International Military Acquisitions Program Model:

A Game Theory Approach

Major Geoffrey G. BOWMAN*

Abstract

The nations of the world spend a significant portion of their wealth on militaries. Every year, billions of dollars go to recruiting, training, maintaining, and equipping the men and women who serve their countries in uniform. This paper looks into one aspect of military spending, acquiring new equipment and systems. In particular, the research focuses on international cooperation in weapon system development and proposes a model to aid decision makers to decide whether and when to join a joint development program. The main goal is to determine what factors are most important in choosing military acquisitions program partners and then to create a model using those factors that will produce policy recommendations for program cooperation.

Keywords : Game Theory, Military Cooperation, Acquisitions, Procurement

* Senior Military Fellow, National Defense University's Center for Applied Strategic Learning, United States Air Force

1. Introduction and Background

Cooperation between nations in military acquisitions is a way in which countries can lower the financial burden of national defense. However, deciding what programs as well as at what point in the development of those programs to join are difficult policy problems that the world's military leadership must solve. This paper presents a model to aid in this decision making process developed by an analysis of international military acquisitions programs that uses game theory as its basis. The model also uses the United States Department of Defense's (US DoD) Acquisition Management procedures to provide more of its framework. From inputs such as estimated costs, program security level, program technology level, and an evaluation of a partner country's ability to contribute to the weapon program, the model calculates the estimated security per unit cost of the program and the estimated security per unit purchased of the weapon system. As an example, the model could calculate the amount of security per dollar gained by developing and acquiring a new fleet of 100 fighter jets.

The paper follows this introduction with the connections the research has to international public policy as well as information on both the United States Department of Defense acquisition management process. Section 2 delves into some ongoing cases of international military acquisition programs used to determine the important factors a country considers when deciding whether to enter into a joint development program. The model is developed in Section 3 including variable definition and model payoff functions. Section 4 presents an example of how this model could be used in a hypothetical international community with example weapon programs. Finally, Section 5 concludes the paper with a qualitative analysis of the example model recommendation, and a presentation of the proposed use of this initial version of the model.

Military spending makes up a large portion of most nations' budgets. Each country must determine its own policies for the best way to obtain and use these large sums of money in order to maintain their military. For concrete numbers, one can turn to the United States Central Intelligence Agency (CIA)'s World Factbook. (CIA World Factbook, 2014) According to the CIA, the five top economies in the world by GDP in 2013 were 1: United States, 2: China, 3: India, 4: Japan, and 5: Germany. (CIA World Factbook, 2014) The military spending of just these five nations exceeded $1 trillion in 2013. While this total includes more than just the costs of acquiring new equipment, acquisitions makes up a large proportion of the total. For instance, of the approximately $550 billion the United States spent on its military in 2012, roughly $200 billion went to acquiring new equipment through the acquisitions process. (Riley 2012, 398)

The domestic defense budget decisions of a country often extend well beyond that country's border when the purchase of foreign equipment is necessary to meet national defense needs. For example, the F-16 fighter aircraft from the US, is flown by 28 countries around the world. (F-16 Fighting Falcon, 2014) Many countries look to international suppliers because they lack the economic, industrial, or technological ability to develop weapons programs on their own. If national defense acquisition needs cannot be met through domestic means, a nation must develop policies for importing weapon systems from abroad. Additionally, weapons exporting nations must decide if selling weapons is in their best interest. The answer is not only based on the financial benefits of the sale, but must also consider potential future national security concerns.

The large amount of money allocated to military spending in general and on new system acquisitions in particular combined with the complex business of international military sales and joint development programs show how important this problem is on the international relations and public policy agendas. With the importance of national defense and the responsibility of being good stewards of the taxpayers' money in mind, policy makers around the world must keep the issue of military acquisitions in mind. Policy makers at the US Department of Defense (DoD) have developed the method which this paper uses as part of the framework for model presented in Section 3. Most importantly, the DoD defines three general stages of the acquisition process, the Pre-Systems Acquisition stage, the Systems Acquisition stage, and the Sustainment stage. (Operation of the Defense Acquisition System 2008, 12) These stages are used by the model as steps at which a country can decide to join an international weapons program.

2. Case Studies

Section 2 deals with case studies of some international military acquisition program cases. An analysis of these cases gives justification to the structure of the model presented in Section 3 as well as provides some insights into what factors nations find important when determining the kinds of military weapons technology to share with other nations. The three case studies researched are the F-35 Lightning II multi-role jet fighter aircraft program, a potential military cooperation deal between Japan and Australia for conventional submarine technology, and a Swedish and Brazilian program involving the Saab Gripen NG. Finally. Section 2.4 discusses how the information learned from these case studies applies to this paper's model.

2.1 Case Study 1 – Joint Strike Fighter

The first case researched involves the Joint Strike Fighter program, an international military acquisition program whereby 11 nations will build and deploy the Lockheed Martin F-35 fighter aircraft. This case study shows partner nations joining the program during the three distinct stages mentioned in Section 1. The US started the program and was joined by the United Kingdom during the Pre-Systems Acquisition stage. After the selection of the F-35 as the Joint Strike Fighter winner, Australia, Canada, Denmark, Italy, the Netherlands, Norway, and Turkey all joined in the Acquisition stage. Finally, Israel, Japan, and South Korea decided to join the F-35 program as Foreign Military Sales partners in the Sustainment phase. Some benefits of having the same weapon system are that partners will share common sustainment and maintenance chores and each country will be able to share any potential enhancements thereby allowing each nation's fleet of F-35s to benefit from lessons learned. However, the amount of influence a country has on the initial product depends on when that country joins the program. (About the F-35 2014)

2.2 Case Study 2 – Japanese/Australian Submarine Program

The second case involves a potential naval warship deal in the Asian-Pacific region between Japan and Australia. This Australian national defense program is researching the possibility of purchasing Soryu diesel submarines built by Japanese defense companies. (Kelly, Siegel 2014) One main feature of the Soryu class submarine that attracted Australian attention is the silent running diesel electric propulsion system. By means of this system, the new Australian submarines would be able to reach deep into the Indian Ocean while limiting an opponent's ability to detect them. However, The Japan/Australia joint submarine program faces many impediments. Even though Australia has stated a willingness to produce parts of the submarines domestically, the US based think tank RAND Corporation says that there are not enough Australian engineers for the project. (Kelly, Siegel 2014) On the Japanese side, senior Maritime Defense Force officials have stated their reluctance in releasing the silent running diesel electric propulsion to an overseas partner for security reasons despite the fact that exporting the technology would spread costs over a larger production base thereby increasing efficiency. (Kelly, Siegel 2014)

2.3 Case Study 3 – Sweden/Brazil Jet Fighter Program

The third case in this section looks into an ongoing program between Sweden and Brazil involving the Swedish designed Saab Gripen NG multi-role jet fighter aircraft. The Brazilian Ministry of Defense announced that the Saab Gripen won their F-X2 competition on 18 December 2013. According to Brazil's Minister of Defense Celso Armorim, the Gripen was selected for three reasons: performance, effective technology transfer, and costs. (A Win for Saab: Brazil Opts of the Gripen NG 2013) The cost per purchase and the cost for maintenance and sustainment per flight hour is much less than other competitors. (Gripen: Proud to be Brazilian 2014) However, most importantly, Brazil's deal with Sweden includes full technology transfer of all aspects of the Gripen design. This will allow the Brazilian-based Embraer aircraft company to produce, assemble, test, and upgrade Gripens domestically in partnership with Saab. Therefore, Sweden can further improve the Gripen design by incorporating the skills of the Brazilian aircraft industry while simultaneously opening the possibility of further aircraft exports to other

South American nations. (Gripen: Proud to be Brazilian 2014)

2.4 Case Study Analysis

An analysis of the three case studies presented above reveals some of the reasons nations choose to join in international weapon development programs and some of the factors that go into deciding which program to join. First, each case shows some decisions partners must consider in determining when to join a program. In the F-35 program, the UK joined very early in the process and therefore had the most opportunity to influence the direction of F-35 design. Several other nations joined during the Acquisition stage and have had some influence on the design through domestic production of common F-35 subcomponents and participation in sustainment procedure development. Finally, Japan and Israel have very little ability to change F-35 design to their own particular national defense needs since they are buying finished models as part of the Foreign Military Sales program. Similarly, in the second case, Australia would not be able to change the design of the Soryu class submarine's silent running diesel electric propulsion system since this subsystem would be purchased whole. In the third case, Sweden and Brazil's agreement encourages design revisions as the Gripen NG is still in the Acquisition Stage equivalent thereby allowing Brazil to shape the final product more to their own needs.

The case studies also show that countries consider several factors before deciding to participate in joint weapon development programs. One factor is security. The US has defense treaties with all of its partners in the F-35 program. These treaties are one reason the technology transfer involved in the joint development takes place. Although the F-35 has many innovative features, the US maintains good enough relations with the program partner nations through defense alliances that cooperation on this level is seen as a matter of course. On the other hand, Japan has stated some serious reservations about selling Soryu class engines to Australia. The design of the engines is a closely held military secret and Australia and Japan have not yet developed a well-defined defense alliance.

Another factor to consider is technology level. As mentioned above, Australia could not provide much potential enhancement to the Soryu class submarine program because of its lack of engineers. Contrary to that, because of its large domestic aircraft industry, Brazil offers Sweden a wealth of knowledge to improve the ongoing Gripen NG program. In addition to the synergistic effects that accompany technological cooperation, these programs also have the potential for improved security through interoperability synergy. The F-35 alliance partners gain additional benefits in sustainability and interoperability by sharing their knowledge and lessons learned from using the same aircraft. Also, maintenance facilities will be the same for any base that houses F-35s making it easy to host alliance deployments.

3. Model Development

This section presents the details of the international military acquisitions model created for this paper. The structure of the model is defined to include the players, strategies, and decision timeline. This basic structure is accompanied by diagrams of the model's extended form. Also presented are the mathematical portions of the model's payoff equations, definitions of the terminology used therein, and how the payoff equations relate to the case study analysis above. The payoff equations are based in part on the participating players and the weapon program being modeled so these factors will also be discussed.

3.1 Structure

The players, strategies, and decision timeline define the structure of this model. First, there are two players that represent countries deciding policies for international military acquisitions cooperation. Player 1 is defined as the country where the weapon program originates and Player 2 is another country that could potentially join in the acquisition process. Each player has a set of strategies. Player 1 has the following three strategies: 1) Invite Player 2 to join the weapon program, 2) Continue Solo Development, and 3) Cancel Program. Player 2's strategies are 1) Join the program to acquire some whole number of weapon system units, or 2) Not Join the program. These strategies are abbreviated as A1, A2, and A3 for Player 1; and B1(#) and B2 for Player 2 with # being the number of whole units Player 2 acquires. The model also assumes that players cannot leave a program until completion. Finally the decision timeline is

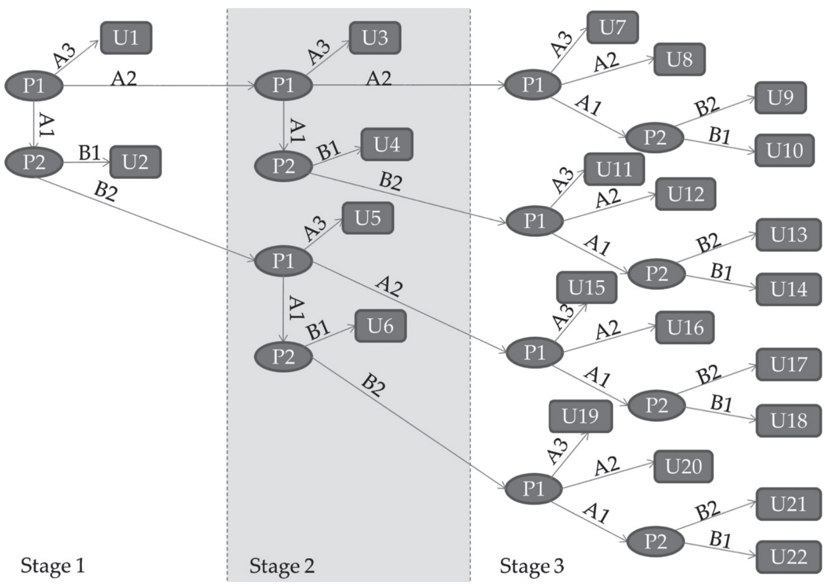

Figure 1 International Military Acquisition Program Model Extended Form

broken into three stages: Stage 1 – Pre-Systems Acquisition, Stage 2 – Systems Acquisition, and Stage 3 – Sustainment as per the information presented in Sections 1 and 2. The extended form of the model, shown in Figure 1, shows a tree-like diagram representing the model structure described above.

The ovals with P1 or P2 written inside them represent decision points or nodes for either Player 1 or Player 2. The connecting arrows labeled by A1, A2, A3, B1, or B2 are the strategies that a player can execute based on a particular decision node. The stages mentioned along the bottom of the model are the Pre-Systems Acquisitions, Systems Acquisitions, and Sustainment stages from above. The rectangles represent the 22 potential outcomes of the model. Each player's payoffs are partially based on the strategies used to reach a certain outcome.

3.2 Payoff Function Value Definitions

A payoff equation for each player has been created to account for each of the 22 outcomes in the model. The payoff functions use a set of common values based on player's evaluations of each other, of the program, and on aspects that can be determined during program negotiations. The payoff functions calculate a value for the amount of security gained per unit cost for each player in each of the outcomes. Then, by means of backward induction, the model predicts the set of strategies followed by each player.

This model uses four types of values. The first type is based on evaluations of one player by the other. Each player selects a value for Player 2's technological ability. This value ranges continuously from 0, meaning no technical ability to contribute to the weapon program, to 1 meaning world leader in a technical area. As mentioned in the case studies, the technological ability of a potential partner nation has some impact on whether and when an invitation to join the program is sent. Each player also evaluates their relationship with the other. This value also ranges continuously from 0, meaning completely antagonistic, to 1, meaning completely cooperative. The JSF and Soryu class Submarine cases give evidence as to the importance of the relationship between potential partner nations. Next the model's payoff equations use variables that determine how much additional gain in security and cost savings the players through cooperation. The value is a positive real number that takes into account how complimentary the efforts of the partners are in addition to their individual inputs as is commonly used in strategic complement partnership games in game theory. (Watson 2013, 82) The P_2S_3 value is used for interoperability cooperation. This value also varies continuously from 0 to 1 with 0 meaning no overlap in national security interests and 1 meaning exactly the same national security interests. As an example, the Kingdom of Swaziland and the Federated States of Micronesia could use a P_2S_3 value close to 0 as their national security interests likely have little overlap.

The next type of values are those based on a player's evaluation of the weapon system program. There are five cost values based on Player 1's estimates of the overall program cost. These include the initial cost of determining there is a national security deficiency that must be addressed (C_i). The model also uses the cost estimates to complete Stages 1, 2, and 3 (C_1, C_2, and C_3). The final cost covers the work required to send invitations, evaluate the proposal, and negotiate an agreement (I).

Next, the number of weapon system units Player 1 (Up_1) acquires is set by the model. Another value Player 1 chooses is the program's level of security (P_s) which, in conjunction with a player's relationship value, the model uses to determine if sharing military technology of that security level is Player 1's best national interest. For example, the Japanese are determining if their silent running diesel electric propulsion system is too secret to sell to Australia. The value of the program security variable ranges from 0 (open to anyone) to 1 (as secretive as possible). Player 1 also determines the weapon system program's technological requirement level (P_t) and the program technological cooperation difficulty value (P_d). The P_t level varies between 0 and 1 corresponding to the expected technological rigors of the weapon system development with a value of 0 meaning technologically easy and a value of 1 meaning technologically difficult. The P_d value is greater than 1 and is used to calculate how much technological assistance a country can provide depending on their abilities (P_{2tech1} or P_{2tech2}) and the program's technological requirements level (P_t). Higher values of P_d mean that partner countries provide exponentially less benefit through cooperation if their technological levels are less than the program's technological requirement level. The last two program specific values are estimates of national security gained per unit from a weapon program without cooperation for both Players 1 and 2. It should be noted that this paper does not propose to define the security per unit value.

The third value type is based on considerations that are part of the negotiations during which the players agree to cooperate on a joint program. The first of these are the amount Player 1 adjusts costs already paid for weapon development to date when including Player 2. These are based on which stage Player 2 joins the program and are set such that Player 1 recoups some of the money already spent or gives Player 2 a discount on program costs. The values for these variables are real numbers ranging from 0, meaning a portion of the weapon development is free to Player 2, up to infinity with a value of 1 meaning Player 1 and Player 2 pay proportionally the same amount.

The final type of values are used to activate certain portions of the equations. They are either 0 or 1 based on the outcome for which a payoff is being calculated. The first three of these values are N_1, N_2 and N_3 where a value of 1 means Player 1 has decided to continue the project at Stage 1, 2 or 3 respectively and a value of 0 means that Player 1 has decided to cancel the program at those stages. Values V_1, V_2, and V_3 are set to 1 if Player 1 extends an invitation to Player to join the program at Stage 1, 2, and/or 3 respectively, but are set to 0 if no invitation is sent at a stage. Finally, J_1, J_2, and J_3 are set to equal 1 if Player 2 joins at Stage 1, 2 or 3 respectively, and set to 0 if player 1 decides not to join at a stage. Table 1 below presents a summary of all the variables used in the payoff functions in this model.

Table 1 Model Variables' Definitions

Variable Symbol	Range, Units	Definition
P_{2tech1}	$0 \le P_{2tech1} \le 1$	Player 1's evaluation of Player 2's pertinent technological ability
P_{2tech2}	$0 \le P_{2tech2} \le 1$	Player 2's evaluation of Player 2's pertinent technological ability
P_{rel1}	$0 \le P_{rel1} \le 1$	Player 1's evaluation of relationship with Player 2
P_{rel2}	$0 \le P_{rel2} \le 1$	Player 2's evaluation of relationship with Player 1
C_i	$C_i \ge 0$, monetary	Cost of initiating the weapon system development program
C_1	$C_1 \ge 0$, monetary	Cost of weapon system development program during Stage 1
C_2	$C_2 \ge 0$, monetary	Cost of weapon system development program during Stage 2
C_3	$C_3 \ge 0$, monetary	Cost of weapon system development program during Stage 3
I	$I \ge 0$, monetary	Cost of participating in negotiations to join weapon program
Up_1	$Up_1 \ge 0$, integer	Number of weapon system units Player 1 will acquire (constant)
Up_2	$Up_2 \ge 0$, integer	Number of weapon system units Player 2 will acquire (variable)
P_s	$0 \le P_s \le 1$	Player 1's evaluation of the weapon system's security level
P_t	$0 \le P_t \le 1$	Player 1's evaluation of the weapon system's technology level
P_d	$P_d > 1$	Player 1's evaluation of the weapon system's technological difficulty level
$\left(\frac{Sp_1}{u}\right)_i$	Left as variable	Evaluation of national security gained by Player 1 per unit of weapon system acquired prior to any program cooperation
$\left(\frac{Sp_2}{u}\right)_i$	Left as variable	Evaluation of national security gained by Player 2 per unit of weapon system acquired prior to any program cooperation
Mf_1	$Mf_1 \ge 0$	Change in amount Player 1 charges Player 2 for all work completed prior to Player 2 joining the program in Stage 1
Mf_2	$Mf_2 \ge 0$	Change in amount Player 1 charges Player 2 for all work completed prior to Player 2 joining the program in Stage 2
Mf_3	$Mf_3 \ge 0$	Change in amount Player 1 charges Player 2 for all work completed prior to Player 2 joining the program in Stage 3
P_2S_1	$0 \le P_2S_1 \le 1$	Cooperation synergy factor for joint work done during Stage 1
P_2S_2	$0 \le P_2S_2 \le 1$	Cooperation synergy factor for joint work done during Stage 2
P_2S_3	$0 \le P_2S_3 \le 1$	How closely the 2 players' national security concerns interact
N_1	0 or 1	1 if Player 1 continues weapon program in Stage 1, otherwise 0
N_2	0 or 1	1 if Player 1 continues weapon program in Stage 2, otherwise 0
N_3	0 or 1	1 if Player 1 continues weapon program in Stage 3, otherwise 0
V_1	0 or 1	1 if Player 1 invites Player 2 in Stage 1, otherwise 0
V_2	0 or 1	1 if Player 1 invites Player 2 in Stage 2, otherwise 0
V_3	0 or 1	1 if Player 1 invites Player 2 in Stage 3, otherwise 0
J_1	0 or 1	1 if Player 2 joins weapon program in Stage 1, otherwise 0
J_2	0 or 1	1 if Player 2 joins weapon program in Stage 1, otherwise 0
J_3	0 or 1	1 if Player 2 joins weapon program in Stage 1, otherwise 0

3.3 Equations

The payoff equations for this model are designed to allow flexibility within the structure presented above. Once the evaluations of player's relationship, technological ability, program security level, technological needs, per player per unit initial security gain, negotiations, and cooperation factors are set, the payoff functions use the number of units Player 2 acquires as the independent variable and security gained per unit money as the dependent variable. The strategies executed by both players activate or de-activate portions of the payoff equations to calculate the payoff values for each player in each outcome of the model. To create this final function, the model calculates the final per unit security gain and the final program cost for each player for each of the 22 distinct outcomes. The security gain portion of the equations are created such that working together in Stage 1 or Stage 2 with a close enough ally ($P_s < P_{rel1}$) that has the technological ability to contribute to the weapon system program ($P_t < P_{2tech1}$) should yield some additional security gains through the synergistic cooperation. However, if these thresholds are not met, there will be minimal security gain or a possible security loss through pursuing a joint program. The cost portion of the equations also takes into account the possibility of synergistic cooperation. However, Player 1 can also adjust how much of the already completed development cost Player 2 must pay for through the Mf_1, Mf_2, or Mf_3 values.

Player 1 *security gain equation:*

$$Sp_1 = \left(\frac{Sp_1}{u}\right)_i * Up_1 * N_3$$

$$+ \begin{pmatrix} +\left(\frac{Sp_1}{u}\right)_i * P_2 S_1 * (P_{rel1} - P_s) * \left(P_d^{P_{2tech1} - P_t - 1}\right) * \frac{Up_2}{Up_1 + Up_2} * Up_1 \\ +\left(\frac{Sp_1}{u}\right)_i * P_2 S_2 * (P_{rel1} - P_s) * \left(P_d^{P_{2tech1} - P_t - 1}\right) * \frac{Up_2}{Up_1 + Up_2} * Up_1 \\ +\left(\frac{Sp_2}{u}\right)_i * (P_{rel1} - P_s) * P_2 S_3 * Up_2 \end{pmatrix} * J_1$$

$$+ \begin{pmatrix} \left(\frac{Sp_1}{u}\right)_i * P_2 S_2 * (P_{rel1} - P_s) * \left(P_d^{P_{2tech1} - P_t - 1}\right) * \frac{Up_2}{Up_1 + Up_2} * Up_1 \\ +\left(\frac{Sp_2}{u}\right)_i * (P_{rel1} - P_s) * P_2 S_3 * Up_2 \end{pmatrix} * J_2$$

$$+\left(\frac{Sp_2}{u}\right)_i * (P_{rel1} - P_s) * P_2 S_3 * Up_2 * J_3$$

Player 1 *program costs equation:*

$$Cp_1 = C_i + I * V_1 + I * V_2 + I * V_3 + C_1 * N_1 + C_2 * N_2 + C_3 * N_3$$

$$+\begin{pmatrix} -(C_1+C_2+C_3)*P_{rel1}*(P_{2tech1}\text{-}P_t)*P_2S_1*\dfrac{Up_2}{Up_1+Up_2} \\ +(1-Mf_1)*C_i*\dfrac{Up_2}{Up_1+Up_2} \end{pmatrix}*J_1$$

$$+\begin{pmatrix} -(C_2+C_3)*P_{rel1}*(P_{2tech1}-P_t)*P_2S_2*\dfrac{Up_2}{Up_1+Up_2} \\ +(1\text{-}Mf_2)*(C_i+C_1)*\dfrac{Up_2}{Up_1+Up_2} \end{pmatrix}*J_2$$

$$+(1-Mf_3)*(C_i+C_1+C_2+C_3)*\frac{Up_2}{Up_1+Up_2}*J_3$$

Player 2 security gain equation:

$$Sp_2=\begin{pmatrix} \left(\dfrac{Sp_2}{u}\right)_i*Up_2 \\ +\left(\dfrac{Sp_2}{u}\right)_i*P_2S_1*(P_{rel2}-P_s)*\left({P_d}^{P_{2tech2}-P_t-1}\right)*\dfrac{Up_2}{Up_1+Up_2}*Up_2 \\ +\left(\dfrac{Sp_2}{u}\right)_i*P_2S_2*(P_{rel2}-P_s)*\left({P_d}^{P_{2tech2}-P_t-1}\right)*\dfrac{Up_2}{Up_1+Up_2}*Up_2 \\ +\left(\dfrac{Sp_1}{u}\right)_i*(P_{rel2}-P_s)*P_2S_3*Up_1 \end{pmatrix}*J_1$$

$$+\begin{pmatrix} \left(\dfrac{Sp_2}{u}\right)_i*Up_2 \\ +\left(\dfrac{Sp_2}{u}\right)_i*P_2S_2*(P_{rel2}-P_s)*\left({P_d}^{P_{2tech2}-P_t-1}\right)*\dfrac{Up_2}{Up_1+Up_2}*Up_2 \\ +\left(\dfrac{Sp_1}{u}\right)_i*(P_{rel2}-P_s)*P_2S_3*Up_1 \end{pmatrix}*J_2$$

$$+\left(\left(\frac{Sp_2}{u}\right)_i*Up_2+\left(\frac{Sp_1}{u}\right)_i*(P_{rel2}-P_s)*P_2S_3*Up_1\right)*J_3$$

Player 2 program costs equation:

$$Cp_2=I*V_1+I*V_2+I*V_3$$

$$+\begin{pmatrix} (C_1+C_2+C_3)*\dfrac{Up_2}{Up_1+Up_2} \\ -(C_1+C_2+C_3)*P_{rel2}*(P_{2tech2}-P_t)*P_2S_1*\dfrac{Up_2}{Up_1+Up_2} \\ +Mf_1*C_i*\dfrac{Up_2}{Up_1+Up_2} \end{pmatrix}*J_1$$

$$+\left(\begin{array}{c}(C_2+C_3)*\dfrac{Up_2}{Up_1+Up_2}\\-(C_2+C_3)*P_{rel2}*(P_{2tech2}-P_t)*P_2S_2*\dfrac{Up_2}{Up_1+Up_2}\\+Mf_2*(C_i+C_1)*\dfrac{Up_2}{Up_1+Up_2}\end{array}\right)*J_2$$

$$+Mf_3*(C_i+C_1+C_2+C_3)*\frac{Up_2}{Up_1+Up_2}*J_3$$

Using the model structure and payoff functions defined in this section, Section 4 provides a demonstration of how this model can be used to provide policy recommendations for potential international military acquisitions programs.

4. Example Cases

In Section 4, a sample international community is created to demonstrate how the model provides policy recommendations for particular weapon development programs. Six countries comprise this sample international community including the project originator, two countries that enjoy a close relationship to the project originator, two countries that are antagonistic to the project originator, and one neutral country. These names are fictional and not intended to represent any real country. The project originator country, is designated Asu and represents Player 1 for the purposes of the model. Therefore, the example in this section will present the models results for Asu and each of the remaining five countries. Asu is a technologically advanced nation and is assumed to have sufficient budget to complete the projects solo. Pajan and Romincan Depublic are both close allies of Asu, but Pajan has a large budget and high levels of technological achievements whereas Romincan Depublic does not. The antagonistic countries are Nicha and North Rokea. Nicha and Asu are near peer rivals in technology and military budget but North Rokea has only meager means and limited ability to design advanced weapons domestically. The final country, Keximo has fair relations with Asu, a moderate level of technological achievement and maintains a moderate military budget.

In addition to the six countries, this example includes two fictional weapon development programs. The first is the X-69 Belchfire, a new generation of jet fighter aircraft that incorporates many advanced technologies so the project technology level (P_t) is close to 1. The program security level (P_s) for the X-69 is also near 1 meaning Asu does not want their advanced designs to go just anywhere. Finally, the costs $(C_i,\ C_1,\ C_2,\ C_3)$ and expected security gain per item $\left(\left(\frac{Sp_1}{u}\right)_i,\ \left(\frac{Sp_2}{u}\right)_i\right)$ are both high. The second program is the BFG Infantry Support Weapon. The BFG program does not incorporate any technological advancements but instead uses universally understood technologies to improve performance over the previous editions of Asu's infantry support weapons. Because infantry support weapons are used by all six nations, Asu evaluates the program security level as near 0. Individual BFGs will not provide as much security as X-69s, but because of the lower program costs potential partners can acquire more units. Tables 2 and 3 below define the values for each country per project and are taken as givens in the model's calculations.

Table 2 Country Interaction Values Chart

Variable	Pajan	Rominican Depublic	Nicha	North Rokea	Keximo
P_{2tech1} (X-69)	0.95	0.05	0.95	0.05	0.5
P_{2tech1} (BFG)	1	0.7	1	0.7	0.9
P_{2tech2} (X-69)	0.95	0.05	0.95	0.05	0.5
P_{2tech2} (BFG)	1	0.75	1	0.9	0.9
P_{rel1}	0.9	0.9	0.15	0.1	0.5
P_{rel2}	0.9	0.95	0.2	0.05	0.5
Mf_1	1	1	1.1	1.1	1.1
Mf_2	1	1	1.2	1.2	1.2
Mf_3	1.1	1.1	1.3	1.3	1.3
P_2S_1	0.5	0.5	0.1	0.1	0.2
P_2S_2	0.5	0.5	0.1	0.1	0.2
P_2S_3	1	1	1	1	1
$\left(\frac{Sp_1}{u}\right)_i$ (X-69)	12	5	8	5	15
$\left(\frac{Sp_2}{u}\right)_i$ (BFG)	1	1	1	1	1
Budget	$500,000,000	$100,000,000	$1,000,000,000	$100,000,000	$500,000,000

Table 3 Program Specific Values Chart

	X-69	BFG
C_i	$1,000,000	$1,000,000
C_1	$999,000,000	$999,000,000
C_2	$2,500,000,000	$2,500,000,000
C_3	$1,500,000,000	$1,500,000,000
I	$50,000	$50,000
Up_1	1,000	10,000
P_s	0.8	0.3
P_t	0.9	0.1
P_d	2	2
$\left(\frac{Sp_1}{u}\right)_i$	10	1

The program cost is calculated from which, based on each country's budget, the total number of units Player 2 should purchase to maximize their payoff at each outcome is determined. The security gained per unit cost is then calculated and each outcome's ordered pair of values for Players 1 and 2 are available for analysis in the model via backward induction. The final output from the model is a recommended set of strategies for each player to reach the optimal outcome. Table 4 below displays the results of the model analysis.

Table 4 Model Results

			Player 1		Player 2	
Program	Country	Recommended Outcome	$\frac{Sp_1}{Cp_1}$	Strategies	$\frac{Sp_2}{Cp_2}$	Strategies
X-69	Pajan	U2	2.04227E-06	A1,X,X	2.97446E-06	B1(113),X,X
	Rominican Depublic	U10	2.00533E-06	A2,A2,A1	1.20247E-06	X,X,B1(18)
	Nicha	U8	0.000002	A2,A2,A2	0	X,X,X
	North Rokea	U8	0.000002	A2,A2,A2	0	X,X,X
	Keximo	U8	0.000002	A2,A2,A2	0	X,X,X
BFG	Pajan	U2	2.60771E-06	A1,X,X	6.84231E-06	B1(2019),X,X
	Rominican Depublic	U2	2.0785E-06	A1,X,X	4.95664E-06	B1(297),X,X
	Nicha	U10	2.04835E-06	A2,A2,A1	1.63626E-06	X,X,B1(1818)
	North Rokea	U10	2.00297E-06	A2,A2,A1	1.17126E-06	X,X,B1(156)
	Keximo	U2	2.08197E-06	A1,X,X	2.94474E-06	B1(1219),X,X

There are several policy recommendations that follow from the results of the model listed in Table 5 above. First, looking at the programs individually, in the X-69 program, Asu should invite Pajan in Stage 1, invite Rominican Depublic to join in Stage 3, and not invite the other 3 countries. Pajan should join the X-69 program by acquiring 113 planes. This number of units comes from Pajan's available budget divided by the Pajan's cost per unit as estimated by the model in outcome U2. Other recommended number of units are calculated similarly. Rominican Depublic should join the X-69 program and buy 18 planes. Next, for the BFG program, Asu should invite Pajan, Rominican Depublic, and Keximo each to join in Stage 1. Pajan should join in Stage 1 and acquire 2019 BFGs, Rominican Depublic should join in Stage 1 and acquire 297 BFGs, and Keximo should join the in Stage 1 and acquire 1219 BFGs. ASU should invite both Nicha and North Rokea to join the BFG program in Stage 3. Both Nicha and North Rokea should join the BFG program and buy 1818 and 156 BFGs respectively.

Additionally, the model outcomes allow for analysis of programs within one country. For instance, from Table 4 Pajan's estimated security gain per unit cost for the BFG program is $6.84231*10^{-6}$ and the estimated security gain per unit cost for the X-69 program is 2.97446E $*10^{-6}$. So, through cooperation on these programs, the model estimates that Pajan would gain approximately twice as much security by joining the BFG program than by joining the X-69 program. Therefore, in the absence of any other military acquisition programs, Pajan should spend its budget on buying BFGs. Rominican Depublic gets approximately four times as much security gain per unit cost for the BFG program than the X-69 program. Therefore, Rominican Depublic should also spend their budget on BFGs if there are no other military acquisition programs available. In Section 5 the focus is on qualitative assessments of the model's policy recommendations.

5. Qualitative Assessment and Conclusions

Section 5 begins with a qualitative look at the model's policy recommendations from the example in Section 4, and concludes with a discussion of the model applicability and its proposed place in the military public policy process. Using the variables defined in the example from Section 4, the model results lead to recommendations for how each country should direct their military acquisitions policies. The model recommended that Asu and Pajan should join together during Stage 1 on both the X-69 and the BFG projects. Because of the two countries' good relations and Pajan's high technological ability this early cooperation makes sense. More cooperation on the project should yield a better end product as each country's experts work together on the design and production. Also, because Asu and Pajan share good relations, a stronger military, through improved equipment, should make the alliance stronger. The model predicts that the security gained per unit cost for the BFG program is greater than that of the X-69 program. Therefore, with its available budget, Pajan would do best to acquire only BFGs.

The recommendations for Asu and Rominican Depublic were for cooperation but at different stages of the projects. First, because of Rominican Depublic's lack of expertise in aircraft manufacturing, the model recommended that Asu not extend an invitation until Stage 3. At that point, Rominican Depublic should buy a limited number of X-69s. This prediction makes sense because Asu would not gain any benefit through design cooperation with Rominican Depublic. However, because of their close relations, both nations benefit from the other's stronger military so cooperation is warranted. In the BFG project, the model recommended that Asu and Rominican Depublic begin their cooperation at Stage 1. Rominican Depublic's technological ability in infantry support weapons was enough that early cooperation yields a better final product.

The model recommended that the best course of interaction between Asu and Nicha was no invitation for the X-69 program and cooperation in Stage 3 of the BFG program. Despite Nicha's advanced technological ability, the two countries should not cooperate on the X-69 program because of poor relations and high program security. Exporting or collaborating on advanced weapons technology with a potential rival should reduce security because of the possibility of having to fight against a rival armed with that technology. However, even with that in mind, the model recommended that Asu should invite Nicha to join the BFG program in Stage 3. This recommendation stemmed from the monetary gains associated with the defined mark-up value overcoming the loss in security of selling a weapon system to potential rival country. The program security for the BFG program was not high so the loss of security due to Nicha joining the program was less than with the X-69 program. Therefore Asu's monetary gain from BFM exports to Nicha should overcome the small loss of security. This case has historical precedence for example between Germany and Republican Spain during the Spanish Civil War. Despite fighter, bomber, and ground support units in the German Condor Legion actively fighting against the Republican Spanish forces, Herman Göring, while holding both the German Aviation and Economics Ministerial positions, authorized exports of arms to Republican Spain because of the prices the Germans could exact (Beevor 2006, 329-330). If the mark-up values for cooperation between ASU and Nicha were changed to the same as the values between ASU and Pajan (i.e.; from $Mf_1=1.1$, $Mf_2=1.2$, $Mf_3=1.3$ to $Mf_1=1$, $Mf_2=1$, $Mf_3=1.1$) then the monetary gains through cooperation no longer overcome the security loss associated with Nicha joining the weapon program in Stage 3. In this case, the model recommends that ASU complete the program by itself.

The model recommended the same outcomes for Asu and North Rokea as it did for Asu and Nicha; only the number of BFGs were different. North Rokea did not have the technological ability to contribute to the X-69 program. Additionally, because of poor North Rokea/Asu relations, Asu would suffer a security loss by allowing North Rokea to acquire any X-69s. However, because of the lower security level of the BFG program, the model recommended North Rokea join that program at Stage 3. As seen above with the Asu/Nicha interaction in the BFG program, the monetary benefits outweigh the security losses for Asu by allowing North Rokea to join in Stage 3.

Finally, the recommendations for Asu/Keximo interaction were split based on the program. Because of the high program security and marginal relations, Asu should not invite Keximo to join the X-69 program at any stage. Additionally, because of Keximo's limited technical ability in aircraft production, cooperation would not have yielded much improvement over an Asu-only developed X-69. On the other hand, with a lower program security value and taking Keximo's technical ability with infantry support weapons into consideration, the model recommended that Asu and Keximo should begin joint development of BFG in Stage 1. Both countries would benefit from cooperation on the BFG development and Asu would get some minimal monetary gain as well through the mark

Based on the US DoD Acquisition Management Framework presented in Section 1 and the case studies of recent and ongoing international military acquisitions programs described in Section 2, the model presented in this paper produces recommendations on when countries should join together to produce military weapon systems. The case studies revealed that nations must consider technological level of and international relations with a potential partner, the technological difficulty of a weapon program, and the security level of a program. Taking these factors into consideration and adding benefits of interoperability stemming from partner nations sharing the same equipment, a game theoretic model and payoff equations for possible model outcomes were presented in Section 3. Section 4 described a sample international community and weapon programs and used the model to create policy recommendations for which country should join which program at what level and when. Section 5 qualitatively reviewed the policy recommendations from Section 4.

In its current form, this model's intended use is by the US DoD to systematically produce recommendations for international military acquisitions cooperation with the objectives of decreasing program costs, decreasing program schedule, and improving final product quality. With those objectives in mind, the model could be used for a timely review of all Department of Defense weapon development programs to take into account changes in international relations, national defense requirements, budget, and new program potential security gains. In a larger sense, this model could be used to aid military leaders in determining the most efficient use of budget resources for all aspects of military activities. If a definition for national security gained per action or per unit cost could be created, or if the security gain of all actions could be ranked relatively, this model could be used to compare whether acquiring new equipment would provide as much benefit as other activities such as training additional soldiers or updating military facilities.

Bibliography

"About the F-35." *F-35 Lightning II*. Lockheed Martin. n.d. Web. July 22 2014.
https://www.f35.com/about

Beevor, Antony. *The Battle for Spain: The Spanish Civil War 1936 – 1939*. New York: Penguin, 2006. Print.

CIA World Factbook. Central Intelligence Agency. Web. July 18 2014.
https://www.cia.gov/library/publications/the-world-factbook/

Kelly, Tim. Siegel, Matt. "Japan & Australia Consider Submarine Deal That Could Rattle China." Reuters. 28 May 2014. Web.
http://www.reuters.com/article/2014/05/28/us-japan-australia-submarine-idUSKBN0E82ET20140528

"F-16 Fighting Falcon." *Lockheed Martin*. Lockheed Martin, 2014. Web. July 19 2014. http://www.lockheedmartin.com/us/products/f16.html

"Operation of the Defense Acquisition System." *Department of Defense Instruction 5000.02*. December 8 2008. Web. 19 July. http://www.acq.osd.mil/asda/docs/dod_instruction_operation_of_the_defense_acquisition_system.pdf

Riley, Bryan A. "Running With Scissors: Defense Budget Cuts and Potential Industry Responses." *Defense Acquisitions Research Journal* Vol.19 No.4 (2012): 394–421. Web. October 2012. http://www.dau.mil/publications/DefenseARJ/ARJ/ARJ64/Riley_ARJ64.pdf

Watson, Joel. *Strategy: An Introduction to Game Theory*. New York: Norton, 2013. Print.

"A Win for Saab: Brazil Opts of the Gripen NG." *Defense-Update*. Defense-Update. 19 December 2014. Web. 24 July 2014.
http://defense-update.com/20131219_brazil_gripen.html#.U9BXPvmSySo