Logistics Management Institute

Characterizing Commercial Market Effects on Military Electronics Development Program Costs

An Analytical Framework

PA805T1

September 1998

Anthony L. Clippinger
Eric M. Gaier

LMI ®

Characterizing Commercial Market Effects on Military Electronics Development Program Costs

An Analytical Framework

PA805T1

September 1998

Anthony L. Clippinger
Eric M. Gaier

Prepared pursuant to Department of Defense Contract DASW01-95-C-0019. The views expressed here are those of the Logistics Management Institute at the time of issue but not necessarily those of the Department of Defense. Permission to quote or reproduce any part except for government purposes must be obtained from the Logistics Management Institute.

LOGISTICS MANAGEMENT INSTITUTE
2000 CORPORATE RIDGE
MCLEAN, VIRGINIA 22102-7805

Characterizing Commercial Market Effects on Military Electronics Development Program Costs
An Analytical Framework

PA805T1/SEPTEMBER 1998

Executive Summary

The Office of the Secretary of Defense, Program Analysis and Evaluation tasked the Logistics Management Institute (LMI) to assess the usefulness of existing Department of Defense (DoD) tools for estimating the costs of large-scale development programs. Technological progress, market forces, and fiscal necessity have combined to cause radical changes in the processes by which industry, both commercial and defense, develops new products. Program Analysis and Evaluation is concerned that the changes are so profound that they call into question the validity of the methods used to estimate the cost of new product developments for DoD.

We believe a better understanding of firms' behavior in a competitive environment may provide useful insights about the validity of current methods. It may also point the way toward building better ones. Key questions for analysts to consider include: Is there a significant commercial market? Are there many competing firms, or just a few? How will the government compensate firms for overruns? To what degree are the firms competing in both commercial and military markets?

To address these questions, we have conducted a separate analysis of the economic factors that affect developers of military electronics. We specifically look at manufacturers of Global Positioning System (GPS) receivers as a model product for the industry. We believe that the GPS receiver industry is a good example for our analysis because of its robust commercial market. GPS originated from military requirements and solely for military applications. But the industry has experienced tremendous change during recent years: today, technology advances are driven by commercial incentives. There are two separate and distinct markets, however, and the military and commercial GPS markets remain subject to fundamentally different economic forces. These differences have several implications for the development of military GPS applications.

We conducted an extensive review of the GPS receiver industry, specifically targeting the forces that drive new product development and innovation. This report draws on an earlier report by the RAND Corporation, *The Global Positioning*

System: Assessing National Policies, published in 1995. Our literature review also included a survey of selected market research reports, database reports, magazine articles, and manufacturers' web sites. We interviewed key personnel from several major GPS receiver manufacturers, including GEC Marconi, Rockwell-Collins Avionics and Communications Division, and Trimble Navigation. In addition, we interviewed personnel from the military's GPS Joint Program Office.

This report is organized into a main body and a supporting appendix. The main body of the report is divided into two chapters. Chapter 1 establishes the background and context for our analytical work. Chapter 2, titled "A Model of the Commercial Market Effect on Military Electronics Product Development," presents an original model characterizing the commercial market's interaction with military product development.

Significant results from the model include these:

- Given the existence of a commercial market for a product, firms have a real incentive to underbid true costs for a military development contract.
- Firms will also lower their bids in an attempt to win a military development contract if it is known in advance that the government will pay some fraction of cost overruns.
- The number of firms in the commercial market will affect commercial market profits and, indirectly, military market bidding.

Conclusions about using the model include the following:

- For products with commercial applications, military development costs may be lower than when no commercial applications exist. The amount by which the military development costs decrease ties directly to the value firms obtain in the commercial market from winning the military contract.
- Developer buy-in can be recognized and considered when assessing contractor cost estimates.

The appendix presents the second major portion of the report. Titled The Global Positioning System Industry, it outlines findings from our research on the GPS industry and the economic factors influencing it.

Major findings in the appendix include the following:

- GPS products span a wide range, both in terms of market segments (from hand-held units to aviation components) and product levels (from elemental chips and boards to elaborate systems that integrate GPS functions with other capabilities).

- GPS technology — particularly hardware — is commodity-like, driving competition to lower costs in much the same way as does the computer industry. Embedded software enhancements help maintain price levels in some GPS products.

- The overall GPS industry is expanding. However, there are sharp differences between the commercial market, characterized by intense competition and relatively free entry, and the military market, which has barriers to entry and contains far fewer firms.

- The number of GPS commercial patent families increased by a factor of five between 1988 and 1993. Firms use GPS patents as bargaining devices and to prevent imitation.

- The commercial market drives innovation in the GPS industry. Military products benefit from commercial innovations.

Contents

FIGURES

TABLES

Chapter 1
Background

OVERVIEW

This chapter outlines the basic motivation for conducting this study. Chapter 2, A Model of the Commercial Market Effect on Military Electronics Product Development, is the heart of this report. It details an original model that describes the interaction between the commercial market and military product development. The framework we create provides one way to characterize this interaction.

While this framework grew out of research on the Global Positioning system (GPS) industry (see the appendix), it is not restricted to that application. It can accommodate a variety of industries. The essential component of the model is a product with both military and commercial market applicability. Using a two-stage process in which the stages are interdependent, the framework captures the effects of firms' behavior in bidding on military product development contracts. It also characterizes their subsequent competition in the commercial marketplace.

OBJECTIVES

This study is concerned with *how* the existence of a commercial market affects military electronics product development. Our goal is to provide an analytic framework that captures the effects of the commercial market on the development of military electronic items. Specifically, given a commercial and a military market for a product, we explore two questions:

- How do firms react with their bid submission on a military development contract?
- How do firms react in competition with each other in the commercial marketplace?

The reader will find that the answers to these questions are interdependent.

ISSUES AND BENEFITS: DOD'S REQUIREMENTS

Under the auspices of the project "Improved Methodologies for Estimating Development Costs" (PA805), the Cost Analysis Improvement Group (CAIG) in the Office of the Secretary of Defense, Program Analysis and Evaluation tasked the Logistics Management Institute to assess the usefulness of existing Department of

Defense (DoD) tools for estimating the costs of large-scale procurement programs. The CAIG's motivation is based on the hypothesis that dramatic consolidation of defense prime contractors, DoD's "reformed" acquisition practices, new technologies, and contractors' lowered expectations for large production runs of defense systems have so radically changed the way defense systems are developed that the existing estimating tools are no longer valid.

This report identifies and analyzes the major *economic* forces impacting developers of military electronics products. In the framework of the overall study, recognition of such economic forces will aid the larger analysis of DoD's current cost-estimation tools. It also will provide insights into which (if any) alternatives to current methods and tools may prove promising.

METHODOLOGY: GENERALIZING A MODEL FOR ESTIMATING INDUSTRY ECONOMIC BEHAVIOR

For this analysis, we specifically address manufacturers of Global Positioning System receivers as proxy for the military electronics industry. We believe that the GPS receiver industry is representative of many industries because of its strong commercial market. While GPS originated as a military application only, technology advances are currently driven by commercial incentives. The military and commercial GPS markets, however, remain subject to fundamentally different economic forces. These differences have several implications for the development of military GPS applications.

We conducted an extensive review of the GPS receiver industry, specifically targeting the forces that drive new product development and innovation. In 1995, the RAND Corporation released a report entitled *The Global Positioning System: Assessing National Policies*. According to the report's preface, RAND conducted a year-long study "for the White House Office of Science and Technology Policy (OSTP) and the National Science and Technology Council (NSTC). The goal of this research was to assist OSTP and NSTC in assessing alternative national objectives, opportunities, and vulnerabilities in the exploitation of GPS as a national resource."[1] This report draws on that document.

Our literature review also included a survey of selected market research reports, database reports, magazine articles, and manufacturers' web sites (see the appendix). We interviewed key personnel from several major GPS receiver manufacturers, including GEC-Marconi, Rockwell-Collins Avionics and Communications Division, and Trimble Navigation. In addition, we interviewed personnel from the military's GPS Joint Program Office (JPO).

[1] Scott Pace, et. al., *The Global Positioning System: Assessing National Policies* (Santa Monica: RAND, 1995.

REPORT STRUCTURE

The reader should focus on Chapter 2 and the appendix together for the major content of this report. Chapter 2, A Model of the Commercial Market Effect on Military Electronics Product Development, details an original model we developed of the interaction between the commercial and military markets. The appendix contains several subsections that describe our findings from research into the GPS industry. *Product and Industry Characteristics* describes GPS as a product and how the industry is organized. *Market Structure* outlines the size of the GPS market as well as the differences between the military and commercial markets and implications therein. *Patenting GPS Intellectual Property* details the role of patents in the development of GPS technology. Finally, *Factors Driving GPS Innovation* theorizes on origins for innovation in GPS.

Chapter 2

A Model of the Commercial Market Effect on Military Electronics Product Development

MODEL DESIGN OVERVIEW

The essential component of the model is a product with both military and commercial market applicability. Using a two-stage game theory model, we capture the effects of firms' behavior in bidding on military product development, as well as their subsequent competition in the commercial market. We find that the two stages are interrelated. The following subsections list the relevant aspects of both the commercial and military domains from which we draw our model parameters.

The Global Positioning System Industry

The GPS industry exhibits some of the most relevant characteristics for this model. First, a strong and growing commercial market exists for GPS products. GPS sales are projected to grow from the $510 million recorded in 1993 to over $8 billion by 2000.[1] More and more products are incorporating GPS functions, including automobile navigation, aviation, public transportation, communications, emergency response, surveying, environmental protection, and recreation.[2] For more detail on the GPS industry, see the appendix.

Interestingly, as GPS has spread into commercial markets, standards for commercial and military products may be converging. For example, commercial aviation requires an anti-interference capability similar to the military anti-jamming capability, so these requirements may be satisfied by the same development effort. Not only is there a strong commercial market, but products are becoming increasingly transferable across markets.

A second important characteristic concerns product development in the GPS industry. As in many other industries, this development is mostly evolutionary—slight modifications on existing products create a "new" product. While this is not always the case, the majority of GPS "innovations" consist merely of finding software solutions to specific problems with existing technologies, or simply integrating GPS into legacy systems. For example, GEC-Marconi won a recent mili-

[1] United States GPS Industry Council, press release and informational packet,(Washington: USGIC, January 1995).

[2] Scott Pace, et al., *The Global Positioning System: Assessing National Policies(Santa Monica:* RAND, 1995), p. 97.

tary development contract by innovating a GPS helicopter navigation system which adds GPS features to a fielded doppler navigation system.[3] Both technologies existed prior to the development; integration was the innovation. In this sense, we will tell the story of commercial off-the-shelf (COTS)/non-developmental item acquisition, where the military contracts for the "development" of an item that uses existing technology to make a "new" product. This second characteristic is not central to our model but, in the generalized form presented below, evolutionary development most easily satisfies our assumptions.

Military Acquisition Process

A word about how development cost estimates come about may be appropriate at this point. The method by which the military contracts for product development plays a major role in our model. The military has a very structured development system, but one which has been relaxed somewhat by recent "acquisition reform." In skeletal form, the process that we will use as the basis for our model is as follows:

- A military end-user determines some "mission need." DoD determines whether that need calls for a material solution. If so, DoD asks the service to spell out the characteristics of the item in "requirements" documents.

- If DoD determines that the requirements are valid, it then approves an acquisition program. The service (usually through a program office) administers the program.

  Note: Part of acquisition reform is a shift in how these requirements are spelled out. Formerly, not only would the services outline the capabilities they desired, but they would also specify *how* contractors would go about providing the capabilities. Now, the services generate broad (and sometimes vague) requirements for end capabilities and place the onus on commercial firms to figure out the best way to deliver them.

- A round of cost estimating takes place. Estimates are made by several players to include potential commercial developers, the service requiring the item (usually through a program office), and the Secretary of Defense's Cost Analysis Improvement Group.

The Players and Their Incentives

The players face different motivations when producing their estimates. For commercial firms, their estimate of costs will determine what they are willing to bid. We assume that if all else is equal, the low bid wins the

[3] Interview with GEC–Marconi personnel, 1998, Jul 17.

contract. This assumption abstracts from the reality of differentiated products, but is not critical to our results.

Industry Behavior

Our analysis shows that firms are faced with two incentives to lower their bids. First, military contracts often allow for cost overruns to be partially compensated. This practice is known as "cost-plus" contracting. Knowing this, firms engage in a game of optimizing the amount they "buyin," or underbid, in hopes of winning the contract. We term this incentive "artificial" downward pressure on their bids because it ultimately does not result in actual lower costs to the military.

Second, given that a commercial market exists for the product, firms will presumably enjoy some advantage in the commercial market by winning the military contract.[4] To the extent that firms profit commercially by winning the military contract and are therefore willing to transfer some of their development costs from the military contract to the commercial market, they will reduce their bids accordingly. We term this incentive "real" downward pressure on costs because it results in actual lower costs to the military.

Military Behavior

The military service and program office have incentives to submit low cost estimates to get initial funding for projects. In this environment, obtaining initial funding is seen as the most difficult hurdle for a project. Once a project gets underway, it is assumed that a percentage of costs beyond those estimated will be met (that percentage could be zero). They seek to take advantage of what we term "funding stream inertia."

The services' incentive to lowball is significantly weaker than the program office's. The service will produce the lowest possible *defensible* estimate for research and development (R&D) costs. While the service wants to have the best possible chance of obtaining funding, it is also concerned with its long-term reputation with OSD and lack of institutional flexibility to deal with unreimbursed cost overruns.

The program office meanwhile has an incentive to minimize its cost estimate subject only to the restriction that eventually the "true" cost of

[4] Specifically, we model the winners of the military contract as commercial market leaders in the Stackelberg framework. Market leaders enjoy "first-mover" advantages, which essentially means they have more information when making profit-maximizing decisions than their competitors. The Stackelberg framework will be explained at greater length in a later section of this report.

the project will become known. The difference between the program office's estimate and the true cost cannot exceed some level at which the project will be judged to have breached cost growth thresholds. A program experiencing extreme or numerous breaches will be canceled.

The last actor is the CAIG, which serves as a sort of watchdog over the Pentagon's purse strings. In this role, the CAIG's responsibility is to make an independent assessment of costs aimed at minimizing expected future cost overruns. Its incentives fall directly on pinning down the true costs of the project. And since *minimizing overruns* is the goal, we expect the CAIG estimate to equal or exceed those of the other parties.

This brings us, then, to the central problem this framework will address: how to discern between the artificial downward pressure on cost estimates ("funding stream inertia") and the real downward pressure on costs (commercial market applicability). By establishing relationships between these parameters, we will provide a method of analyzing whether low bids from firms indicate legitimate reduced costs or will simply result in cost overruns down the line.

In the final stage of the game, the military awards the development contract. Our model then considers commercial market competition among all firms, not necessarily limited to those who participated in the military competition. Classic Cournot competition among few firms assumes that each firm's output affects market price, but firms do not consider each other's production decisions when optimizing their output.[5] The Stackelberg model extends this analysis by awarding one firm, the market "leader," first-mover advantage in which it recognizes how other firms ("followers") will make production decisions.[6] The leader maximizes its own profits using this knowledge of other firms' reactions.

Our model of the commercial marketplace assumes Stackelberg leadership for the winner of the military contract. Simply winning the contract may indicate the firm's leadership prima facie—it already beat its competitors in the military market. However, we can also factor in the benefits of winning the military contract. First, the firm will gain some monopoly-like rents from being the primary supplier of the military product. Second, the firm will have the military reimburse a portion of its development costs.

We will calculate the value in the commercial market of being the Stackelberg leader. Since the military contract winner is the leader, this is also the value to the firm of being the low bidder. This in turn will illustrate the firm's "real" incentive to bid low for the military contract—the commercial market effect.

---

[5] Walter Nicholson, *Microeconomic Theory Basic Principles and Extensions*, (Ft. Worth: Dryden Press, 1995), 6th ed., pp. 643-644.

[6] Nicholson, pp. 650-651.

Two-Stage Game Basis

Our model takes the form of a two-stage game from the bidding firm's perspective. In the first stage, the firm engages in a buy-in game when submitting a bid for the military development contract. As noted, we assume that the low bid wins the contract, all else being equal.

In light of the possibility of cost-plus contracts, the firm's problem is to calculate the optimal amount of buy-in or underbidding. As an aside, the military's optimal strategy to eliminate buy-in would be to eliminate overrun compensation, the equivalent of offering fixed price contracts. Although our model can address fixed price contracts, in practice fixed price contracts have been ineffective because of changing requirements during the project's life-cycle. However, we include a parameter that can handle such fixed price scenarios.

In the second stage of the game, firms compete in the commercial market. We show that the commercial market effect also influences the firm's optimal bid strategy.

Model Assumptions

In its most generalized form, our model employs several abstractions that may seem to limit its applicability. We make many of our assumptions, however, only in the interest of simplicity. Complexities *can* be added by relaxing these assumptions.

Critical assumptions associated with the model include the following:

- *No product differentiation.* All firms produce like products.
- *Homogeneous production costs.* All firms face identical production cost schedules.
- *Constant capabilities.* All firms have identical technological capabilities.
- *Market leadership for the military contract winner.* The firm receiving the military contract gains certain advantages that enable it to become the commercial market "leader."
- *Homogeneous bid functions.* We seek a symmetric equilibrium to the bidding stage of the game. Thus, in equilibrium, all firms use an identical bid function to map their R&D cost draws into bids.

For a discussion of relaxing some of these assumptions, see the subsection titled Actions to Take Next.

MODEL DEVELOPMENT

We begin with the Stackelberg competition, the final stage of the game, to determine the end result for the winner of the military contract. Once we know the benefits of being the winner of the military contract, we can take this result and incorporate it back into the buy-in stage of the game to see what firms will do. In short, we need to know a firm's incentives before we can model its actions.

We begin with simple linear demand and cost functions:

$$P = a - bQ \text{ and} \qquad \text{[Eq. 2-1]}$$

$$TC = c + dq_i \ , \qquad \text{[Eq. 2-2]}$$

where P is the market price, Q is the total market quantity, and q_i is any individual firm's production. Equation 2-1 represents a standard downward–sloping linear demand curve. The parameter a measures the intercept and the parameter b measures the slope. Thus, higher values of a and lower values of b indicate increased demand. Equation 2-2 represents a standard linear total cost-function. The parameter c measures the intercept, or fixed costs, and the parameter d measures the slope, or variable costs.

We can model the leader and follower firms' profit functions by taking the standard approach of profit equaling total revenues less total costs. Substituting in for P and dividing Q into individual firm quantities yields

$$\pi_L = q_L[a - b(q_L + (n-1)q_i^*(q_L))] - c - dq_L \text{ and} \qquad \text{[Eq. 2-3]}$$

$$\pi_i = q_i[a - b(q_L + q_i + (n-2)q_j] - c - dq_i \ , \qquad \text{[Eq. 2-4]}$$

where π is profit, n is the number of firms in the market, subscript L denotes the market leader, and subscripts i and j denote all other firms, or market followers. We can see the first-mover advantage here in the profit equation for the market leader [Eq. 2-3]. The leader's profit is a function of the optimized production decisions by the followers, $q_i^*(q_L)$. Followers, on the other hand [Eq. 2-4], do not take into account optimized production decisions by other firms.

Next we maximize a follower's profit with respect to its production decision q_i:

$$q_i^* = \frac{(a-d) - bq_L}{nb} \ , \qquad \text{[Eq. 2-5]}$$

and substitute this result back into the original profit equation for the leader. Optimizing the leader's problem and substituting this result into Eq. 2-5 yields:

$$q_L^* = \frac{(a-d)}{2b} \text{ and} \qquad \text{[Eq. 2-6]}$$

$$q_i^* = \frac{(a-d)}{2nb} , \qquad \text{[Eq. 2-7]}$$

which are the profit-maximizing quantities produced by the leader and followers, respectively. From these optimized quantities, we derive optimal profits for the leader and followers:

$$\pi_L^* = \frac{(a-d)^2}{4bn} - c \qquad \text{[Eq. 2-8]}$$

$$\pi_i^* = \frac{(a-d)^2}{4bn^2} - c . \qquad \text{[Eq. 2-9]}$$

At this point, one notices that maximum profits in this competitive framework are a function of *n*, the number of firms in the market. The optimized profit equations show the standard result for monopoly profit, but reduced by a factor of $\frac{1}{n}$. This gives us some clue as to the value of being the market leader. Namely, the leader is entitled to $\frac{1}{n}$ share of monopoly profits, while each of the followers only receives $\frac{1}{n^2}$ share. Subtracting π_i^* from π_L^* yields

$$\Delta\pi_c^* = \frac{(a-d)^2}{4bn^2} \times (n-1) , \qquad \text{[Eq. 2-10]}$$

where $\Delta\pi_c^*$ is the difference in optimized profits between being the leader and being a follower. *This is the value of being the leader in the commercial marketplace.*

Before moving to the buy-in stage, we can make another observation about the Stackelberg leadership phase of our model. By examining the derivatives of the optimal profit equations with respect to *n* [Eq. 2-8 and 2-9], we see that the leader's profit falls more quickly than the followers' as *n* rises. Thus, it is more valuable to be the leader when the market is small. This is intuitive because as *n* rises, the market approaches perfect competition in which the leader has no advantage.

Armed with our knowledge about firms' incentives in the commercial market, we can turn our attention to the buy-in stage of our model. Here, firms bid on military projects with the knowledge that some underbidding, or buy-in, will be compensated. We model the firm's payoff function with some slight alterations to a standard procurement where Π_i now represents the firm's expected payoff from participating in the procurement.

We need to make explicit some assumptions about this stage of the game. We seek a symmetric equilibrium that enables us to assume that all firms use the same bid function, *X*. In addition, all firms randomly draw their costs from the same cumulative distribution, *F(.)*. We define the choice variable for the firm, *x,* as the effort (in number of hours) it *bids* to do the development. Last, we assume the other variables to be constant across all firms:

- r = the hourly rate at which firms *bid* to do the development.
- z = the *actual* number of hours it will take to do the development.
- c = the *hourly* cost of the firm's labor.
- α = the percentage of cost overruns for which the government will compensate the firm.

While these assumptions may seem constricting, in a competitive environment this scenario may not be far from reality.

The firm's objective is

$$\max_x(\Pi_i) = [1 - F(X^{-1}(x))]^{(n-1)}[xr - zc + (z - x)\alpha r] \qquad \text{[Eq. 2-11].}$$

The first bracketed term shows the firm's probability of having the lowest bid. The bid function *X* will map any cost onto an optimal bid *x*. Hence, X^{1} does the opposite. So $X^{1}(x)$ yields the corresponding cost for any bid *x* derived from the symmetric equilibrium bid function. Then, recall that *F(.)* is the cumulative distribution of cost, so $F(X^{-1}(x))$ yields a value on the cumulative cost distribution. Subtracting from one gives the probability that bid *x* corresponds to a cost draw lower than one other competitor. Raising the bracketed term to *(n-1)* then gives the probability of beating all other competitors. The second bracketed term in Eq. 2-11 shows the benefit of winning the bid. The firm will receive the value of its bid, *xr*. The firm also will incur the actual cost of doing the development, *zc*.

Now we detour from standard procurements to capture the effect of cost overrun compensation. The amount of cost overrun a firm incurs on a project is captured by *(z-x)r,* the number of hours the firm works on the development in excess of its bid multiplied by the hourly rate of the bid. We multiply this figure by α, the percentage of cost overruns the government will reimburse. The variable α, which is expected by all players, runs continuously from 0 to 1, where 0 is equivalent to a fixed fee contract and 1 is equivalent to a full cost-plus deal.

When we maximize the firm's payoff with respect to the choice variable x, we obtain the firm's optimal bid function:

$$X^*(z) = \frac{(c-\alpha r)}{(1-\alpha)} \frac{\int_z^{\bar{z}} [1-F(k)]^{(n-2)}(n-1)f(k)kdk}{[1-F(z)]^{(n-1)}}, \qquad \text{[Eq. 2-12]}$$

where the second term on the right-hand side (the integral and its denominator) is the standard result for procurement models. However, the first term yields interesting results. We see that the optimal bid for a firm is a function of the amount the government will reimburse cost overruns. When α equals 0 (fixed price), the firm's optimal bid converges to the standard procurement result in the absence of buy-in. Conversely, when α approaches 1, implying a full cost-plus contract, firms essentially have an incentive to bid infinitely small hours (x) to win the contract. Again, this follows intuition because firms in this case will be reimbursed for their entire cost overrun.

Finally, we blend the commercial market effect into the firm's optimal bid function. The combined maximization problem is

$$\max_x(\Pi_i) = [1-F(X^{-1}(x))]^{(n-1)}[xr - zc + (z-x)\alpha r + \pi_m + \pi_L^*] + [1-[1-F(X^{-1}(x))]^{(n-1)}]\pi_i^*, \qquad \text{[Eq. 2-13]}$$

where the first right-hand side term is the full payoff of winning, including military market profit (π_m) and leadership profit in the commercial market. The second term simply represents the payoff to the firm when losing the military contract, which is one minus the probability of winning multiplied by a follower's share of commercial market profit.

Maximizing yields

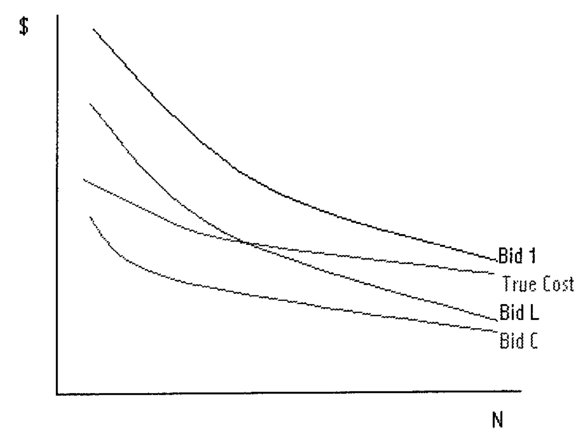
$$X^*(z) = \frac{(c-\alpha r)}{(1-\alpha)} \frac{\int_z^{\bar{z}} [1-F(k)]^{(n-2)}(n-1)f(k)kdk}{[1-F(z)]^{(n-1)}} - \pi_m - \Delta\pi_c^*, \qquad \text{[Eq. 2-14]}$$

recalling that the commercial market value of winning the military contract, $\Delta\pi_c^*$ from Eq. 2-10, is the difference in profit between being the leader and the follower. Competitive forces will compel the firm to lower its bid for the military contract commensurate with this value, as well as the amount of profit it gains from the military market.

This result is supported by actual examples of firms systematically lowering costs to the government because of the existence of a commercial market for a product. For instance, during our round of interviews with personnel from the GPS industry, one firm expressed reluctance to receive "non-recurring engineering" (NRE) funding for military developmental items it felt had commercial market applicability.[7] Since it wants to own the technology itself for the purposes of gaining commercial profit, the firm would deliberately take NRE costs out of its bid, lowering the government's cost of development.

Figure 2-1 illustrates the relationships between the winning firms' actual costs and their bids influenced by the forces described above. It shows hypothetical expected winning costs and expected winning bids as a function of the number of firms in the market.[8] True cost is the actual cost of developing the product (zc in our bid payoff function). True costs of the winning bidder decline as a function of N because more bidders increase the probability of low cost draws. Bid 1 represents the expected winning bid in absence of buy-in and the commercial market. Bid 1 converges to true cost as N increases due to simple competitive pressure of more firms bidding on the project.

Figure 2-1. Hypothetical Expected Winning Bid Functions



Bid L is the expected winning bid taking account of the buy-in game. Since our buy-in result does not directly depend upon N, Bid L is a parallel shift from Bid 1,

---

[7] Industry interviews, June-July, 1998.

[8] There is a subtle difference in the graphs between the number of firms in the military market (n) as opposed to the total number of firms in the commercial market (N). We assume that n is a subset of N. For n, the graph will look the same as the one presented except for the Bid C curve, which would be flat and everywhere below Bid L. For N, Bid 1, true cost and Bid L will be flat. True cost will be everywhere below Bid 1. Bid L will lie at or below Bid 1, and be indeterminate relative to true cost, depending on the level of α. Bid C will asymptote upwards to Bid L as N increases. We believe the generalized version of the graph presented suitably captures the relationships in question.

the magnitude of which is determined by α. Where Bid L is below true cost shows buy-in among bidders.

Bid C is the expected winning bid taking account of both buy-in and the commercial market effect. Bid C is everywhere below Bid L but converges to Bid L as N increases. As we observed from the derivatives of the firms' optimal quantities [Eq. 2-10], the value of being the commercial market leader falls as N increases.

Model Results

This model confirms and quantifies the intuitive belief that, given the existence of a commercial market for the product in question, firms have a real incentive to underbid true costs for a military development contract. If we assume commercial market leadership for the military contract winner, then the advantages conferred upon the winner will make the military contract all the more valuable. Firms will be willing to subsidize the military contract up to an amount equivalent to the extra profit they enjoy in the commercial market from being the leader.

In addition, the percentage of cost overrun reimbursed by the government will affect firms' bids. If it is known in advance that the government can meet none of the cost overrun, the incentive to buy in is eliminated. Conversely, firms will adjust their bids downward in an attempt to win the contract if the government is known in advance to meet some fraction of cost overruns. Firms optimize their bids to account for the tradeoff of higher chances of winning versus decreased expected margins.

A final result from this analysis is that the number of firms in the commercial market will affect profits and, indirectly, military market bidding. The value of being the commercial market leader ($\Delta\pi_c^*$) varies inversely with n. Recall also that $\Delta\pi_c^*$ exerts negative pressure on the firm's optimal bid function. Thus, as n grows, we would expect underbidding to decrease as a result of the commercial market effect. We see this illustrated in Figure 2-1 in that Bid C approaches Bid L at large values of N.

Conclusions About Using the Model

This model indicates that, for products with a commercial market application, the cost to the military for product development may be lower than when no commercial application exists. The amount by which the costs will decrease ties directly to the value firms will obtain in the commercial market from winning the military contract. This value may be affected by many factors not considered in this model, including, but not limited to, these:

- *Size of the commercial market.* Obviously, the share of profits that the commercial market leader receives is a function of the total size (in dollars) of the commercial market. For GPS, commercial market sales dwarf the military market, so we may expect this effect to be large. For other products, the reverse may be true; in those cases, there may be little or no commercial market effect.

- *Ease of technology transfer.* The less a firm has to alter a military product to sell it commercially, the more valuable the military product development will be.

Inasmuch as this model captures reality, it is a tool for cost estimators of military product development projects. The parameters identified in this framework, and the relationships among them, may help estimators discern between artificially low project bids generated by buy-in games among firms and reflect truly lowered costs produced by the commercial market effect. In the end, DoD's recognition of buy-in by potential contractors may save money by minimizing unexpected cost overruns during the development life cycle.

ACTIONS TO TAKE NEXT

The model, as it stands, can offer only qualitative advice to the CAIG's cost estimators. To develop a more complicated model capable of yielding quantitative advice would require the nontrivial task of collecting and analyzing a massive amount of relevant data. But the current model *does* furnish a framework for understanding how commercial market forces may impact military product development, and it establishes relationships among significant variables.

Another possible avenue for future steps would be to further examine these relationships by relaxing some of the assumptions made for this iteration of the model. In particular, we recognize that not all firms have identical technological capabilities. Some firms are more advanced in certain areas than others. We could account for this by allowing z (the *actual* number of hours it will take to do the development) and c (the *actual* cost of those actual hours) to vary by individual firm. We also can relax the homogeneous production cost assumption by varying the cost schedules by individual firms.

Finally, we also recognize that not all firms will produce identical products to meet the military's requirements. Future iterations could allow for product differentiation in the model by introducing an array of criteria by which military bid winners are chosen. This would enable accounting for factors such as quality or product compatibility, which our industry interviews indicated are important.

Appendix
The Global Positioning System Industry

INTRODUCTION

> The growth of commercial GPS firms has in turn provided benefits back to the U.S. government. In the Persian Gulf War, commercial suppliers were able to meet the higher-than-expected demand for GPS receivers, even if suppliers of GPS receivers could not meet all military specifications. The revenues from commercial sales of GPS receivers have supported private R&D investments, which have led to technical innovations that did not require taxpayer funds. These innovations have led to international patents by U.S. firms, declining prices, and increasing export sales. The lower costs, lighter equipment, and improved performance of commercial GPS receivers have provided stringent competitive benchmarks for military receiver manufacturers. *The existence of a strong commercial GPS industry means that a significant part of the U.S. defense industrial base can be maintained without government funding* (emphasis added).[1]

This quote from a 1995 RAND report on the Global Positioning System highlights the commercial GPS industry's significant effect on military GPS product development. During the past decade, the commercial GPS market has grown rapidly, both in terms of volume and product lines. The military, meanwhile, has seen its share of the GPS market fall consistently. Consequently, it is no surprise, as our model concludes, that the commercial GPS market strongly influences military product development.

PRODUCT AND INDUSTRY CHARACTERISTICS

Principal findings include the following:

- GPS products span a wide range, both in terms of market segments (from hand-held units to precision aviation components) and product levels (from elemental chips and boards to elaborate systems that integrate GPS functions).
- GPS manufacturers can be characterized along a "food chain"—from basic chip and board producers to makers of systems that integrate GPS functions with other capabilities.

[1] Pace et al., pp. 17-18.

- GPS is both an end-product itself as well as a component in other products.

- GPS technology—particularly hardware—is commodity-like, driving competition to lower costs in much the same way as technology does in the computer industry. Embedded software enhancements help maintain price levels in some GPS products.

GPS receiver technology does not fit any single product definition very well. Users employ GPS in a vast array of applications, from hand-held navigation units to integrated modules on aircraft. GPS products also run the gamut from elemental chips and boards to elaborate systems into which the chips and boards are integrated. Manufacturers fall along this spectrum as well. A RAND report on GPS notes:

> A broad view of the GPS industry would include original equipment manufacturers (OEMs) of GPS receiver 'engines,' suppliers of GPS-related peripheral equipment such as displays and antennas, and GPS-related service providers. Some firms compete in the consumer electronics market, whereas others use GPS to provide professional services such as surveying and mapping. Some GPS products are tied to the fortunes of their platforms, such as the automobile and aircraft markets, while other GPS products aid commercial activities such as managing transportation and communication networks.[2]

A partial list of markets with products that use GPS functions includes the following:

- Aviation
- Maritime and waterways
- Highway and construction
- Public transportation
- Railroads
- Communications
- Emergency response
- Surveying
- Weather, science, and space
- Environmental protection

[2] Pace et al., p. 102.

- Recreation
- Law enforcement and legal services
- Agriculture and forestry.[3]

Prices in these markets differ significantly according to the differences in functionality required by users.[4] For instance, a hand-held unit need not do much more than produce information in a reasonably timely manner. Prices in this segment have fallen into the low hundreds of dollars. However, aviation units need anti-interference capabilities as well as integration into complex avionics systems. As a result, prices in this segment remain well into the thousands of dollars. This also applies in the military market:

> While it may be possible to give a soldier a $500 commercial GPS receiver that benefits him and his unit, integrating a GPS-based navigation system into a modern fighter plane starts with costs of $100,000.[5]

GPS manufacturers benefit from *market segmentation*, or the ability to charge different customers different prices according to the value they place on products. In essence, by dividing the market vertically manufacturers maximize the total revenue they receive in each segment (consider the effects if fighter planes could use hand-held units for navigation). In our industry interviews, we were not surprised to find evidence that manufacturers organize themselves in response to market demands. Trimble Navigation, for instance, is organized into 37 subgroups arranged by vertical markets.[6]

Market segmentation also may have an effect on innovation. If in fact fighter planes were able to use hand-held units for navigation (an exaggerated example, to be sure), manufacturers would face little incentive to develop sophisticated aviation units at much higher prices. To warrant higher prices, more complex units would have to deliver significantly better capabilities. Presumably, this would require much higher, and possibly prohibitive, investments in R&D than are required to innovate units in a segmented market.

Those market segments also highlight the fact that GPS is not just a stand-alone product. Rather, many products use GPS technology as a component that adds features and productivity. The RAND report on GPS states, "in some respects, GPS is likely to become an 'add-on' capability like modems or sound cards for personal computers."[7] Furthermore:

---

[3] Pace, et al., p. 97.

[4] Pace, et al., p. 94.

[5] Pace, et al., p. 21.

[6] Interview at Trimble Navigation, Ltd., Sunnyvale, CA., 25 Jun 1998.

[7] Pace, et al., p. 108.

. . . the generic applicability of GPS makes it an enabler of productivity improvements through reducing costs, enabling new functions, or enhancing revenues. The economic benefits of civil and commercial applications of GPS are thus broader than might be measured by sales of GPS equipment and service-related sales alone.[8]

The United States GPS Industry Council (USGIC), an industry association of U.S. GPS manufacturers, estimates that "GPS improves productivity in user industries, typically by 100 to 300%."[9]

That GPS functions as a component in other technologies or systems has implications for its growth. The industry has experienced growth in "waves as different markets adopt the technology."[10] An important aspect of this growth is that GPS must meet different price thresholds in each of the markets to generate mass demand. For instance, automobile navigation units first appeared on the market only in luxury models because of high prices. However, USGIC predicts that car navigation will constitute the fastest growing market segment over the next few years because of falling prices (see Table A-1).[11] The RAND report concludes: "New commercial exploitations of GPS are increasingly dependent on other technologies, such as wireless communications and software that are closely tailored to specific customer needs."[12]

Table -1. Global Positioning System Market Projections—Worldwide (Sales in millions of dollars)

Application	1993	1994	1995	1996	1997	1998	1999	2000
Car navigation	100	180	310	600	1,100	2,000	2,500	3,000
Consumer/cellular	45	100	180	324	580	1,000	1,500	2,250
Tracking	30	75	112	170	250	375	560	850
OEM	60	110	140	180	220	275	340	425
Survey/mapping	100	145	201	280	364	455	546	630
GIS	25	35	50	90	160	270	410	650
Aviation	40	62	93	130	180	240	300	375
Marine	80	100	110	120	130	140	150	160
Military	30	60	70	80	90	100	110	130
Total	510	867	1,266	1,974	3,074	4,855	6,416	8,470

Source: United States GPS Industry Council, 1995.

[8] Pace, et al., p. 103.

[9] United States GPS Industry Council.

[10] Pace, et al., p. 107.

[11] United States GPS Industry Council.

[12] Pace, et al., p. 102.

Our interview with the military's Joint Program Office (JPO) also indicated that, while stand-alone units will remain effective tools, the future of GPS in the armed services will likely lie in its integration as a function in "some other box."[13]

Despite these complexities, GPS receivers at the core deliver a very basic set of capabilities. Consider that users have certain, specific expectations of the technology, or systems which contain the technology—within certain parameters, location information by latitude, longitude and altitude, as well as the time. In this rudimentary sense, a user does not expect to get significantly different capabilities from buying a Trimble receiver versus a Rockwell unit, or from a hand-held unit versus a more complicated device. We do not contend that all receivers are alike. Rather, we simply state that GPS technology offers certain consistent capabilities across the market.

In this sense, GPS receivers exhibit some characteristics of a commodity or a product that has been standardized across its market. Commodities can have significantly different characteristics, in terms of development, than do more differentiated or developing products. James M. Utterback of the Massachusetts Institute of Technology's Sloan School of Management outlines a progression through which products advance from innovation to obsolescence.[14] In general, innovations stem from existing capabilities. While the market may have several differentiated products at the outset, eventually, a *dominant design* will emerge. This means that the product has become a commodity in the terms outlined above—not significantly different across manufacturers. At this point, the terms of competition in the market change:

> The appearance of a dominant design shifts the competitive emphasis in favor of those firms—large or small—that are able to achieve greater skills in process innovation and integration and with more highly developed internal technical and engineering skills. *Once the dust has settled on the contest for product innovation, then competitive engagement shifts to a new battleground: process innovation.* When the marketplace decides that the QWERTY keyboard, or some other design standard, is what it wants, then innovators start figuring out how to make that particular keyboard as efficiently as possible, and some firms will be better able to do that than will others (emphasis added).[15]

All else being equal, consumers select the product with the lowest price tag, so manufacturers will emphasize (and invest in) processes that reduce their production costs.

[13] Interview at GPS Joint Program Office, Los Angeles, CA, 25 Jun 1998.

[14] James M. Utterback, *Mastering the Dynamics of Innovation* (Boston: Harvard Business School Press 1994), pp. 18-19.

[15] Utterback, p. 30.

We found evidence of this behavior in the GPS market, particularly with the elemental GPS hardware, which produces the basic set of capabilities that are common across the market. Observers have compared GPS hardware's evolution with that of other electronics products—relatively short product cycles and emphasis on smaller, lighter, and most importantly, cheaper units.[16] The result is significantly declining costs for GPS hardware in a manner very similar to the computer chip industry. USGIC notes:

> GPS receiver products are rapidly becoming 'commodity' items with costs dropping at 30% per year. Hand-held GPS receivers are now available for less than $200. Costs for OEM modules for integration into other systems are now below $75 per unit.[17]

However, not all GPS products experience declining prices. Software enhancements serve to stabilize prices for some products:

> While prices of consumer GPS products are falling, professional and commercial GPS equipment at the upper end of the market have maintained higher price levels with increasing contributions from embedded software. That is, as the profit margins for hardware decline, some GPS firms are relying on software to provide added value to their products.[18]

As an example of these phenomena, we reviewed the product development "roadmap" for a certain GPS product in one industry interview.[19] Interestingly enough, as the project progressed, the GPS hardware in the product remained constant—a "dominant design." The "innovations" that made "new" products were all software adjustments or additions to a base technology.

MARKET STRUCTURE

Principal findings include the following:

- The GPS industry, as measured by sales, is growing rapidly, from $510 million in 1993 to projections of over $8 billion by 2000.
- The commercial GPS market is highly competitive with relatively free entry to firms, while the military market has barriers to entry and contains fewer firms.
- Costs drive the commercial GPS market.

[16] Pace, et al., p. 114.

[17] USGIC.

[18] Pace, et al., pp. 105-106.

[19] Industry interviews, June-July, 1998.

The GPS industry is expanding. The overall market for receiver equipment totaled approximately $3 billion in sales in 1997, and it is expected to nearly triple by 2000.[20] However, the military and civilian GPS markets are strikingly different. Though it started out as a strictly military application, GPS has become a fully dual-use industry. The USGIC notes:

> GPS, originating as a military R&D program, has become an engine for economic growth, which in turn has benefited the national security community through new technology, a stronger industrial base, and global market leadership.[21]

As GPS components have spread into many civilian applications, we have experienced a divergence of characteristics describing the two markets. These differences are mainly in terms of size and competitive structure.

Since the early 1990s, the commercial GPS market has overtaken its military correlate in total sales (see Table A-1). While the military GPS market continues to grow, it occupies a progressively smaller share of the total market. In 1993, military products accounted for 5.9 percent of GPS sales. This figure was projected to shrink to 2.9 percent in 1997, and to 1.5 percent in 2000.

The much bigger commercial market is marked by fierce competition, but entry of new firms is relatively easy. In its 1998 annual receiver survey, *GPS World* magazine listed 70 manufacturers and 429 different receivers.[22] This is an increase from 40 and 160, respectively, when the survey began in 1992, and from 54 and 275 in 1995.[23]

As we would expect from a competitive market, the commercial side of the industry responds to costs. On the demand side, according to the RAND report:

> Price is a major concern of commercial users, particularly as GPS is integrated into other consumer electronic products in computers and automobiles. As prices for GPS equipment drop, more commercial users adopt GPS or explore its use . . . According to a leading GPS manufacturer, civil and commercial buyers are price-elastic, and thus price is a greater influence per se on overall demand levels than accuracy.[24]

Firms in the commercial market respond to these competitive pressures. Industry interviews indicated, as expected, that costs are the major market driver on the commercial side.

---

[20] USGIC.

[21] USGIC.

[22] *GPS World,* "1998 GPS World Receiver Survey," Vol. 9, Number 1, January 1998, p. 46.

[23] *GPS World,* back-order information.

[24] Pace, et al., p. 96.

In contrast, there are only a few significant participants in the military GPS market, most notably Rockwell-Collins Avionics and Communications Division, the Interstate Electronics Corporation (IEC), and Trimble Navigation.[25] From our industry interviews, we learned that Rockwell had long been essentially the sole supplier of military GPS technology. Recently though, Trimble, IEC, and a few others have gained footholds in the market. Trimble, for instance, has captured significant subcontracts as the GPS circuit board supplier to GEC-Marconi, a producer of GPS-integrated products to the military and to Raytheon on a major military GPS development contract.

Several factors may contribute to the exclusiveness of the military market. First, firms may not find it worthwhile to compete for already occupied market share. Given that the military market is relatively small and becoming smaller by percentage, firms may not find it economical to vie for limited space in a market with a leader already established. In fact, Trimble's entree into the military market came only through a large contract. Some firms indicated it may not be efficient to compete for smaller military contracts.[26]

Prohibitive participation costs form another barrier to entry into the military market. To compete for a military contract, a potential participant may be required to produce a representative product sample. This may require special tooling and "turning on" the production line to produce a small lot. These are extremely costly processes that may prove forbidding to new entrants to the military game when winning further business is not assured.[27] Another military-exclusive cost concerns the gap between military and civilian GPS technology. Though we have seen some evidence that standards are converging, military equipment is often subject to more rigorous testing than civilian equipment. In addition, to operate in a military environment, firms incur costs of gaining security clearances and meeting other military-specific requirements. These serve as barriers to entry and result in a significantly different market structure than the competitive commercial market.

In general terms, these different market structures impact how firms behave in the respective markets. Firms in highly competitive markets have little choice but to price similar products at cost simply to compete. However, firms in markets with few participants and significant barriers to entry face different pressures. Collusion, either outright or tacit, is a possibility and will result in higher prices to the consumers in that market. *We must stress that we saw no direct evidence of collusion in the military market.* Military market firms did express reluctance to compete in the commercial marketplace. This could be indicative of a number of things. Among them is the possibility that military market firms suffer an inflated cost structure.

---

[25] Industry interviews, June-July, 1998.

[26] Industry interviews, June-July, 1998.

[27] Industry interviews, June-July, 1998.

PATENTING GPS INTELLECTUAL PROPERTY

Principal findings include the following:

- GPS user equipment manufacturers use patents to protect their R&D investments.
- The number of commercial patent families increased by a factor of five between 1988 and 1993.
- Patented technology focus is moving from broad to narrow.
- Non-GPS firms hold/generate a significant number of GPS-related patents.
- Firms use patents in two ways: to prevent technology imitation and as goods to be traded, or cross-licensed, for other firms' technologies.

GPS user equipment manufacturers, for both core components and integrated systems, protect their investments in research and development through vigorous patenting of new technology. Trimble, for instance, employs a dedicated patenting office and holds nearly 170 patents on GPS technology—more than the U.S. government.[28] In industry interviews, other firms also indicated the importance of patenting GPS technology. Chapter 4 of the 1995 RAND report examines the commercial GPS market and its implications for national policy. A portion of that chapter deals directly with commercial GPS patents.

Under a subcontract to RAND, Mogee Research and Analysis Associates conducted an international patent analysis of GPS technology. Though patent analysis cannot capture all aspects of technical competition—some innovations are kept as trade secrets, for instance—the RAND report states that "patent analysis is increasingly used as an objective measure and a means of testing anecdotal perceptions of technical competition."[29] According to Mogee:

> International patent records and patent citation data make each report an objective source of quantitative data on trends and competitors in the technology. The patent data are treated as indicators (i.e., indirect measures) of the output of research and development (R&D), and they are intended for use as a source of information on technology development and exploitation. Patenting reflects the level of R&D in a field and an interest in commercializing the results of the R&D. Thus, it provides a window into the pre-market stage of technology.[30]

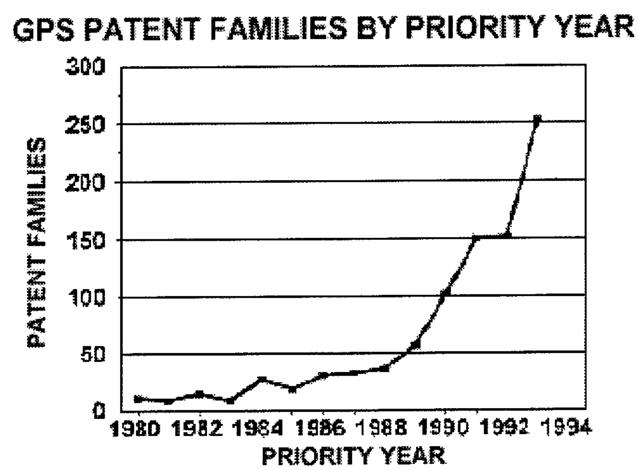
[28] Interview with Ken Spratlin of Trimble Navigation, San Jose, CA, 27 June 1998, and Trimble website: www.trimble.com/about/at_prof.htm.

[29] Pace, et al., p. 115.

[30] Mogee Research and Analysis Associates' website: www.mogee.com/ctr.htm (1996).

The Mogee report on GPS technology yields interesting and important results, as summarized in the RAND report. Commercial patents on GPS technology rose rapidly after 1988 (see Figure A-1), around the time that government-funded R&D "began a long-term decline."[31] Care should be taken in drawing conclusions from this fact, however. We cannot say conclusively that the number and rate of commercial patents grew because of increasingly limited government funding. The GPS satellite constellation was deployed between 1989 and 1993 providing a useful system from which to develop applications. It may be that as GPS grew into more and more applications over time, opportunities for innovation increased.

Figure -1. Global Positioning System Patent Families by Priority Year



Source: Mogee Research and Analysis Associates, 1996

The RAND report concludes that innovation of GPS technology, as measured by patents, "does not appear to depend on continued government investment in user equipment R&D."[32] Our research supports this conclusion as well. Some firms now insist on funding their own NRE costs for technologies they wish to sell commercially.[33]

RAND includes several other findings regarding GPS user equipment technology innovation:

> Industry interviews gave the impression that the nature of GPS is changing, from very basic, broad patents to narrow applications such as vehicle tracking and aircraft collision avoidance . . . some of the most 'interesting' competition

[31] Pace, et al., p. 117.

[32] Pace, et al., p. 117.

[33] Industry interviews, June-July, 1998.

> was coming from non-GPS companies that were finding innovative GPS uses. The significance of changes in who develops new GPS technology is hard to assess at present, but it is clear that innovations are coming from private firms, not governments.[34]

The RAND report concludes that one potential result of GPS innovations coming from non-GPS companies may be that strategic partnerships between these firms and GPS manufacturers will be created. In fact, we saw evidence of this during our field interviews. Trimble, a GPS chip and board manufacturer, partnered with GEC-Marconi, the producer of a GPS-integrated helicopter navigation system for the military. Trimble indicated that it actively looks for strategic partnerships in the commercial market as well.[35] For instance, Trimble has worked with Ford Motor Company to develop GPS integrated navigation systems for automobiles.

To stretch the analysis a bit further, we may note that GEC-Marconi acquired Canadian Marconi Corporation, a commercial GPS manufacturer, in an attempt to become more "vertical."[36] This move may be interpreted as an extreme example of strategic partnering in which the "partner" companies have actually merged.

A company's business strategy likely will dictate how the company views patents. Some, while maintaining a vigorous patenting operation, view their patents as portfolios of "chits to trade."[37] Effectively, a company may gain rents not from temporary monopoly status its innovations may confer, but from the benefits it can realize through cross-licensing its technology to other firms. Other firms may compensate the patent holder with royalty payments or in-kind trades of their own technology.

Some firms rarely cross-license their technology or acquire technology from outside sources. Rather, they use patents to prevent competing firms from using or imitating technology, and to a lesser extent to prevent market exclusion. For instance, if another firm holds a technology they wish to acquire, as mentioned above, GEC-Marconi may decide to acquire the other firm rather than license or trade technology. For some firms, this may be the most efficient way for them to secure technology and inputs to their primary systems.

We can draw some conclusions based on our limited findings. First, the use of patents generally will coincide with an individual firm's risk management strategy. All firms indicated to us that they acquire technology externally, albeit in different ways. Large, diversified firms may find it efficient to simply acquire other companies whose products or capabilities are needed to pursue a particular market. They would rather become more "vertical"—owning the means to develop

[34] Pace, et al., p. 118.

[35] Interviews with Ken Spratlin of Trimble Navigation, San Jose, CA, 27 June 1998, and GEC-Marconi personnel, Wayne, NJ, 14 July 1998.

[36] Interview with GEC-Marconi personnel, Wayne, NJ, 14 July 1998.

[37] Industry interviews, June-July, 1998.

and produce a product from beginning to end—than to establish relationships with supplier firms. Other companies, even those large by GPS standards, may operate at a scale where it is not efficient to purchase firms to acquire technology. Their alternatives are to pay royalties to a patent holder or to trade their technology for that of others. What we see is that both types of firms face risk in falling behind their competitor's technology. They simply manage this risk by different methods.

Second, the fact that the focus of GPS technology patents has steadily moved from broad to narrow has devalued patents. The narrower or more specific patents become, the more likely the products to which they pertain are to face competition from only slightly differentiated products. For instance, even if one firm holds a patent on a product developed to satisfy some specific customer need, a second firm's solution to the same problem may perform the same functions yet not be governed by the first firm's patent. In effect, this "narrowing" of patents' foci serves to decrease their overall effectiveness as companies find their own product niches.

FACTORS DRIVING GPS INNOVATION

Principal findings include the following:

- The commercial GPS market, because of its large size relative to the military market (among other factors), drives innovation in the industry.
- Military market products benefit from innovations in the commercial market.

Though GPS started out as a solely military venture, its commercial market has become the industry's prime engine for growth (as shown in Chapter 1 and Table A-1). The commercial market now dwarfs the military market both in terms of sales and number of participants. By all indications, this trend will continue, with the military market becoming a smaller and smaller percentage of the total market.

Because of its size, and the potential rewards to manufacturers investing in it, the commercial market has also become the prime engine for *innovation* in the GPS industry:

> In the case of GPS, there was no commercial rationale for expending over $10 billion to develop and implement the GPS constellation and control segment. The reason for doing so was to gain military advantages for the United States. After GPS existed, however, a commercial market appeared for GPS user equipment, and with commercial pressures and incentives this market has ad-

> vanced more rapidly and made greater investments than the government could have justified for its purposes alone.[38]

Our industry interviews indicated that firms conduct internal competitions for R&D dollars, with emphasis on producing the "best bang for the buck."[39] Clearly, with the potential returns available, commercial market products have an advantage when competing for a firm's internal R&D funds.

Another reason the commercial market drives innovation involves the types of products the military requests from contractors. By all accounts (including those of GPS JPO personnel), military GPS needs do not push the envelope of current technology.[40] A contributing factor is the military's recent emphasis on commercial off-the-shelf (COTS) acquisition programs. COTS products are by definition non-developmental items, so innovation of these products is not required.

This is not to say, however, that military products have suffered at the hands of the commercial market. Rather, there is evidence that just the opposite is true:

> The demand by civilian commercial users of GPS for smaller, better, cheaper receivers has directly benefited systems designed specifically for military use. For example, the precision lightweight GPS receiver used by U.S. military forces and designated a 'non-developmental item' was built at a low cost and delivered on time in large part due to technical benefits derived from research and development being conducted for civilian commercial applications.[41]

The presence of a strong commercial market for GPS technology actually enhanced its development, a conclusion we also draw from the model described in this report.

---

[38] Pace, et al., p. 144.

[39] Industry interviews, June-July, 1998.

[40] Industry interviews, June-July, 1998.

[41] Pace, et al., p. 251.

Bibliography

Freedonia Group. *Global Positioning Satellites*, Report #869. February 1997.

Frost and Sullivan. *North American Global Positioning System (GPS) Markets*, Report #5332-22. March 1997.

Fudenberg, Drew, Richard Gilbert, Joseph Stiglitz, and Jean Tirole. "Preemption, Leapfrogging and Competition in Patent Races." *European Economic Review 22,* 1983.

Gholz, Eugene. "Getting Subsidies Right: U.S. Government Support to the Commercial Aircraft Industry." MIT IPC working paper. January 1997.

Global Positioning Satellites. Freedonia Group, Report #869. February 1997.

GPS World. "1998 GPS World Receiver Survey." Vol. 9, Number 1. January 1998.

GPS World. Back-order information. (1-800-598-6008).

Grossman, Gene, and Carl Shapiro. "Dynamic R&D Competition." *The Economic Journal*, 97. June 1987.

Harris, Christopher, and John Vickers. "Racing with Uncertainty." *Review of Economic Studies,* 1987.

Industry interviews (GEC-Marconi, Rockwell-Collins Avionics and Communications Division, and Trimble Navigation, Ltd.). June-July, 1998.

Interview with GPS Joint Program Office. Los Angeles, CA. 25 June 1998.

Kelley, Maryellen, and Todd Watkins. "In From the Cold: Prospects for Conversion of the Defense Industrial Base." MIT IPC working paper. December 1994.

Lachow, Irving. "The GPS Dilemma: Balancing Military Risks and Economic Benefits." *International Security*, v20, n1. Summer 1995.

Laffont, Jean-Jacques, and Jean Tirole. *A Theory of Incentives in Procurement and Regulation*. Cambridge: MIT Press, 1993.

Nicholson, Walter. *Microeconomic Theory: Basic Principles and Extensions*. 6th ed. Fort Worth: Dryden Press, 1995.

Pace, Scott. *Promoting Commercial Space Activity*. Santa Monica: RAND, 1996.

Pace, Scott, Gerald Frost, Irving Lachow, David Frelinger, Donna Fossum, Donald K. Wassem, and Monica Pinto. *The Global Positioning System: Assessing National Policies*. Santa Monica: RAND, 1995.

Pincus, Walter. "Cargo plane with strings attached." *The Washington Post,* 23 July 1998.

Preston, Bob. *Plowshares and Power: The Military Use of Civil Space*. Washington National Defense University Press, 1994.

Reinganum, Jennifer. "Innovation and Industry Evolution." *The Quarterly Journal of Economics.* February 1985.

Spence, Michael. "Cost Reduction, Competition, and Industry Performance." *Econometrica*, Vol. 52, No. 1. January 1984.

Tirole, Jean. *The Theory of Industrial Organization*. Cambridge: MIT Press, 1988.

United States GPS Industry Council, press release and informational packet. Washington: USGIC, January 1995.

Utterback, James M. *Mastering the Dynamics of Innovation* Boston: Harvard Business School Press, 1994.

REPORT DOCUMENTATION PAGE

Form Approved OPM No.0704-0188

1. AGENCY USE ONLY *(Leave Blank)*	2. REPORT DATE	3. REPORT TYPE AND DATES COVERED
	Sep 98	Final

4. TITLE AND SUBTITLE

Characterizing Commercial Market Effects on Military Electronics Development Program Costs: An Analytical Framework

5. FUNDING NUMBERS

C DASW01-95-C-0019

PE 0902198D

6. AUTHOR(S)

Anthony L. Clippinger, Eric M. Gaier

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)

Logistics Management Institute
2000 Corporate Ridge
McLean, VA 22102-7805

8. PERFORMING ORGANIZATION REPORT NUMBER

LMI– PA805T1

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)

Office of the Secretary of Defense, Director, Program Analysis and Evaluation

10. SPONSORING/MONITORING AGENCY REPORT NUMBER

11. SUPPLEMENTARY NOTES

12a. DISTRIBUTION/AVAILABILITY STATEMENT

A: Approved for public release; distribution unlimited

12b. DISTRIBUTION CODE

13. ABSTRACT *(Maximum 200 words)*

OSD(PA&E) tasked LMI to study how defense acquisition reform, advanced business processes and new high technologies have affected how products are developed for DoD and what methods should be used to estimate the costs of those developments. LMI first looked at the defense electronics sector using Global Positioning System (GPS) receivers as an analog. A portion of that investigation looked at the influence of the commercial marketplace on what DoD pays for product development. LMI developed an economics-based analytical model that characterizes how the existence of commercial market potential for a new product impacts industry interactions with DoD. The model, which uses a two-stage game algorithm, captures the motivations and incentives of the various players involved in a competitive bid for a DoD product development contract. It provides DoD with an analytical framework for assessing contractor bids for development programs with dual military and commercial potential. This report also contains a brief market description and analysis of the GPS receiver industry that provides some insights into how the LMI model applies in that domain.

14. SUBJECT TERMS

Product development, development costs, cost estimating, Global Positioning System, GPS, commercial markets, economic analysis, economic models, analytical framework

15. NUMBER OF PAGES

40

16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT