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When More is Better: Design Principles for Prediction Markets in Defense Acquisition Cost Forecasting

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Abstract

This paper discusses the applicability of prediction markets in Defense Acquisition projects, specifically in estimating their cost and schedule.

Several temporal and political factors can sometimes limit the effectiveness of traditional methods of project tracking and cost estimation, which may be overcome by using prediction markets. A prediction market provides an environment for traders to buy and sell contracts whose values are tied to uncertain future events. Efficient prediction markets have been shown to outperform available polls and other forecasting mechanisms.

There are various prediction markets based on different models and algorithms. Our focus is not to analyze these models, but to identify the design principles of implementing a proven prediction market model in a defense acquisition project. Some pilot studies have been carried out that provide insight into the behavior of the market participants. We found increased involvement of participants and greater interest in the projects to be major benefits. The areas that need to be considered in the design and implementation of markets are related to the participants (like, which traders to include); the information to be collected, or the stocks; the marketplace to be used; and the incentive structure to keep the participants motivated to trade.

Introduction

Historically, defense programs for weapons acquisition have taken longer, cost more and delivered fewer quantities and capabilities than planned (GAO, 2006).

Some of the reasons for such discrepancies include:

- Lack of discipline in estimation. Sometimes all the required factors or experienced people are not consulted during the estimation process. There is also a lack of transparency and accountability (GAO, 2006).
- Unrealistic expectations. The estimates can sometimes be too optimistic (GAO, 2008).
- Initial estimates tend to “anchor” expectations (Aranda & Easterbrook, 2005). Initial figures of estimates set too high expectations from the start, which is difficult to meet later on. Also, it is later on difficult to incorporate any modifications.

A recent study by RAND involved an analysis of data in the Selected Acquisition Reports (SARs) for a sample of 68 completed programs. The results showed that the

average cost growth (including both cost overruns and cost under runs) for these programs was 46% over the baseline estimate made at Milestone B and 16% over the baseline estimate at Milestone C. While cost growth occurred earlier in acquisition projects, the development cost growth at completion for programs initiated in 1970s, 1980s and 1990s remained relatively steady (Arena, Leonard, Murray & Younossi, 2007).

It is also worthwhile to note that of the 23 programs assessed in the GAO report (GAO, 2006), around 10 are expecting development cost overruns greater than 30%, or have delayed the delivery of initial operational capability by at least 1 year. The impact of such conditions is the reduction in the value of the DoD's defense dollars and lower return on investment (ROI) (GAO, 2006). See Table 4 in the Appendix for more details.

The key recommendation for the executive action from the report is to ensure that appropriate knowledge is captured and used at critical junctures, specifically at the following key points:

- Program start,
- Design review for transitioning from system integration to system demonstration, and
- Production commitment.

An effective way to capture knowledge and utilize collective intelligence of all team members is to use prediction markets or information aggregation markets. Such markets can be used as a supplement to existing estimation methodologies in generating more accurate cost and schedule estimates.

Prediction Markets: History and Purpose

Prediction markets are emerging as a promising forecasting mechanism for efficiently handling the dynamic aggregation of dispersed information among various agents (Tziralis & Tatsiopoulos, 2007). Various terms such as "information markets," "decision markets," "electronic markets," and "virtual markets" can be used to describe this. In essence, prediction markets are speculative markets created for the purpose of predicting the outcome of an uncertain future event. They provide an environment for traders to buy and sell contracts whose values are tied to uncertain future events.

In the late 80s, some academics at the University of Iowa's business school came up with idea of giving students hands-on experience in trading markets, such as stock and commodities. Instead of using play money, they created a real market in which anyone could bet modest sums on the outcome of future events—e.g., the next president of the United States. The Iowa Electronics Markets (IEM) is now a thriving nonprofit enterprise (Tetlock, 2006).

Figure 1 shows a sample prediction market that is commercially available:

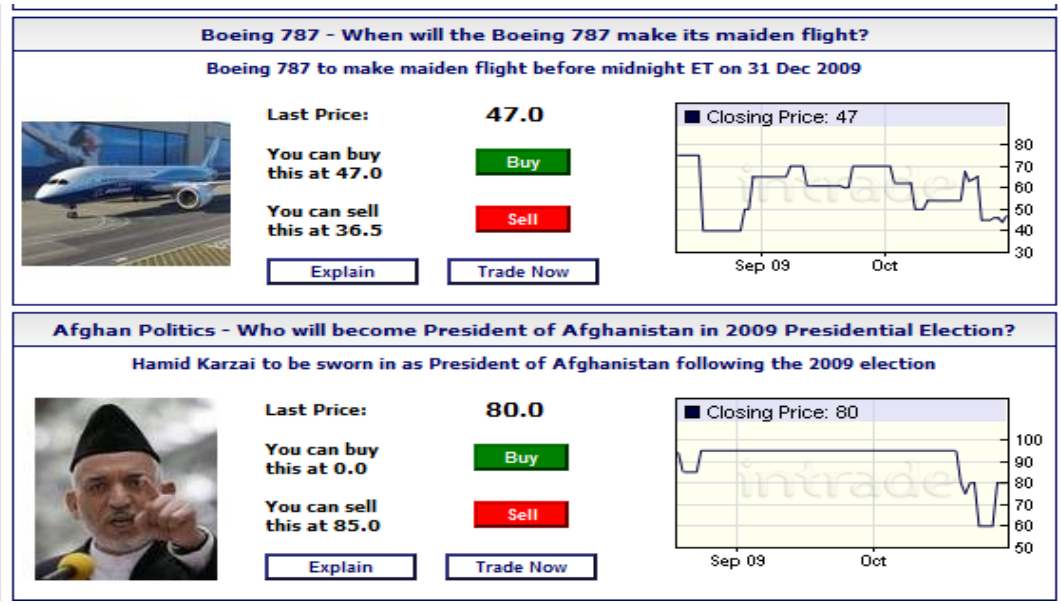

Figure 1. A Sample Prediction Market
(Intrade.com, 2010)

The theoretical foundations of prediction markets lie in the efficient market hypothesis, which states that a sufficient number of marginal traders with rational expectations, who maximize utility through maximizing profits, drive prices in the market in such a way that there is no opportunity for arbitrage (Shvarts & Green, 2007).

It is believed that if the market is well functioning, then contract prices reflect the collective wisdom of market participants. There are three primary types of prediction markets (Wolfers & Zitzewitz, 2004):

- Winner Takes All Market: In this, the contract pays a specified amount if and only if the world achieves some specific conditions, with the price of the contract reflecting the market's assessment of the probability of that occurrence.
- Index Market: In this, the contract pays an amount reflected in some condition of the world, such as the percentage of the vote a candidate receives or the inches of cumulative snowfall in a city.
- Spread Market: In this, contracts specify the cutoff that determines whether an event occurs (such as win margins in football). These basic contract types can be extended to generate additional predictions and measures of market uncertainty, such as the probability that a candidate will receive 40% of the vote, 50%, 60%, etc.

Table 1 illustrates some examples for each:

Table 1. Types of Prediction Markets
(adapted from Wolfers & Zitzewitz, 2004)

Contract	*Example*	*Details*	*Reveals market expectation of . . .*
Winner-take-all	Event y: Al Gore wins the popular vote.	Contract costs $\$p$. Pays \$1 if and only if event y occurs. Bid according to value of $\$p$.	Probability that event y occurs, $p(y)$.
Index	Contract pays \$1 for every percentage point of the popular vote won by Al Gore.	Contract pays $\$y$.	Mean value of outcome y: $E[y]$.
Spread	Contract pays even money if Gore wins more than y^*% of the popular vote.	Contract costs \$1. Pays \$2 if $y > y^*$. Pays \$0 otherwise. Bid according to the value of y^*.	Median value of y.

Prediction markets are most notably used today for predicting election outcomes, movie box office returns, terrorist attacks and sporting events (Wolfers & Zitzewitz, 2004). Information markets have also been deployed at Hewlett-Packard Corporation for making sales forecasts and were found to be more effective than traditional methods. "Not only did the market predictions consistently beat the official HP forecasts; the outcomes predicted are consistent with the probabilistic predictions of the IAM (Information Aggregation Market)" (Plott & Chen, 2002).

Google also launched an internal prediction market in April 2005. The Google markets are similar to Iowa Electronic Markets, and have survey questions like "How many users will Gmail have?" Common type of markets included those forecasting demand (Masse, 2008). "Google's prediction markets are reasonably efficient, but did exhibit four specific biases: an overpricing of favorites, short aversion, optimism, and an under-pricing of extreme outcomes. New employees and inexperienced traders appear to suffer more from these biases, and as market participants gained experience over the course of our sample period, the biases become less pronounced" (Masse, 2008).

Some of the factors that are involved in prediction markets are:

- **Illiquidity:** Prediction requires enough buyers and sellers making enough transactions to produce a clear market price that summarizes the market prediction. In "thin" markets where buyer, sellers and their trades are few, the prediction market can sometimes be ineffective. Some research suggests prediction markets can be effective with as few as sixteen active traders (Christiansen, 2007).
- **Rationality:** While prediction markets have been strikingly accurate when they meet the criteria for effective markets, scholars have noted some deviations from "perfect" rationality. First, while traders' preferences may bias their trades, such as when partisans buy political futures contracts for their favored candidate (Forsythe, Rietz & Ross, 1999), the prediction market price of contracts will remain accurate so long as the enough marginal traders remain objective (e.g., their profit motives outweigh their preferences).

Prediction markets do not require all traders be rational as long as marginal market exchange is motivated by rational traders (Gruca & Berg, 2007; Tziralis & Tatsiopoulos, 2007). Second, as in horse racing, prediction markets participants exhibit over price long shots (so that contract holders receives a smaller payoff relative to the true probability of the event occurring) and under price high probability events, though Cowgill, Wolfers, and Zitzewitz (2009) suggest that precisely the opposite biases occurred when Google employees traded in internal company prediction markets forecasting Google's future. Moreover, prediction markets may be less effective at accurately predicting extremely likely or unlikely events (Wolfers & Zitzewitz, 2004).

- **Manipulation and Bubbles:** A sufficiently endowed and motivated trader might attempt to manipulate a prediction market by purchasing contracts in desired directions. A candidate for elected office, for example, might purchase contracts on himself to generate apparent momentum and publicity. Speculative bubbles are possible in prediction markets, a non-trivial concern in light of recent macroeconomic events. Wolfers and Zitzewitz (2004) propose that a speculative bubble occurred in political prediction markets on whether Hillary Clinton would win the 2004 Democratic presidential primary, and bubbles may have occurred in experimental prediction markets reported in Plott and Sunder (1988). To some extent, markets may self correct manipulation and bubbles (Strumpf, 2004). The best defense against manipulation is sufficient liquidity so that profit seeking traders, recognizing that the manipulated market prices are inaccurate trade for contracts to bring predictions back into line.

Prediction Markets for Defense Acquisition Projects

The DoD's ability to meet its acquisition targets is becoming increasingly critical as defense budgets are reduced and expectations to deliver on time and on budget remain high. Costs overruns are one aspect of this issue. Please refer to Table 5 in the Appendix for a sample of cost overruns in large federal projects.

A recent GAO report (Edwards, 2009) concluded that "weapon programs are taking longer, costing more and delivering fewer capabilities than originally planned." It also noted that "systematic problems both at the strategic and at the program level" (GAO, 2008) were to blame. The GAO also noted that military branches "overpromise capabilities and underestimate costs to capture the funding needed to start and sustain development programs" (GAO, 2008).

In 2008, the GAO reviewed cost and schedule of 72 weapons programs and found that the average cost overrun for systems development was 40% (GAO, 2008) and concluded that "DOD's acquisition outcomes appear increasingly suboptimal" (GAO, 2008). A study by Deloitte consulting also agrees that defense cost overruns are getting worse (Irwin, 2009).

Table 2 gives a brief comparison between existing cost estimation techniques and the prediction markets. The goal here is to compare the probable shortcomings of the former with the possible advantages of the latter.

Table 2. Value Propositions of Prediction Markets

Probable limitations of existing cost methods	Possible value propositions of prediction markets
• Cost Estimating Relationships (CERs) based on technical factors rather than programmatic "soft" factors.	• Shift of focus from estimating by individuals to groups.
• Not dynamically updated as a program evolves, making the original estimate outdated as soon as the climate changes.	• Provide way to leverage information from diverse sources.
• Manifestation of a few decision-makers, under tremendous time pressure, working with limited and perhaps biased information.	• Mitigate biases stemming from pressure to "price to win" or hide damaging information.
	• Enable frequent sampling of information.
	• Incentivize traders to seek out quality information that will help them do better.

Prediction markets are a judgmental forecasting method (Graefe, 2009) in which the price mechanism of the market automatically aggregates all the dispersed information among participants. Various aspects of the prediction markets are also discussed in further sections.

Design Principles of Prediction Markets

As with any markets, prediction markets may fail—and produce inaccurate forecasts—if not properly designed and executed. They should follow specific mechanisms, contracts and contexts to ensure participants are adequately incentivized to participate.

Some other factors to be incorporated are (Suda, 2009):

- Should require unbiased tacit knowledge of crowd,
- Should be designed in well-incentivized environments,
- Should be designed for a non-hierarchical environment,
- Generally not suitable for idea generation process,
- Should have well-defined end dates or closing criteria, and
- Choices should be mutually exclusive and have a definitive outcome.

Pilot Studies on Prediction Markets

In order to study the prediction markets, we conducted some simulations on a group of students at MIT to study the effectiveness of prediction markets, and some interesting observations were noted. Details of the study are given below.

Pilot Study 1: Predicting Ratings for Sunday Night Football

A group of 17 participants (N=17) were asked to participate in a private marketplace for predicting the Nielsen Rating (NBC – USA) for Sunday Night Football (Oct 25). Please

refer to Figures 8, 9, and 10 in the Appendix for the screenshots of the market. The following rules were set in place:

- Time duration for trading was 5 days, with the market set to close 30 minutes prior to game start.
- Each participant was allotted an initial amount of $5,000 for trading (play money).
- Winning Criteria was generating maximum worth.
- Incentive—Points for class participation grade and a popular book for winner.
- Minimum of four trades per person (tied to the incentive of class grade), with no maximum limit on trading.
- 11 rating ranges were presented as choices or contracts for participants to trade on, with each rating range being assigned equal probability (9.09% each) to start with (See Figure 2).
- Participants could "buy" or "sell" shares of the choice or contract they found most likely to occur. Every time a user bought a share for a particular idea, the price went up. Similarly, each time users sold a share, the price went down. The user's account was also credited or debited based on his/her choice.
- There was a direct correlation between price and probability—share price of $9.09 indicated 9.09% chance of that particular rating range.
- The buy and sell transactions were managed by an automatic market maker.

Results

Around 236 trades were conducted in total by 17 participants.

The highest rating range predicted was of (9.6-10) with a 19% likelihood prediction, followed by range (9.1-9.5) with a 17.3% chance (see Figure 3).

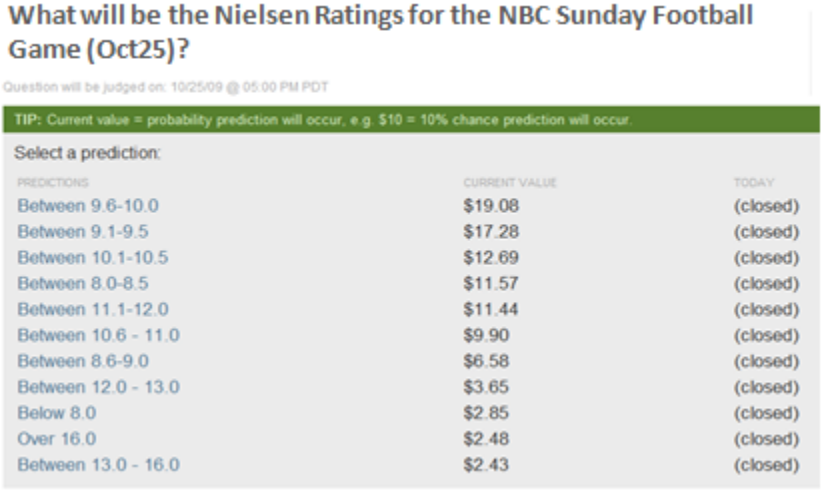

Figure 2. The Stocks in the Prediction Market
(Inklingmarkets.com)

The actual rating range turned out to be (9.1–9.5).

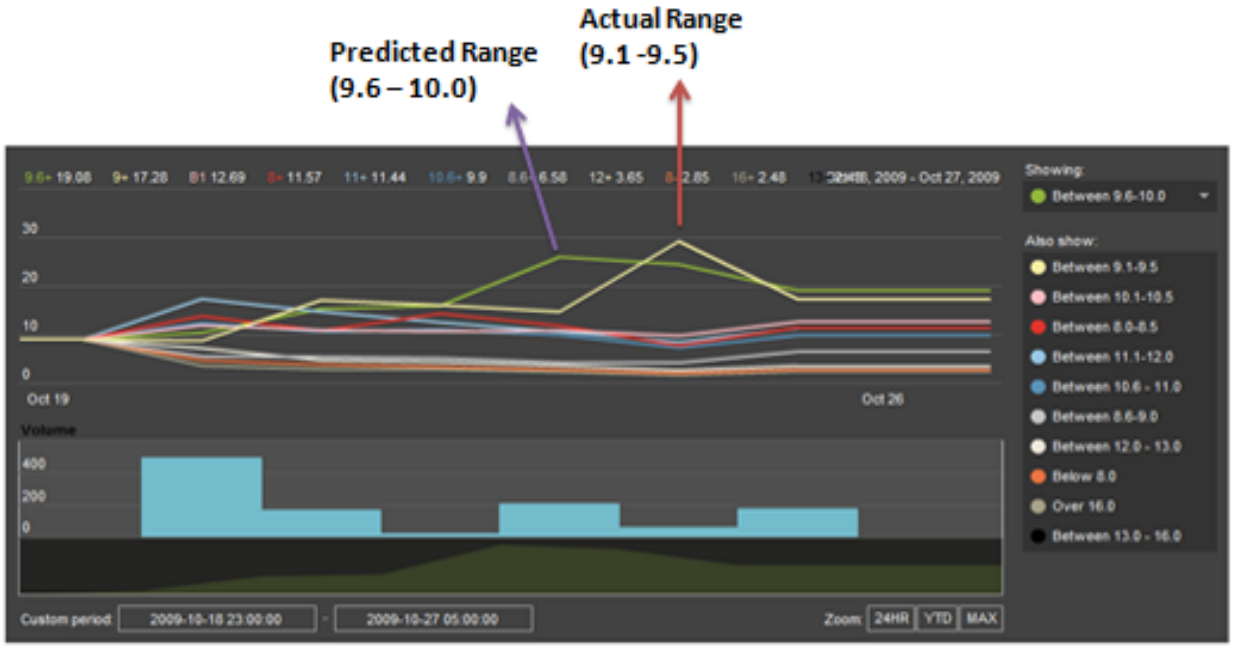

Figure 3. Results at the Close of Prediction Market

A probability distribution function (Pdf) for the result is shown in Figure 4, which demonstrates how close the predicted result was to the actual result.

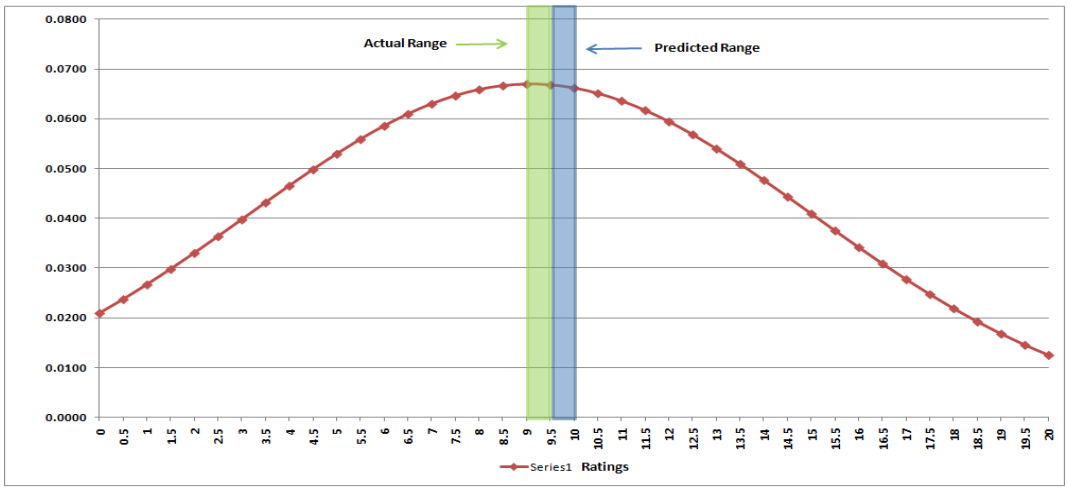

Figure 4. Pdf of the Prediction Market Results

Although market predicted range was close, there can be two reasons why the market forecast was not absolutely accurate:

- On the day of the game, a World Series game ran into overtime—overlapping with the football game and impacting the expected ratings for the Sunday night football. It turns out that there were no baseball fans in the participating traders, and hence this information was not captured.

- In a study on markets on NFL football games from tradesports.com, there was an observation of mispricing (Solomon & Hartzmark, 2008) visible primarily in sporting markets. This was due to a behavioral bias known as disposition effect, which is the tendency of investors to sell stocks that have risen in value and hold on to stocks that have fallen in value, with the objective of earning maximum profit. Thus there might be mispricing in such scenarios and the hypothesis that the prices in prediction markets reveal unbiased estimates of true probabilities of the event happening might not be true.

Pilot Study 2: Predicting Ratings for Monday Night Football

Based on the previous pilot study feedback, the structure of the next market was modified. The participants (N=13) were asked to predict the Nielsen Rating (Cable TV - US) for Monday Night Football on ESPN. Instead of providing range choices to participants for bidding, they were asked to bid on an indexed market. Rules were similar to the last market, except for the following changes:

- Instead of ranges, participants now saw only one rating. They had to predict if the rating as per their opinion was to be higher or lower. Based on their responses, the price or rating was adjusted automatically.
- The initial rating set was 10.
- The price and rating scale was 1:1, i.e., a price of $10.00 meant the current projected value of rating was 10.00 (see Figure 5).

Results

Around 116 trades were conducted by 13 participants. The final rating predicted by the market was 10.00 (see Figure 6).

Figure 5. The Stocks in the Prediction Market
(Inklingmarkets.com)

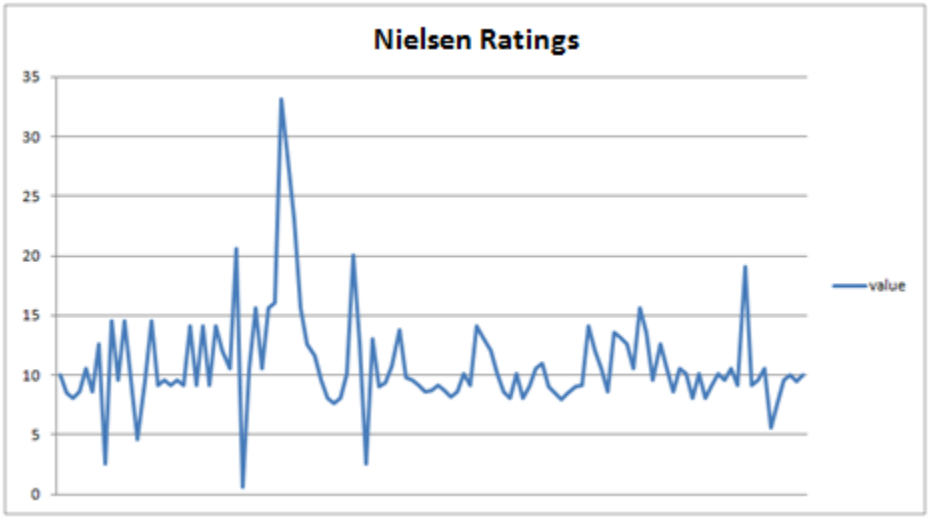

Figure 6. Graph Showing Change in Value of the Stock upon Trading

There was a huge variation in the ratings predicted, with the highest value being 33.1 and the lowest value being 0.6.

The actual rating turned out to be 7.7, which was different from the market value. The major reason for this was that market place was too volatile. A single participant could buy a large number of shares and alter the rating to a great extent, which is not a good design principle for prediction market.

Observations

Behavioral Observations of Participants

The participants comprised a mix of people with football knowledge and others with no knowledge at all. The actual result of the rating was quite close to the rating range that the test market predicted. But the main benefit was observed in the behavior of the participants. An unbiased, incentivized market piqued their interest and motivated them to remain involved throughout the market duration. Some other observations were:

- Increased participation due to internal competition,
- Attempts at market gaming,
- Trying to make use of First mover advantages,
- Forming alliances to manipulate the market,
- High incentive to participate led participants to gain more knowledge on the subject, and
- Use of statistical models by some participants to forecast ratings.

Other Useful Insights from Pilot Studies for Implementing Prediction Markets

- Ensure enough liquidity. Research done on prediction markets (Christiansen, 2007) suggests at least 16 participants for an effective market. Based on the two pilot studies, the number of participants was lesser in the second study,

potentially explaining the volatility and resulting significant error in the prediction.

- Avoid volatility by choosing the right scale for trading in market. The market needs to be less volatile, so that it is not easily influenced by a single trader.
- Ease of use. The prediction market should be easy to use, as many participants were initially reluctant to trade due to perceived complexity.
- Ensure regular information update. In both the studies, there were not enough "happenings" regarding the game ratings, during the trading duration to sustain participants' interest. The market is expected to fare even better is some new knowledge is available throughout the trading duration.
- Leads to increased awareness and interest. A significant contribution of prediction markets in the field of cost or schedule estimation is to keep the participants involved and make the process exciting. Traders with no knowledge of football got involved by researching more on the subject.
- Align incentives with the participants' interests. Some people just executed the minimum required four trades and stopped. Although there was high trading, some people did not care to do all the research. One reason for this was due to incentives not aligning directly with the objectives of these participants.

Designing Prediction Markets for Defense Acquisition Projects

There are various components of a market that need to be considered prior to designing and implementing a prediction market for a project. A prediction market is composed of the following:

- **Stocks:** These are the outcomes or possibilities of the market that are collectively exhaustive and mutually exclusive. These act as stocks and securities for the traders to trade against, with a "buy" indicating a belief of occurrence of that particular outcome and a "sell" indicating a belief of non-occurrence.
- **Marketplace**: This refers to the software environment that contains the market or the questions for trading. It also encompasses the market manager that facilitates trades among the traders and manages the information distribution process.
- **Traders:** These are the participants or team members in a project that will be trading information in the form of stocks in the market.

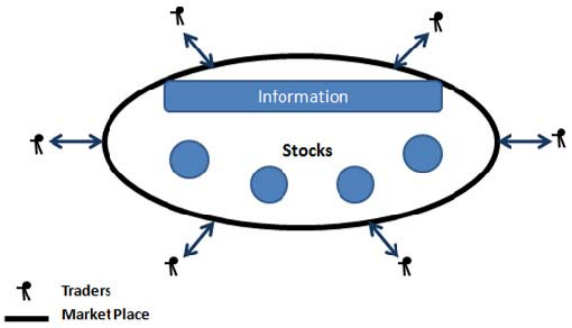

Figure 7. The Composition of the Prediction Marke

There needs to be a continuous flow of information for the traders to base their decisions on and trade throughout the market duration.

Incentive structure is another important factor that should be considered during market design, as it acts as the motivating factor for the traders.

The success of the project hinges on identifying an acquisition program willing to participate. The ideal characteristics of the program are:

- uncertain cost and schedule components that can be specified clearly in a contract,
- a sufficiently large program community to ensure a liquid market,
- ample "soft" relative to "hard" information and information is broadly and unevenly held by diverse actors,
- one-of-a-kind program or a program with limited relevant historical information, and
- susceptible to performance impacts as a result of external events (i.e., political landscape, policy changes, personnel attrition, technology maturity, design modifications).

Based on initial pre-screening, we identified "Shallow Water Combat Submersible" (SWCS) as a suitable project, with a plan to implement the prediction market for duration of 3-6 months.

Below is some of the discussion on the design components for the prediction market.

1. **Stocks:** The stocks or the outcomes traded in the prediction market form the most important component of the market. The stocks traded will give us an indication of the beliefs of the participants, and the number of stocks traded will show us the level of confidence in their beliefs.

Hence, the questions that are asked in the market are very important.

There are mainly two categories of questions that can be asked.

- Type I questions: Asking these questions can directly provide the required information. $Q_1 \rightarrow A$
- Type II questions: Asking these questions can indirectly provide the required information, and a series of questions might be required for getting the information directly. $Q_2 \rightarrow Q' \rightarrow Q'' \rightarrow A$

This is similar to another perspective, as per which the state of the world can be divided on basis of two dimensions (Healy, Ledyard, Linardi & Lowery, 2009). Some questions can based on an unobservable factor whose value can impact realization in second dimension, e.g., the underlying monetary policy of a central bank .While some questions can be based on a directly observable factor, e.g., interest rate each quarter.

The latter type of questions correspond to Type I questions, while the former compare to Type II questions.

Handling Type II Questions

The distinction of questions based on these categories is important because these allow us to focus more carefully on the "stocks" or outcomes of Type II questions, so that the required information is available.

- The suitable approach with the Type II questions is to ask multiple questions in the first round of prediction market, and, subsequently, drill down to specific questions in further rounds.
- If we consider a single question as a single market, then one of the approaches can be to run multiple markets at a given time, and then to add follow-up questions based on the responses. New markets (i.e., questions) can be run every week, and old questions can be updated weekly based on new information. The important factor with this approach is to decide which questions need to be deployed first.

Designing Questions for the Market

There is a lot of information that can prove useful in case of a defense acquisition project. This information can be either related to any factors impacting the cost or schedule of the project, or can be related to the current or future decision processes within the project. Based on the type of information required, we have further categorized the market questions.

- Questions of the First Order: These are the questions that give us the information about the program of interest. Some examples of questions for the pilot project are:

  Table 1. Will SWCS be certified by August 1, 2010?

  Table 2. The cost of the first unit will be $x.

  Table 3. The final cost of the program will exceed the baseline estimate by x%.

- Questions of the Second Order: These are the questions that give us the information about traders and the trading process. For the pilot project, some of the questions are:

  Table 4. What is your motivation for trading (e.g., to win/to solve the problem/to validate my knowledge)?

  Table 5. What is your role in the Organization?

  Table 6. What are useful sources of information about the project?

- Questions of the Third Order: These questions give us information of the behavior outside of the prediction markets. Some of the questions are:

Table 7. How have you used the prediction market in your job? If you notice a change in a contract price, how have you used that information?

Table 8. Did trading improve your confidence in your opinion?

The First Order questions will be asked in the prediction market for trading. The Second Order and Third Order questions are more of profiling questions, which can help decide how to improve the markets, or how the participants are gaining from the market information. These questions can be sent to the participants as a survey and can be tied to incentives so as to encourage them to participate. Incentive can be additional bonus money (like, Earn $100 more (of play money) for answering 5 questions)

The above factors helped to shortlist some of the questions to be used in the prediction market for the pilot defense project (SWCS). A risk mapping, showing the risk covered by a specific question of the First Order, along with the modified version of the question, is shown below. Note that the first four questions are of Type I, while the last question is of Type II.

Table 3. Risk Mapping for First Order Questions

Question Type	First Order Questions (Information about the program of interest)	Measured Risk	Alternate way of asking the question	
Type I	Will SWCS be certified by August 1, 2010?	Schedule Overrun	When will SWCS be certified?	Or
			By how many days will the certification date be exceeded?	
Type I	The cost of the first unit will be $x.	Cost Overrun	What do you think is the most significant cost driver for the first Unit? Follow up question: Based on the below ranking of cost drivers for the first Unit, what do you think the cost of first Unit will be?	
Type I	The final cost of the program will exceed the baseline estimate by x%.	Cost Overrun		
Type I	What will be the 2011 Fiscal Year appropriation for the SWCS?	Cost and Schedule		
Type II	The SWCS program will be adequately resourced to meet its milestones?	Resource Allocation Errors	By how many days/months will the milestone be missed?	Or
			Which resource do you think is most necessary to meet the program's schedule objective?	Or
			Given the available resources, will the project be able to meet its planned schedule?	

Another important aspect is to mix some fun questions (like, who will win the Monday night game, etc.) along with serious questions to keep the participants involved.

- **Marketplace:** There are two important aspects of design for the marketplace—the software environment in which the participants perform trades and the market manager who facilitates the trading process.

Considerations for the Software Environment

The following are the design considerations for the software environment, based on observed behaviors in pilot simulations and requirements for a defense environment:

- The software environment will be easy to access and use.
- The software environment will be commercially available, with prior success in defense related environment.
- The environment will satisfy the IT security considerations—like secure login, user access rights, data security, etc.
- The software environment will have dashboard and administrative capabilities to analyze the data and generate reports based on the user behavior.
- It will be possible to share new information with the traders and/or close or open new markets whenever required.

Considerations for the Market Manager

The matching mechanism in prediction markets has most often been a continuous double auction in which computer software matches buyers offering bids with sellers and their asking prices. Prediction markets have been successful using real-world money, purely "play money," with no economic value (beyond the satisfaction of "winning), and "prize money" that can be exchanged for prizes and entries in prize drawings. We will establish prediction markets with play and prize money and will establish contracts for the cost and duration of particular features of the acquisition program. This is more realistic than focusing on the entire program completion, given the limited time we have to run the market. Fully specified, clear and enforceable contracts in prediction markets require the future state of the world (or events) on which the contracts can be easily adjudicated.

Market Scoring Rule, invented by Professor Robin Hanson at George Mason University, will be used in the prediction market. This will ensure that fewer traders can be present in the market, and lot of concepts related to stock markets that are difficult to understand (like bid-ask spreads, etc.) can be avoided (Siegel, 2010). The price of the stock represents whatever the last trader was willing to pay for shares and is set automatically according to the volume and sentiment in the question. For example, if someone buys 10 shares of an answer, the price of the share will be increased automatically according to an algorithm.

To ensure sufficient liquidity, we will use a prediction market with automated market maker, which means that the buying and selling of stocks will happen between traders and the market and not between the traders themselves.

- **Traders:** While prediction markets require some disagreement among potential traders over forecast, (else no trades would occur) excessive information heterogeneity can be harmful to the markets functioning. If some traders posses significant private information (and hence become insiders), the outsiders may refuse to participate, ultimately killing the market. Prediction markets are most likely to be successful if traders hold sufficiently balanced information about the event but have differing beliefs about the

meaning of common information. It is also critical that when new information becomes available, it will be widely known.

We will recruit market participants from those employed in the Acquisition program or those surrounding the Acquisition program (i.e., subcontractors, end users, consultants). The traders in the defense project comprise of the different team members across different cross-functional areas. There will be many people in a project who will have limited information as to what is going on with a program at large, and they might be biased to their individual projects. Hence, it will be ensured that participants from all smaller projects, as well as people from other departments are included in the trading process. The acquisition project will have sufficiently broad following to attract participants from inside and outside the government. These can include administrative personnel, sub-contractors, engineers, end users, consultants, etc. The markets will be implemented for duration of 3 to 6 months, giving ample trading time to the participants.

Sometimes, due to fear of hierarchy or work environment pressures, people do not reveal uncomfortable information related to the project. In the prediction market, anonymity of traders will be maintained so that they can disclose useful information without hesitation.

- **Incentives:** The incentive structure is perhaps the most important component of prediction market in the DoD environment. Incentives should be such that they are non-biased and encourage participation independent of any hierarchical considerations. "As with any business incentive system, a considerable challenge exists in choosing incentives that motivate the right behavior. . . With information markets, incentives must serve a dual role: to motivate participation and to motivate participants to provide truth-revealing opinions. Incentives that satisfy both criteria can be difficult to define" (LaComb, Barnett & Pan, 2007).

Performance-based incentives in the project can be provided in various ways. For example, participants can be rewarded based on the portfolio value at the closure of the market. Awards can also be given to the most active traders, or the traders contributing the most valuable information.

Non-monetary awards can be as effective as monetary awards when used as incentives. For example, Google found that in their internal markets, participants cared more about non-cash prizes like t-shirts rather than cash prizes (Coles, Lakhani & McAfee, 2007). Similarly, by announcing user rankings, the play-money markets in Christiansen's field experiment (2007) were successful, even without monetary incentives.

Other factors like social competition, recognition and opportunity to contribute towards the project can also act as important motivating factors.

For the pilot defense acquisition project, we feel the following incentives will encourage participation:

- Declaring winners based on the maximum portfolio value at market closure,
- Maintaining a leadership board displaying the top players, and
- Including results of the prediction market in regular status reports to track any new or less visible information.

Conclusion

In his book *The Wisdom of Crowds*, James Surowiecki (2005) argued that if we take a crowd of diverse people and correctly aggregate their judgments, we will be able to get more accurate results based on the collective intelligence of the crowd. This wisdom of crowds can be seen in action every day (Coles, Lakhani & McAfee, 2007) with the collective intelligence also driving Wall Street—the probabilities generated from the market displayed through the stock prices.

The prediction markets can be implemented for defense acquisition projects to aggregate the dispersed information across different functional areas. This information can help keep track of any cost or schedule variances, and also identify any potential risks that can impact the project. We anticipate prediction markets can outperform existing Defense Acquisition estimation techniques (i.e., parametric, analogy, activity-based (Boehm, Valerdi, Lane & Brown, 2005) in cases where there is ample "soft" relative to "hard" information and information is broadly and unevenly held by diverse actors.

Markets need to be compatible with the political and regulatory contexts in which they operate. For example, federal regulations permit play and prize money prediction markets but have restricted real money markets. Perhaps the most notorious prediction market was the ill-fated DARPA sponsored policy prediction markets (Hanson, 2007), which collapsed from a political firestorm over the (quite illogical) proposition that terrorists might benefit from trading in terrorism futures.

Based on the various case studies and literature available on prediction markets, our observations through simulations of markets, and discussion on various aspects of defense acquisition projects, we consider the following design principles:

- The acquisition project should have a sufficiently broad following to attract participants from inside and outside the government. These can include sub-contractors, end users, consultants, etc.
- Although play money should be used for participation in the markets, the traders can be incentivized based on their constant participation and ability to predict accurate results.
- Ample historical data should be available on similar projects, so that participants who are new to the project have some basis of gaining knowledge and predicting.
- The questions for the market should be very carefully designed so that the required information can be revealed. "Fun" questions should be mixed with "hard" questions so that the participants remain involved.
- To ensure sufficient liquidity, prediction markets with automated market makers should be used, and at least 15-16 participants should be targeted for trading (Christiansen, 2007).
- Results of the prediction markets should be carefully studied and reported as part of regular status reports.
- Anonymity of participants with respect to responses should be maintained to encourage information-sharing.

- The length of the market and closure of each specific question need to be given proper consideration while designing the market. The support of senior management in Defense projects is essential for starting the prediction market.
- Markets need to be compatible with the political and regulatory contexts in which they operate.

As part of the ongoing research project, the observations and feedback from preliminary and literature research will be used to run the field trial with the DoD (Department of Defense) acquisition programs for a fixed duration (up to 6 months). The prediction market for the selected pilot acquisition project still needs to be implemented, and other design and implementation factors will be added or the current ones revised based on new information.

If prediction markets improve in forecasts in the defense arena, as they do in other venues, our aim will be to assist in implementing and then studying additional markets, including those over the longer term and a wider variety of programs. It is clear from our research that a significant contribution of prediction markets in the field of cost or schedule estimation is to keep the participants involved and make the process exciting. Used with right implementation guidelines, these markets can prove to be helpful in capturing the collective wisdom of the project members for the specific duration.

Table 4. Development Cost Overruns by Decade
(GAO, 2006)

1970 - 1979	1980 - 1989	1990 - 1999
Development cost overrun: **$13 billion** (30%)	Development cost overrun: **$12 billion** (39%)	Development cost overrun: **$15 billion** (40%)
Key Studies and Initiatives Impacting the Defense Acquisition Process		
• **1970** Fitzhugh Commission • **1972** Commission on Government Procurement	• **1981** Carlucci Initiatives • **1982** Grace Commission **1986** Packard Commission	• **1994** Federal Acquisition Streamlining Act • **1996** Clinger-Cohen Act
DOD Acquisition Policy Changes		
• **1971** DOD 5000 policy established • **1975** Policy revised • **1977** Policy revised	• **1980** Policy revised • **1982** Policy revised • **1985** Policy revised • **1986** Policy revised • **1987** Policy revised	• **1991** Policy revised • **1996** Policy revised

Source: DOD (data); GAO (analysis and presentation).

Table 5. Sampling of Federal Cost Overruns
(Edwards, 2009)

Defense Development Costs ($2008)[63]	*Original Estimates*	*Final Estimates*
Global Hawk surveillance plane	$989m (2001)	$3.7b (2007)
Expeditionary Fighting Vehicle	$1.6b (2000)	$3.6b (2007)
C-130J Hercules	10.9m (1996)	430.3m (2007)
Extended Range Munitions	86.9m (1997)	500.1m (2007)
DDG 1000 destroyer	2.2b (1998)	9.3b (2006)
V-22 Osprey helicopter	4.0b (1986)	12.5b (2006)
Armed Reconnaissance Helicopter	388.3m (2005)	750.9 (2007)
Space Based Infrared System High	4.2b (1996)	8.5b (2006)
Armed Reconnaissance Helicopter	388.3m (2005)	750.9 (2007)
NPOESS Satellite System	5.0b (2002)	7.9b (2007)
Other Defense		
Coastal Patrol Ships[64]	$220m (2004)	$350m (2007)
Joint Strike Fighter[65]	$232b (2001)	$337b (2008)
Marine One (VH-71) helicopters[66]	$6.1b (2005)	$11.2b (2008)
Coast Guard, NSC ships, per unit[67]	$250m (2002)	$536m (2007)

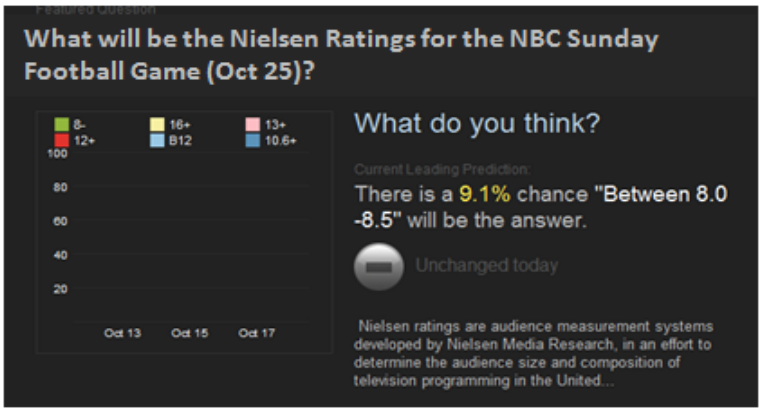

Figure 8. Screenshot 1 from the Prediction Market Simulations
(inklingmarkets.com)

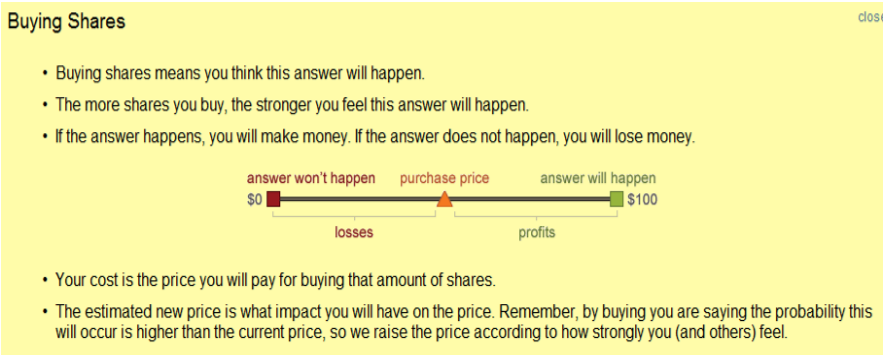

Figure 9. Screenshot 2 from the Prediction Market Simulations (inklingmarkets.com)

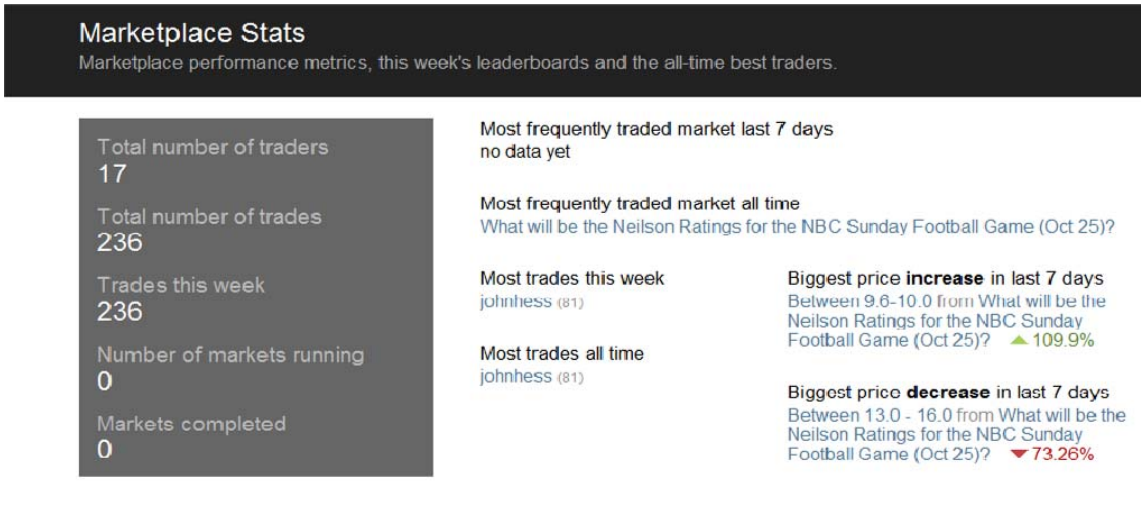

Figure 10. Screenshot 3 from the Prediction Market Simulations
(inklingmarkets.com)

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