PATRIOT PAC-2 DEVELOPMENT AND DEPLOYMENT IN THE GULF WAR

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This case study explores the development of the Patriot PAC-2 and its historic deployment in the Gulf War from the vantage point of five senior technical managers. In addition to in-depth interviews with these senior managers, U.S. Army Aviation and Missile Command (U.S. Army Missile Command) historical documents, unclassified government reports, and other public sources were reviewed for information regarding PAC-2 development. Patriot PAC-2 is a case study in effective project management that resulted in the extraordinary acceleration in the final stages of development, production, and deployment in time to play a historic role in the Gulf War. The Patriot PAC-2 lessons may benefit future project managers engaged in the final stages of system development prior to a major conflict.

Beginning in 1966, Defense Secretary Robert McNamara authorized the contract definition for the Surface-to-Air Missile Defense (SAM-D). In 1967, Raytheon was awarded the contract for the advanced development program for SAM-D. This four-year program developed and demonstrated hardware elements and computer software that coordinated the operation of all elements performing the air defense functions from target detection through intercept (Oldacre, personal interview, May 29, 2001). SAM-D benefited from technology transferred from the original missile designed as a defense against ballistic missile attack, Nike-Zeus. While Nike-Zeus was never actually fielded due to technological limitations, much was learned that aided the development of SAM-D.

By 1970, the Track-via-Missile (TVM) guidance seeker was demonstrated

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through a series of real-time flight simulations. In mid-1970, Raytheon's contract was expanded to include an engineering development definition effort. The SAM-D engineering development program was initiated in 1972. The emphasis in this program was on the early initiation of missile flight tests. The advance development radar, computer and guidance hardware were modified to support guidance flight tests of the engineering development model missile. During the same timeframe, the engineering development model ground equipment was initiated in parallel development (Oldacre, personal interview, May 29, 2001).

During the early part of the engineering development program, critics questioned the tracking via missile concept. These discussions reached Secretary of Defense Schlesinger who concluded that the importance and the cost of the program required that the guidance system be thoroughly proved before continuing the development program. Based on these discussions, the reoriented program, called Proof-of-Principle, focused on the missile guidance system. In addition, in January 1974 Congress directed the Army to conduct a Cost and Operational Effectiveness Analysis (COEA) in coordination with the General Accounting Office (GAO).

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The results of the COEA reaffirmed the need for an air defense system with SAM-D's capabilities. Initial testing conducted in 1974 verified SAM-D's on-board control system, aerodynamic and structural design of the missile, and in-flight acquisition and tracking by the ground based fire control group. In early 1975, in a test at White Sands Missile Range, SAM-D successfully destroyed a drone in its first engineering development test of the TVM guidance system. Subsequent tests proved that the TVM guidance system was robust against a variety of maneuvering targets and countermeasures. As a result of the performance in the Proof-of-Principle program, SAM-D was approved for return to full-scale development in January 1976 (Capps, personal interview, April 26, 2001).

In 1976, with the resuming of full-scale development, SAM-D was renamed Patriot. By 1977, an Army System Acquisition Review Council (ASARC) decision was made to accelerate the program. This decision moved the production date up from the original schedule of March 1983 to April 1980. This entailed the risk that the initial production equipment would not have the required operational reliability and software maturity. This decision resulted in the elimination of the third phase development tests and operational tests (DT/OT III). These tests were replaced with a production confirmatory test and a follow-on evaluation (Fenstermacher, 1990).

In September 1980, following the Defense Systems Acquisition Review Council III (DSARC III) production readiness review, low rate production for Patriot was approved subject to a verification test program. In October 1980, Raytheon began the initial low rate production that included five fire units and 155 missiles. This initial production was accompanied by a series of Follow On Evaluation (FOE) tests that included operational software tests, testing of diagnostic software, retrofitting and testing of the missile, and checking reliability, availability, and maintainability (RAM). The final set of tests would be completed with the production equipment and with operational personnel. This test would be known as FOE-II.

The first production units came off the line in early 1983. The operational tests began in June 1983 at White Sands Missile Range under the supervision of the Army Operational Test and Evaluation Agency (OTEA; Annual Historical Review, 1984). FOE-II would be the first time combat troops would actually use Patriot in an operational environment. The tests would include search and track scenarios, simulated and live missile firings, including day and night operations. (Fenstermacher, 1990).

FOE-II did not go well and the test results were substandard. There was excessive equipment downtime. Diagnostic and corrective action was complicated and led to delays in returning the equipment to an operational status. It became immediately clear that much of the equipment failure was due to production quality control deficiencies. As the tests continued problems multiplied, disagreements emerged regarding the design of the operational tests, and an adversarial relationship began to develop between Raytheon and OTEA. Before FOE-II was completed, OTEA made the decision to discontinue the operational testing. This turn of events was a shock to both Raytheon and the Patriot project office.

Following the discontinuation of FOE-II, Patriot was placed on what was labeled a "milestone schedule." The previous schedule for deployment to Europe was cancelled and Raytheon was instructed to systematically correct each problem that had been identified during the FOE-II tests. The milestone schedule meant that deployment and full-rate production were postponed indefinitely. Only after a new Follow On Evaluation (FOE-III) would full-rate production begin.

Lesson 1: A Corporate Culture that Responds to Adversity

Raytheon had been prepared to launch full-rate production. With the failure of FOE-II, production capacity and staffing would not be utilized. Patriot was Raytheon's largest single program, and in 1983 it represented approximately 20 percent of the company's total sales revenue. Both Raytheon corporate management and the engineers in the Missile Systems Division knew that Patriot would either be deployed or cancelled based on the success of the impending FOE-III testing (Fenstermacher, 1990).

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What transpired next can only be described as a massive corporate response to the challenge that entailed extraordinary effort on the part of Raytheon's Missile Systems Division. Engineers scrutinized every aspect of the FOE-II test results in an effort to identify every potential problem source and take corrective action. A concerted effort was mounted to improve software diagnostics. Sensors were added to the system so that operators could detect faults more readily. The technical manuals were rewritten based on the Patriot project office guidance on specific procedures (Annual Historical

Review, 1984). Raytheon corporate management brought in William Swanson, a very talented production manager, to turn around the Andover, Massachusetts production facility. Swanson overhauled the entire quality control system and vastly improved production quality.

Steve Stanvick, the Patriot chief engineer at Raytheon, was placed in charge of the FOE-III preparation. Stanvick realized that the existing organization within the Missile Systems Division resulted in diffused responsibility. To correct this problem, he created a temporary organizational structure in which engineers were grouped into ad hoc teams with a single technical manager over each major area. John Kelley, the manager of flight tests, observed that many of the technical professionals were routinely working 60-hour weeks during this period. Levels of exhaustion were high, but the relentless effort to correct each problem in preparation for FOE-III continued on its compressed schedule (Kenger, personal interview, June 28, 2001).

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In July 1984 FOE-III was initiated. The tests were extraordinarily successful. Patriot surpassed all the acceptable target values, and in some cases by margins in excess of 50 percent. During the tests the system was operational over 90 percent of the time. The missile flight tests achieved a 100 percent rating by OTEA and the testing was completed ahead of schedule in September 1984 (Annual Historical Review, 1985). Immediately following the successful FOE-III tests, the decision was made to ramp up production and begin the deployment of Patriot in Europe.

The corrective action system that was instituted resulted in impressive improvements in a period of less than one year. This structured response to the FOE-II crisis literally reshaped the company's approach to the transition from development to production for the future (Capps, personal interview, April 26, 2001). This would turn out to be important as the program moved into PAC-1, and historically significant, during the accelerated transition to production for the PAC-2 Gulf War deployment. It is to Raytheon's credit that the firm possessed the corporate culture that embraced such a radical turnaround.

The lesson that may be learned from this is that those companies that are able to develop a corporate culture that can respond to adversity will be able to succeed when faced with enormous challenges. However, those that are unable to develop corporate cultures with this characteristic will tend to fail. There may also be an ancillary lesson. The government OTEA and program managers were very astute in creating a situation between FOE-II and FOE-III where the large incentive of the production contract was placed in jeopardy. When faced with potentially large financial consequences, most firms will respond accordingly.

Lesson 2: The Tactical Missile Threat and Obtaining Support for PAC-1 and PAC-2

The original requirements for Patriot (SAM-D) included an anti-tactical ballistic missile capability. However, the Training and Doctrine Command (TRADOC; the Air Defense Command) eliminated this requirement early in the program. The program prior to the start of full-rate production in 1984 focused exclusively on the anti-aircraft requirement. The issue of the added anti-tactical missile (ATM) capability had encountered some resistance from the beginning within TRADOC. The reasons were varied, but included the issues of cost, schedule, and technical difficulty. In this regard, in order to achieve the anti-aircraft capability, the technical development effort was so significant that the consensus between TRADOC and the Patriot project office was to focus resources on this critical task. To attempt to achieve both objectives from the beginning would diffuse resources and inevitably prolong the development schedule (Capps, personal interview, April 26, 2001).

A second counter-argument that was generally accepted by TRADOC was that tactical missiles were inherently inaccurate, and therefore, posed a lesser threat to military targets (Capps, personal interview, April 26, 2001). As events unfolded in 1990 and 1991, however, the fallacy in this argument would become extremely clear because of their potential as a weapon of terror against civilian populations.

In any case, by 1985 Patriot was progressing in high rate production, and Colonel Lawrence Capps replaced Brigadier General Donald Infante as project manager of the Patriot project office. With production under way, the timing was right to shift attention to the tactical missile threat. The specific threat was the Soviet SS-21, and this became Colonel Capps primary objective. Achieving the anti-tactical missile capability would require resources, and TRADOC (the Air Defense Command) was ambivalent. However, Colonel Capps persisted in successfully convincing the Office of the Secretary of Defense (OSD) to allocate budgetary resources to the program (i.e., OSD directed funds). During this same timeframe the Patriot project office succeeded in negotiating a multiyear production contract (five year contract) with Raytheon (Capps, personal interview, April 26, 2001). This was an important development because it provided the level of funding stability that would be required to keep the anti-tactical missile program on track.

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Initial efforts were called Patriot Anti-tactical Missile Capability-1 (PAC-1), which involved software changes to reshape the radar search pattern and to reshape the missile trajectory (Annual Historical Review, 1986). The test results were promising, but it was clear that changes were needed to the warhead and fuze to make the system more effective. However, it was apparent that these measures would still not be sufficient to gain the increase in the guidance accuracy needed. Thus, in order to increase both political and budgetary support, the Germans were approached regarding a joint program. The Germans communicated a high level of interest. They were already acquiring Patriot missiles and the anti-tactical missile capability was attractive to them.

In 1986, the Germans agreed to fund 40 percent of a program for an experimental new seeker called the multi-mode seeker. This 60/40 split was sufficient to fund a phased effort that was to test the seeker in hardware-in-loop ground simulation tests, and then incorporate it into the missile and conduct flight tests (Capps, personal interview, April 26, 2001). However, this new missile seeker was destined never to reach production, as events would drive the schedule into rapid production of the existing PAC-2 design.

These events suggest an important lesson. Exceptional project managers, like Lawrence Capps, will have the foresight to understand the evolving threat. Exceptional project managers will also succeed where others may fail in obtaining the necessary resources to accomplish the task in the face of resistance and competition for scarce resources. In the case of Patriot, Lawrence Capps not only succeeded in obtaining OSD directed funds, but by thinking outside the box, he was able to help assemble the joint venture with the Germans. This resulted in the acquisition of the additional resources necessary to support the anti-tactical missile development.

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PAC-1 AND PAC-2 PROGRAMS PROCEED ON SCHEDULE AND WITHIN BUDGET

The first phase of the advanced capability program, PAC-1, involved software modifications to the Patriot ground equipment and improved guidance and control. These software changes would allow the Patriot missile to essentially fly up the reverse trajectory of an incoming SS-21 missile. The PAC-1 software changes allowed the radar to orient into a high altitude search mode for surveillance tracking and launch against the inbound missile.

In April 1985, Raytheon completed the system definition effort for the PAC-1 ATM software modifications. The PAC-1 software development contract was awarded to Raytheon in June 1985. By July 1986 the software changes had been completed and validated. In a test at White Sands Missile Range in September 1986, a Patriot missile successfully intercepted a Lance missile similar to the Soviet SS-21. Following the testing, the PAC-1 capability was deployed with the release of the Post Deployment Software Build #2 in July 1988 (Annual Historical Review, 1989).

The second phase of the advanced capability program, PAC-2, involved missile modifications including the fuze, warhead, software modifications, and new guidance algorithms. The PAC-2 program provided Patriot with catastrophic kill capability against longer range, Intermediate-range Nuclear Forces (INF) treaty compliant missiles such as the Soviet SS-23. The modifications to the warhead included larger hardened steel fragments that would be released following detonation of almost 100 pounds of high explosive. This improvement was necessary in order to penetrate the shell surrounding the Tactical Ballistic Missile's (TBM's) warhead. The fuze, developed by the Harry Diamond Labs and Bendix Corporation, had a faster reaction time that was necessary for high closing-speed engagements (Moore, personal interview, April 27, 2001).

The Patriot system consisted of a ground radar, an engagement control station, an antenna, an electric power plant, and typically eight launchers per fire unit. Each launcher contained four missiles in its individual storage, transportation, and launch containers. The radar was a multifunctional phased arrayed radar that performed a variety of surveillance, acquisition, and guidance tasks in directing a battery of launchers. With multiple guidance modes, the system had the capability to switch modes to adjust to enemy electronic counter measures. The missile was 17.4 feet in length and was powered by a solid propellant rocket motor that approached mach 3 speeds. The missile itself weighed 2200 pounds and had a range of 43 miles (Annual Historical Review, 1990).

PAC-2 development proceeded through 1986, 1987, and 1988. In addition to the work on the fuze and the warhead, software development proceeded on incorporating the pulse doppler search/track capability. Additional preplanned product improvements during this timeframe included the clutter canceller modification, integration of the modular azimuth and positioning system with Patriot, the standoff-jammer counter, and improvements to reliability, availability, and maintainability (Annual Historical Review, 1989).

The testing program included component level, subsystem level, and system level testing. Extensive software testing included stand alone tests and hardware in the loop tests. The warhead testing verified its spray pattern, fragment velocity, and fragment ruggedness. The fuze underwent testing to verify its performance on a variety of targets with different trajectory geometries and closing velocities. With the success of the test program, by December 1988, the Army In-Process Review (IPR) approved production for PAC-2 (Moore, personal interview, April 27, 2001; Kenger, personal interview, June 28, 2001).

The PAC-2 production run began in February 1989. Raytheon in Andover, Massachusetts built the guidance section. Morton Thiokol at Redstone Arsenal produced the propulsion section. Martin Marietta in Orlando completed the final assembly. Given the long lead-time on production, the first PAC-2 missiles were scheduled to be fielded in early 1991 (Annual Historical Review, 1990).

Lesson 3: PAC-2 Schedule and Cost Performance Can Be Attributed to Sound Acquisition Strategy, Technological Readiness, and Effective Project Management

One important factor that contributed to the PAC-2 schedule and cost performance was a sound acquisition strategy. Following initial development, the first Patriot production contract was awarded on a cost plus incentive fee/award fee basis. This type of contract was selected by design in order to distribute risk at a level acceptable to both the contractor and the government. As the Patriot system matured, and cost and technological uncertainty decreased, cost type contracts began to be partially replaced by fixed price incentive and, in some instances, firm fixed price contracts. On a proportional basis, this placed increased monetary risk on Raytheon and the subcontractors relative to the government (Capps, personal interview, April 26, 2001). However, with risk being reduced as a result of technological readiness and production knowledge, this was acceptable to Raytheon and the subcontractors.

In March 1987, a multiyear production contract was awarded to Raytheon. This five-year contract allowed Raytheon and the subcontractors to lower costs through economies of scale in lot purchasing, efficient utilization of facilities, and reduction in contract administration costs. While PAC-2 did not transition into production until 1989, the primary effect of this multiyear contract on PAC-2 was the overall funding stability that it provided. Retired Brigadier General Capps (personal interview, April 26, 2001) observed that this funding stability for the Patriot program was important in keeping PAC-2 development on schedule. The PAC-2 program could be injected into the ongoing production program by cutting in engineering change proposals rather than starting an entirely new production line. This approach resulted in maximum efficiency.

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While incentive fees were commonly utilized with the development contracts, the most critical incentive was the continuation of the large production contracts. Therefore, by creating incremental project milestones for design and testing during engineering development, the financially lucrative production contract could be obtained by successfully achieving each of the sequential milestones.

The technological readiness level, or maturity, was also a factor that contributed to PAC-2 schedule and cost performance. A.Q. Oldacre (personal interview, May 29, 2001), the deputy project manager for the Patriot project office during PAC-2, observed that because work on Patriot had been progressing at Raytheon since 1967, Raytheon had built a large base of pertinent technical knowledge. In the Raytheon laboratories, knowledge of the basic technologies such as phased array radar, guidance and control, and software had reached a high level by the time of the inception of PAC-1 and PAC-2.

Similarly, in the Army laboratories a large base of technical knowledge had developed over the same timeframe. For example, in the Research, Development, and Engineering Center (RDEC) at Army Missile Command (MICOM), the Software Engineering Directorate managed the Patriot software verification and validation program in cooperation with the Patriot project office. The RDEC Guidance and Control Directorate assisted with hardware validation and developed simulations for Patriot jointly with Raytheon. The PAC-2 fuze was developed with Harry Diamond Labs, and RDEC at MICOM assisted in fuze testing. In addition, Aberdeen conducted the PAC-2 warhead testing. This extensive base of expertise in the government laboratories and test facilities contributed to the high technological readiness level that facilitated PAC-2 development schedule performance (Oldacre, personal interview, May 29, 2001).

Effective project management also contributed significantly to the PAC-2 schedule and cost performance. The government project office utilized a functional structure with a program management office that included an acquisition management branch, a cost estimating/budget branch, and a cost/schedule control branch. There was a production/configuration management office, a hardware engineering division, a software engineering division, a product assurance division, and a systems engineering division. In addition, there was an office for Patriot support that included deployment management, logistics management, and a Patriot readiness center. The project office also included a project counsel legal office, an administrative office, and liaison offices for Germany, Japan, and the Netherlands (Moore, personal interview, April 27, 2001).

At Raytheon, the Patriot program office within the Missile Systems Division included personnel who would interface with the government counterpart in the various functional areas. The program office contained a large technical staff. Raytheon utilized a laboratory structure where engineers in the Bedford system design lab, systems engineering lab, software engineering lab, test lab, and so forth, were in a matrix organization with the program office functional areas.

This system worked effectively for several reasons. First, during the PAC-2 timeframe Raytheon retained a large technical staff in the program office itself. These individuals, for the most part, had extensive Patriot experience in their respective areas of specialization. Secondly, there was significant technical depth in the Bedford labs in each area that pertained to the Patriot system. Third, the coordination within this matrix system in terms of task assignments was managed effectively. Finally, the interface between the Raytheon program office, the subcontractors, and the government Patriot project office was effectively managed (Kenger, personal interview, June 28, 2001; Sanborn, personal interview, June 28, 2001).

PAC-2 development occurred in an era before integrated product teams began to be used widely. However, temporary or informal modes of cross organizational integration were implemented that had some similar characteristics to integrated product teams. Larry Moore (personal interview, April 27, 2001), Patriot project office technical director, observed this occurring in the software engineering area with the creation of teams that included Raytheon personnel, project office personnel, and the contractor or Software Engineering Directorate personnel involved in validation. However, Moore also observed that structural modes of integration (like cross functional or cross organizational teams) are only effective to the degree that the individuals involved have the requisite level of technical knowledge and to the degree that those individuals are striving to work cooperatively. In the absence of cooperation and requisite technical expertise, structural modes of coordination are ineffective. A.Q. Oldacre (personal interview, May 29, 2001), the deputy project manager during PAC-2, noted that the level of cooperation and the openness regarding disclosure of problems was such that coordination

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between Raytheon and the project office was extremely effective.

When PAC-2 entered production, the effectiveness of this coordination was facilitated by the fact that the Patriot project office had a team of engineers on site at the Raytheon Andover manufacturing facility as liaisons. Furthermore, internal coordination at Raytheon had improved significantly over the initial production runs. To facilitate the transition to production, engineers that were involved in Research and Development (R&D) design work served in an advisory capacity during the transition to production. Similarly, production engineers at Raytheon provided input into design decisions at earlier stages in order to insure design for manufacturability (Oldacre, personal interview, May 29, 2001).

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This was a clear case of organizational learning. In the initial production runs, this type of integration, which is characteristic of concurrent engineering, was not in place. By 1989, when the PAC-2 changes and the other preplanned product improvement changes were moving into production, integration had been improved significantly. These factors demonstrate the high production readiness level at Raytheon that also contributed to schedule and cost performance.

Lesson 4: In War, One Must Learn To Expect the Unexpected

On August 2, 1990, Saddam Hussein launched the Iraqi invasion of Kuwait. At this point, the PAC-2 missiles were in the production build-up cycle with the first missiles scheduled to come off the production line in approximately five months. Only three PAC-2 R&D missiles were in the inventory in August 1990, and these had been scheduled for use in operational testing. While the development testing had been completed, there was still operational testing that remained to be conducted (Annual Historical Review, 1991).

The intelligence reports coming back from the Middle East immediately communicated the nature and the extent of the Iraqi missile threat. The missile was the Soviet-built Scud. However, PAC-2 had been designed to counter the SS-21 and SS-23 threats. The Scud had been discounted because it was an older system that the Soviets had replaced with their more modern systems. The Soviets had sold their aging fleet of Scud missiles to their third-world allies, and Iraq was preparing to use this weapon against the U.S. forces and our Coalition allies. To make matters worse, the Iraqi Scuds had the capability of delivering both conventional and chemical warheads. Furthermore, the Iraqis had modified the propulsion section so that the Scuds range was capable of reaching the population centers of Israel.

As if the situation could not be any worse, the Iraqi propulsion modifications also resulted in higher velocities than the SS-21 or SS-23. Hence, the modified Scud Al-Hussein reached velocities of 6,500 to 7,200 feet per second. The Soviet missiles the PAC-2 had been designed to intercept reached velocities between 5,200 and 5,900 feet per second. As Herb Sanborn (personal interview, June 28, 2001), Raytheon Patriot systems engineering manager, observed, "in war, one must learn to expect the unexpected."

In the first week of August 1990, what was unfolding was nothing less than an engineering and production challenge of historic proportions. Not since 1944 had an American defense firm and a government project office been faced with a challenge of this magnitude. Colonel Bruce Garnett, the Patriot Project Manager, was summoned to Washington where he was asked to present the simulation data that had been developed by RDEC at MICOM and Raytheon. Upon reviewing the information, the Army Chief of Staff, and subsequently General Colin Powell, made the decision to deploy PAC-2 in the Persian Gulf (Oldacre, personal interview, May 29, 2001). The Program Executive Officer, Brigadier General Robert Drolet, directed an emergency early release of Post Deployment Build-3 (PDB-3) with necessary software modifications, and parallel final tests to assure that adaptations for the Iraqi Scud worked properly (Annual Historical Review, 1992).

What transpired next could only be described as an extraordinary acceleration of effort. A.Q. Oldacre, the deputy project manager, without any formal contract, on a phone call alone, instructed the Raytheon program office to accelerate production as rapidly as possible. Raytheon immediately moved into 24 hour, 7 days per week, full-plant capacity production. The actual production contract followed weeks later and formalized the agreement. This unusual event illustrated the level of trust that existed between the prime contractor and the project office. It also illustrated that, when faced with the imminence of war, both Raytheon and the Patriot project office were prepared to do whatever was necessary in the national interest (Oldacre, personal interview, May 29, 2001).

With production under way, concurrently, Larry Moore and Don Adams at the Patriot project office in Huntsville, in cooperation with Raytheon, initiated the effort to make the necessary software modifications to counter the Scud threat. The software engineers at Raytheon immediately realized what the challenge entailed and moved into a mode of extraordinary effort. In order to make the necessary software modifications and conduct the validation testing, it was reported that software engineers at Raytheon were working 16-hour days. For Walt Trainor at Raytheon, and A.Q. Oldacre at the Patriot project office, this effort would be their greatest challenge (Moore, personal interview, April 27, 2001; Oldacre, personal interview, May 29, 2001).

While this was occurring, the German PAC-2 production line also transitioned to full capacity. In coordinating production, it soon became apparent the production of the new warheads in the United States was roughly two months behind the German contractor, MBB, as a result of a labor strike. Consequently, the Patriot project office coordinated a transfer of German-built warhead parts to the United States for assembly. As a result, daily deliveries of parts were shipped from the MBB plant in Bavaria to Ramstein, then on to Dover Air Force Base in Delaware, then to East Camden, Arkansas for warhead subassembly, and finally, to Orlando for final missile assembly (Moore, personal interview, April 27, 2001).

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By January 1991, 424 PAC-2 missiles had been shipped to the Persian Gulf (Davis, 1992). However, it was unclear if this would be sufficient as intelligence data revealed the magnitude of the Iraqi Scud threat. By this time warhead production in Arkansas, guidance section production at Raytheon in Massachusetts, and fuze production in Baltimore were exceeding the final assembly capacity of Martin-Marietta in Orlando.

As a consequence, the Patriot project office shifted its focus to converting PAC-1 missiles in the inventory into PAC-2's. This assembly process involved changing the warhead, fuze, software, and other changes to a number of the existing missiles in the inventory. The missile forebody was sent to Raytheon for the replacement of components, then a second final assembly facility was brought on line at Red River Army Depot, and a third was brought on line in Germany. Running parallel assembly operations resulted in a significant increase in the number of missiles being shipped to the Persian Gulf as hostilities erupted in January 1991 (Oldacre, personal interview, May 29, 2001).

"In large complex projects, learning curves should not be underestimated."

Several important factors contributed to the ability of Raytheon and the Patriot project office to exhibit such extraordinary organizational agility in adjusting rapidly to the changed requirements and the need to accelerate PAC-2 production. A.Q. Oldacre (personal interview, May 29, 2001) and Larry Moore (personal interview, April 27, 2001) from the Patriot project office, and Herb Sanborn (personal interview, June 28, 2001) from Raytheon considered stability and continuity in staffing to be an important contributing factor. This was important particularly in the effort to rapidly modify and test the software to allow for the interception of Scud missiles. Many of the key technical people at both Raytheon and the government project office had worked on the program for over 10 years. This depth of experience that was system-specific proved to be critical when the rapid changes were required.

In large complex projects, learning curves should not be underestimated. While there is an advantage to some degree of movement of technical personnel to transfer knowledge and ideas from other projects, this can reach a suboptimal level. What is needed is a core of highly talented individuals with extensive system specific or domain specific knowledge. This was critical, particularly in areas like software, and this contributed significantly to the ability to adjust so rapidly.

The dramatic acceleration of production was made possible by several important factors. First, the Army had the foresight to contract with Raytheon (and the subcontractors) to develop the tooling and production facilities so that the capacity would be in place in the event of war. A second contributing factor was the level of training and expertise of Raytheon production personnel. This had the effect of ensuring quality as production ramped up to 24-hour, 7-day schedules at full-plant capacity. Another factor that affected quality was the numerous quality control initiatives implemented by the production manager, Bill Swanson, during the period between FOE-II and FOE-III (Fenstermacher, 1990). The changes that were implemented during that timeframe paid very real dividends as production accelerated in preparation for war.

Finally, the Patriot project office had the foresight to insure multiple production sources of critical components. Thus, when Chamberlain was seriously behind schedule on warhead production, the adjustment could be made to procure the warheads from MBB in Germany. Similarly, parallel production could be brought on line when the effort shifted to transforming a number of existing missiles to PAC-2 missiles.

Brigadier General Larry Capps (personal interview, April 26, 2001) observed one other factor that allowed for the extraordinary acceleration in production — the restricted level of breakout. During the mid-1980s there had been an effort on the part of the Department of the Army to increase the level of breakout, or the level and number of subcontractor production contracts, on numerous programs. The logic of this strategy was to reduce costs through increased competition. In the case of Patriot, the project office carefully managed this effort, and breakout was actually relatively restricted as a result. This proved to be providential because when Patriot production had to be accelerated to meet the requirements of the Gulf War, a larger network of suppliers would have inevitably slowed production due to the complexities and inevitable uncertainties of coordination.

Another important factor that contributed to the ability to rapidly shift the systems' guidance from aircraft, SS-21 and SS-23 missiles to Scud missiles, was the fact that Patriot was designed to be extremely robust. As Herb Sanborn (2001) observed, in order to be prepared for unexpected eventualities, a missile with multiple guidance modes (to avoid electronic countermeasures), and the capability to modify guidance algorithms as well as other ground software in a short period of time, allows for greater versatility.

There was one more factor that contributed to the dramatic acceleration in production and the rapid implementation of software changes. This can perhaps be described as a cultural characteristic that Americans seem to possess. It is an extraordinary ability to rise to challenges and exhibit extreme levels of motivation in the face of a national crisis. A. Q. Oldacre (personal interview, May 29, 2001) described it in this way: "I have often wondered whether or not this country could still do things like it did in World War II. I know now that it can. If we turn it on, and ask our industry and our people to do things like we did in World War II, there is no doubt in my mind that we could do it again."

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PAC-2 Plays a Critical Role in the Gulf War

The United States and Coalition forces launched the massive air attack on Iraq on January 17, 1991. On January 18, Iraq initiated use of its weapon of terror by launching Scud missile attacks on military targets and civilian populations. Due to the tremendous production acceleration that had been occurring since August, there were over 400 Patriot PAC-2 missiles in the Persian Gulf by this date. Patriot units immediately went into action to counter the threat. This would be the first time in history that tactical ballistic missiles would be used in hostile wartime attacks on civilian populations. This would also be the first time in history that these attacks would be countered with an anti-tactical ballistic missile.

"While incentive fees were commonly utilized with the development contracts, the most critical incentive was the continuation of the large production contracts."

As the war progressed, software adjustments were made to respond to observations from combat (Blair, Obenski, & Bridickas, 1992). Because the Scud missile tended to breakup during the final phase of its trajectory (re-entry into the atmosphere), multiple targets would appear on the radar screen. Engagement operations were modified to reduce undesirable engagements. Raytheon and Patriot project office personnel worked rapidly to make further adjustments to reduce tracking and engagement of false targets (targets that were not incoming warheads).

Other forms of radar interference (i.e., backload reflection) were discovered and rapidly corrected by Raytheon engineers in Saudi Arabia and Massachusetts as the Scud attacks proceeded (Moore, personal interview, April 27, 2001). By February 28, 1991, estimates of successful interception ranged as high as 70 percent in Saudi Arabia and 40 percent in Israel (Oldacre, personal interview, May 29, 2001).

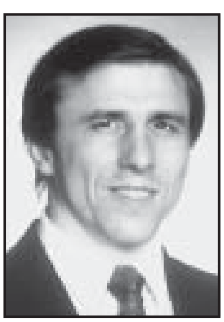
There was some controversy over the question of exactly how many of the 159 Patriot missiles launched during the conflict actually intercepted their targets (Davis, 1992). Part of the controversy can be attributed to reporting deficiencies. Performance assessments were also subject to differing definitions. For example, if a Scud missile was approaching an airbase, and the Patriot did not destroy the warhead but did divert its path so that the warhead landed in the desert, some defined this as a successful intercept. Others defined this as a failed intercept.

Another issue was the difference between the performance in Saudi Arabia and Israel. In large part, this could be explained by the differences in training levels between U.S. and Israeli units, differences in engagement control, and the fact that it was used to defend large geographic urban areas in Israel versus small geographic area military bases in Saudi Arabia (Oldacre, personal interview, May 29, 2001).

Regardless of any controversy regarding the number of Scuds that were destroyed, disabled or diverted, the fact remains; Patriot saved many lives, both civilian and military. For an incremental development investment under $150 million, the PAC-1 and PAC-2 programs enabled the Patriot air defense system to be upgraded from anti-aircraft to anti-tactical ballistic missile capability. This achievement made the Patriot PAC-2 one of the most cost effective defense systems in the U.S. inventory.

Perhaps the most important contribution made by PAC-2 in the Gulf War was its critical role in holding the fragile multinational Coalition together. The historical significance of this role has been underestimated. Patriot was the only defense against the Scud attacks on Israel. When Saddam Hussein began launching Scud missiles at the major population centers in Israel, the pressures mounted for Israel to be drawn into the conflict. Had this occurred, the likelihood of the Coalition unraveling would have been extremely high. With such a chain of events, and in light of the chemical, biological, and nuclear capabilities in the region, one can only speculate as to where the escalation would have ended.

Note: Patriot PAC-2 continued to be fielded throughout the 1990s. Following the Gulf War, engineering development was initiated on Patriot PAC-3. PAC-3 would include an improved interceptor, enhanced radar and communications equipment, and updated software. Operational test and evaluation occurred in 2002 (Patriot Advanced Capability-3, 2002).



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Acronyms

AMCOM – US Army Aviation and Missile Command

ASARC – Army System Acquisition Review Council

COEA – Cost and Operational Effectiveness Analysis

DSARC III – Defense Systems Acquisition Review Council III

DT/OT III – Development Tests and Operational Tests

FOE – Follow On Evaluation

GAO – General Accounting Office

INF – Intermediate-range Nuclear Forces

IPR – In-Process Review

MBB – German defense firm

MICOM – U.S. Army Missile Command

OSD – Office of the Secretary of Defense

OTEA – Operational Test and Evaluation Agency

PAC-2 – Patriot Advanced Capability-2

PDB-3 – Post Deployment Build-3

RAM – Reliability, availability, and maintainability

RDEC – Research, Development, and Engineering Center

SAM-D – Surface to Air Missile Defense

TBM – Tactical Ballistic Missile

TRADOC – Training and Doctrine Command

TVM – Track-via-Missile