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The Barrel Reshaping Initiative: Planning and Execution

by Mark Bundy, James Garner, Walter Roy, and Albert Pomey

ARL-SR-125 **September 2004**

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REPORT DOCUMENTATION PAGE	*Form Approved* *OMB No. 0704-0188*

1. REPORT DATE *(DD-MM-YYYY)*	**2. REPORT TYPE**	**3. DATES COVERED (From - To)**
September 2004	Final	1997–2003

4. TITLE AND SUBTITLE The Barrel Reshaping Initiative: Planning and Execution	**5a. CONTRACT NUMBER**
	5b. GRANT NUMBER
	5c. PROGRAM ELEMENT NUMBER
6. AUTHOR(S) Mark Bundy, James Garner, Walter Roy, and Albert Pomey	**5d. PROJECT NUMBER** AH80
	5e. TASK NUMBER
	5f. WORK UNIT NUMBER
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) U.S. Army Research Laboratory ATTN: AMSRD-ARL-WM-BC Aberdeen Proving Ground, MD 21005-5066	**8. PERFORMING ORGANIZATION REPORT NUMBER** ARL-SR-125
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)	**10. SPONSOR/MONITOR'S ACRONYM(S)**
	11. SPONSOR/MONITOR'S REPORT NUMBER(S)

12. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release; distribution is unlimited.

13. SUPPLEMENTARY NOTES

14. ABSTRACT
The U.S. Army Research Laboratory has discovered a process that will allow tank gun barrels to be produced with tighter tolerance in their centerline contour. Improved centerline uniformity translates into improved shooting consistency from barrel to barrel. This report describes the approach taken and the lessons learned, from searching for and acquiring a program sponsor, through planning and execution of hardware development, test validation, and preparation for transition to implementation.

15. SUBJECT TERMS
research, development, program, project, planning, execution, management

16. SECURITY CLASSIFICATION OF:			**17. LIMITATION OF ABSTRACT**	**18. NUMBER OF PAGES**	**19a. NAME OF RESPONSIBLE PERSON** Mark Bundy
a. REPORT UNCLASSIFIED	**b. ABSTRACT** UNCLASSIFIED	**c. THIS PAGE** UNCLASSIFIED	UL	18	**19b. TELEPHONE NUMBER** (*Include area code*) 410-278-3815

Standard Form 298 (Rev. 8/98)
Prescribed by ANSI Std. Z39.18

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1. Introduction

Tightening the tolerance on gun barrel "straightness" produces more consistent shooting performance from tube to tube. This correlation is based on the underlying principle that the launch dynamics of the projectile as it negotiates the centerline path of the barrel affects the resultant flight path, producing a projectile point of impact that differs (jumps) from the gravity-corrected line of fire. Thus, if all barrels have essentially identical centerlines, they will shoot more uniformly and predictably, displaying virtually the same jump characteristics for a given round type. Such consistency is especially beneficial when tanks utilize the common, or fleet-zero, approach to adjust their fire control solution to the fleet-average jump for each of the five or six round types available.

However, imposing and achieving tighter tolerances on the centerline contour would have been impossible without the recent discovery of a method to precisely control the centerline shape. This review is about the "approaches taken," "lessons learned," and "best practices uncovered" in bringing the barrel reshaping capability from the laboratory to the initial stages of field implementation.

2. Funding the Process

Every researcher knows that many good ideas remain unexploited for lack of funding; somewhere, somehow, money must be made available to carry the idea from concept, through development and validation, to the implementation stage. This is particularly problematic when the scientific discovery, such as barrel reshaping, does not occur under the auspices of a larger overriding program with a well-defined funding line.

As previously described, the primary benefit of barrel reshaping is improved accuracy for the fleet-average barrel. Figure 1 outlines a significant events calendar, with time zero marking the onset of the fully-funded, well-defined barrel reshaping initiative (BRI). Scientists at the U.S. Army Research Laboratory's (ARL's) Weapons and Materials Research Directorate (WMRD) demonstrated that a barrel could be precisely shaped ~3 years prior to the timeline origin. In the terminology of technology readiness level (TRL), it was a TRL 3/4 event. Demonstrating that barrel reshaping positively affects the mean projectile jump, as shown in figure 2, occurred a year later.

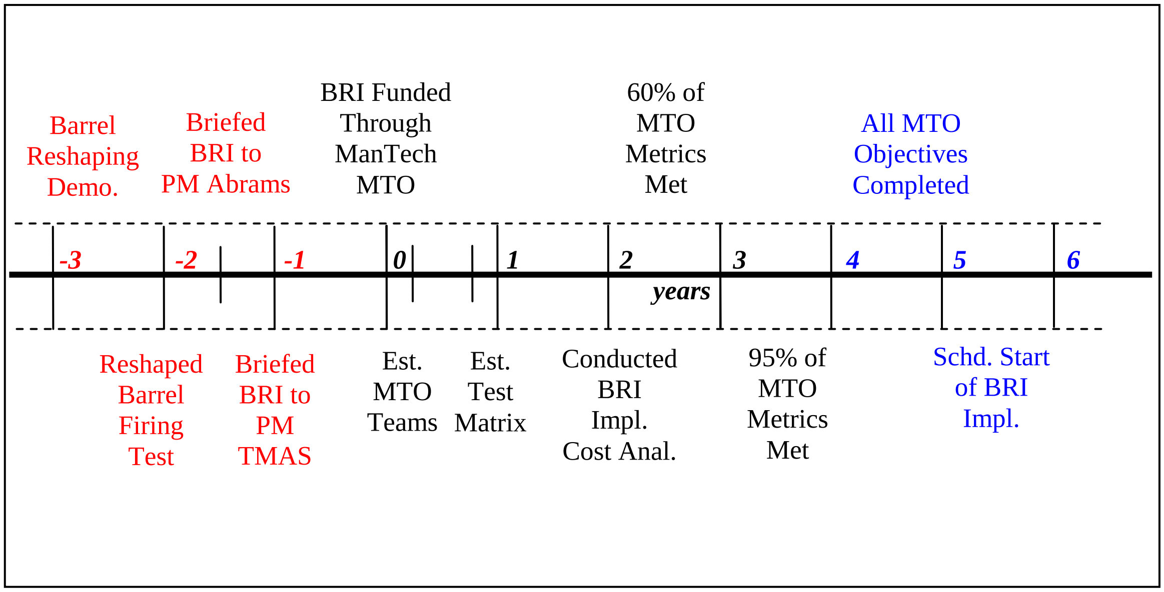

Figure 1. BRI timeline of events.

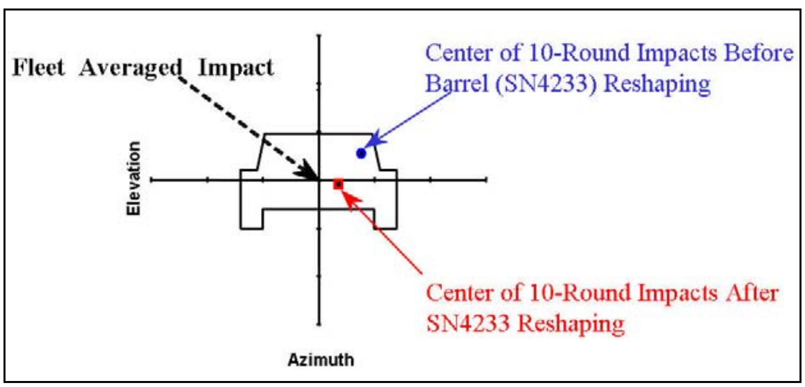

Figure 2. Initial performance improvement example.

If, as noted, there was no existing umbrella program, then it might be asked, who incurred the concept-demonstration costs of the first 2 years? The answer to that question is many-sided; first, in practice, there is latitude given to researchers at the "bench level" to explore fresh ideas and innovative techniques that may lead to new program start-ups. The WMRD Director's Research Initiative program is such an example. Secondly, in a case where funding would normally be an explicit requirement (such as range testing), an economical solution is to piggy-back one investigation onto another, provided there is no added risk or cost. This was the method used to acquire the firing data of figure 2, where the BRI proof-of-principle benefited from the ranges and the cooperation of the U.S. Army Test Center (ATC), colocated with WMRD at Aberdeen Proving Ground. Lastly, it is not unheard of for managers outside the immediate chain of the researcher's command, or even outside the researcher's agency, to invest "seed money" in promising new ideas on the chance that their organization may eventually gain from it. This later option was also used to offset the BRI concept demonstration costs, again benefiting from ATC's start up investment in BRI. (Note: ATC eventually did reap a 10-fold return in benefits from BRI, in that they acquired the use of new centerline measurement equipment purchased in the BRI program, and were paid to do all the BRI live-fire validation testing once the program became fully funded.)

Even with the potential performance benefits of figure 2 clearly evident, it took 2 additional years to find a funding source for the full-scale BRI program. This emphasizes the difficulty of securing developmental dollars for a project that is outside the research and development pipeline of an overarching program.

During the decade prior to the barrel reshaping breakthrough, WMRD had a line-item budgeted program entitled "enhanced tank gun accuracy;" however, it transitioned into a "smart munitions" program prior to the start of the events in figure 1. Thus, BRI was an independent idea looking for a financial backer at the level of ~$1–2M/yr, for 3–5 years, to bring the technology from concept demonstration to the point of wide-scale implementation.

The original program solicitation was built around the reshaping method and preliminary firing results of figure 2, complemented with the benefits to be gained under the Training and Doctrine Command's (TRADOC's) fleet-zero policy. Recognizing the importance of the technology breakthrough, WMRD's director enlisted the joint support and participation of the U.S. Army Benet Laboratory, colocated with Watervliet Arsenal (where tank gun barrels are manufactured), and the recognized experts in barrel manufacturing technology. Next, with the combined endorsement of both WMRD and the U.S. Army Benet Laboratory directors, the BRI proposal was briefed to the overall gun system manager (at the time), the project manager's office for the M-1 Abrams main battle tank (PM Abrams, now incorporated into PM Combat Systems [PM CS]); this event is marked at "–1.5 years" on the timeline of figure 1.

Although PM Abrams thought the initial results were promising, and pledged support in the "out years," their existing budget commitments prevented them from serving as the program patron in the near term. A second organization, known to have previously sponsored improvements to barrel-related subsystems was the program management office of Tank Main Armament Systems (PM TMAS, now incorporated into PM Maneuver Ammunition Systems [PM MAS]). Acknowledging the potential benefits of barrel reshaping, but also unable to solely and immediately underwrite the project costs, PM TMAS briefed the BRI proposal up their chain of command; however, this was without success. These failed attempts to fund the BRI took 2 years to explore, but fortunately, the search had generated attention and brought awareness to a wide group of individuals, one of whom made the pivotal suggestion to propose BRI to the U.S. Army Material Command's Manufacturing Technology (ManTech) program.

Following this suggestion, the coordinator for existing ARL ManTech projects was contacted, and a BRI ManTech proposal drafted and submitted. In accordance with ManTech proposal requirements at the time, it was necessary to identify a proposal cosponsor from within the U.S.

Army who would invest at least 25% of the total program cost. Although PM TMAS had not been able to fund the entire request, they were able and willing to serve as 25% cosponsor should the ManTech proposal win approval.

Having met the minimum ManTech requirements, several additional steps were initiated that were helpful, if not decisive, in the proposal evaluation and ranking process. First, in addition to obtaining the signatures of PM TMAS as a financial coinvestor, and the endorsement of PM Abrams, as well as both ARL and the U.S. Army Benet Laboratory directors, a key decision was made to enlist the endorsement of BRI from the armor soldier's most direct spokesperson, the TRADOC Systems Manager (TSM) for the M-1 Abrams main battle tank. Secondly, a TSM Abrams representative was enlisted to accompany the BRI proposal team on several one-on-one briefings with individual members of the ManTech review board prior to their final selection meeting. This petitioning and constituency-building from the combined voice of both the technical and the user community was believed to be critical in not only gaining approval, but in attaining a high program ranking (which helped ensure that if there were unexpected ManTech budget cutbacks, BRI would remain funded). These events brought the program to time zero on the scale of figure 1.

3. Team Tasking

The objectives and milestones of the ManTech-funded BRI manufacturing technical objective (MTO) were set out in the approved proposal, as displayed in figure 3, but the team structure was not quantified until funding was secured. The division of tasks was guided by the process and goals of the program, as laid out in figure 4. Specifically, since the tank barrel is exposed to high pressures, a safety certification team was commissioned to ensure that any changes made to the barrel would not affect the safety of the barrel or shorten its service life. A fire and evaluation team was created to quantitatively describe the accuracy improvements of the process. A machine design team was initiated to build machines to process the barrels both in the field and in production. An algorithm team was initiated to predict where and to what degree the reshaping process is needed in order to transform a given barrel centerline to the preferred shape. A transportation team was assembled to identify and configure the conveyance vehicle for the field-unit reshaping machine. Measuring the initial barrel centerlines is the starting point for the process, so a measurements team was formed to optimize that process. Finally, a business team was formed and tasked with the job of promoting the program and assuring continued compliance with user needs.

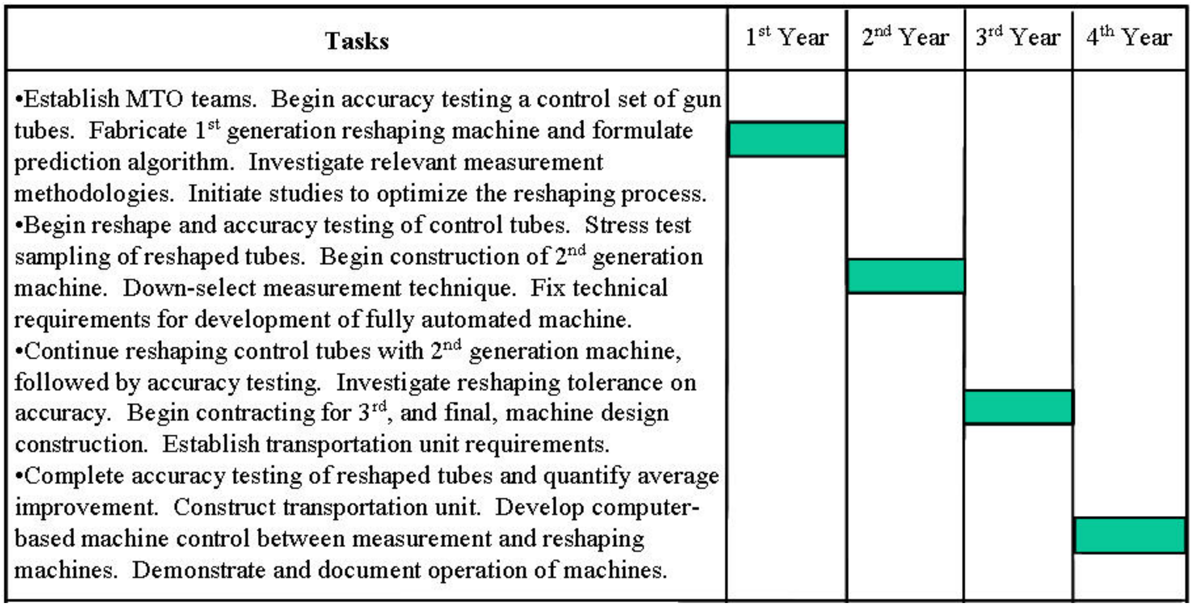

Figure 3. Initial timetable for BRI objectives.

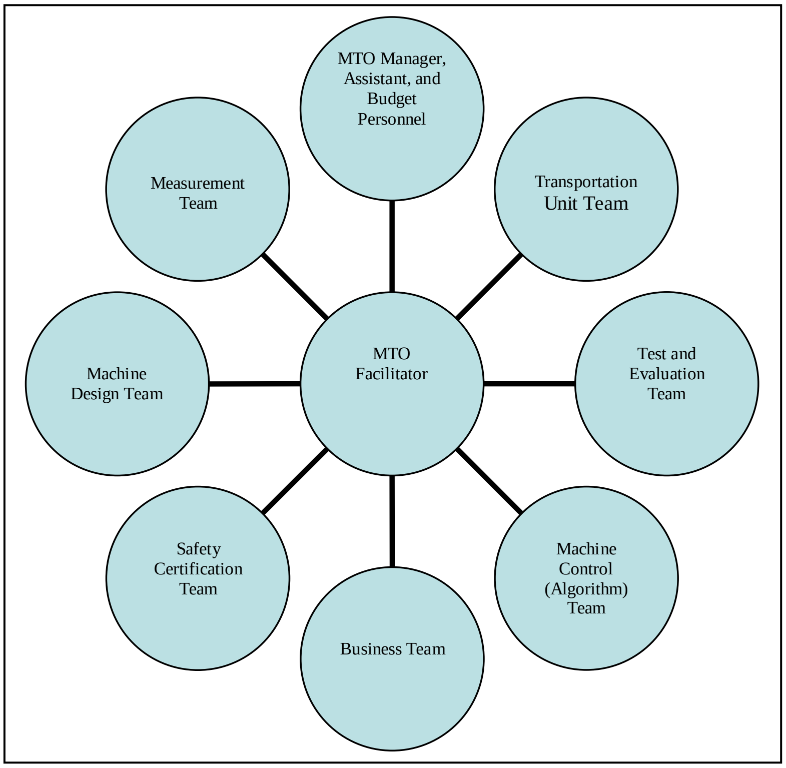

Figure 4. MTO team structure.

In addition to the seven teams, there was a management group consisting of an overall MTO manager, an assistant manager, and an interteam facilitator, as well as a laboratory-connected support group for assisting with program budgeting, fund transfers, and purchase requests. The objectives of each team and the duties of the administrators were formally described in a BRI management plan that was distributed to all team leaders.

Team members were selected from both inside and outside of ARL based upon who was most capable of contributing to the team objectives. For instance, the safety certification team was located at the U.S. Army Benet Laboratory, where gun barrel stress and fatigue analysis is routinely conducted. The firing and evaluation team was managed from within ATC, recognized experts in conducting large-scale weapon accuracy tests. The machine design team was led from within ARL, but had team members from Watervliet Arsenal and U.S. Army Benet Laboratory. The business team was managed either by a representative from PM TMAS, the cosponsor, or TSM Abrams. Program funds to cover the cost of labor and testing materials were transferred to the parent branch or organization of team members.

The idea of a business team may seem superfluous to a technically-related MTO; therefore, it is deserving of a more detailed explanation. The objective of the business team was to direct the course of action in areas relevant to transitioning the technology into practice. Even though all the major weapon system managers and the user endorsed the MTO, invariably, there would be new mangers and new performance and financial priorities at the end of the 4-year BRI MTO. Implementation questions would again be asked: “why should we do this,” “what is it going to cost,” and “is it worth the cost.” The goal of the business team was to anticipate such questions and have answers at the ready. For instance, the business team first deliberated whether the emphasis of the test and evaluation team should be placed on promoting the worst-to-best gain in accuracy performance, or whether success should be sold on the fleet-average performance improvement. Also debated was how the performance data should be presented, whether in the form of hit probability increase, potential round savings, or combat loss exchange ratio improvement. Furthermore, who should be involved in such comparison studies, and how often should the intermediate results be briefed?

4. Progress Reviews

Each team met with the MTO manger two to three times per year to discuss progress, findings, or perhaps redirection of the specific goals that had been agreed upon at the beginning of the year. Notes from each meeting were recorded and circulated to all team members. When important results were obtained, such as an MTO milestone met, the news was forwarded to ManTech and laboratory supervisors. At year’s end, there was an all-team annual review, where every team made a formal presentation of their year-long accomplishments. These annual reviews were held at various geographic sites, such as West Point, NY; Aberdeen Proving

Ground, MD; and PM Abrams Headquarters, Warren, MI, to help disseminate program objectives to a wide spectrum of potentially-affected groups.

In addition to the “self-imposed” internal MTO reviews previously described, there were numerous (some mandatory) progress reports and informational briefings given to ManTech review panels, laboratory management at both ARL and the U.S. Army Research Benet Laboratory, the PM offices, Watervliet Arsenal, TSM Abrams, and special armor groups, such as the U.S. Army’s Tank Gun Accuracy Committee and the U.S. Marine Corps’s Tank Officers Advisory Group.

In the category of “best program practices,” the external progress reports previously noted were more than a one-way exchange of information; they provided valuable feedback to the MTO manager and business team on what questions were still left unanswered or unaddressed in the list of tasks highlighted in figure 3. Taking to task the search for answers to open questions ultimately strengthened subsequent presentations and prepared BRI for the final challenge of securing implementation funds.

5. Hardware Development and Testing Strategy

The overall 4-year MTO Gantt chart was structured to investigate parallel hardware exploration and development in high-risk, high-payoff areas, such as improved speed and precision in the centerline measurement process. Down-selection to the most promising design-track was scheduled for the second year, along with fixing critical design specifications for either sole-source purchases or open-bid requests for proposals.

With regard to MTO contracts and purchases associated with hardware development, it was extremely important, from an expediency perspective, that the laboratory management authorized discretionary control and direction of MTO funds to the BRI program manger. Equally important was the very rapid execution of purchase requests; typically, the sequence of events from request by team leaders, to approval by MTO manager, to confirmation of available funds, and submission of purchase order by budget specialists took only 2 days. Had laboratory supervisors asked for justification for each of the hundreds of items ordered, it would have, in all likelihood, protracted the program another year. These “best procurement practices” were a key to meeting the BRI timetable of figure 3.

As indicated earlier, decisions on testing strategy were made in the first year to provide time for gun barrel (centerline) selection, as well as time to request and receive delivery of the requisite ammunition. However, this statement alone may not convey the level of importance placed on validation testing for the purpose of unequivocally proving that the benefits of barrel reshaping are worthy of implementation. There was no doubt that barrel reshaping affects accuracy, as evidenced in figure 2. The concern was that if the size of the test (number of barrels, number of occasions, and number of rounds per occasion) was not large enough, other confounding factors, such as round-to-round and occasion-to-occasion errors, would bring the level of confidence in the demonstrated improvement below the desired statistical degree of certainty. As insurance, a comprehensive statistical analysis was conducted during the first year (marked on the timeline of figure 1) to determine the size of the test needed to provide a confidence level of at least 80% in the certainty of the testing results. To accomplish this, nearly one in every five program dollars went into testing, in what is believed to be the single largest accuracy test ever conducted on a tank-caliber main gun.

In hindsight, there was wisdom acquired with regard to test planning. A review and report of the intermediate firing results was promised and delivered to the program sponsors when the testing was 25% complete. However, no forethought or attention was paid to selecting a balanced mix of "poor and good shooters" in the first test group. As chance would have it, the first group was composed of fairly uniform centerlines (relative to the overall group). Consequently, they shot fairly consistently, even before reshaping. Not surprisingly, after further tightening the centerline consistency with the reshaping process, there was only a small accuracy improvement. As a result, the initial BRI results did not leave a good first-impression, diminishing early interest in BRI. This made it more difficult to promote its success when all barrels shapes were taken into account and the average improvement was shown to be substantial. The lesson learned: plan, to the extent possible, to acquire and publicize intermediate test results that are indicative of the final performance norm.

6. Gauging Success

There were five metrics posted in the original proposal for measuring the final success of the MTO program. Without specifically quantifying these metrics, they were, in general form:

1. Demonstrate a (stipulated percentage point) reduction in the after vs. before center of shot impact.
2. Improve the first-round probability of hit (PH) for reshaped barrels (by a stipulated number of PH-points over a stipulated range of interest).
3. Acquire a 20-fold reduction in the manufacturing tolerance for barrel straightness.
4. Obtain a six-fold reduction in barrel straightness measurement time.
5. Achieve a two-fold increase in the precision of barrel straightness measurements.

Metrics 3–5 were met in the second year of the program, as shown in figure 1. After completion of the firing tests and analysis of the data, it was possible to state that metric 1 was substantially, but not completely met, while metric 2 was fully met.

Although essentially all the metrics were met, the program did not complete on time all of the objectives planned at the outset (figure 3). Part of this shortcoming could be attributed to good, if not accurate planning, in that the scheduled second-year design team goal of investigating in alternative ways to optimizing the reshaping process did indeed find a significant process improvement, which then required time to incorporate. However, because BRI was such a resounding success, ARL offered to fund the cost of completing the machine construction (TRL level 9) by the end of the fifth year, as noted on the timetable of figure 1.

7. Assuring Implementation

As expected, leadership changed at both PM TMAS and PM Abrams during the course of the 4-year MTO. In fact, it was not merely leadership change, but both PMs ceased to exist before the end of the program. The roles of PM TMAS were taken over by PM MAS; similarly, PM Abrams was consolidated into PM CS. Obviously, the new PMs needed to be appraised of what the MTO was about, and take a fresh look at the questions: why should BRI be implemented and is it affordable? Because the business team had anticipated such questions as a likely prerequisite to implementation, and because the numerous interim progress reports had, in response to a wide range of technical inquiries, generated an abundance of vantage points from which to view BRI, the program was well-prepared with answers to such questions.

With regard to the question on its affordability, the business team commissioned a comprehensive cost estimate from Rock Island Arsenal for implementing BRI on all existing tanks. Their analysis showed that the estimated implementation cost, per tank, was less than the cost of one tactical round of ammunition. But the most compelling reason to implement BRI was the outstanding performance improvement it offered. PM CS was quoted as saying, “this is the kind of quantum leap forward we’re looking for.” Presently, BRI is scheduled to begin implementation at the end of year five on the timetable of figure 1.

8. Summary

The BRI was a ManTech-funded program (with an MTO) to develop machinery capable of shaping, or reshaping, tank gun barrel centerlines to a much tighter profile consistency, thereby enhancing the accuracy of the fleet-average barrel. Although the MTO was a 4-year program, it took 8 years to bring the fundamental concept of BRI from the point of discovery and demonstration by U.S. Army scientists, to U.S. Army acceptance for implementation. The best practices discovered and lessons learned are as follows:

1. The concept originated as a result of exploratory research in an area no longer synched with a mainstream mission or customer program. The lesson for laboratory managers: new programs can arise in old areas with new technologies, provided scientists and engineers are given the latitude and encouragement to explore such possibilities.
2. After successfully demonstrating the concept, the scientists proceeded to inform management of the potential benefits to be gained and solicit their help in finding a funding source to pursue further development. Laboratory management recognized the merit of the research, and strengthened the planned proposal by forming an interlaboratory partnership. With a joint laboratory voice, the proposal was brought to the attention of U.S. Army weapon system program managers. Although this approach didn't lead directly to developmental funding, it exposed the proposed performance payoff to leadership levels in the gun community and netted the pivotal suggestion for the most appropriate funding source—the ManTech program.
3. It was highly effective to individually prebrief the proposal review-board prior to the final selection committee meeting, accompanied by a representative from the TSM's office, to ensure a full appreciation of the proposed benefits from the scientist's and soldier's point of view.
4. Breaking down the MTO into teams, each with common purpose, was the most natural way to address the program goals and objectives, but having the resources and capacity to handpick the best individuals from multiple organizations to lead and serve on teams was critical to the program's resounding success.
5. Of course, periodic team and project reviews were essential, but there was an unexpected bonus in holding numerous external reviews before gun-knowledgeable audiences who were seeing the program outlined for the first time. External exposure invited challenge to the programs precepts. Responding to these challenges either reinforced or redirected the program approach. In either case, the final product was strengthened.
6. Hundreds of items were procured during the 4-year BRI program. All purchases were reviewed and approved by the MTO manager. For expediency sake, however, it was an extremely valuable practice that the laboratory granted the MTO manager the authority to authorize program-related purchases and supplied the program with the budgeting personnel to quickly process purchase order requests.
7. Proper test planning should be done to ensure that the intermediate reporting of partially completed testing will be representative of the final test results, thereby avoiding inaccurate performance projections and misleading generalizations.

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