# A Study on the Cannon Tube Industrial Base in the United States

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**Abstract**

Watervliet Arsenal is a long standing and historic producer of cannon tubes in the United States. Having this capability in the United States is critical to arm our warfighters and to project power around the world in an era of great power competition. As the sole producer of cannon tubes in the United States, Watervliet Arsenal's capacity is the limiting capacity for large cannon tube production to meet the demand of multiple customers with reasonable delivery lead times in the United States. This paper explores some of the causes and ramifications of having a single point of supply for the manufacturing of large cannon tubes in the United States. This report is a qualitative case study to examine the constraints on cannon tube production in the United States. It explores how cyclic rates of demand affect cannon tube production. And given the constraints and cyclic demand, how the Army maintains sufficient production capacity for large cannon tubes in the United States. It reviews the protectionist legislation of the Arsenal Act and Stratton Amendment, and how they affect cannon tube production in the United States. It also provides specific recommendations on how to change those protectionist legislations to bolster the cannon tube production in the United States. It also goes over the cyclic nature of cannon tube production and provides actions that can be taken to address and possibly alleviate the issue of surging production quantities of cannon tubes in times of war.

Key Words

Watervliet Arsenal, Cannon Tube Manufacturing, Arsenal Act, Stratton Amendment, National Defense Industrial Base, Organic industrial base, government-owned government-operated, manufacturing arsenals

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# Chapter 1 – Introduction

## Background

There is one main source for large cannon tube production in the United States. Watervliet Arsenal, established in 1812, has been the primary government cannon barrel foundry since 1889 (Kinard, 2007). Watervliet Arsenal is a government-owned government-operated facility that has a long history of cannon tube production. The United States Congress recognizes Watervliet Arsenal "in its long-standing role as the historic sole source of cannon tubes" (United States Congress, 2022, p. 14).

When there is a single source of an item in production, this can lead to manufacturing capacity limitations in times of increased demand. However, the same characteristics that led to the manufacturing capacity limitations also serve to pace the cost for carrying the set production capacity in times of lean demand. In times of conflict, there can be a sudden unexpected increase in demand. The conflict in Ukraine is helping to highlight this phenomenon (Schneider, 2022). The conflict in Ukraine has become an "Artillery War" which has drastically increased the need for cannon tubes.

To compound the problem, there are multiple customers who provide demand signals for production of cannon tubes. At the same time, there are multiple Army Modernization priorities which require the development of new cannon tubes. Two of the Army's modernization priorities include Long Range Precision Fires (LRPF) and Next Generation Combat Vehicle (NGCV) (Bates, 2022). The LRPF Cross Functional Team (CFT) has led to many new artillery programs which has increased the demand on cannon tube production. The NGCV CFT also has many new combat vehicle programs which has increased the demand on tank tubes. Both programs are in addition to the volume of cannon tubes required to maintain current Artillery and

Tank programs for both new production and legacy systems in sustainment. There is also Foreign Military Sales which is another source of production demand.

The Arsenal Act was first enacted in 1920 (AMERICAN FEDERATION OF GOVERNMENT EMPLOYEES 2119 v. General Dynamics Land Systems, Incorporated, Intervener-Appellee., 2001), and gave rise to the current Army Arsenal Act, 10 U.S.C. 4532 which states that "The Secretary of the Army shall have supplies needed for the Department of the Army made in factories or arsenals owned by the United States, so far as those factories or arsenals can make those supplies on an economical basis" (10 U.S.C. 4532 - Factories and arsenals: manufacture at., 2015).

Another piece of legislation that also affects cannon tube production is the 10 U.S.C. 4542, commonly called the Stratton Amendment, which prohibits transfer to foreign countries any technical data for any large-caliber cannon being manufactured or developed in an arsenal (10 U.S.C. 4542 - Technical data packages for large-caliber cannon: prohibition on transfers to foreign countries; exception., 2010).

**Problem Statement**

The problem is that there is set capacity for large cannon tube production in the United States to meet the demand of multiple customers with reasonable delivery lead times. The Army has identified the risks of having a sole source for cannon production within the industrial base (Bush, 2022). This paper explores some of the causes and ramifications of having a single point of supply for the manufacturing of large cannon tubes in the United States.

**Purpose of This Study**

The purpose of this qualitative descriptive case study is to describe the impact of the Army Arsenal Act and the Stratton Amendment on the ability of the National Defense Industrial Base to meet large caliber cannon production in times of increased demand. The intended audience for this research is senior Department of Army and Department of Defense officials who are responsible for the production and delivery of weapon systems that include a large cannon tube.

**Significance of This Research**

The significance of this research documented in this paper is to explore the challenges of unique critical national defense production resources. These facilities and capabilities need to be protected. They also need to be modernized to meet demands of multiple customers simultaneously and have the capability to surge production when required. The production of large cannon tubes is a unique need for the Department of Defense. There are no commercial markets for these products or similar products. These unique challenges need to be understood to develop courses of action to mitigate them. The significant contribution of this research will be to re-examine the production capability during a time of high demand and provide recommendations. The findings and recommendations could be used by Department of Defense leadership to help inform industrial base investments.

**Overview of the Research Methodology**

One of the key elements to my research will be a literature review to bring together the relevant published sources on large cannon tube production. Some of the key variables include

the legislation that drives some of the decision making of where cannon tubes can be produced. This paper will be a qualitative review of the currently published sources that address different aspects of maintaining a functional organic industrial base for cannon tube production.

**Research Questions**

The research questions explored in this paper are as follows.

1. What are the constraints on cannon tube production in the United States?
2. How do cyclic rates of demand affect cannon tube production?
3. Given the constraints and cyclic rates of demand, how may the Army maintain sufficient production capacity for large cannon tubes in the United States?

These questions directly relate to the research purpose and help provide an elaboration on the concepts behind what is driving and limiting the National Defense Industrial Base to meet large caliber cannon tube production. The unique issues associated with cannon tube production will be explored as well as how the current circumstances evolved over time to lead to the current situation.

Yin (2018) argues that when explaining existing situations, the correct research methodology is case study research. This is especially true when the research questions are mostly “how” type questions. The questions being explored in this research paper are mainly “how” questions exploring the current situation with cannon tube production. Therefore, a case study review or qualitative research is an appropriate methodology for this research paper.

## Objectives and Outcomes

There will likely be clear responses and answers to the research questions found in the open literature. The synthesis of that data explored through these research questions will help address recommendations to the problem statement. I anticipate there will be an immediate interest in this research paper due to the critical nature of cannon tube production and timely discussion on how Watervliet can meet the demands facing it.

## Limitations

This research is limited in scope to the cannon tube production itself as that can be a pacing item for overall weapon system delivery. The focus of this paper is on production of cannon tubes in the United States. A limitation to this research is it is limited to published sources. Removing the ability to use interviews with current industry and government professionals within this research paper does not allow current problems and possible solutions to be explored. It also does not allow for some of the unique aspects of cannon tube production to be incorporated in the paper's findings. Limiting the scope of this research to large cannon tubes prevents other industries from being explored including small and medium caliber cannons. There are enormous startup costs and barriers to entry into the cannon tube production industry, so therefore, most of the research will focus on cannon tube production at Watervliet Arsenal. If there was more time and access to company proprietary information, those start-up costs would be explored to justify the necessity of investing in the modernizing of the production capabilities and flexibility at Watervliet Arsenal.

# Chapter 2 – Literature Review

## Introduction

A literature review was conducted to determine what is already known around the problem statement. Several different searches were completed to find the existing studies and information on this topic. A search in ProQuest for cannon tube AND manufacturing yielded 18,710 results. Quotation marks were added around "cannon tube" which reduced that to fifty-one results. With the Dissertations & Theses filter applied, those results were thinned down to nine results, of which, only one was a relevant source for the problem being researched. A search in Ebscohost for cannon tube yielded 222 results. Adding military with the AND bullion search narrowed the results to ninety-two sources. When the peer review filter was checked there were nine sources remaining and none were relevant for the problem being researched. Searching for Army manufacturing arsenals in Ebscohost yielded 110 sources. When narrowed down to Military and Government collection, there were twenty-seven sources left; of which two were relevant. My literature review then switched to google scholar to increase the number of relevant sources on this problem area. A search of "cannon tube production" yielded 77,800 results. Narrowing down that search to "cannon tube production Watervliet" yielded 936 results. However, most of the results were on the technical aspects of cannons and cannon production. A search in Google Scholar for "Army Manufacturing Arsenal" returned 49,300 results. The search was narrowed by adding "Army Manufacturing Arsenal Watervliet" to 3,880 results. Another search of "Army Organic Industrial Base" yielded 215,000 sources. This search was narrowed by adding "Army Organic Industrial Base Watervliet" yielded 684 results. These results were reviewed for relevancy by looking at the titles and determining if they could be a study that would define what is the existing knowledge on the topic. Additionally, the

bibliographies of the more current studies were reviewed for other relevant sources. In addition, a few sources were sent to me that did not show up in the searches including Phil Clark's "Naval Post Graduate School" research paper. A summary of the relevant studies that were found are detailed in the literature review.

**Literature Review**

Dees and Williams (1992), conducted an executive research project on Watervliet Arsenal (WVA) to help direct future investments and focus the corporate strategy of Watervliet Arsenal and other industrial base capabilities post-cold war. The paper addresses the historical and current mission of WVA, the current and future environment impacting the arsenal, and the strategic considerations of WVA's capabilities. The conclusion of the research was that cannon production is a unique production capability of WVA and sets it apart from other facilities. As such, WVA should focus on its strengths in developing a strategy to bring it into the 21st century, as well as focusing in on new technology both in cannon products as well as manufacturing techniques. The data presented supports the conclusions. The strength of this research from the perspective of my current research is its focus on WVA which both validates that it is the sole manufacturer of cannon tubes in the United States organic industrial base, and that its capabilities should be continued. One of the weaknesses of this research was that it was sponsored by Watervliet Arsenal, so some of the conclusions and analysis might not be completely objective which could undermine its validity and introduce some bias. For example, it might include the assumption that Watervliet Arsenal should continue to exist as a government owned, government operated manufacturing facility.

Potts (1994) wrote a research paper titled "Watervliet Arsenal: Snapshot of Industrial Base Future" during his time at the Industrial College of the Armed Forces. He presents Watervliet Arsenal's history, its current conditions, and provides some ideas on what Watervliet Arsenal might do in the future. The report tries to address where Watervliet Arsenal fits within the broader Defense Industrial Base. However, most of the paper is dedicated to a study of ceramics and composites as well as several other technologies and applications (Potts, 1994). There is not a sound collection nor analysis methodology for this study. It does have several interesting sections, but it is more a compilation of disparate sources and topics. The data does not support the conclusions, so therefore, I find it hard to include this study in the body of knowledge.

The U.S. Government Accountability Office (GAO) (1998) wrote a report for Congress titled "Army Industrial Facilities: Workforce Requirements and Related Issues Affecting Depots and Arsenals." This report was requested to focus on workforce issues which affect Army's Maintenance depots. It specifically addresses the depot in Corpus Christi, Texas. The report explores the Army's rationale for reduction of personnel during fiscal year 1998, the Army's status on putting together an automated system for making decisions on manpower to meet planned workload, issues that affect the cost-effectiveness of operations, and workload trends which affect productivity at the Army's manufacturing arsenals. The conclusions stated that the Army has not formed a decision on the plan for its industrial activities including its depots and manufacturing arsenals. The Army needs to improve its workload forecasting to improve personnel management decisions. The arsenals have broader problems which an automated system will not solve, and their future viability is in question (United States General Accounting Office, 1998). The data presented supports its conclusions. The strength of this report includes

its primary focus on people and the workforce of the depots and arsenals. One of the weaknesses was the underlying focus on the facility in Corpus Christi, Texas which does not represent the broader depots and arsenals. The report was also issued in the late 1990s where defense budgets were in decades of decline with the end of the cold war and the success of the first gulf war. Additionally, it was before the sharp focus on defense and increase in defense spending that started with 9/11 and the start of the global war on terrorism.

Albright (2000) wrote a strategy research project titled "Is there a future for the arsenal system? A discussion of a methodology for determining the viability and efficiency of the arsenal system" during his time at the U.S. Army War College. His study questions whether the arsenal system, which started operating shortly after the founding of our nation, will provide the same value in the future. It also questions the methods for which the Arsenals can operate efficiently and if they are of continued value to the Department of Defense. He concludes that the arsenals need to determine their core capabilities and make the case to the Army that those need to be sustained so the Army can meet its requirements for mobilization for war (Albright, 2000). The data is clear, logically presented, and supports his conclusions. One of the strengths of his research was it highlighted what the Arsenals need to do to stay relevant and continue to operate into the future. While the conclusions and recommendations are sound for the arsenal system overall, he does not pull in the uniqueness of each facility nor address the unique challenges of maintaining cannon tube production.

The GAO (2003) issued a report to congress on the "DOD CIVILIAN PERSONNEL: Improved Strategic Planning Needed to Help Ensure Viability of DOD's Civilian Industrial Workforce." The GAO did this study due to the over 50% decline in the government workforce in its twenty seven industrial facilities in the period 1987 through 2002. It studied if the

Department of Defense has implemented a depot maintenance strategic plan, the level at which those strategic plans exist, and the challenges affecting the workforce and personnel planning for the Department of Defense. The conclusion was that the Department of Defense did not implement a depot strategic plan to help define the workload of the depots to help meet future requirements (United States General Accounting Office, 2003). The data supports the conclusions. The strength of this report was the detailed information presented. However, this report was very similar to the GAO report from 1998 as the personnel challenges did not improve, and the long-term planning was still missing. In addition, the report did not differentiate between depots and manufacturing arsenals which have different requirements and competencies.

Hix et al. (2003) published a study titled "Rethinking Governance of the Army's Arsenals and Ammunition Plants" for RAND at the request of the Department of Army G-8. This work presents a detailed analysis of the Army's ordnance industrial base. There is a specific focus on arsenals and ammunition plants which includes Watervliet Arsenal. It proposes different forms of management and organization for the different types of facilities. The work highlights many of the problems facing these facilities and the Army, including retaining more capacity than the nation needs and an assessment of options of what to do about it including the privatization of some facilities (Michael Hix, 2003). The analysis is sound, and the data supports the conclusions. The strengths of this work include its detailed review of the entire government owned ordinance industrial base facilities. There is a clear focus on ownership of the assets and how to manage or change them. One of its weaknesses is that the recommendations of who owns the facilities will not address many of the problems it identifies in the manufacturing assets.

Clark (2003) wrote a case study for program management considerations with regard to the use of national arsenal assets. His paper explored the impacts regarding using national arsenals as it relates to considerations for program managers. The research question focused on the impact of the Army Arsenal Act and the Stratton Amendment on the development and procurement of the LW155, which is a large cannon weapon system. The research was primarily qualitative using literature research and personal interviews as the primary source of data. The conclusion included that the Army Arsenal Act and the Stratton Amendment are laws which serve to defend the sustainability of the national arsenals. Those laws limit the program manager's ability to pursue potential cost saving measures for the program as well as limiting their ability to make decisions aimed at providing the best product to the users. The data supports the conclusions and is a good guide for a program manager who must work with national arsenals such as Watervliet Arsenal. However, a key limitation is the assumption that the ability to produce large cannon tubes would continue to exist without those pieces of legislation, and more generally, that a producer of large caliber cannon tubes exists. The paper is a good guide for program managers but does not address how to maintain large cannon tube production from the perspective of the U.S. defense manufacturing base and specifically the Arsenals.

The GAO (2015) conducted another study titled "DOD Manufacturing Arsenals: Actions Needed to Identify and Sustain Critical Capabilities." This study by GAO fulfilled a request from Congress to review the Department of Defense's manufacturing arsenals which include Pine Bluff Arsenal, Rock Island Arsenal, and Watervliet Arsenal. The report looked at the Department of Defense's actions to provide work to these arsenals so they can have sufficient revenue to cover their operating expenses as well as how the Department of Defense sustains the

critical capabilities at these arsenals. There were a couple recommendations including that the Department of Defense should implement guidance on make-or-buy decisions, identify basic elements on what is required to implement its strategic plan, and to determine what are its critical capabilities so a minimum workload can be determined to sustain those capabilities (United States Government Accountability Office, 2015). The study has clear and defensible data which supports its conclusions as the GAO usually has access to all the information the Department of Defense has. This is one of the report's strengths. One of the weaknesses of the report is that it does not consider that make-or-buy decisions may reduce revenue going to the arsenals, and it does not address how the arsenals can acquire sufficient revenue which will cover the operating expenses to maintain those critical capabilities.

Ryu (2016) wrote a research paper titled "Investing in the Army Organic Industrial Base to Operate and Win in a Complex and Austere Environment" for the School of Advanced Military Studies at the United States Army Command and General Staff College. He argues that the Army Organic Industrial Base contains critical capabilities to ensure the readiness of our Armed Forces. There is a cyclical nature of the Department of Defense's budget following every war which creates budget constraints which reduces investment in development and procurement of Army systems. That makes it difficult for the Army organic industrial base to remain responsive and flexible to meet the Army Operating Concept. He uses the perspective of modernization, capacity, and public-private partnerships in determining the extent that the Army organic industrial base can meet future requirements through case studies of Watervliet Arsenal and Anniston Army Depot. He argues that these facilities need to designate a minimum workload to remain competitive and find a way to reduce or remove non-mission costs like facilities overhead (Ryu, 2016). The data supports the conclusions. The report has a logical

flow and states a clear, compelling case for investment. However, the main conclusions are not always in the Army organic industrial base's area. This can lead to an oversimplification of the problem set with short term budget fixes and accounting offsets which do not address the core issue of how to maintain the critical capabilities and capacity through those historical budget cycles.

Gansler (1978) wrote his PhD thesis titled "The Diminishing Economic and Strategic Viability of the U.S. Defense Industrial Base" at American University. His key findings were that the market forces were not working in the military-industrial complex, and that policy makers were not taking that into account in their decisions. These inefficiencies lowered the effectiveness of military equipment production and were exacerbated by extremely cyclical demand (Gansler, 1978). The data presented is sound and supports the conclusions. Some of its strengths are that it is extremely detailed with over 800 pages and approached the problem completely independently from the defense establishment. It looked at the economic side of the defense production to avoid nationalization of the assets or forced government expenditures. One of its weaknesses is that the economic focus does not consider some of the realities of the defense business and budgeting cycles.

## Conclusion

The research found helped to lay out the foundation of knowledge around the industrial base for cannon tube production. There is a good amount of knowledge published on the Army's manufacturing arsenals. The research found underscores the importance of Watervliet Arsenal as a cannon tube production facility. Many of the constraints and challenges with a government -owned, government-operated facility are detailed. Some of the research discusses options for

low demand times and specifically stating the need for minimum quantities required. This provides a good knowledge base to start this research paper. The research found does not talk about how to optimize the facility to cope with the cyclical nature of the production demands. There remains a knowledge gap around how to optimize the cannon tube production capability and capacity during times of cyclic demand. How does Watervliet Arsenal, and by extension the U.S. Army, maintain a sustained low rate of cannon tube production as well as to maintain the surge capability in times of increase demand? This is the knowledge gap that I will research in this paper. How to maintain the right level of capacity in both high demand and low demand environments.

# Chapter 3 – Research Methodology

The purpose of this chapter is to lay out the research methodology that was followed for this research paper. The chapter goes over the research questions, research design, data collection methodology, that addresses the bias and error, including the validity and reliability of the research. This research paper uses a qualitative case study approach to review existing knowledge and data to conduct the research analysis.

## Research Question

The primary problem that is explored in this research paper is that there is a set capacity for large cannon tube production in the United States to meet the demand of multiple customers with reasonable delivery lead times. The purpose of this research paper is a qualitative descriptive case study to describe the National Defense Industrial Base's ability to meet large caliber cannon production in times of increased demand. The research questions are:

1. What are the constraints on cannon tube production in the United States?
2. How do cyclic rates of demand affect Cannon Tube production?
3. Given the constraints and cyclic rates of demand, how may the Army maintain sufficient production capacity for large cannon tubes in the United States?

## Research Design

This section will go over the research design and the key processes and methods used to collect and analyze the collected data. The specific research strategy that will be employed to provide answers to these research questions is a qualitative descriptive case study. Since the questions are mainly "How" questions, Yin (2018) writes that case study research is appropriate

when explaining situations that are current and already exist. Based on the research I am conducting and the research questions I have, a qualitative case study is most appropriate.

To find answers to these research questions, I searched Google, Google Scholar, ProQuest, and Ebscohost to find published data. I also searched through GAO reports, and other government sources to find publicly released data to use in my research. I also reviewed and searched the bibliographies of the published research to find additional sources of data. The data primarily came from published articles about Watervliet arsenal and production at government - owned, government-operated manufacturing arsenals. Several different searches were conducted to find the existing data. A search in ProQuest for cannon tube AND manufacturing yielded 18,710 results. Quotation marks were added around "cannon tube" which reduced that to fifty-one results. A search in Ebscohost for cannon tube yielded 222 results. Adding military with the AND bullion search narrowed the results to ninety-two sources. Searching for Army manufacturing arsenals in Ebscohost yielded 110 sources. When narrowed down to Military and Government collection, there were twenty-seven sources left. My literature review then switched to google scholar to increase the number of relevant sources on this problem area. A search of "Cannon Tube production" yielded 77,800 results. Narrowing that down that search to "cannon tube production Watervliet" yielded 936 results. However, most of the results were on the technical aspects of cannons and cannon production. A search in Google Scholar for "Army Manufacturing Arsenal" returned 49,300 results. The search was narrowed by adding "Army Manufacturing Arsenal Watervliet" to 3,880 results. Another search of "Army Organic Industrial Base" yielded 215,000 sources. This search was narrowed by adding "Army Organic Industrial Base Watervliet" yielded 684 results. These results were reviewed for relevancy by

looking at the titles and determining if they include data that could be used to help answer the research questions.

The setting and environment in which my research was conducted was primarily using internet resources limited to currently existing publicly released data. This is primarily due to the restrictions of not having an Institutional Review Board, so interviews could not be conducted with existing practitioners and subject matter experts. The requirement to publicly release this research paper also drove to this research design and restricted my ability to use limited distribution sources of data in the research. The research was restricted to the use of internet resources as a requirement of the Senior Service College Fellowship and a result of pandemic restrictions. The data found is detailed in chapter four. The relevant sources were then put into a data analysis table to sort through themes of data which would answer the research questions. Thirty-six different sources of data were tabulated and analyzed in this data analysis table.

**Data Collection**

The key research instruments used to collect data were internet searches primarily using Google, Google Scholar, ProQuest, and Ebscohost. For the data collection, Google and ProQuest were the most useful. There were a lot of articles published in non-peer reviewed journals and other internet data publications like press releases. Google scholar lacked results from these sources and therefore did not add much data above the existing knowledge sources detailed in chapter two. I used Google to search for "Watervliet Arsenal" cannon tube production which yielded 6,670 results. The DAU library was utilized to access ProQuest. In ProQuest, all databases were checked, and the search terms included (Cannon tube) AND

production AND Watervliet which yielded 210 results. Including "Watervliet" as a search term was necessary to narrow down the results, but it could skew the data. However, this should not introduce a significant amount of bias because Watervliet is the sole source of supply for cannon tubes in the U.S. However, it will limit the scalability of the research to cannon tube production and unique production processes of government owned, government operated manufacturing arsenals and facilities.

**Bias and Error**

There were a few limitations to this research which were highlighted in chapter one. I will discuss how I attempted to mitigate each of those limitations and to what extent it limited the results and might have biased the data and therefore the conclusions that were drawn from that data.

The research in this paper is limited in scope to the cannon tube production itself. The cannon tube is a pacing item for an overall weapon system, as well as being a replacement part, so that fact should limit the impact of this limitation. The focus of this paper is on production of cannon tubes in the United States. Watervliet Arsenal is the sole source of cannon tube production in the United States. This limitation should not result in bias or error within the data. Additional sources of cannon tube production will be briefly explored along with the benefits and limitations of utilizing those sources and included in the conclusions.

Another limitation to this research is it is limited to published sources. Removing the ability to use interviews with current industry and government professionals within this research paper does not allow current problems and possible solutions to be explored. This limitation will be mitigated by scouring existing published sources and staying within publicly available

sources. The richness and thoroughness of the conclusions and findings would be enhanced with the use of distribution limited material and interviews with government professionals who wrestle with the challenges of cannon tube production daily.

The scope of this research paper is limited to large cannon tube production. This prevents other industries from being explored including small and medium caliber cannons. There is enormous startup costs and barriers to entry into the cannon tube production industry, so this limitation should not affect the results of the data or analysis, nor the resulting conclusions. The research will focus on cannon tube production at Watervliet Arsenal, so a potential bias in my data and conclusions is a focus on the organic government industrial base which includes Watervliet Arsenal included within it. If there was more time and access to company propriety information, start-up costs and barriers to entry would be explored and would likely further justify the necessity of investing in the modernization of the production capabilities and flexibility at Watervliet Arsenal.

In total, these limitations should not introduce unacceptable bias and errors into the data and conclusions of this research paper. Many of the sources of data will stem from press releases from Watervliet Arsenal public affairs, however, the facts will be gleaned to remove the interpretation or rhetoric from the data.

**Validity of the Research**

The research will be done until data saturation is achieved using the search terms that were identified. When the results of the data sources started to be repetitive with the same type of information, that would indicate data saturation was reached. When data saturation was achieved and the existing information and data was gathered, the research will be complete.

The findings and conclusions of this research are primarily applicable for the United States Army. It can be generalizable to the United States Department of Defense especially for government-owned and government-operated manufacturing facilities. However, it is likely not applicable to private industry. Cannon tubes are a uniquely military item, and there are not many commercial products that have similar features required.

This qualitative descriptive case study is the right methodology to yield the data that is appropriate and adequate to answer the variables in the research questions. The data gathered appropriately answers the research questions. Even with the limitation of not being able to conduct interviews and publicly released data, the data collected does span the gamut to cover the information required to answer the research questions.

The research being conducted follows the standard five-chapter research format. With the processes explained in chapter three, it would allow others to arrive at the same results in chapter four and conclusions in chapter five. The research format is dictated by the Senior Service College Fellowship program, and this research follows that prescribed format.

**Reliability of the Data**

The research can be easily duplicated by other researchers utilizing the sources and search terms provided. The data found falls into straight forward themes. There were also different people looking at the research including an independent reviewer, the Senior Service College Fellowship Director, a Research Advisor, and Research Director to ensure the logic of the research, analysis, and the conclusions are sound. The reliability of the data is supported by well documented and researched articles, government reports, as well as GAO and RAND reports.

In summary, this section detailed the design of my research methodology. The actual data collection as well as the findings results will be presented in the next chapter.

# Chapter 4 – Findings

## Introduction

"The history of the Watervliet Arsenal is best understood as a constant cycle of expansion and atrophy — adding capacity in times of war and falling into underutilization during peace" (Witcher, 2022).

We are in the midst of one of those times of war. It is estimated that the artillery ammunition that is produced in one year in the United States would last less than two weeks in the current conflict in Ukraine (Schneider, 2022). One of the ways to address burning through your stockpile is to produce more of that item. The stockpile can serve as a buffer as the industrial base increases production to meet the sudden, rising demand. As long as the industrial base has the capacity to produce items faster than they are used within the buffer of the stockpile, there is not a critical issue to address. However, in the case of large gun tubes, this is not the case. The lead time to deliver new gun tubes is far greater than the rate of usage minus the stockpile on hand.

There are a couple of themes that emerged from the research. A basic pattern emerges. There are times of low production, times of high production, and then the expansion or contraction cycling between those two extremes. The issue of maintaining the production capacity to minimize the impacts of cycling between those two rates of production was readily apparent.

The Army recognized the need for an organic manufacturing capability and that was validated by Congress through legislation like the 1920 Arsenal Act. Besides the Army directives and congressional laws, there is a commonsense reason to retain an organic manufacturing capability: that there are core capabilities that are critical to warfighting that they

should not be relegated to a manufacturer whose priority is not the Department of Defense (Gourley, 2011).

**Collected Data**

Ramping up a war machine:

Harry Thomson and Lida Mayo (1955) wrote a book which included a chapter about the procurement and supply of Artillery in World War II. They state that the "neglect of artillery development was a sad mistake, for the design and manufacture of big guns cannot be improvised on the spur of the moment." The design, development, and manufacturing process take years, however the simple fact that arsenals existed that knew how to manufacture and produce guns was invaluable to help get production started. Watervliet Arsenal was the focus for production of finished guns. The arsenal supplied about twenty five percent of what was needed for World War II, but they supplied the expertise and know-how to quickly ramp up the entire commercial industry to make the cannons required by the magnitude of World War II. This was only possible due to the fundamental knowledge of gun making arts which were carefully preserved and fostered at the arsenals during the years between wars (Harry Thomson, 1955). There are a lot of lessons to be learned from the experience in World War II's production of large guns. While there are limitations to the applicability of the specific experiences, including changing production processes and the sheer magnitude of weapons required, the principles are very much translatable and transferable to how to manage drastically changing production demands for cannon tubes. A key take-away is the importance of having a current arsenal that maintained the expertise on how to build cannon tubes. Not all the gun tubes have to be made at that facility, but having a current facility and some current production allowed those skilled

craftsmen in gun making arts to exist. Those experts could then turn into consultants or subject matter experts to work with contracted vendors to bring their production facilities online.

Another history lesson comes from when the Army purchased a new "rotary forge" in 1975. A rotary forge is a very large machine about 195 feet long and weighing 910 tons which could produce cannon tubes at a six times faster rate than the contemporary methods. There was a lot of discussion whether to place this machine in the public sector or the private sector. Due to the high-risk market of cannon tube production, and the high cost of the equipment, no private manufacturers were willing to buy it on their own. While there is an argument that the capability might have had a greater return on investment in the private sector, the Army had a very real concern that they would have full access to this forge capability when they needed it. The economic arguments were trumped by the national security requirements to maintain the unique production capability for cannon tubes (Gansler, 1978). As is the case from the war of 1812, if the United States wants to maintain the capability to produce cannons, then the United States must maintain a government owned arsenal to do so. There was a real concern that if that capability was put into the private sector, there would not be the commercial industry available to support that equipment over a long period of time.

Moving through history, Watervliet expected production capacity at the Arsenal to double between 1981 and 1987 under the Reagan Administration with its plans to increase the nation's defense budget. One of the reasons Watervliet is a sole source for cannon manufacturing is that manufacturing cannons is not a viable peacetime proposition and companies found it to be unprofitable (New York Times, 1981). While the buildup of defense was critical for deterrence during the cold war, it also represented building up a facility's capacity which would have high carrying costs over the next couple of decades. This build up is

similar to the challenges facing Watervliet currently. The high rate of demand from multiple customers simultaneously puts the facility under large pressure to grow capacity quickly.

Scott Gourley (2011) wrote an article titled "Two Centuries of Commitment to the Warfighter, Watervliet Arsenal" tracing the history of Watervliet Arsenal. The Arsenal peaked during World War II at 9,300 employees, manufacturing 23,211 cannons. The production quantities have fluctuated through the years and our country's many wars including Korea, Vietnam, and the first Gulf War. One of the last major investments in Watervliet was in the 1980s with the Renovation of Armament Manufacturing (REARM) project which modernized a significant portion of the facility. One of the challenges highlighted includes that the products that are produced do not have an expiration date. Cannon tubes typically last until they are shot out or otherwise damaged which can take generations when not in combat. In 2011, the arsenal workforce was down to 631, but continued to produce all the U.S. Army's gun barrels for tanks and artillery weapon systems. Despite the dwindling workload, maintaining enough trained machinists is critical. In 2004 the arsenal brought back an apprentice program in conjunction with a local community college which originally started in 1905 to ensure there is a local pipeline of manufacturing talent. The program comprises of 8,000 hours of on-the-job training as well as four years of evening instruction at the community college to become a journeyman machinist (Gourley, 2011). The article is written by Watervliet Arsenal Public Affairs, so they are trying to publish positive stories and could be slanting the story to garner support toward Watervliet. Despite this, the facts and data presented are clear and give a picture of what is required to have a trained workforce to produce cannon tubes over a long period of time.

Statutes and Regulations:

Daniel Else (2011) provides a good summary of the Arsenal Act through the Congressional Research Service. He argues that while the language of the Arsenal Act is relatively simple, it can be easily mis-understood, especially when it comes to an economic basis. The act does not detail exactly what goes into making supplies on an economical basis.

> The Arsenal Act, 10 U.S.C. §4532, requires the Secretary of the Army to have all supplies needed by the Army to be made in government-owned factories or arsenals if this can be accomplished "on an economical basis." (House of Representatives, Congress., 2015)

AR 700-90 (Headquarters, Department of Army, 2020) provides the policy for the use of the Army Industrial Base Process including the manufacturing industrial base and its ability to effectively support operation, to surge, and its sustainability. Paragraph 5-1 begins by stating, "The intent of the Army-owned industrial base is to be postured to support the force structure with efficient, economical, practical, responsive, multifunctional, environmentally responsible, and compliant facilities." Nevertheless, paragraph 5-2 states that, "The Army will rely on the private sector for support of defense production to the maximum extent practical and Government facilities also may be necessary when no commercial producer can be induced to supply needed items, to ensure continued availability of important capabilities and capacities in time of national emergency, or Government facilities are more efficient or economical than private industry."

"The only way we can keep our own mobilization base is to keep enough people working there on cannon manufacturing, Stratton said of the arsenal, noting that in the past allies had purchased U.S. arms technology and then sold it to third countries, cutting demand" (Mitchell, 1986).

The Arsenal Act law provides a clear emphasis to use government-owned arsenals for supplying the Army, while AR700-90 directs PEOs and PMs "to rely on the private sector to the

maximum extent possible unless Army-owned factories are more economical" (Headquarters, Department of Army, 2020). Cannon tube production has extremely high start-up costs and there are not many commercial equivalent applications for a material like a large cannon tube. Therefore, it is unlikely that there will be an economical alternative in the United States other than Watervliet Arsenal. The "economical" piece also must include lead times for production. When defense articles are needed for operations, schedule often trumps cost, so, both should be allowable considerations for where items are produced. One sentence is often overlooked in this AR when discussing the organic industrial base. It is to ensure continued availability for the important capabilities and capacities in a time of national emergency. Large cannon tubes are clearly an important capability for war. This should lead to the analysis of how much production capacity is necessary to maintain at the ready, and how much can be brought online quickly. That analysis should not be restricted to the continental United States but extend to what our partner nations could produce as well. The Stratton Amendment makes that illegal to even pursue, which prevents a realistic assessment of options from even being completed.

Workload management and forecasting:

When customers buy products from the Army Organic industrial producer, their unit-cost price includes an allotment of the operating costs which are the cost of production, as well as the entire cost of maintaining underutilized capacity (Doherty & Rhoads, 1997). As production quantities decrease, the cost per unit to customers increase which makes the arsenal even more uncompetitive.

*Table 1: Reported Arsenal Workload and Employment Levels for Fiscal Years 1988 through 1998 (United States General Accounting Office, 1998)*

| | Rock Island | | Watervliet | |
|---|---|---|---|---|
| Fiscal year | Workload[a] | Workforce | Workload[a] | Workforce |
| 1988 | 1,944,291 | 2,501 | 1,894,000 | 2,013 |
| 1989 | Not known | 2,609 | 1,703,000 | 1,928 |
| 1990 | 1,843,268 | 2,442 | 1,583,000 | 1,767 |
| 1991 | 1,790,685 | 2,460 | 1,556,000 | 1,719 |
| 1992 | 2,029,436 | 2,377 | 1,444,335 | 1,623 |
| 1993 | 1,849,193 | 2,289 | 1,313,044 | 1,538 |
| 1994 | 1,583,674 | 2,144 | 1,129,575 | 1,422 |
| 1995 | 1,557,574 | 2,033 | 834,000 | 1,103 |
| 1996 | 1,258,073 | 1,853 | 800,000 | 1,024 |
| 1997 | 1,225,849 | 1,730 | 681,000 | 971 |
| 1998 | 1,140,941 | 1,531 | 593,000 | 897 |

[a]Workload is expressed in the number of direct labor hours

> An arsenal official estimated that as of April 1998 the Watervliet facility was utilizing about 17 percent of its total manufacturing capacity—based on a single 8-hour shift, 5-day workweek—compared with about 46 percent 5 years ago and about 100 percent 10 years ago. Underutilized industrial capacity contributes to higher hourly operating rates. Over the last 10 years, the hourly rates charged to customers increased by about 88 percent at Watervliet. (United States General Accounting Office, 1998, p. 57)

According to the United States General Accounting Office (1998) there are several uncertainties that the Army's arsenals must confront due to inadequate long-range plans. The Army was considering converting two of its arsenals to government-owned, and contractor-operated facilities. However, some key questions remained which prevented this, including the cost-effectiveness and efficiency of this move, how that will improve the workload management, and the relative importance of retaining specialized manufacturing capabilities within the government. One area held up by program managers is that The Arsenal Act includes a "make or buy" process. However, the arsenals reported the "make or buy" process was rarely used. For

example, Watervliet reported that it did not participate in a "make or buy" decision since 1989 nor has it received any new work through the Arsenal Act through the reporting period in 1998. Officials at both arsenals expressed that they do not expect to receive future work because of any "make or buy" analyses (United States General Accounting Office, 1998). Even though there is protectionist legislation, it is not meeting the intended purpose and only adding additional bureaucracy to program managers in an already lengthy and cumbersome acquisition process. Since those processes do not bring in additional work, they don't help the calculation of rates. In a declining demand environment, the cost calculation will continue to rise. This will make the products those arsenals produce even more un-economical.

For day-to-day operations, the Army Working Capital Funds is the primary source of funds used by the Army arsenals. The army industrial activities at the arsenals are required to break even and to operate in a business-like manner. This breaks down when the Army requires a facility like Watervliet to maintain cannon tube production capability and capacity even if there are not enough orders to execute that in a cost-effective manner. There is an authority to pursue funding for "underutilized plant capacity." As shown in table 2, funding for this account was reduced drastically from 1996 to 1997. Army officials report that the reduction was made primarily to fund other higher priority programs. The did say that in future years, this trend could be reversed. This adds to the inability of manufacturing arsenals like Watervliet to adequately plan for the future (United States General Accounting Office, 1998). The arsenals have sought to diversify their business operations to improve the utilization of available capacity and to reduce their overhead costs. There are limitations and risks in doing this diversification. Both arsenals have tried to develop new business areas because their traditional weapon-making responsibilities were not providing enough work to allow them to operate efficiently.

*Table 2: Army Underutilized Plant Capacity Funding (United States General Accounting Office, 1998)*

Dollars in millions

| FY | Arsenals | Depots | Total |
|---|---|---|---|
| 1996 | $56.1 | $73.8 | **$129.9** |
| 1997 | 22.0 | 24.1 | **46.1** |
| 1998 | 20.6 | 24.2 | **44.8** |

Source: Army Budget Office.

In the report "Future Capability of DoD Maintenance Depots Report", Avdellas (2011) writes that depot maintenance work could provide manufacturing arsenals an option to maintain their skill base when their primary mission work is slow. This can happen when there is an absence of a core minimum workload. The manufacturing arsenals are unable to accurately forecast manufacturing work more than twelve to twenty-four months in advance when there is not an existing customer and demand. One example is the Future Combat System. When that program was cancelled, it would have represented almost half of Watervliet Army Arsenal's out-year workload. The Future Combat System cancellations followed shortly after the cancellation of the Crusader and the non-line-of-sight howitzer. The workload uncertainty and rapid fluctuation led to nine reductions in force between 1991 and 2002 (Avdellas, Berry, Disano, Oaks, & Wingrove, 2011). This challenge of planning future work is part of the reason why it so difficult to run Watervliet and other manufacturing arsenals in a business-like manner. When the Army demands that a specific manufacturing capability exists, the Army must provide the necessary workload and funding to keep that capability available.

Maintaining capability with low demand:

Snyder (2015) wrote an article titled "Watervliet Arsenal adds luster, durability to today's howitzers" stating that the Army does not have any new programs that involve the production of

large cannon tubes for the next decade. He states that the arsenal must figure out ways to incrementally modify current systems through product improvement efforts to bring any workload into the arsenal. He indicates this is not a new phenomenon for Watervliet Arsenal as there have been numerous ebbs and flows in the defense budgets. That has led to significant decline in orders of cannon tubes. One such improvement has been the chrome plating of artillery tubes which serves to extend the life of the cannon tube by over 50% (Snyder, 2015). While that is good for the Soldiers, it does not help maintain steady demand for cannon tubes when there is not a major shooting conflict. The article is written by Watervliet Arsenal Public Affairs, so they are trying to publish positive stories. The conclusion is clear that the arsenal is just trying to figure out how to adapt to the realities of 2015 of shrinking defense procurement budgets for the foreseeable future. In another article Snyder (2016) wrote titled "Marines have landed at Watervliet…with money", he highlights a $2.6 million order in new, un-forecasted work which added nearly 15,000 hours of direct labor. This is during a time of declining defense budgets, and each order is essential to sustain critical skills of the arsenal workforce. The arsenal worked hard to secure this order as well as foreign military sales to ensure there is sufficient work to sustain the workforce (Snyder, 2016). This again highlights the arsenal trying to navigate the difficult budget situation to keep their workforce employed. Snyder (2013) wrote that the Arsenal's business model and manufacturing focus has changed from cannon production to the production of mortars and non-tube manufacturing. While that can help the arsenal maintain a steady workload, it does not necessarily help to maintain Watervliet Arsenal's capability and capacity to produce advanced cannons on which Watervliet is solely relied upon to do. In a business setting, diversification is critical to sustain a business, especially when one product line takes a negative hit, or to weather the cyclic nature of many industries. For a place

like Watervliet, getting business outside of the large gun manufacturing and the core reason why they need to exist, could be a risk to those projects when demand for cannon tubes increase.

Watervliet Arsenal hosted a workload summit in 2014 with its various stakeholders and customers to develop a strategy that would ensure the Arsenal remained relevant and positioned to support future Army needs. Sequestration, which was a provision of the Budget Control Act of 2011, had wide ranging across-the-board spending reductions which had Army customers reducing orders of products from Watervliet Arsenal. The Arsenal weathered countless reductions of wartime requirements since its inception during the War of 1812. Watervliet held another workload summit in 2017 with a completely different tenor. They received more than $100 million in new contracts with most deliveries between 2018 and 2020. The volume of work received required changes to their workforce and facilities to accommodate the large volume of deliveries. Part of the challenge is to grow the Arsenal's capability and capacity to meet future requirements in an unpredictable environment (Snyder, 2017). It is a better challenge to have the issue of growing to meet demand verses trying to secure enough work to keep the lights on from a manufacturer's perspective. However, it is very costly and inefficient to have such extreme changes in a short amount of time. In 2014, Watervliet was at the nadir of demand and was looking to non-traditional sources and production to stay open. But three years later, they were scrambling to increase capacity for cannon tube manufacturing. This drastic change in requirements reduces the amount of flexibility to surge production in the case of a wartime spike in demand. AR 700-90, The Army Industrial Base Process, defines surge as "the ability of the industrial base to rapidly accelerate production output to meet requirements of selected items with existing facilities and equipment" (Headquarters, Department of Army, 2020, p. 39). Colonel Morrow, the Watervliet Commander, states that Watervliet leadership is trying

to increase capacity and capability by investing in the Watervliet workforce and infrastructure. He acknowledges that whether it is new personnel or machinery, both take time to ramp up (Morrow, 2017). This whipsaw of demand from 2014 to 2017 put Watervliet in a very challenging position to fully support the multiple modernization priorities and the spike of demand that was coming.

John Snyder (2017) wrote an article "Watervliet Arsenal receiving a non-standard contract, but one that will save Soldiers' lives" was about receiving a vehicle armor plate contract. Even though it is relatively small order of $3.7 million with 16,000 hours of direct labor, it allows the Arsenal's manufacturing skills to be leveraged and maintained. He goes on to point out that this work does not require as high of precision as large cannon tubes with its tight tolerance (Snyder, 2017). This article was released by Watervliet public affairs office, so it is accurate and shines the best light on the work being done. While it is good to keep the arsenal work loaded, this type of work does not exercise all the necessary skills required to produce large caliber cannon tubes. If this work is being used to train machinists and keep their professional skills honed, that is good. However, if it takes time away from producing large caliber gun tubes; it could take away from the core mission of why Watervliet exists. The amount and percentage of this type of work needs to be balanced and supplemental to the cannon production mission. There also must be a path to divest this work quickly if it takes away from Watervliet Arsenal's ability to be immediately responsive when spikes of demand happen for cannon tubes. Time to ramp up production again:

Watervliet Arsenal received its largest military sales contract in decades in 2017 to support an India FMS sale of M777A2 (Snyder, 2017). While the deal took over eight years to finalize, it represents only two years of production along with about two years of lead time to

start deliveries. Even with this production order, it will only fill the gap in workload requirements to sustain the workforce at the time for two years. The Army and the arsenal valued the size and importance of this order as it could lead to further orders later. The Arsenal Deputy Commander stated that this order came at the right time for the arsenal because of the dramatically weakened manufacturing requirements since the drawdown in Iraq in 2010. The importance is not only the manufacturing work, but the justification to maintain its highly trained manufacturing workforce. The production order brought a little over 100,000 direct labor hours which allows the exercising of every critical cannon manufacturing skill set at Watervliet. Even with the order size, it will not solve the ills of an uncertain and declining defense budget (Snyder, 2017). This article is written by Watervliet public affairs, but it is filled with accurate facts and data of the realities at that time. Watervliet highlighted the lean budget years and trying to maintain their workforce. As large as the order was, it only represented a fraction of the yearly production loading that the Arsenal was capable of in the 1990s based on data in Table1. It is also the initial large commitment from an additional and external customer that the Army made leading into their current large production backlog. When one customer capitalizes a majority of the production capacity for a period of time, there is a dramatic reduction in flexibility that is possible over that time period. As referenced, coming out of the drawdown in Iraq; any customer was a positive for the Arsenal. However, this highlights the difficulty that Watervliet and other manufacturing arsenals face when trying to operate like a business. Especially when Watervliet does not have the luxury of turning down orders for Large Cannon tubes as they are the only place in the United States where these cannons can be built.

One of the biggest challenges to ramping up production at Watervliet Arsenal is the element of time. It takes Watervliet Arsenal almost two years to get a new machine online for

production due to the small number of vendors who produce unique machines for the manufacturing requirements for cannon tube production. Additionally, it takes the Arsenal four years and 8,000 hours of hands-on training to turn an apprentice into a fully qualified machinist (Snyder, 2017). These lead times must be kept in mind when there are fluctuations in the amount of demand. Keeping a relatively steady state of production would allow these two extreme lead times to be carefully managed. Time is usually not a luxury that exists when scaling up for combat operations. As Donald Rumsfeld is famously quoted "You go to war with the Army you have. Not the Army you might want or wish to have at a later time." What makes this an extremely relevant quote is what comes immediately before that famous sentence "It isn't a matter of money. It isn't a matter, on the part of the Army, of desire. It's a matter of production and capability of doing it" (Sonnenfeldt & Nessen, 2004). The element of time is critical when it comes to combat operations and is one of the only variables that is nearly impossible to secure more of when you need it most. It would be unaffordable to keep a hot production line for every war item, especially since each war has its unique requirements and specific needs for that fight and theater of operations. However, having access to large guns has been a constant in every war and conflict the Army has been involved with. Keeping a warm production line for critical Army requirements should be a consideration to ensure there is flexibility to provide what our Soldiers need when they are called upon to deploy to fight and win our Nation's wars.

Gourley (2018) wrote an article "Forging Ahead" for the Army magazine where he states that Watervliet is a strategic single point of failure. There is no other place the Army and Department of Defense can turn to for cannon manufacturing in the United States to meet its requirements. General LeMasters stated that there are other places in the world that produce

cannons but expressed concern if the Army and Department of Defense relied on that for its critical systems. He went on to highlight the benefit of having an organic asset that can surge production of critical cannons if required. Having unique capabilities like the rotary forge allows public-private partnerships that allow industry like Electralloy to use forge time. Electralloy used to buy forge time, but then turned the relationship into a partnership to use the government forge to do commercial products in a steady state. The benefits of that arrangement include increasing the base level of maintenance, shared cost of maintenance, and skill sustainment (Gourley, 2018). While single points of failure are usually not seen as a positive robust manufacturing management practice, it can serve to focus the energies of the government to preserve this critical capability. This is part of the value proposition of having Watervliet as an Army owned and operated facility. The public-private partnership is also a great way to diversify the customer base to ensure ongoing demand and production of the critical manufacturing capabilities if it is in Watervliet's core competencies.

The Interagency Task Force in Fulfillment of Executive Order 13806 (2018) chartered by the Office of the Deputy Assistant Secretary of Defense for Industrial Policy highlighted that markets thrive on predictability. This allows businesses to formulate informed decisions for the future. The Department of Defense spending oscillates dramatically with the buildup and arming for conflict. The subsequent drawdown after the conflict is over, comes with the corresponding decreases in program funding. Figure 1 shows the large changes in funding for weapon systems procurement and research, design, test, and evaluation. These defense spending uncertainties at the top level make forecasting the overall market size difficult and it can impede the forecasting up and down the supply chain. The impact is limited investment in capabilities even when defense spending increases. The suppliers who build for large scale production have excess

capacity when programs end which creates long-term market distortions (Interagency Task Force in Fulfillment of Executive Order 13806, 2018). These macro trends impact the manufacturing arsenals like Watervliet. Not only in dramatic swings in customer requirements, but also with the availability or scarcity of defense dollars. When there are build ups, the availability of funds is usually only in areas of focus for that current conflict and only in timescales which will be relevant to the current operational construct. In the downturn, there is a large scarcity of dollars which makes it very difficult to justify any investments for potential future contingencies. Both highlight challenges for securing long-term internal capital investment decisions which lead to situations where capital equipment at Watervliet Arsenal are 250% past their expected service life as shown in Figure 4. This puts future production orders and delivery schedules at risk for catastrophic failures and unacceptable delays if that equipment fails during a required surge in production.

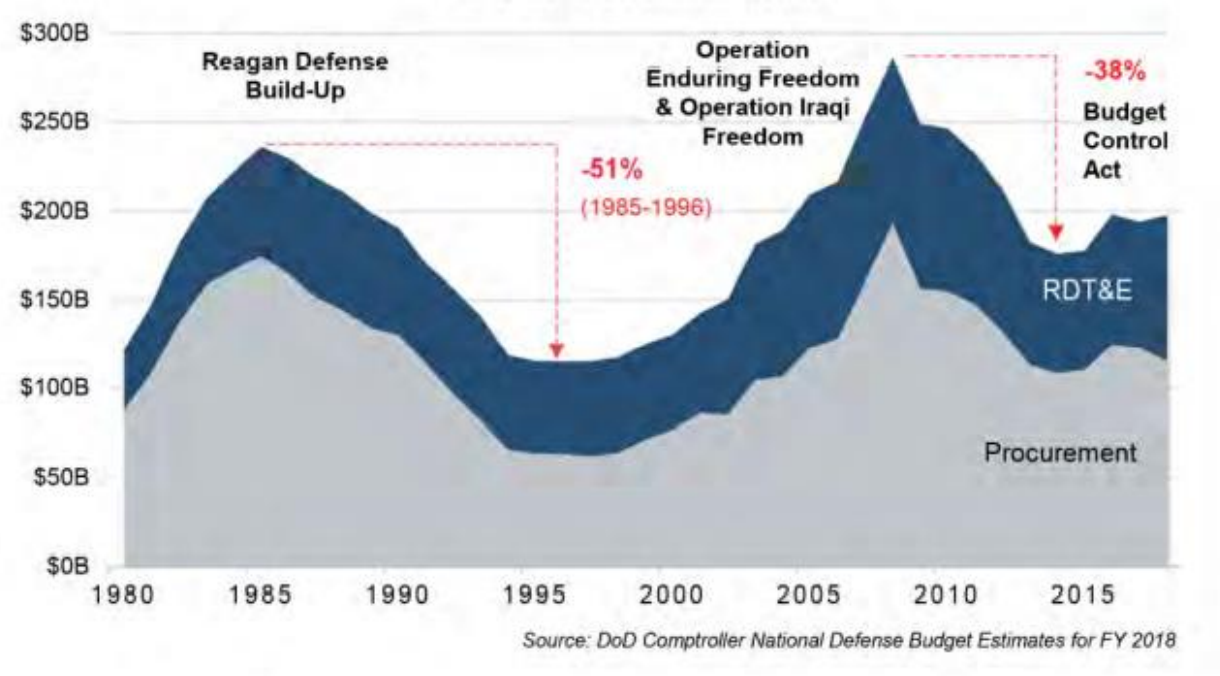


*Figure 1: Defense Investment Spending From 1980 to 2017 (Interagency Task Force in Fulfillment of Executive Order 13806, 2018)*

As shown in Figure 2, there is a sharp decline in manufacturing related jobs relative to the rest of the U.S. economy. There is a macro decline and lack of skilled manufacturing workers in large part due to a decreasing number of jobs. There is also a widening gap between the number of job openings and hires in manufacturing skilled positions as shown in Figure 3 (Interagency Task Force in Fulfillment of Executive Order 13806, 2018). It makes the ability to attract and retain skilled manufacturing workers like machinists much harder on a local level including at such places like Watervliet Arsenal. As was discussed earlier, there is almost a four-year lead time from when a new hire is identified to start the apprentice program to when they are a fully qualified machinist. What this means for manufacturing arsenals is that having a consistent demand and an accurate production forecast, is even more critical. The economy overall in the United States does not have an excess of this type of skilled labor for any manufacturer to pull from. It makes the job market more competitive, and retaining those trained workers is essential.

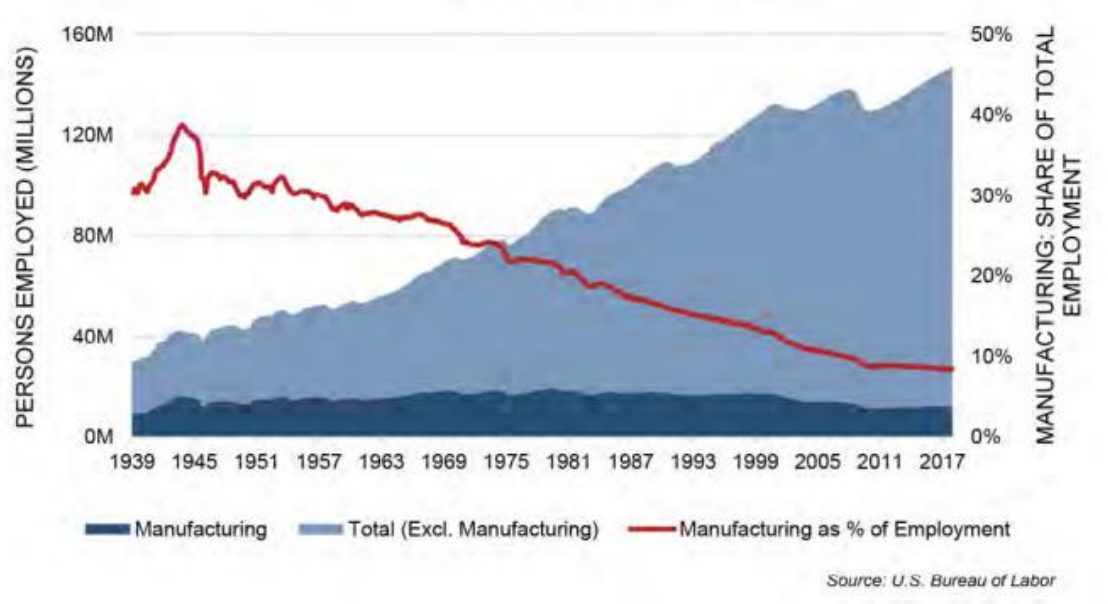


*Figure 2: Employment in Manufacturing verse all other industries (Interagency Task Force in Fulfillment of Executive Order 13806, 2018).*

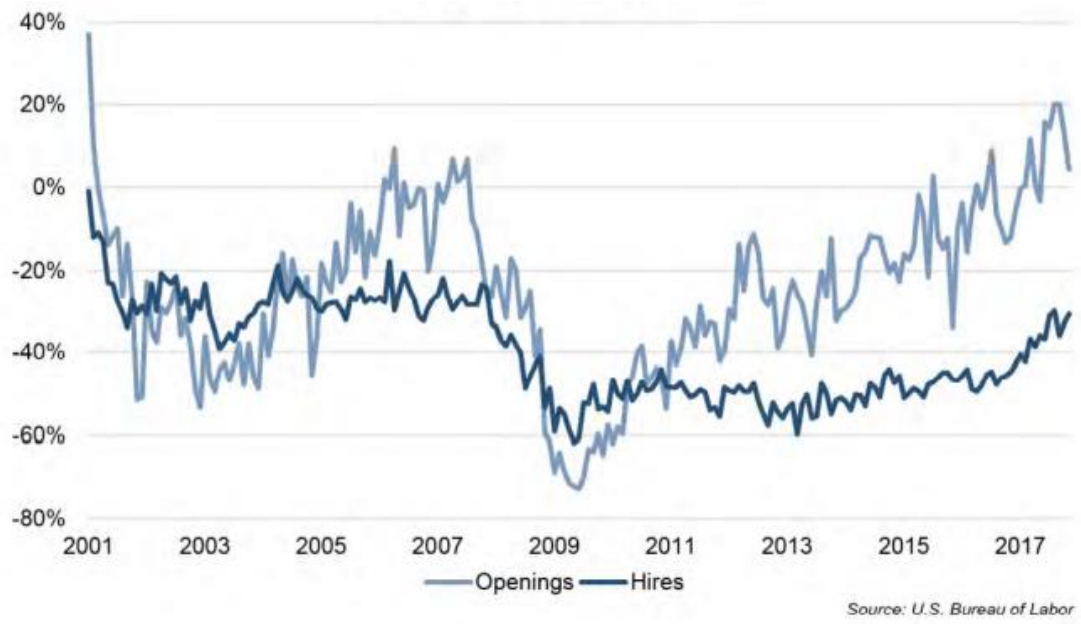


*Figure 3: Change in Manufacturing Openings verse Hires (Interagency Task Force in Fulfillment of Executive Order 13806, 2018).*

The Interagency Task Force report (2018) also includes a couple case studies on ground vehicle sector impacts on national security. It illustrates how these gaps reduce the capabilities for maintaining a forward military presence required to deter and/or defeat any adversary and adapt to new strategies and tactics, techniques, and procedures of battle.

> Legislation and DoD industrial policy requires DoD to manufacture all large caliber gun barrels, howitzer barrels, and mortar tubes at one organic DoD arsenal. There is only one production line at the arsenal for all of these items, and policy modifications to meet demand and surge from overseas have led to a lack of capacity to meet current production requirements (Interagency Task Force in Fulfillment of Executive Order 13806, 2018, p. 70).

This quote further emphasizes the special case that is Watervliet Arsenal. Large Cannons are critical for battlefield success. There is a reason artillery is nicknamed the King of Battle. The production capacity of Watervliet Arsenal must be carefully managed and the Department of Defense must invest in Watervliet as a strategic asset, not just as a simple manufacturing plant governed by supply and demand and the requirement to produce product on an economical basis.

Mathew Day (2019) highlights that the Army has prioritized long-range artillery and there is a push to increase cannon production capacity at Watervliet Arsenal. This served to breathe new life into the Arsenal as they need to install new machines to meet the increased cannon production capacity for this new large-gun capability. In addition to the increase in capacity, they are installing new machines with the thought to future-proof the manufacturing capabilities. This is so the Arsenal can meet future production requirements. Major cannon production ended in the 'Big Gun Shop' building in the 1990s which resulted in machines being removed from the building and the shifting of cannon work to different buildings (Day, 2019). This is another article put out by Watervliet public affairs, so it is again highlighting positive stories. However, it shows the scale of the challenge when the arsenal must pivot from low production demand to high production demand. This comes with a significant influx of

resources to modernize buildings, equipment, and production processes. If proper lead time and delivery schedules are factored in, this would not cause an issue. However, when this magnitude of modernization of Watervliet's production process aligns with a surge of demand for production of cannon tubes, that can lead to unacceptable lead times or an extremely expensive rapid increase in production capacity.

Every piece of manufacturing equipment has an expected service life. This is the number of years that the manufacturer expects the equipment to operate. Figure 4 shows the capital equipment at Watervliet Arsenal is running well past its service life and is significantly more so than all other depots and manufacturing facilities. Any manufacturer can operate its equipment past the expected service life, but that production equipment is at an increased risk for maintenance delays and higher maintenance costs. This could affect their ability to manufacture product. Aging equipment has numerous challenges including more frequent breakdowns, less effective or efficient operation, and it could potentially lead to safety hazards (United States Government Accountability Office, 2022).

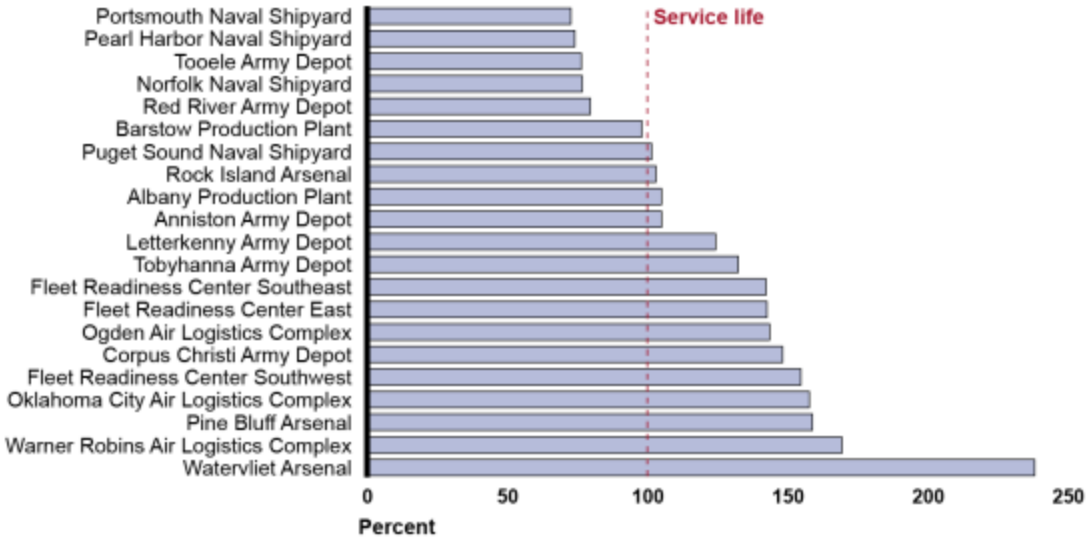


*Figure 4: Depot Capital Equipment Age as a Percentage of Expected Service Life, Fiscal Year 2020 (United States Government Accountability Office, 2022)*

In the state of the Organic Industrial Base report (Daly, 2021), Watervliet Arsenal showed a very high composite rate per direct labor hour. As shown in Table 3, Watervliet is reporting a carryover which is double their yearly expenses. Carryover is the total dollar value including parts and labor of unfinished workload carried into the next fiscal year. That is on the high side. Some level of carryover is essential for maintaining continuity of operations and to avoid disruptions. Typically, six months is a good amount. Watervliet is also called out for doing the most for facility modernization especially in the realm of Extended Range Cannon Artillery which requires new forging equipment. Without this investment and capability, the entire Extended Range Cannon Artillery (ERCA) readiness would be put at risk. There is also a $39 million investment to repair the chrome facility, which is a very large, but very necessary one-time investment to repair and modernize that critical capability (Daly, 2021).

*Table 3: Watervliet Arsenal (WVA) Performance (Daly, 2021)*

| WVA | Primary Systems | Secondary Items | Other Customer | Total Production |
|---|---|---|---|---|
| **Total Production** | | | **22** | **22** |
| HOWITZER SP | | | 22 | 22 |

| WVA Financial Highlights (in Millions) | |
|---|---|
| **Item** | **FY 2021** |
| Revenue | 197.2 |
| Expenses | 225.5 |
| Carryover | 460.5 |
| **WVA Operational Highlights (in Thousands)** | |
| **Item** | **FY 2021** |
| Workload (Direct Labor Hours) | 271.6 |
| Productive Yield (Direct Labor Hours) | 554 |
| Performance to Promise (Percentage) | 98% |

*Table 4: Composite Rate per Direct Labor Hour, FY21-FY23 (Daly, 2021)*

| Composite Rate | FY21 | FY22 | % Δ | FY23 | % Δ |
|---|---|---|---|---|---|
| AMC Roll Up | $ 155.28 | $ 169.89 | 9% | $ 195.04 | 15% |
| By Site | | | | | |
| ANAD | $ 200.24 | $ 211.08 | 5% | $ 223.60 | 6% |
| BGAD | $ 153.17 | $ 157.00 | 3% | $ 164.20 | 5% |
| CAAA | $ 157.88 | $ 153.61 | -3% | $ 165.93 | 8% |
| CCAD | $ 287.31 | $ 292.55 | 2% | $ 335.83 | 15% |
| LEAD | $ 192.80 | $ 199.69 | 4% | $ 229.09 | 15% |
| MCAAP | $ 119.25 | $ 122.17 | 2% | $ 126.99 | 4% |
| PBA | $ 150.00 | $ 150.00 | 0% | $ 164.00 | 9% |
| RIA | $ 235.00 | $ 356.76 | 52% | $ 277.83 | -22% |
| RRAD | $ 186.86 | $ 222.99 | 19% | $ 308.58 | 38% |
| SIAD | $ 125.81 | $ 120.08 | -5% | $ 148.13 | 23% |
| TEAD | $ 137.95 | $ 139.63 | 1% | $ 168.18 | 20% |
| TYAD | $ 148.15 | $ 163.70 | 10% | $ 181.02 | 11% |
| WVA | $ 317.33 | $ 317.33 | 0% | $ 490.00 | 54% |

Hix (2022) released a report titled “Securing Defense-Critical Supply Chains” which included casting and forging as critical manufacturing capabilities. She recognizes that these parts are of high importance and are low-volume items that support critical go-to-war weapon systems that effect military readiness. The assessment is that producers need predictable

demand, costs, and returns to compete like all businesses. While there have been recent investments to update some equipment, the organic industrial base casting and forging plants have aging equipment limited by existing facilities and infrastructure (Hicks, 2022).

One of the dangers of sizing the production capacity for cannon tubes to the foreseeable demand, is that changing capacity is costly. Both in increasing and decreasing capacity. However, it would be in the times of increasing capacity that the acute pain would be felt in the lead time. If there is a large demand signal to increase capacity, that usually has to do with a war or a confluence of multiple programs with overlapping delivery schedules. The easier of the two is multiple programs which has happened recently. Production delivery schedules can be negotiated between the multiple programs and prioritization can be factored in. However, if there is a war; typically, time is a resource that is not available. Therefore, the time associated with increasing capacity is typically more precious than the associated costs. The Army sent their plan for ensuring sources of cannon tubes to Congress (Bush, 2022).

**Analysis**

The importance of our World War II experience producing cannon tubes is an example to learn from and cannot be overstated (Harry Thomson, 1955). This is the primary underpinnings on why having government owned and operated arsenals are critical for uniquely military production and production processes like making large cannon tubes. The World War II experience also shows the value that Arsenals, and especially Watervliet arsenal can provide to increase capacity not only through organic production, but also through training and teaching other contracted producers how to produce cannons to meet the demanding specifications required for large guns. Hopefully we are not in an active shooting war to the scale of World

War II again. Even in smaller conflicts, the responsiveness of the industrial base is critical as time is of the essence and is critically important during war and can be the difference of the outcome of a conflict. Keeping all cannon tube production within Watervliet Arsenal is not always the best solution when demand is high enough and delivery schedules are paramount. However, turning on other producers outside of Watervliet Arsenal, even those who have capability to produce cannon tubes, is not a quick process. The qualification of different sources of supply for cannon tubes must be done outside of the time pressures of an active war since the timeline will be measured in years, and not weeks or even months. A re-examination of the Stratton amendment can be done through this lens.

As was indicated in Scott Gormley's (2011) article, the nature of cannon tube production is very cyclical based on demand signals from different wars and conflicts the United States is involved with. The cannon products that are produced at Watervliet can last as long or longer than the machines that produced those parts. These Cannons are critically needed in times of war and are likely only wearing out in times of war. This makes demand forecasting very difficult as there are no predictable intervals in which Watervliet can plan for a replenishment of stocks for the Army. Even those items with a predictable wear rate and replacement timeline, will not lead to a high enough production rate to sustain the Watervliet Arsenal production capability. During times of war, delivery schedules are paramount; so, the Arsenal must be ready to go into a maximum production rate with very little notice. The timeline for training skilled machinist makes surge production an impossible challenge if that workforce is not consistently maintained at an adequate level.

John Snyder's (2015) article highlights having orders of $34 Million. While this is good, only $20M are in their core business of cannon tube production. This is not sufficient to

workload Watervliet on a continuing basis to maintain production capacity over many years. The fact that Watervliet's public affairs office indicates that there are no new programs only a couple years before the Army Modernization efforts hit is a clear indication of the challenge that manufacturing arsenals face to maintain the right production capacity. The defense industrial base capability and capacity should not constrain which modernization efforts should be pursued. The priorities should be based upon war fighter requirements. However, the costs and lead times for those modernization efforts will be greatly influenced by how ready and available the defense industrial base is to support those efforts.

Mathew Day's (2019) article shows some of the inefficiencies caused by going from high demand to low demand. Cannon production was removed from a building due to low production demand, only to be put back in 30 years later when new production requirements necessitated the increase in capacity. Some of that equipment might have had to be modified for the new production requirements to produce the new longer-range cannon tubes. However, there seems to be an inefficient use of resources to spend money to move equipment out of a building only to set that same facility back up during the next high demand cycle. Watervliet Arsenal is clearly relied upon to produce cannons, and likely will be relied upon to produce cannons in the United States for the foreseeable future. As long as Army doctrine includes using gun launched artillery and the use of Tanks and the United States wants to retain the capability to produce those gun tubes within the country, Watervliet Arsenal will be required.

In Jerry McGinn's (2020) essay "Building Resilience: Mobilizing the Defense Industrial Base in an Era of Great-Power Competition", he argues one of the key lessons for the future in building resilience for capacity is stockpiling. Stockpiling can be a cost-effective way to build and maintain capacity in the defense industrial base. The DoD can build additional capacity in

cannon tubes by stockpiling this extremely relevant capability for great-power competition (McGinn, 2020). Although stockpiling is typically thought about for ammunition and end weapon systems, large cannon tubes can be inventoried and stockpiled in a similar fashion to ensure continuous production can be maintained to hold a surge capability while having product on hand to meet immediate program and battlefield needs.

# Chapter 5 – Interpretation

## Introduction

This chapter provides a synthesis of the findings and data of my three central research questions. It reviews the conclusions that can be drawn from the data in the context of the three research questions. It also provides recommendations to the central problem statement of how to address the set capacity for large cannon tube production in the United States to meet the demand of multiple customers with reasonable delivery lead times. This chapter will also document the shortcomings in the existing body of knowledge in this area as well as how future researchers can address those limitations.

## Conclusions

The three central research questions are addressed below. Several themes emerged from the research that are detailed in the findings and analysis in chapter four. The themes include: ramping up cannon tube production in times of war and greater demand; the guiding statutes and regulations governing production of cannon tubes in the United States; the need for workload management and forecasting at the organic industrial base; and balancing the need to maintain the capability to produce cannon tubes in the United States during times of minimal demand. These themes align closely with the central research questions. The analysis and conclusions are detailed below under each of the three research questions.

1. What are the constraints on cannon tube production in the United States?

There is a single source of supply for cannon tube production in the United States. There are significant barriers to entry for any other producer of cannon tubes in the United States. These barriers serve as a major constraint on the capability and capacity for production. Barriers to entry for large cannon tube production include the Arsenal Act and the Stratton Amendment. Those statutes are designed to protect and utilize the production capacity and capability within the organic manufacturing arsenals and to protect the defense industrial base to maintain organic capability and capacity for production of large cannon tubes in the United States. However, they can unintentionally serve to limit production capacity and ability to surge production capacity and capabilities in times of dramatic increases of demand such as in times of war. Besides the protectionist legislation, there are other barriers to entry as well as reasons industry does not want to enter the cannon tube production business. One of the reasons why companies will be reluctant to invest their own funds to set up cannon tube production is because they know the Army will fund Watervliet production first and only compete any remaining excess orders. Typically, there will not be enough continuous production demand to economically carry more than a single producer in the United States. Only after those minimum order quantities are satisfied for Watervliet, will other sources be able to compete for left over funds which in most years is nothing. Only in times of a significant surge in demand will there be enough resources, funding, and a demand signal to consider a producer other than Watervliet Arsenal.

For complex defense articles like cannon tubes, it takes several years to qualify a production source. Trying to do this in times of conflict is not likely to provide a successful outcome in the timeframes that those articles of war are required. Therefore, any qualification of sources outside of Watervliet arsenal would have to occur outside of those contingency operations. Since the Stratton Amendment restricts the ability for the export of cannon designs,

that restricts the ability of the Department of Army to qualify a source of production outside of the United States. Qualifying an international producer of United States designed cannon tubes should take place outside of contingency operations. Given the high cost of standing up a new production source for cannon tubes, it is unlikely that it will make sense to qualify a second source within the United States. Therefore, the constraints of Watervliet's production of cannon tubes are the de-facto constraints on cannon tube production in the United States.

The constraints on cannon tube production at Watervliet Arsenal include the availability of trained manpower, such as qualified machinists. Watervliet runs an apprentice program to manage this constraint. Having the average age of production equipment being 250% past its service life can also serve as a constraint on cannon tube production. That aging equipment needs to be carefully managed and modernized so it does not limit the capacity nor capability of cannon tube production.

2. How do cyclic rates of demand affect cannon tube production?

In theory, cannon tube production capability itself should not change when rates of demand are high or low. However, the production capacity is limited to the collective bottlenecks of the production process which will constrain capacity when demand is high. There is a cost to maintain excess capacity when it is not utilized for ongoing production. That cost is a non-value-added expense when demand is low. Having flexible machining allows production to switch between different commodities or operations. Flexible machining will never be as fast or efficient as a dedicated production line. Balancing flexible machining cells and dedicated

production lines becomes a challenging, if not impossible exercise when rates of demand fluctuate dramatically in short amounts of time.

Another area where cyclic demand affects cannon tube production is the challenge with right sizing the skilled workforce. It takes four years to fully train a machinist to be fully qualified. The overall manufacturing sector in the United States has declined to the point where the Army can only rely on its own ability to recruit, train, and qualify that skilled workforce. Retaining that skilled workforce when production is low is an enormous expense. The excess workforce can even be seen as a non-value-added expense in times of low demand. However, a lack of a skilled workforce will be a production capacity limitation in times of high demand. Since it takes years to develop that trained expertise, demand fluctuations in short amounts of time make it especially difficult to right size that workforce.

Availability of raw material can also drastically change the ability to meet timely production deliveries in times of rapidly changing demand. The good news is that storing metal billets should be relatively inexpensive compared to the schedule time of having to wait for a foundry to produce the needed raw material. However, the Army's accounting and budgeting system must allow for the purchasing and stockpiling of in-process material, as well as end products, when necessary, in times of low demand in order to be responsive when demand dramatically increases in a short timeframe. Fortunately, cannon tube designs don't change that frequently. Any investment in purchasing and storing raw material billets should not be a wasted expense.

3. Given the constraints and cyclic rates of demand, how may the Army maintain sufficient production capacity for large cannon tubes in the United States?

This research question really gets at the heart of the issue for the Army in terms of managing the production of cannon tubes in the United States. The constraints on cannon tube production are well known and documented. The effects of cyclic demand rates on cannon tube production are unfortunately well known since that is effectively the history of Watervliet Arsenal.

The production capacity for Cannon Tubes can be viewed through the lens of "Just-in-Time" verses "Just-in-Case" strategies (Jenkins, 2021). "Just-in-Time" is essentially production on demand, or when a customer comes through the door. This is how Watervliet currently runs its operations. As a government entity, Watervliet cannot start the production process, which includes ordering the required raw material, until it has received a production order and the corresponding funding. If Watervliet was empowered to be allowed to purchase its long lead items for cannon tube production and have those materials in inventory, then the time between when an order is received, and when production can start can be significantly reduced. For the most part, these long lead materials are metal billets which do not spoil over time. Unless the design changes, which does not happen very often, then the inventory is still good to use and does not age out. Watervliet could even turn some of those raw material billets into work in process cannon tubes to level production in times of low demand if they were given the ability and authority to do that. However, the current financial management system does not allow for this to happen without significant obstacles. This is an accounting and budgeting challenge as eventually those cannon tubes will be required, produced, and delivered. It is just a matter of when.

Maintaining production levels at full surge levels is prohibitably expensive for all other times when demand is not at its highest. Finding the right balance is critical and helps to answer the "waste" of producing more then you need in times of low production/demand, while still providing the surge capability required in times of war. If a more consistent rate of production could be established, then the large expenses of increasing or reducing production capacity could be greatly reduced.

The Department of Defense must pay the expense to maintain production capacity for large cannon tubes in the United States. Large cannon tubes do not have a commercial use, so the department cannot rely on private industry to maintain the production capacity or even the capability to produce large cannon tubes unless the department directly pays for it. Those costs will not be drastically different regardless of who owns or operates the production facility. Debates about government ownership and operation of Watervliet Arsenal are interesting, but mainly irrelevant with regard to the cost of cannon tube production. There are no commercial equivalent products to large cannon tubes. Furthermore, there aren't commercially equivalent products that utilize similar production processes to the scale or precision required to produce cannon tubes. The rotary forge and precision gauging machinery at Watervliet Arsenal is unique to cannon tube production, especially for the size and precision required for production. Therefore, Watervliet Arsenal is critical to remain as the producer of cannon tubes in the United States.

The conclusions support the problem that there is set capacity for large cannon tube production in the United States to meet the demand of multiple customers with reasonable delivery lead times. The research conducted confirms this problem statement. Watervliet Arsenal is the sole source for cannon tube production within the industrial base in the United

States for the Army. While having a single point of failure within a supply system is a large risk, the nature of the demand for cannon tubes and the expense of diversifying the industrial base prohibit bringing on an additional source of supply within the United States.

**Recommendations**

The recommendations are as follows:

- The Army should set and resource a pre-set negotiated production volume of cannon tubes that does not change frequently.

The Army needs to define the minimum sustaining rate of production for cannon tubes required. That would allow Watervliet Arsenal to surge production to required levels in times of increased demand. Stated differently, the maximum rate of demand should be calculated based on different operational scenarios, and then Watervliet Arsenal should conduct the analysis on a minimum level of production that has to be maintained to quickly surge to those levels when required. History has taught a clear lesson starting from the War of 1812 through every major conflict that having an organic production capability for large caliber guns is critical. The Army is committed to maintaining Watervliet Arsenal so it can keep an organic production capability for manufacturing large cannon tubes in the United States. Therefore, the Army should resource Watervliet on a year over year basis to produce a minimum number of cannon tubes. Whether there is a specific customer identified or not. Customer orders can be filled from this quantity of production or inventory with the corresponding funding being allocated to other priorities within the Army. Keeping a façade that Watervliet should operate like a commercial business will only prolong the heartaches and headaches as well as the unnecessary expenses of the rapidly

changing demand signals for cannon tube production. The reality is that large cannon tubes are not a commercial product, and the demand cycles do not follow a predictable pattern throughout the years to staff and maintain a workforce and facility to meet customer requirements on demand. A consistent production quantity could also allow for a forecasted and scheduled production equipment and facilities maintenance and modernization cycle. The rate of procurement of cannon tubes should be based around historical averages that span decades to smooth out the spikes of demand that happen around arming for a conflict and the subsequent drawdowns. A model similar to how ammunition war time stockpiles are calculated should be utilized so there is a sufficient buffer to allow a more measured pace to ramp up production. Watervliet might not even have to surge production in a time of war when that stockpile would be quickly utilized.

- The Stratton Amendment should be repealed.

The prohibition from utilizing foreign cannon producers as stated in the Stratton amendment adversely affects the Army's ability to meet its customers' needs in times of increased demand. If the Army commits to keeping a minimum sustained rate of cannon tube production at Watervliet, that should eliminate the needs for protectionist legislation like the Stratton Amendment. Watervliet has in the past and should always be the go-to place for cannon tube production and expertise in the United States. Which means, that Watervliet should be advising program managers when a good time is to seek sources of supply from outside the United States, rather than seeing those sources of supply as potential competition. That would likely increase the stature of Watervliet as the premier producer of cannons tubes globally.

Additionally, those foreign producers would be more willing and likely to seek the expertise of Watervliet. That would increase the amount of business going into Watervliet, which is precisely what the Stratton Amendment was intended to do. However, the protectionist legislation is preventing those relationships from forming and building over shared experiences. Which will ultimately limit the amount of work going into Watervliet Arsenal.

Additionally, the Stratton Amendment prohibits the transfer of technical data for large-caliber cannons being manufactured or developed in an arsenal. This prevents things like RFPs and other market research from being conducted so Watervliet Arsenal and the Army can fully explore their full range of options. Since it takes years to qualify a new cannon design, or even a new producer of an existing cannon design; trying to qualify another source for U.S. cannons in times of war will not yield the results that a battlefield Army requires. Those activities must take place well in advance and almost at a repeated cycle to always have that option available when required. Another side benefit of having those additional sources of supply is that those companies that built those cannons have developed a relationship with Watervliet Arsenal during that process. If those companies have a sudden surge of demand from their customers which they can not meet; they are a lot more likely to recommend to their customers that they work with Watervliet to help resolve that specific supply and demand crunch. It will be very difficult if not impossible to develop a trusting relationship as long as the Stratton Amendment remains a law. Trust can only really be built with two-way, effective communication. There are trade secrets that Watervliet obviously should not share with a potential competitor, but that should be at Watervliet's discretion, rather than having that dictated by law.

- The Arsenal Act should be repealed for manufacturing arsenals.

The Arsenal Act has not yielded positive results for Watervliet or other manufacturing arsenals while adding unnecessary paperwork and analysis burdens on program managers trying to deliver product. Therefore, the Arsenal Act is not delivering the results originally intended. This piece of legislation does not seem to currently help the organic industrial base and adds unnecessary bureaucracy to the already excessively bureaucratic and cumbersome process of government acquisition. Cannon tube production is so highly specialized, and there is only a single source of supply in the United States. Watervliet is a de-facto monopoly in this space. Therefore, regardless of the "economical basis," program managers are forced to utilize Watervliet Arsenal for cannon tube production. Trying to rely on a commercial entity type pricing model does not work when there are drastic, and unpredictable changes in demand signals from multiple different customers. Other mechanisms can be utilized to ensure Watervliet continues to remain a good steward of the taxpayer dollars. When the first recommendation is implemented, that should help stabilize the expected costs and corresponding prices for large cannon tubes. When that happens, it is further reason to repeal the Arsenal Act for manufacturing arsenals; or at least as it applies to Watervliet Arsenal.

Below are a list of potential areas of further research and studies based on this research effort. These different areas of research could further show the value or risk of incorporating any of the recommendations.

- Research the advantages and disadvantages of protectionist legislation including the Arsenal Act and Stratton Amendment as to whether their intent is still being met or is

still required, the costs for implementing those laws, and the benefit that the legislation has provided over time including if they are still relevant and required.

- Conduct an economic analysis of the equivalent cost of Cannon tube production over the last 50 years if the production rate was constant verses the actual rate of production which changed drastically over time.
- Research the accounting and budgeting constraints and considerations to allow Watervliet to produce cannons to a pre-defined quantity to maintain production capability and utilize a stockpile, or just in case model, versus the just in time and producing upon demand after a customer order comes in and is fully funded.
- Explore the budgeting and accounting processes for how products from manufacturing arsenals are priced to customers and how that affects decisions to modernize production capabilities.
- Conduct a similar case study on how large cannon tubes are produced in Europe over a similar time period.

**Limitations of the Study**

As was discussed earlier, there are several constraints on the type of research that was allowed for this paper. Specifically, one limitation was the prohibition of using interviews. If I did not have that constraint, I would have conducted interviews and talked with experts and leaders at Watervliet Arsenal to gain their perspectives. I would have also interviewed the experts at TACOM and AMC who have the responsibility for the manufacturing Arsenals to understand the current realities of the budgetary and logistics processes to maintaining the manufacturing arsenals. I also would interview the different Program Managers who have

requirements for cannons in their portfolios. Through all these interviews and interactions, the conclusions and recommendations could be further refined based on access to current information and data.

Another constraint was the requirement to publicly release this paper. If that constraint was lifted, more fidelity could be used to define the specifics of different operations and areas within the process that could be changed to maintain the right production capacity for production of cannon tubes in the United States.

The validity and reliability of the issues are identified in chapter three and limit the generalizability of my research and data in chapter four. This is an academic paper based on publicly available research and information. There is a lot of nuances required to go along with the changes in laws and army policies that would be required to implement the recommendations. This paper primarily focused on Watervliet Arsenal as they are the sole producer of large cannon tubes in the United States.

**Summary**

This research paper lays out the problem of the set capacity for large cannon tube production in the United States. It summarizes existing knowledge in this area and the gaps in that knowledge base. It utilizes specific research questions and collects data to be analyzed to fill those knowledge gaps. The data is then synthesized and distilled into relevant conclusions with specific recommendations. The final areas that were presented lay out what can follow this research paper and the limitations of this study.

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## Glossary of Acronyms and Terms

CFT ..... Cross Functional Team

DAU ..... Defense Acquisition University

DoD ..... Defense of Defense

FY ..... Fiscal Year

GAO ..... General Accounting Office (now known as the Government Accountability Office)

LW155 ..... Lightweight 155mm

LRPF ..... Long Range Precision Fires

NGCV ……..... Next Generation Combat Vehicle

U.S.C ..... United States Code

WVA ..... Watervliet Arsenal