecting the FFP contract parameters is defined as:

$$\text{S}_{\text{DAA}_{Opt}} = \underset{\forall \text{i}}{\text{Min}} \{PCF_{DAA\_KTR_i} = \text{PF}_{\text{KTR}_n}\} = \underset{\forall \text{i}}{\text{Min}} \left\{ \text{S}_{\text{DAA}_i} \overset{\text{p}_\text{i}^{\text{DAA}}}{\rightarrow} (\text{P}_c - \text{c}_i); \text{i} = 1, 2, \ldots \text{N} \right\} \tag{42}$$

From Eq. (17), the optimum government fixed price, $P_{C_{opt\_Gov}}$, can be found by solving the following optimization problem:

$$P_{C_{opt\_Gov}} = \underset{\forall i}{\text{Min}} \{(PF_{KTR_i}\} + c_i = \underset{\forall i}{\text{Min}} \{b_i - c_i\} + c_i \text{ for } b_i \geq c_i \text{ and } i = 1, 2, \ldots N \tag{43}$$

Note the actual production cost c_i for the i^{th} contractor cannot be minimized. And $b(c_i)$ is the i^{th} contractor bidding function given by [11]

$$b(c_i) = \left\{ \begin{array}{l} b_i, \text{for } b_i \geq c_i \\ 0, \text{for } b_i < c_i \end{array} \right\} \tag{44}$$

Using calculus of variation approach, the optimum fixed price from the government perspective for uniform distribution can be shown to have the following form [9]:

$$P_{C_{opt\_Gov}} = \underset{\forall i}{\text{Min}} \left\{ \frac{C_{max} - c_i}{N}, \right\} + c_i, \text{ for } c_i \in [C_{min}, C_{max}\ ], \text{ and } i = 1, 2, \ldots N \tag{45}$$

The expected contractor cost c_i or the "Target Cost" T_C can be determined from the cost analysis using the cost "S-Curve" or using the expected value of the cost distribution. For uniform case, the target cost is found to be [9]:

$$E\{c_i\} = T_c = T_{c\_Uni} = {}^{(C_{Max}+C_{Min})}/_2 \tag{46}$$

The optimum fixed price from when the production cost c_i has the triangular distributed over [C_{min}, m, C_{max}] with m as the mode, can be shown to have the following form [9]:

$$P_{C_{opt\_Gov}} = \left\{ \begin{array}{l} \underset{\forall i}{\text{Min}} \left\{ \frac{A + [B + 2C]^{0.5}}{(2N-1)} \right\} + c_i, for\ \ C_{min} < c_i < m, and\ i = 1, 2, \ldots N \\ \underset{\forall i}{\text{Min}} \left\{ \frac{c_{max} - c_j}{(2N-1)} \right\} + c_i, for\ m < c_i < C_{max}, and\ i = 1, 2, \ldots N \end{array} \right\} \tag{47}$$

where:

$$\left\{ \begin{array}{l} A = N.C_{min} - (N+1).c_i \\ B = (N.c_{min} + (N-1).c_i)^2 \\ C = ((N-1) + 0.5).(\rho - c_{min}^2 - 2(N-1).c_i.c_{min}) \\ \rho = (C_{max} - C_{min}).(m - C_{min}) \end{array} \right\} \tag{48}$$

As point out in Ref. [9], the "Nash strategy" indicates that the optimum contractor profit is determined by the maximum expected cost C_{max}, contractor actual production cost c_i, and the number of contractors "N" participating in the bidding. Using the optimum "Nash strategy," an optimum bidder can make a smaller profit compared to the non-optimum bidders on a specific bid; however, in the long run, the optimum bidder is expected to make more profit than the non-optimum bidders since he wins more bids. The DAA-AWGE algorithm for FFP Contract Type is shown in **Figure 7**.

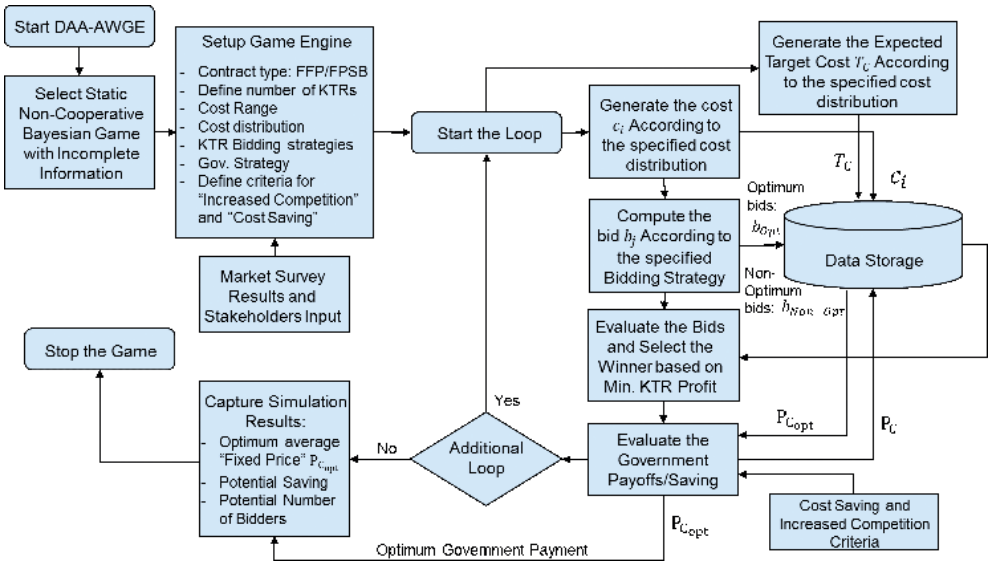

Figure 7. DAA-AWGE modeling and simulation approach for FFP contract type [9].

6.2.2. DAA-AWGE for CPIF contract type

This game assumes that the PTB solution obtained from the DAA-PWGE model described in Section 5 above is the "Type 3 PTB Solution" and the corresponding optimum "Contract Type" is CPIF (see **Figure 5**). The modeling development approach for the DAA-AWGE CPIF contract type is identical to FPIF approach described in Ref. [9]. The model assumes that both the government and the contractor will cooperate to maximize their minimum saving/profit. Therefore, their bargaining objective will be the maximization of the minimum outcome of the saving/profit, i.e., the "maximum" value of the saving/profit. Let PCF_{Gov} and PCF_{KTR_i} be the final compromised saving/profit points, and PCF^0_{Gov} and $PCF^0_{KTR_i}$ be the benchmark saving/profit points for the negotiation between the government and the i[th] contractor, respectively. The optimum CPIF contract parameters can be obtained by solving the following optimization problem [9]:

$$\underset{\forall i}{\text{Max}} \left\{ \mathrm{F_i} : \mathrm{F_i} = \left(\mathrm{PCF_{Gov}} - \mathrm{PCF^0_{Gov}}\right).\left(\mathrm{PCF_{KTR_i}} - \mathrm{PCF^0_{KTR_i}}\right); \mathrm{i} = 1, 2, \ldots \mathrm{N} \right\} \tag{49}$$

Note that PCF_{Gov} and PCF_{KTR_i} are also defined as the government's "Cost Saving" and the i[th] contractor profit, respectively, and they are given by [9]:

$$PCF_{Gov} = C_p + SR_{G_i}\left(T_c - A_{C_i}\right) - \left(A_{C_i} + PCF_{KTR_i}\right); i = 1, 2, \ldots N \tag{50}$$

$$PCF_{KTR_i} = \left(T_{p_i} - T_c\right) + SR_{C_i}.\left(T_c - A_{C_i}\right); i = 1, 2, \ldots N \tag{51}$$

where SR_{G_i} is the government sharing ratio and A_{c_i} is the actual production cost for the i[th] contractor, which is unknown and as before, it is assumed to be either uniformly distributed

over $[O_c, P_c]$, or triangularly distributed over $[O_c, P_c]$ with mode "m." Substituting PCF_{KTR_i} into PCF_{Gov}, the government's "Cost Saving" in terms of the contract parameters can be obtained as:

$$PCF_{Gov} = C_p + 2.\left(1 - SR_{C_i}\right).\left(T_c - A_{C_i}\right) - T_{p_i}; i = 1, 2, \ldots N \tag{52}$$

Substituting Eq. (52) into Eq. (49), and using the calculus of variation approach, the optimization problem can be solved by searching for the Sharing Ratios (SRs) that can maximize F_i and then search for the optimum target price T_P that can maximize F_i. For both DAA and KTR games, we first maximize the cost function F_i with respect to the contractor sharing ratio, SR_{C_i}, by solving the following equation:

$$\frac{\partial \mathrm{F_i}}{\partial \mathrm{SR_{C_i}}} = 0, \mathrm{i} = 1, 2, \ldots \mathrm{N} \tag{53}$$

Note that the contractor sharing ratio ranges from 0 to 1 and the government sharing ratio for the ith contractor, SR_{Gi}, is defined as:

$$\mathrm{SR_{G_i}} = 1 - \mathrm{SR_{C_i}} \tag{54}$$

For DAA-AWGE game from the DAA perspective, the optimization occurs with the following partial differential equation with respect to the contractor:

$$\frac{\partial \mathrm{F_i}}{\partial \mathrm{PCF_{KTR_i}}} = 0, \mathrm{i} = 1, 2, \ldots \mathrm{N} \tag{55}$$

Note that for KTR-AWGE game from the contractor perspective, Eq. (52) becomes:

$$\frac{\partial \mathrm{F_i}}{\partial \mathrm{PCF_{Gov}}} = 0 \tag{56}$$

Solving Eq. (50) and Eq. (52), the optimum win-win sharing ratio, $SR_{C\_Opt_i}$, and optimum win-win target price, $T_{P_{Opt_i}}$, from the DAA perspective are found as follow [9]:

$$SR_{C\_Opt_i} = \frac{2\,PCF^0_{KTR_i} - PCF^0_{Gov} - \left(3T_p - 4T_C\right) + \left(C_p - 2A_{C_i}\right)}{4.\left(T_c - A_{C_i}\right)}, i = 1, 2, \ldots N \tag{57}$$

$$T_{p_{Opt_i}} = \left(2A_{C_i} - C_P\right) + \left[PCF^0_{Gov} + 2PCF^0_{KTR_i}\right]; i = 1, 2, \ldots N \tag{58}$$

For CPIF, the optimum contract parameters depend on whether the contract is the under-run or over-run case. The under-run case occurs when the actual cost of the ith contractor is less than or equal to target cost, i.e., $A_{C_i} \leq T_c$. The over-run case occurs when $A_{C_i} > T_c$.

- **Case 1**: Under-run case: $A_{C_i} \leq T_c$

For this case, the benchmark saving/profit points for the negotiation between the government and the ith contractor become:

$$PCF^0_{Gov} = \propto \left(T_c - A_{C_i}\right); i = 1, 2, \ldots n \tag{59}$$

$$PCF^{0}_{KTR_i} = \left(C_p - T_c\right) \tag{60}$$

Substituting Eqs. (59) and (60) into Eqs. (57) and (57), we obtain the optimum target price,[8] $T_{p_{UOpti}}$, and the optimum win-win contractor sharing ratio, $SR_{C_{UOpti}}$, for the under-run case:

$$T_{p_{UOpt_i}} = C_P - 1.5SR_{CU_i}.\left(T_c - A_{C_i}\right); i = 1, 2, \ldots, n \tag{61}$$

$$SR_{C_{UOpt_i}} = \frac{2(2 - \propto)}{3}, (1/2) \leq \propto \leq 2, \forall i \tag{62}$$

Using the optimum $T_{P_{UOpt_i}}$ and $SR_{C_{UOpt_i}}$, the optimum government payment can be calculated from:

$$P_{Gov_{UOpt_{CPIF}}} = A_{C_i} + \left(T_{p_{UOpt_i}} - T_c\right) + SR_{C_{UOpt_i}}.\left(T_c - A_{C_i}\right); i = 1, 2, \ldots n \tag{63}$$

The parameter α in Eq. (59) will be selected to minimize the government payment.

- **Case 2**: Over-run case: $A_{C_i} > T_c$

For this case, the benchmark saving/profit points for the negotiation between the government and the i[th] contractor become:

$$PCF^{0}_{Gov} = 0 \tag{64}$$

$$PCF^{0}_{KTR_i} = \beta\left(C_p - A_{C_i}\right); i = 1, 2, \ldots n \tag{65}$$

Substituting Eqs. (64) and (65) into Eqs. (57) and (58) above, we obtain the optimum target price,[9] $T_{p_{OOpti}}$, and the optimum win-win contractor sharing ratio, $SR_{C_{OOpt_i}}$ for the over-run case:

$$\mathrm{T_{P_{OOpt_i}}} = \mathrm{C_P} - 1.5.(1 - \mathrm{SR_{CO_i}}).(\mathrm{A_{C_i}} - \mathrm{T_c}); \mathrm{i} = 1, 2, \ldots, \mathrm{n} \tag{66}$$

$$\mathrm{SR_{C_{OOpt_i}}} = 1 - \frac{4}{3}\frac{(1-\beta)(\mathrm{C_P} - \mathrm{A_{C_i}})}{(\mathrm{A_{C_i}} - \mathrm{T_c})}, \left[1 - \frac{3}{4}\frac{(\mathrm{A_{C_i}} - \mathrm{T_c})}{(\mathrm{C_P} - \mathrm{A_{C_i}})}\right] \leq \beta \leq 1; \mathrm{i} = 1, 2, \ldots \mathrm{n} \tag{67}$$

Using the optimum $T_{p_{OOpti}}$ and $SR_{C_{OOpti}}$, the optimum government payment can be calculated from the following equation:

$$\mathrm{P_{Gov_{OOpt_{CPIF}}}} = \mathrm{A_{C_i}} + \left(\mathrm{T_{P_{OOpt_i}}} - \mathrm{T_c}\right) + \mathrm{SR_{C_{OOpt_i}}}.(\mathrm{T_c} - \mathrm{A_{C_i}}); \mathrm{i} = 1, 2, \ldots \mathrm{n} \tag{68}$$

The parameter β in Eq. (65) will be selected to minimize the government payment. The optimum target price depends on the ceiling price, contractor sharing ratio, target cost and

[8] Note that the optimum target price expressed in Eq. (47) indicates the optimum target price that is acceptable to Government when the optimum value of α, α_{Opt}, is selected based on the minimum Government payment.

[9] This is the optimum target price that the contractor is seeking by selecting the optimum value of β based on the maximum contractor profit.

actual cost of the i[th] contractor. **Figure 8** describes the DAA-AWGE-CPIF Monte Carlo simulation approach to determine the optimum target price, sharing ratios, and government payment under government's perspective.

As indicated in **Figure 8**, the output of the DAA-AWGE CPIF model includes the average optimum values of the target fee (F_{T_ave}), minimum fee (F_{min_ave}) and maximum fee (F_{max_ave}), assuming there will be N optimum values for all of the selected contractors by the end of the games. The calculation of these optimum values are derived from Ref. [12] and given by the following formulas:

$$F_{T\_ave} = \sum_{i=1}^{N} \frac{\left(T_{p_{UOpt_i}} - T_C\right)}{N} \tag{69}$$

$$F_{\min\_ave\ i} = \sum_{i=1}^{N} \frac{\left(F_{T\_ave} - SR_{C_{OOpt_i}}(P_c - T_c)\right)}{N} \tag{70}$$

$$F_{\max\_ave} = \sum_{i=1}^{N} \frac{\left(SR_{C_{UOpt_i}}(T_c - O_c) + F_{T\_ave}\right)}{N} \tag{71}$$

where $T_{P_{UOpt_i}}$, $SR_{C_{OOpt_i}}$ and $SR_{C_{UOpt_i}}$ are defined as above. The estimate costs O_c, T_c and P_c are the optimistic cost estimate, target cost estimate and pessimistic cost estimate are given by the cost estimate group from engineering department or finance department or contract department depending on the organization and game rules.

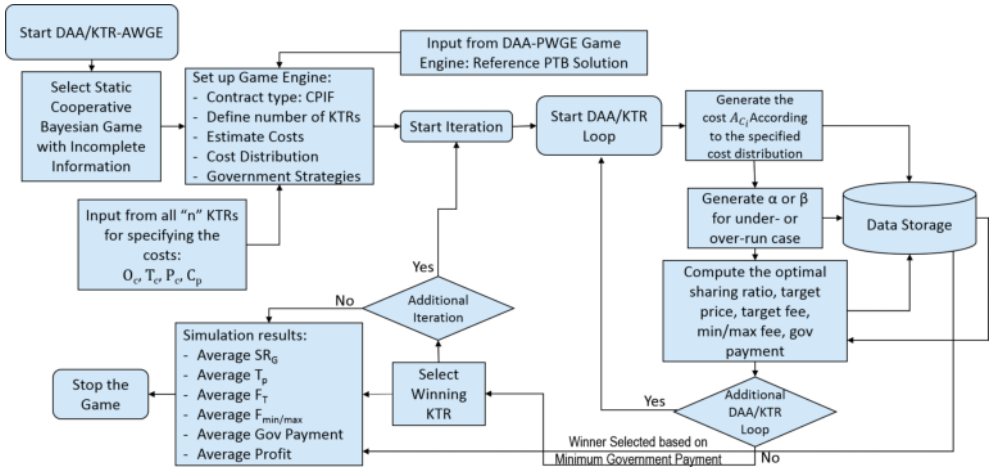

Figure 8. DAA-AWGE modeling and simulation approach for CPIF contract type.

6.3. Analytical and simulation modeling approach for contractor bidding games: KTR-AWGE

6.3.1. KTR-AWGE for FFP contract type

The contractor bidding game, KTR-AWGE, follows the setup described in Section 6.1.2 and [9]. Similar to DAA-AWGE model for FFP, the PTB solution obtained from the KTR-PWGE game model is the "Type 1 Requirement" and the corresponding optimum "Contract Type" is FFP. For FFP, the KTR-AWGE game seeks the optimum contract parameters, including the optimum fixed price $P_{C_{opt}}$, that maximizes the contractor's profit PCF_{KTR_i} [9]:

$$S_{KTR_{Opt_i}} = \underset{\forall i}{\text{Max}} \{PCF_{KTR_i}\}, \text{ for } i = 1, 2, \ldots N \tag{72}$$

where contractor profit function, PCF_{KTR_i}, is defined as:

$$PCF_{KTR_i} = \left\{ \begin{array}{l} b_i(c_i) - c_i, \text{ if } b_i = \min(b_1, \ldots, b_n), \text{ and } b_i > c_i \\ (1/N).[b_i(c_i) - c_i], \text{ if } b_i = b_j, \ldots, b_N, \text{ and } b_i > c_i \\ 0, \text{ if } b_i > \min(b_1, \ldots, b_n) \end{array} \right\} \tag{73}$$

where N, $b_i(c_i)$ and c_i are defined in the above sections as the number of contractors, bidding price and associated actual production cost of the i^{th} contractor, respectively. Using the calculus of variation approach and assuming the cost to be uniformly distributed between [C_{min}, C_{max}], the solution to Eq. (72) is the optimum bidding price, $b_{Unif\_Opt_i}$, from the contractor perspective has the same form as that from the government perspective, i.e.,

$$b_{Unif\_Opt_i} = \underset{\forall i}{\text{Max}} \left\{ \frac{C_{max} - c_i}{N}, \right\} + c_i, \text{ for } c_i \in [C_{min}, C_{max}], \text{ and } i = 1, 2, \ldots N \tag{74}$$

For the triangular distribution case, the optimum bidding price from the contractor perspective can be found in Ref. [9]. The KTR-AWGE model shows that, using the "Nash strategy," the optimum contractor bidding price is also dependent on the maximum expected cost C_{max}, the contractor actual production cost, c_i, and the number of contractors "N" participating in the bidding. The model shows that a contractor's bidding strategy is optimum when it maximizes his profit based on the maximum expected cost, the actual cost and the number of bidders. The modeling and simulation approach proposed for the FFP KTR-AWGE is to combine the above analytical models with Monte Carlo simulation. The flow chart for FFP KTR-AWGE approach is very similar to FFP DAA-AWGE and can be found in Ref. [9].

6.3.2. KTR-AWGE for CPIF contract type

The CPIF KTR-AWGE game described in this section follows [9]. It assumes that the PTB solution obtained from the KTR-PWGE game model is "Type 3 Requirement" and the corresponding optimum "Contract Type" is CPIF. The objective of the KTR-AWGE model is to seek the optimum "bidding" target price and the associated contractor sharing ratios for

http://dx.doi.org/10.5772/intechopen.71044

maximum contractor profit, i.e., maximum benefit from the contractor perspective. Rewrite PCF_{KTR_i} (Eq. (50)) as a function of PCF_{Gov} as follow:

$$PCF_{KTR_i} = C_p + SR_{G_i}(T_c - A_{C_i}) - (A_{C_i} + PCF_{Gov}); i = 1, 2, \ldots N \tag{75}$$

The optimization problem shown in Eq. (49) becomes [9]:

$$\begin{aligned} \underset{\forall i}{\text{Max}} \Big\{ F_i = & \left(PCF_{Gov_i} - PCF^0_{Gov_i}\right).(C_p + SR_{G_i})(T_c - A_{C_i}) \\ & - A_{C_i} - PCF_{Gov_i} - PCF^0_{KTR_i} \Big\}, i = 1, 2, \ldots N \end{aligned} \tag{76}$$

where PCF_{Gov_i}, $PCF^0_{Gov_i}$, C_p, SR_{G_i}, T_c, A_{C_i} and $PCF^0_{KTR_i}$ are as defined in Section 6.2 above.

Again, using the calculus of variation approach described in Eq. (56), the optimum "bidding" target price, $T_{p_{Opt_i}}$ is found to be [9]:

$$T_{p_{KOpt_i}} = (2A_{C_i} - C_P) + 2\left[PCF^0_{KTR_i} + 0.5PCF^0_{Gov}\right); i = 1, 2, \ldots N \tag{77}$$

Note that for the KTR-AWGE game, the optimum win-win sharing ratio from the contractor perspective, $SR_{C_{Opt_i}}$, is identical to the DAA perspective, which is shown to have the form expressed in Eq. (57). As discussed earlier, the optimum contract parameters depend on the whether the contractor is under-run or over-run. The following paragraphs describe the approach to determine the optimum sharing ratios and the target price from the contractor perspective.

- **Case 1**: Under-run case: $A_{C_i} \leq T_c$

For this case, we set $\alpha = 2$ and the benchmark saving/profit points for the negotiation between the government and the i^{th} contractor become [9]:

$$PCF^0_{Gov} = 2(T_c - A_{C_i}); i = 1, 2, \ldots n \tag{78}$$

$$PCF^0_{KTR_i} = (C_p - T_c) \tag{79}$$

From the contractor's perspective, when $\alpha = 2$ the optimum contractor sharing ratio, $SR_{C_{UKOpt_i}}$, is 0% (see Eq. (62)) and the government takes 100% responsibility to pay off the profit when the contractor is under-run. The optimum bidding target price, $T_{P_{KUOpt_i}}$, for this given by [9]:

$$T_{p_{KUOpt_i}} = C_P; i = 1, 2, \ldots n \tag{80}$$

From the contractor perspective, the optimum price is the ceiling price. Using the optimum bidding target price $T_{P_{KUOpt_i}}$ and sharing ratio $SR_{C_{UKOpt_i}}$, the optimum government payment can be calculated from the following Eq. [9]:

$$P_{Gov_{UOpt_{CPIF}}} = A_{C_i} + (C_P - T_c); i = 1, 2, \ldots n \tag{81}$$

- **Case 2**: Over-run case: $A_{C_i} > T_c$

For this case, we set β = 1 and the benchmark saving/profit points for the negotiation between the government and the i[th] contractor become [9]:

$$PCF^0_{Gov} = 0 \tag{82}$$

$$PCF^0_{KTR_i} = \left(C_p - A_{C_i}\right); i = 1, 2, \ldots n \tag{83}$$

The optimum bidding target price for the over-run case, $T_{P_{OOpt_i}}$, is found to be [9]:

$$\mathrm{T_{P_{KOOpt_i}}} = \mathrm{C_P}; \mathrm{i} = 1, 2, \ldots \mathrm{n} \tag{84}$$

Again, from the contractor perspective, the optimum price is the ceiling price. Similarly, the optimum sharing ratio, $SR_{C\_OKOpt_i}$, for the over-run case is given by [9]:

$$\mathrm{SR_{C_{OKOpt_i}}} = 1, \mathrm{i} = 1, 2, \ldots \mathrm{n} \tag{85}$$

This means the contractor takes 100% responsibility when it is over-run! Using the optimum bidding target price $T_{P_{KOOpt_i}}$ and contractor sharing ratio $SR_{C\_OKOpt_i}$, the government payment is given by [9]:

$$\mathrm{P_{Gov_{OKOpt_{CPIF}}}} = \mathrm{C_P}; \mathrm{i} = 1, 2, \ldots \mathrm{n} \tag{86}$$

The modeling and simulation approach for CPIF KTR-AWGE is found to be similar to FPIF KTR-AWGE with the new optimum bidding target prices, $T_{P_{UOpt_i}}$ and $T_{P_{OOpt_i}}$, and contractor sharing ratios, $SR_{C_{UOpt_i}}$ and $SR_{C_{OOpt_i}}$, described above. The flow chart for CPIF KTR-AWGE approach is very similar to CPIF DAA-AWGE and is shown in **Figure 8**.

7. Simulation results for sample PTB solutions and commonly used contract types

Contributors: Brittany Dyer, Claire Goldhammer, Daniel Chertock and Scott Mahan

The models discussed in this chapter to evaluate PTB solutions and associated acquisition strategies for acquiring future space systems were implemented in MATLAB. The simulation results shown in this section were obtained by the 2017 REU team. In particular, we will present simulation results associated with the CPIF model for acquisition strategy. Simulation results associated with FFP contract type can be found in Ref. [13].

7.1. PTB-WGE mixed game model simulation results

The above PTB-WGE models are implemented in MATLAB. The inputs for the PTB-WGE models, which include market survey results and for risk information, potential architecture solutions describing technology combinations, and the PCF information, are manually input into the PTB-WGE program using the input dialog function in MATLAB. The belief function is calculated in a Monte Carlo simulation and aggregates individual technology risk information

http://dx.doi.org/10.5772/intechopen.71044

into a risk assessment for the architecture solution as a whole. The risk and PCF assessments are then combined to form a metric, which is used to select the optimal KTR and contract type using the PTB-ARCS mapping rules shown in **Figure 5**. Examples of the inputs to DAA-PWGE model are shown in **Figures 9–11**.

Notional Payoff-and-Cost Function Template For the Supplier/Contract #1: $PCF_{1,1}^{1}$										
Architecture Assessment for the Architecture Solution #1 and Associated PTB Solution Type 1										
DAA-PWGE Assessment Metric / Yes / No / Plan	Technical Requirements				Affordability Requirements					
	Proposed Tech Reqts and Associated Tech Enablers Incorporated Industry's Input	Align Tech Reqts w/ Warfighter Needs and Tech Enaqblers	Capability Deliveries Meet the Warfighter Needs	Performance Meet Threshold Reqts	Should Cost Data Available for Each Tech Enabler	Should Cost Data Available for Overall System	Leverage DOD IRAD to Lower Cost	Leverage Contractor's IRAD to Lower Cost	Provide Incentives to Allow Contractor to Make IRAD an Allowable Cost	Leverage MOSA for Architecture Design Solution
BBP 3.0 Directive (Weighting factor = 0, 1, 2, 3, and 4)	4	0	0	0	1	2	3	3	3	4
Yes -> Payoff with Weighting factor 1, 2, 3, 4	4	1	3	4	1 (Provide Cost Est)	2 (Provide Cost Est)	3 (Include in Cost Est)	0	3 (Include in RFP)	0
No -> Loss/Cost with weighting factor 0, -1, -2, -3 and -4	0	0	0	0	0	0	0	0	0	0
Plan to do it (Potential Payoff) with weighting factor 0.25, 0.5, 0.75, 1	0	0	0	0	0	0	0	1	0	1
Assessment Score	8	1	3	4	2	4	6	4	6	5
Average Score	4				4.5					
Total Average Score	4.25									

Figure 9. Example of the PCF score for contractor #1 with architecture solution #1 (ARCS #1).

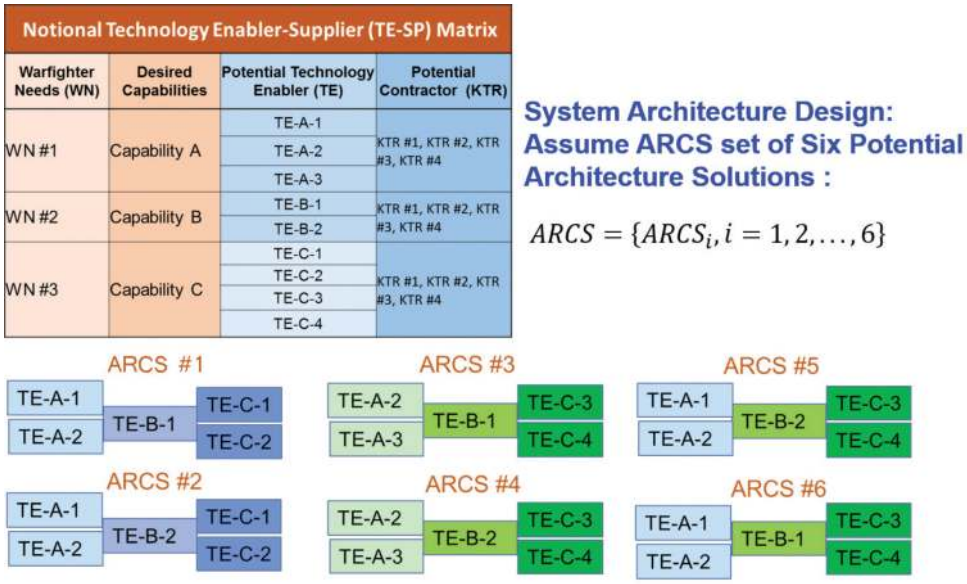

Figure 10. An example of warfighter needs and architecture solution set.

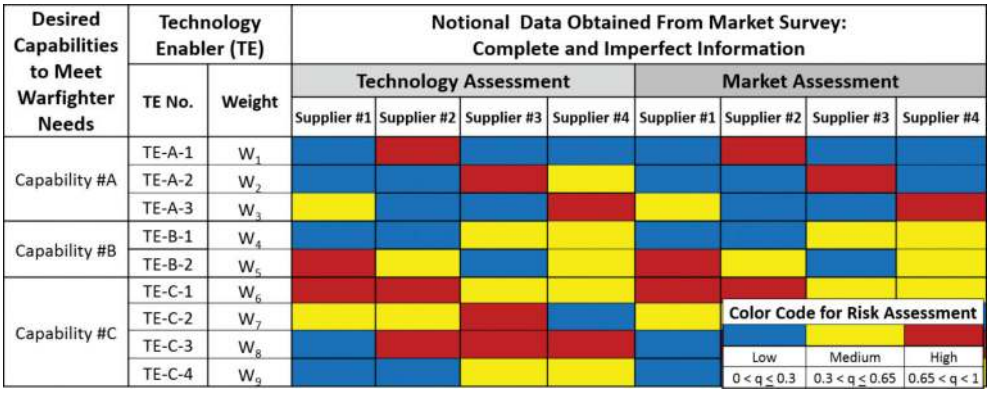

Figure 11. An example of market survey results for DAA-PWGE mixed game model.

Figure 9 shows an example of the PCF score assigned for contractor #1 with ARCS #1. If the architecture solution set consists of 6 architecture solutions (ARCS's) as shown in **Figure 10**, there will be 6 PCF score sheets for each contractor. This example assumes 4 contractors, hence there will be 24-PCF score sheets input to the DAA-PWGE model. **Figure 11** shows an example of the market survey results for four contractors or suppliers.

Example output of the DAA-PWGE program for mixed game model, including the optimum supplier, ARCS, and associated risk, is shown in **Figure 12**.

7.2. DAA-AWGE CPIF model simulation results

To average out the randomness in the optimal solutions, the acquisition and bidding models were iterated several thousand times. The CPIF program outputs the average value for each optimal contract parameter, as well as average government payment, the fee adjustment formula, and average initial conditions PCF_G^0 and $PCF_{K_i}^0$. Here, we present simulation results

```
The following is the optimal solution:

Choose Architectural Solution #4 from Supplier 1.

PTB Solution Composition: {TE-2,TE-3,TE-5,TE-8,TE-9}
Capability 1 is met by TE-2,TE-3.
Capability 2 is met by TE-5.
Capability 3 is met by TE-8,TE-9.


Technical risk is: Low Risk.
Market risk is: Low Risk.
So this is a Type 1 solution.
```

Figure 12. PTB program output example.

of four contractors and three optimal bidders. Among the optimal bidders, the limits for the randomly generated control parameters α and β are adjusted to model different bidding behavior. In this simulation, we treat contractor one as the "average" bidder. The limits for contractor two are changed so that this contractor tends to select unfavorable sharing ratios from the DAA perspective; hence, contractor two is "non-cooperative." On the other hand, contractor three tends to select sharing ratios favorable to the DAA and is called the "cooperative" bidder. The precise limits for these control parameters are depicted in **Figure 13**.

Figures 14 and **15** show the Graphical User Interface (GUI) for DAA-AWGE CPIF input parameters and program output, respectively. The simulation results depicting average government payments and savings as well as sharing rations are shown in **Figures 16–18**. Contract three, the "cooperative" bidder, gives the DAA more savings than the other optimal bidders despite receiving more profit (see **Figure 19**). Hence, it can benefit the contractor to select the sharing ratio that benefits the DAA, both in terms of profit per contract and total long-run profit.

Figure 19 shows a stark difference between the profit earned by optimal bidders and that earned by the non-optimal bidder. **Figure 19**(**a**) depicts that contractor four chooses contract

Contractor Number	Behavior	Lower α limit	Upper α limit	Lower β limit	Upper β limit
1	"Average"	1.25	1.25	0.9	0.99
2	"Non-cooperative"	0.7	1.23	0.9	0.978
3	"Cooperative"	1.27	1.8	0.9	1

Figure 13. DAA-AWGE CPIF optimal bidder α and β limits.

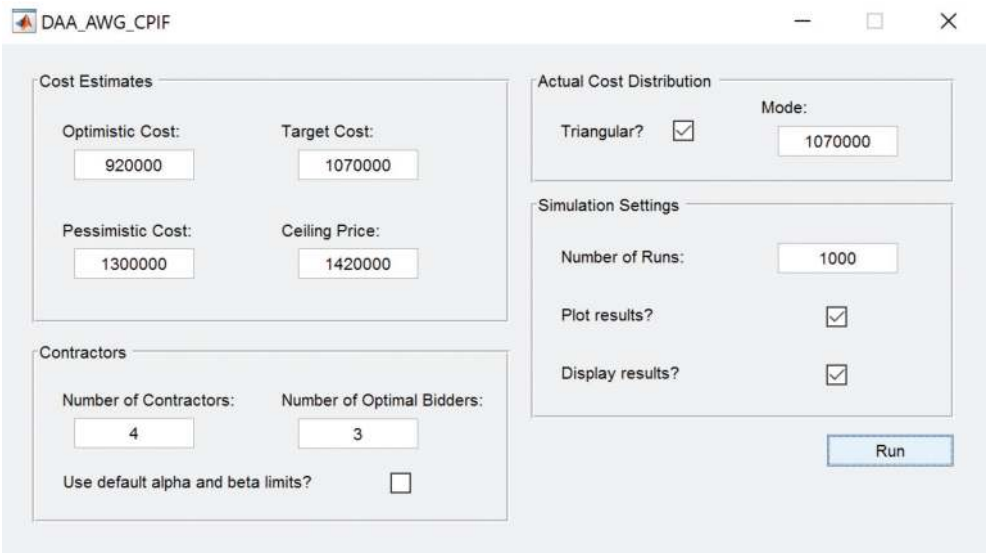

Figure 14. DAA-AWGE CPIF input.

```
The average optimum target price for the under-run case is 1360912.7635.
The average optimum sharing ratio for the under-run case is 0.49353.
The average optimum alpha parameter is 1.2767.
The optimum initial condition for government savings in the under-run case is 106774.4789.
The optimum initial condition for contractor profit in the under-run case is 350000.
The average optimum target fee for the under-run case is 290912.7635.
The average optimum maximum fee is 364941.5759.
The adjustment formula for calculating the optimum fee for the under-run case is F_under = 0.49353*(1070000-Ac) + 290912.7635.
The average government payment for the under-run case is 1318892.4954.
The average government savings for the under-run case is 143127.7726.
The average winning contractor profit for the under-run case is 332525.0907.

The average optimum target price for the over-run case is 1409373.746.
The average optimum sharing ratio for the over-run case is 0.72029.
The average optimum beta parameter is 0.97964.
The optimum initial condition for government savings in the over-run case is 0.
The optimum initial condition for contractor profit in the over-run case is 282138.7333.
The average optimum target fee for the over-run case is 339373.746.
The average optimum minimum fee is 173706.8474.
The adjustment formula for calculating the optimum fee for the over-run case is F_over = 339373.746 - 0.72029*(1300000-Ac).
The average government payment for the over-run case is 1416390.5226.
The average government savings for the over-run case is -3407.2993.
The average winning contractor profit for the over-run case is 284291.5588.
```

Figure 15. DAA-AWGE CPIF output.

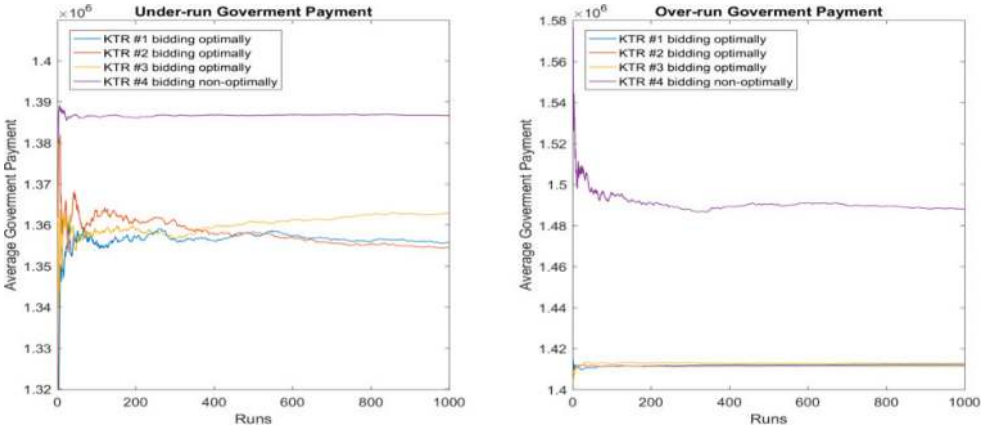

Figure 16. DAA-AWGE CPIF average government payments.

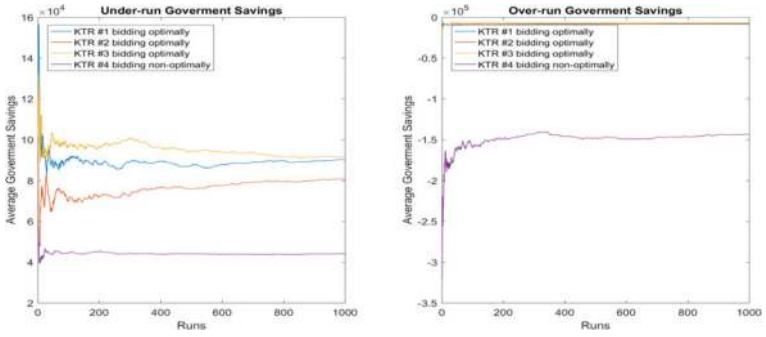

Figure 17. DAA-AWGE CPIF average government savings.

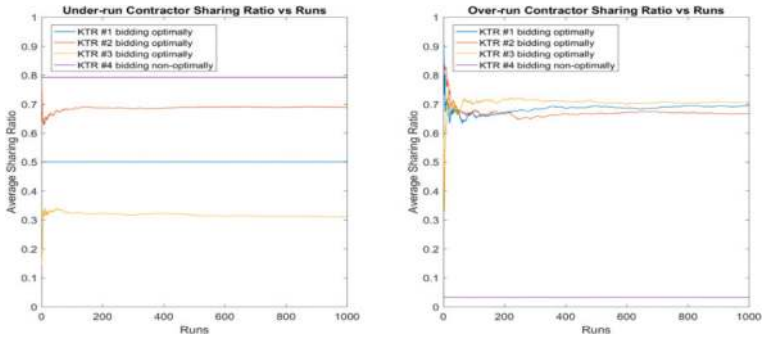

Figure 18. DAA-AWGE CPIF average sharing ratios.

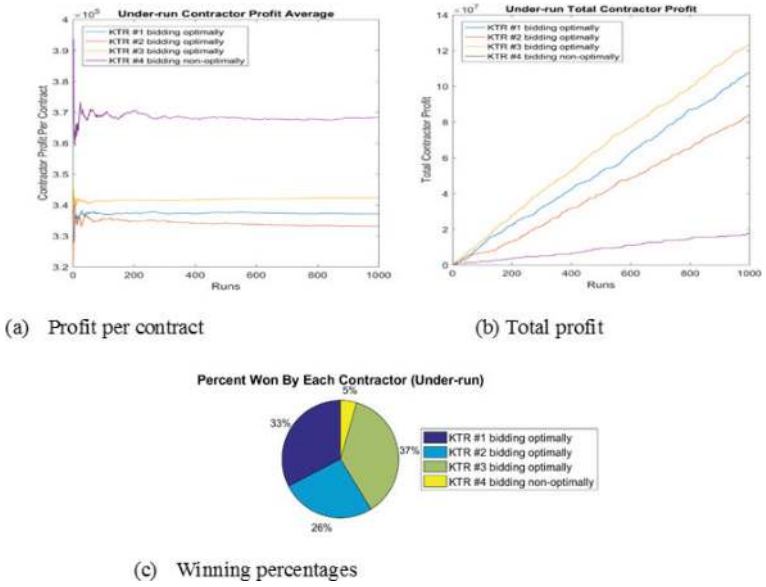

Figure 19. KTR-AWGE CPIF simulation results. (a) Profit per contract; (b) total profit; and (c) winning percentages.

parameters aggressively; the non-optimal bidding strategy demands more profit per contract but wins far less often, as shown in **Figure 19**(**c**). **Figure 19**(**b**) shows that in the long run, the optimal bidders receive more total profit because of their higher winning percentages. Contractor four, the non-optimal bidder, would benefit from using the Nash equilibrium bidding strategy rather than aiming for a fixed profit rate. Changing the control parameter limits for the optimal bidders also affects long-run profit. Note that the "cooperative" contractor three demand more profit per contract than the other optimal bidders in **Figure 19**(**a**) but wins more contracts according to **Figure 19**(**c**). This result is feasible because the DAA and contractors are not playing a zero-sum game, that is, PCF_G and PCF_{K_i} do not sum to zero.

8. Integration of PWGEs and AWGEs

The objective for the development of DAA-PWGE, DAA-AWGE, KTR-PWGE and KTR-AWGE analytical and simulation models is to assist the DAA to understand the contractor's perspective and to seek optimum PTB solution and corresponding acquisition strategy under both Government's and contractor's perspectives. Thus, the government PTB solution for a given set of "requirements" should be optimized to achieve government saving and at the same time to have more than one contractor bidding the solution. This means that there will be at least two contractors converge to the same Government's PTB solution with similar market and technology risks as predicted by the DAA-PWGE. And, the contract type and associated contract parameters and incentives are derived based on the compromised results obtained from both DAA-AWGE and KTR-AGWE. In another word, the PTB solution will be obtained from the integrated DAA-PWGE and KTR-PWGE. The final acquisition strategy for acquiring the PTB solution obtained from the integrated DAA-PWGE and KTR-PWGE is to be generated from the integrated DAA-AWGE and KTR-AWGE. As presented in the proposed UGAF shown in **Figure 3**, the selection of PTB solution and acquisition strategy is a close-loop process and the PTB solution and associated contract type are converge to a single PTB solution with more than one contractor is willing to bid on it. As mention in Section 5, the PTB solution is selected based on the highest PCF score with an assigned "belief" score (or probability). The integrated DAA-PWGE and KTR-PWGE algorithm searches for the highest PCF score and assigned "belief" score that both DAA and KTR can converge to these scores. It is straight

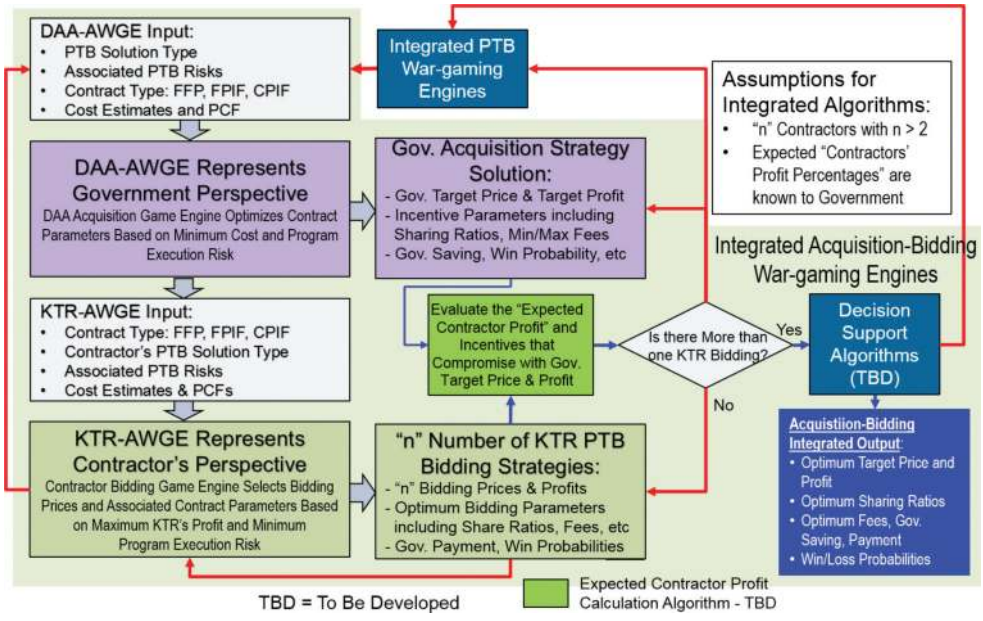

Figure 20. PTB War-Gaming Engines integration algorithm.

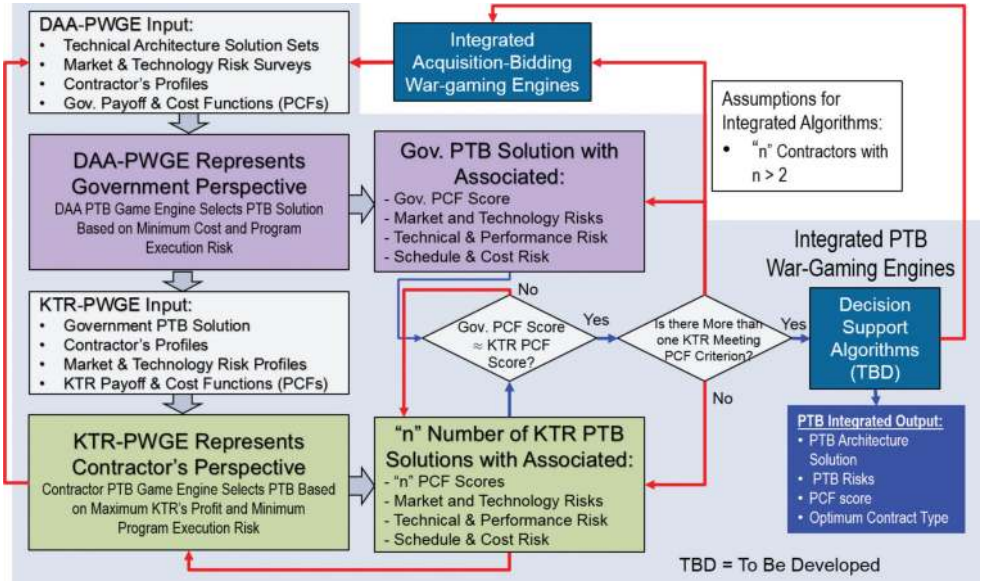

Figure 21. Acquisition-bidding War-Gaming Engines integration algorithm.

forward when the KTR's PCF and "belief" scores converge to DAA's scores. However, when the convergence is not a clear-cut case, a Decision Support Algorithm (DSA) is required to select the optimum PTB solution that can satisfy multiple criteria, including requirements, risks and cost. Our team is currently working on the development of a DSA that leveraged the work done presented in [14–18].

Figures 20 and **21** describe the integration algorithm for integrating DAA-AWGE and KTR-AWGE. The integrated DAA-AWGE and KTR-AWGE algorithm searches for the right "balance" between the DAA's acquisition strategy and KTR's bidding strategy. Our team is currently investigating advanced decision support algorithms that incorporated supervised learning and artificial intelligence to achieve a balance between DAA's and government's perspectives in terms of the government saving and contractor profit, which leads to an estimate the "Expected KTR Profit and Incentives." The "KTR Profit and Incentives" should be compromised with the Government Target Price and associated Target Profit and sharing ratios.

9. Conclusion and way-forward

This chapter provides an overview of the description of PTB optimization games and acquisition-bidding games from both the government and the contractor perspectives. It presents the DAA-PWGE, DAA-AWGE, KTR-PWGE and KTR-AWGE analytical and simulation models. It also provides flow diagrams to show the combination of these models with the

Monte Carlo simulation to generate (i) optimum PTB solutions that can achieve affordability from government perspective, and (ii) optimum FFP and FPIF contract parameters that can achieve affordability from the government's affordability perspective and maximum profit from the contractor perspective. The models were implemented in a collection of MATLAB packages.

Simulation results reveal how contractor behavior affects contractor profit. They show that non-optimal bidders demand more profit per contract which results in a lower winning percentage and less total profit in the long run. Therefore, it is beneficial for contractors to implement the Nash equilibrium bidding strategy. In addition, the CPIF model further separates optimal bidders into cooperative, average, and non-cooperative strategies. The analysis shows that contractors can select a less profitable sharing ratio and in turn increase their long run total profit by cooperating with the government. The resulting information can serve as DAA negotiation tools to encourage cooperative bidding in order to increase government savings. The chapter also discusses the integration of contract parameters from the government and contractor perspectives to generate a set of optimum contract parameters that can achieve the "Increased in Competition." The discussion is at high-level and the subject on the selection of the optimum target price and contractor sharing ratios for the FPIF/CPIF contract types to meet the "Increased in Competition" criterion and the application of supervised learning and artificial intelligence to improve the decision-making process deserve more attention for the future research.

The purpose of the unified framework is to set-up a multi-stakeholder acquisition strategy that encourage cooperative bidding leading to a win-win Nash equilibrium. In such a framework, we seek to change the perspectives of the players from antagonistic to collaborative. Since the simulation results show encouraging evidence that our unified war-gaming framework could help achieve the objective of DII, one of our future research directions is to look into the design of a distributed group decision and negotiation systems that would provide an seamless integration of various acquisition models in such a way that an global optimum solution can be found without negatively affecting local solutions. More importantly, the ultimate goal is to fine-tune our generalized model to help involved parties continuously explore new innovative solutions to meet war fighting needs of the digital age.

Author details

Tien M. Nguyen[1]*, Andy T. Guillen[1], Sumner S. Matsunaga[1], Hien T. Tran[2] and Tung X. Bui[3]

*Address all correspondence to: tien.m.nguyen@aero.org

1 The Aerospace Corporation, El Segundo, California, USA

2 North Carolina State University, Raleigh, North Carolina, USA

3 University of Hawaii at Manoa, Honolulu, USA

References

[1] Hagel HC. Secretary of Defense. Pentagon, 1000 Defense pentagon, Washington D.C.: The Defense Innovation Initiative (DII). p. November 2014

[2] National Defense Authorization Act, § 2446a Requirement for Modular Open System Approach (MOSA) in Major Defense Acquisition Programs. 2017

[3] Air Force Studies Board; Division on Engineering and Physical Sciences. Committee on Owning the Technical Baseline (OTB) in the U.S. Air Force: A Workshop. National Research Council, A Workshop Report. 2015; ISBN: 978-0-309-37431-6

[4] Nguyen TM, Guillen A. Development of an Optimum Technical Baseline for Future Space Systems Using Advanced Game-Based Mathematical Framework—Invited Paper. SIAM—Special Session on Applied Mathematics in Industry, California State University at Fullerton; October 2015

[5] Nguyen TM, Guillen AT, Matsunaga SS. A resilient program technical baseline framework for future space systems. In: Proceedings of SPIE. Vol. 946907-1. 2015

[6] Nguyen TM, Guillen A, Hant J, Kizer JR, Min I, Siedlak DJL, Yoh J. Owning the program technical baseline for future space systems acquisition: Program technical baseline tracking tool. In: Proceedings of SPIE. Vol. 10196. 2017

[7] Nguyen TM, Guillen AT. War-gaming application for future space systems acquisition. In: Proceedings of SPIE. Vol. 983808. 2015

[8] Nguyen TM, Guillen A. War-gaming application for future space systems acquisition: Part 1—Program and technical baseline war-gaming modelling approach. In: Proceedings of SPIE. Vol. 10196. 2017

[9] Nguyen TM, Guillen AT. War-gaming application for future space systems acquisition: Part 2—Acquisition and bidding war-gaming modelling and simulation approaches for FFP and FPIF. In: Proceedings of SPIE. Vol. 10196. 2017

[10] USAF. Report to Congressional Committees: Space Modernization Initiative (SMI) Strategy and Goals. April 2014

[11] Kucsma AI. bidding for contract games—applying game theory to analyze first price sealed bid auctions [master thesis]. Monterey, CA: Naval Postgraduate School; May 1997

[12] Nicolella AJ. Incentive Contracting: Contract Type Overview. Defense Acquisition University.

[13] Vienhage P, Barcomb H, Marshall K, Black WA, Coons A, Tran HT, Nguyen TM, Guillen AT, Yoh J, Kizer J, Rogers BA. War-gaming application for future space systems acquisition: MATLAB implementation of war-gaming acquisition models. In: Proceedings of SPIE. Vol. 10196. 2017

[14] Bui TX. A Group Decision Support System for Cooperative Multiple Criteria Group Decision Making. Berlin, New York: Co-op. Springer Verlag; 1987. p. 1987

[15] Hempsch C, Sebastian H-J, Bui T. Solving the order promising impasse using multi-criteria decision analysis and negotiation. Logistics Research. 2013;**6**(1):24-41

[16] Bui T, Jarke M. A DSS For Cooperative Multiple Criteria Group Decision Making. In: Proceedings of ICIS; 1984;**24**:101-113

[17] Port D, Bui T. Simulating Mixed Agile and Plan-based Requirements Prioritization Strategies: Proof-of-concept and practical implications. EJIS. 2009;**18**(4):317-331

[18] Bui TX, Gachet A, Hans-Jürgen S. Web Services for Negotiation and Bargaining in Electronic Markets: Design Requirements, Proof-of-Concepts, and Potential Applications to e-Procurement. Group Decision and Negotiation. 2006;**15**(5):469-490