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US Army Corps of Engineers®
Engineer Research and Development Center

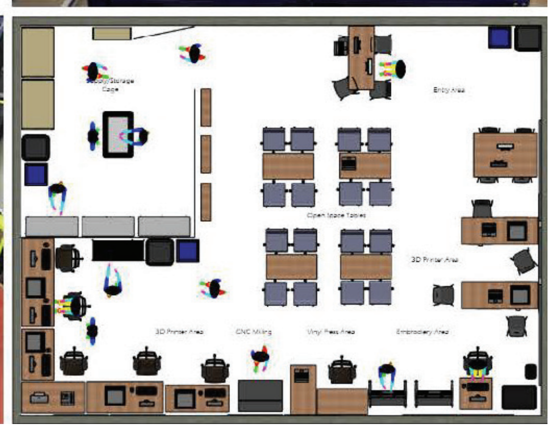
Demonstration Program Using Commercial Technologies

Army Installation Makerspaces in the Morale, Welfare, and Recreation (MWR) Operational Environment

A Business Case Analysis

Shane D. Hirschi, Dawn A. Morrison, Megan A. Kreiger, Mariangelica Carrasquillo-Mangual, Brandy N. Diggs-McGee, Jonathan M. Goebel, and Bjorn K. Oberg

July 2020



Construction Engineering Research Laboratory

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Under MIPR 11095829, "Installation Mad Scientist Event/Feasibility Space on Installations"

Abstract

This work demonstrated the implementation of makerspaces, collaborative workspaces that provide hands-on learning to help prepare the future workforce with critical 21st century applied-technology skills. Researchers from the U.S. Army Engineer Research and Development Center, Construction Engineering Research Laboratory (ERDC-CERL) enhanced and evaluated the pre-existing makerspace at Fort Bliss, Texas to demonstrate the value of a makerspace within the military Morale, Welfare, and Recreation (MWR) environment. The 8-month pilot demonstration, conducted from May to December 2018, focused on investigating program characteristics such as usage trends, optimal locations, equipment, and personnel access. Results from the demonstration indicated that enhanced makerspaces with high quality equipment had a positive Soldier impact. The business case analysis determined that the Fort Bliss Makerspace fits the criteria of, met the 15% cost-to-revenue ratio threshold for, and can operate successfully as, a Category Type A (Mission Sustaining) program asset.

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Preface

This study was conducted for the Office of the Assistant Secretary of the Army Installations, Energy and Environment (OASA[IE&E]) under Project A1000-FY17, "Feasibility of Maker Space on Installation," which was funded via Military Interdepartmental Purchase Request (MIPR) 11095829, "Installation Mad Scientist Event/Feasibility Space on Installations." The technical monitor was John R. Thompson, OASA(IE&E).

The work was performed by the Energy Branch, of the Facilities Division, U.S. Army Engineer Research and Development Center, Construction Engineering Research Laboratory (ERDC-CERL). At the time of publication, Ms. Mariangelica Carrasquillo-Mangual was Acting Chief of the Energy Branch; Ms. Giselle Rodriguez was Chief of the Facilities Division; and Kurt Kinnevan was the Technical Director for Facilities. The Deputy Director of ERDC-CERL was Ms. Michelle Hanson and the Acting Director was Dr. Kumar Topudurti.

The project team received valuable input and support from multiple individuals at OASA IE&E, and wish to thank them for the comments, input, and direction they provided throughout execution of the project.

COL Teresa A. Schlosser was Commander of ERDC, and Dr. David W. Pittman was the Director.

Executive Summary

The Army is seeking to integrate innovative technology into the operations of installations to support readiness, build resilience, increase efficiency, lower costs, and improve the quality of life of Service members and their families. To accomplish that, the Army is conducting a series of technology pilots to demonstrate success or failure for implementing commercially available technology within Army installations.

Test and demonstration programs will include a cost-benefit analysis of expected returns to the Army. An analysis on each pilot will be in accordance with the guidance and approach outlined in the Army's Cost-Benefit Analysis Guide, as prepared by the Office of the Deputy Assistant Secretary of the Army (3d ed., V3.3, 21 January 2020).

Readiness is one of the Army's stated priorities and is an important consideration for return on investment. Technologies in a test and demonstration program must include measures related to supporting a given installation's ability to generate readiness and achieve its stated mission. Specific areas that contribute to readiness include improvements in training, safety, security, warfighting operations, power projection, maintenance and quality of life.

Resilience, in the context of an Army installation, is the ability to quickly recover from a shock and maintain operations. Following the discussion above on risks, resilience is crucial in the current environment of constant attack. Each pilot must clearly include an element that measures whether the technology enhances the installation's ability to protect and recover from an adverse event, whether manmade or from natural causes.

Looking to the future, the Army must consider the contributions that any tested technology has on the quality of life experienced at an installation, and whether that technology influences the recruitment and retention of current and future Soldiers. Communities around the world are developing "smart spaces" that improve the delivery of public goods and services, provide convenience and/or save time. The Army must offer similar environments. Smart installations will be a more appealing environment to work and live for the future Soldier.

This report focuses on the demonstration of makerspaces, collaborative workspaces that provide hands-on learning and support the preparation of the future workforce with critical 21st century skills in applied technology.

Researchers from the U.S. Army Engineer Research and Development Center (ERDC), Construction Engineering Research Laboratory (CERL) enhanced and evaluated the pre-existing makerspace at Fort Bliss, Texas as a case study to demonstrate the value of a makerspace within the military Morale, Welfare, and Recreation (MWR) environment. The eight-month pilot demonstration, conducted from May to December 2018, focused on investigating program characteristics such as usage trends, optimal locations, equipment, and personnel access. Researchers conducted a market survey of the current state of makerspaces within public communities, universities, libraries, and military installations. Market survey results guided equipment purchases and program enhancements of the Fort Bliss Makerspace. Equipment purchases included installation of two 3D printers, two laptops, two 3D scanners, a Computer Numerical Control (CNC) router, workbenches and supply storage, and required supplies and consumables for the duration of the demonstration for this equipment. ERDC-CERL provided installation and certification training on the equipment to makerspace staff and users. Program enhancements to the Fort Bliss Makerspace included numerous marketing activities to promote awareness of the makerspace and two competition engagement programs.

Over the course of the demonstration period, researchers gathered and analyzed data on usage trends and operational costs, assessed mission and business impacts, conducted cost and risk analyses, and proposed mitigation strategies. Researchers also defined specific makerspace characteristics related to objectives, features and costs appropriate for operation within established MWR program asset categories: Category Type A (Mission Sustaining), Category Type B (Basic Community Support), and Category Type C (Revenue Generating) assets. Based on the MWR definitions for program asset categories, the Fort Bliss Makerspace fits the criteria of a Category Type A makerspace defined as Mission Sustaining (15% Non-Appropriated Funds (NAF)). Using data gathered from the makerspace demonstration project, researchers determined that the average cost for setting up a makerspace similar to that at Fort Bliss was approximately $63,000. The makerspace had a projected estimated annual operating cost of $25,276.66 and generated $4,479 in total revenue in calendar year 2018. This amounts to revenue from patrons covering approximately

17.72% of operation costs of the space. This meets the 15% NAF requirement needed to operate as a Category Type A program asset.

Researchers assessed organizational and operational risk factors associated with makerspaces. Organizational risk factors include how the makerspace is organizationally established and where it is physically and operationally required to function. Operational risk factors for makerspaces include hours of operation, types of equipment within the space, physical layout of the space, and safety and associated hazards that vary with the type of space. Based on the Fort Bliss demonstration, ERDC-CERL determined the biggest organizational risk factor was the placement of the makerspace within the larger library MWR environment, rather than as a stand-alone activity. This resulted in the Fort Bliss Makerspace being subjected to library funding, reporting and operational constraints, including limited hours of operation, limited access to the space due to library closings, and lack of full-time, long-term designated staffing. All these factors may have adversely impacted the makerspace.

Additional risk factors for Category Type A, B, and C makerspaces include equipment failures, loss of staff/personnel and insufficient funding/revenue. The impact from these risk factors is projected to be minimal for Category Type A makerspaces, medium for Category Type B spaces, and medium to high for Category Type C makerspaces. Based on observations made during the Fort Bliss demonstration, researchers anticipate the greatest risk to all three types of makerspaces will be the loss of staff and personnel due to the highly transient nature of the employee pool from which staff are typically hired. This will have the greatest impact on Category Type C makerspaces. Equipment in a Category Type C space, due to its increased capabilities, requires more training, and at a higher level, than required at a Category Type A or B facility. High employee turnover in a Category Type C facility thus has the greatest potential for adverse impact due to potential downtime of equipment while new employees are hired and trained, which may result in loss of revenue.

Researchers concluded that makerspace Category Type A, Category Type B, and Category Type C all provide increased knowledge, skills and abilities for Soldiers, civilians, retirees and their dependents, and had the ability to contribute to quality of life improvement. Specifically, the Fort Bliss

Makerspace demonstration usage trends indicate that enhanced makerspaces with high quality equipment had a positive Soldier impact:

> During the demonstration period, there was a 245% increase of 3D printer patrons and 146% increase in the number of 3D printer projects as compared to the same time period in the previous year (2017).

This significant increase suggests that installation personnel and their families see value in the Fort Bliss Makerspace.

The Fort Bliss Makerspace pilot demonstration indicates that makerspaces implemented across the Army enterprise have the potential to make a positive impact on Soldiers, family members and installation personnel. Makerspaces are also capable of operating as a Category Type A MWR asset and may be able to operate as Category Type B and Type C MWR assets if the recommendations made in this report are followed. Specifically, ERDC-CERL recommends that future implementations of makerspaces on military installations be located more prominently within the installation, perhaps on a mobile platform, and have expanded operating hours that are convenient to Soldier's schedules. It is anticipated that doing so will significantly improve the revenue-generating potential of makerspaces making them a more viable MWR asset across the Army enterprise. Furthermore, longer term analysis would be necessary to make a definitive business case to determine what types of MWR facilities (i.e., libraries, gyms, pools, theaters, etc.) are suited for hosting or containing makerspaces.

Non-MWR makerspaces intended to teach technical skills and support mission-critical tasks, including Department of Public Works (DPW) functions, might also yield a positive business case analysis. ERDC-CERL recommends that a future pilot study be conducted to assess and evaluate non-MWR makerspaces. If the Army establishes future makerspaces outside of the MWR framework, these non-MWR makerspaces have the potential to focus more on teaching technical skills and support mission-critical tasks, including DPW functions. Doing so could place makerspaces within a mission context wherein they become part of a training program used to upskill Soldiers to meet job requirements. As a result, the value proposition of makerspaces would expand from simple financial payback and quality of life enhancement to include providing risk reduction for obtaining mission objectives.

1 Introduction

1.1 Background

The operation of sophisticated new technologies that will enable the Army to meet its future military needs requires a higher level of technical understanding. To employ such new technologies to best advantage, it is imperative that the Army modernize the workforce by developing current and future warfighters' and civilians' technical skills. Such training must include hands-on learning and support that prepares the future workforce with critical 21st century science, technology, engineering, and math (STEM) skills.

1.2 Problem/opportunity statement

"Makerspaces" have been used to provide accessible settings for such innovative technological training and skills development. Makerspaces are collaborative workspaces typically located in schools, libraries, or other public/private facilities for making, learning, exploring, and sharing technical (and non-technical) ideas and skills.* This work was undertaken to provide an early demonstration/evaluation of makerspaces within the military Morale, Welfare, and Recreation (MWR) environment on Army installations, and to conduct a business case analysis to aide in the implementation and sustainment of similar type program spaces across the Army.

1.3 Objective/goal

The objectives of this work were to:

- demonstrate an existing makerspace to investigate specific program characteristics.
- develop a business case analysis that will help to implement and sustain similar program spaces across the Army.

1.4 Scope

This work investigated program characteristics such as usage trends, optimal locations, equipment, and personnel access; and developed a business case analysis to aide in the implementation and sustainment of similar

* https://www.makerspaces.com/

type program spaces across the Army. The project sought to define the specific characteristics for makerspaces appropriate for operation within established MWR Category Type A, Category Type B, and Category Type C assets, including the definition of their capabilities, patronage, usage, and potential impacts to the warfighter and to the Army's bottom line.

This report focuses on the Fort Bliss Makerspace as a demonstration site, including its operation, usage, capabilities, and its role within the MWR environment. The Fort Bliss Makerspace was set up and operated by existing support staff for the Mickelsen Library. The demonstration occurred over an 8-month period, from May to December 2018.

2 Facts, Assumptions, and Constraints

2.1 Facts

2.1.1 General facts about makerspaces on the enterprise

- There has been a widespread amount of activity to get modern fabrication technology to the forces throughout the military.
- At the time of this research, makerspaces are permanently operating within the boundaries of only three Army installations: Fort Bliss, Texas; Fort Knox, Kentucky; and U.S Army Garrison (USAG) Kaiserslautern, Germany. The Army makerspaces are implemented through the MWR library and differ by space allocation, equipment, hours, staff, and guidance by location. Furthermore, as of March 2019, over six Army installations have provided "pop-up" makerspace activities to incorporate things like Snap Circuits® and Makey Makey to teach participants introductory technical skills.
- Fort Bliss was the only known location with over 1200 sq ft of fully dedicated space and a wide subset of equipment (Knott 2017) that enable support of additional technical equipment.

2.1.2 Facts about selected site and demonstration

- Fort Bliss operates as a Strategic Deployment Platform, executing deployment operations that enable rapid and efficient unit deployment and redeployment.
- As of 31 January 2018, Fort Bliss supports a total population of 163,197 people including active duty military, civilians, contractors, families, and retirees (Fort Bliss 2018).
- The Fort Bliss Makerspace was set up and operated by existing support staff for the Mickelsen Library and is part of the MWR environment.
- The Fort Bliss Makerspace is the Army's first makerspace with a dedicated space located in a former storage room (approximately 32 ft x 42 ft) in the basement of the Mickelsen Community Library (located at 2E Sheridan Road) that was converted in 2016.
- The Installation Management Command's (IMCOM's) Million Dollar Library Makeover program (FY16) provided $42,000 in funding to repurpose the makerspace area.
- There is no dedicated staffing for the Fort Bliss Makerspace; employees are part of the regular library staff. At the time of this study, there were

3 to 4 staff members providing rotating part-time makerspace support as part of library services.

- The space is open from 1300-1730, Tuesday through Friday, and 1100-1800 on Saturday. During this time (25 hours per week), the space is typically monitored by one staff member that is simultaneously working on library tasks on the computer.
- The space is restricted to library patrons ages 8 and up with a maximum capacity of 20 people. An adult must accompany children between the ages of 8 and 12.
- The makerspace offers programs and classes focused on arts and crafts, STEM, do-it-yourself projects, and hands-on areas.
- Table 2-1 lists the equipment and materials available in the space.

Table 2-1. Equipment and materials available with the makerspace before additions from the demonstration project.

Equipment	Materials
3D printers & pens	Craft supplies
Hand & power tools	Robotic kits
EggBot	Card making kits
Wood burning pens	Educational & recreational board games
Sewing machines	Stamp making kits
Cricut® (dye cutter)	
Professional embroidery machine	
Vinyl Press	

- ERDC-CERL and Fort Bliss Library staff conducted various marketing activities through the course of this study. The first was a demonstration type of event at the Freedom Crossing open-air shopping center located on Fort Bliss to create awareness about the library and the makerspace. The other two were contest type events. An Innovative Ideas Contest and the Design & Manufacture Competition were promoted and held over the demonstration period. Prizes were awarded to the winners of each contest.

2.2 Assumptions

The demonstration and associated analyses were all performed under the assumption and recognition of makerspaces operating within an MWR-controlled environment only. An MWR-controlled environment suggests that all funding, operation, and reporting are driven, governed, and measured via MWR's processes, tools and methods. Researchers deem Fort

Bliss Makerspace to fall under Category A – Mission Sustaining. Details about MWR Makerspace program and categories are explained in section 6.3 of this document and in Appendix A.

2.3 Constraints

Multiple constraints associated with the demonstration played key roles in the analysis and outcomes. The specific constraints outlined here limited the researchers' abilities to develop a robust business case analysis, resulting in an abbreviated business case. The following sections describe four areas that represent constraints to ANY pilot study or demonstration, but particularly the current demonstration.

2.3.1 Physical location

Site identification for pilot or demonstration exercises must be carefully evaluated. The evaluation strategy should consider the physical real estate occupied by the proposed location; its position in relation to adjacent buildings, operations, and activities that may impact the service to be provided; its accessibility; and its attractiveness to the targeted user.

Since the Fort Bliss Makerspace was pre-existing to the demonstration effort, there were constraints associated with the existing location and operation. The Fort Bliss Makerspace is currently operating in conjunction with the Mickelsen Community Library. Both programs operate within, and are funded by, the MWR program.

2.3.2 Changes in personnel

Changes in personnel can significantly impact the operations of the makerspace. Loss of institutional knowledge related to specific makerspace equipment may result in the loss of that capability until a new employee can be found, hired and trained to work in the space. At Fort Bliss, four employees left the makerspace for various reasons during the 8-month demonstration period; two of these four individuals left within 3 months of being hired. Indeed, Fort Bliss personnel indicated that it was rare for an individual to remain on staff for more than a year.

High employee turnover result from the situational context in which the MWR makerspaces operate. Employees may likely be spouses or dependents of Soldiers stationed at the installation, and therefore subject to frequent relocations based on the assignments and missions given to their military family member. Given the transient nature of installation populations, one of the greatest challenges for the makerspace is finding and retaining properly trained employees.

2.3.3 Data and metrics

Original project scheduled included a 4-month demonstration period, from May 2018 through August 2018. However, to gather a greater volume of data, this was extended to an 8-month period from May 2018 through December 2018. Due to their proximity to the demonstration site, Fort Bliss library staff were responsible for collecting usage data resulting in less than rigorous collection standards due to human error.

Fort Bliss provided historic baseline data covering the 16 months (1 January 2017 through 31 May 2018) before the beginning of the demonstration project. This included space usage data in the form of door counts and attendance at sponsored learning and activity events. Due to Fort Bliss Makerspace staff proactively collected these data to satisfy their own curiosity regarding usage rates, the data were collected in an ad hoc manner. As a result, this baseline data collection was not highly controlled and contained many inconsistencies and gaps.

2.3.4 Material costs

Fort Bliss was unable to provide an itemized list of equipment and material costs due to the makerspace costs being rolled into the library's overall budget.

3 Cost Framework

3.1 Cost analysis

Quantitative data analysis was performed using descriptive statistics. This analysis focused on monthly and yearly patronage patterns by usage area, and monthly and yearly usage trends for the 3D printer. The Mickelsen Library staff captured and provided data used in this evaluation (both historic baseline data and data collected during the demonstration). Historic data included space usage data in the form of door counts and attendance at sponsored learning and activity events collected by the library staff before the study.

The makerspace staff collected daily door count totals that tracked visitor demographics and activities. The demographic categories recorded include Active Military, Adult Family and Civilians, Retirees, Children between the ages of 8 and 18, and New Patrons. The activities were recorded by usage area: Internet, 3D printer (# of patrons and # of projects), Programs and Events (# of programs, # of adult patrons, and # of child patrons), and Reference Services. Note that not all usage areas available within the makerspace were tracked in the data collection efforts (i.e., the use of Cricut® machine, embroidery machines, robotic kits, tec., were not tracked). The daily door counts were rolled up into monthly charts. After analyzing the door count data, the ERDC-CERL team determined that the collected door counts might underrepresent actual usage due to inconsistencies on data collection practices.

Mickelsen Library also tracked the funds collected from the makerspace. Certain activities within the makerspace that require supplies, such as the 3D printing or painting, collect fees on a per-project basis to offset the costs of operating the makerspace. The library provided monthly summaries of funds collected, including the number of participants who used features in the space requiring payment and the amount of funds collected.

The data range used in this analysis is from 1 January 2017 through 31 December 2018; data were compiled in Excel workbooks. The library staff provided additional contextual information pertaining to library closures, program cancellations, and staff changes that may have impacted the library and makerspace during this timeframe.

The demonstration at Fort Bliss generated data in the form of space and equipment usage, patron demographics, and hours of operation. Operational costs associated with labor, equipment, materials, and energy consumption were considered in current dollars only. Financial, operational, and equipment costs were also evaluated in current dollars only.

4 Alternatives

4.1 Courses of action (COAs)

As stated on section 1.3, the objective of this work was to perform an early demonstration/evaluation of makerspaces within the MWR environment on Army installations, and to conduct a business case analysis to help implement and sustain similar type program spaces across the Army enterprise. There were two potential COAs to conduct the study: use the pre-existing space as is or enhance the space based on results from market research of current makerspaces within public communities, universities, libraries, and military installations. ERDC-CERL opted to proceed with the second COA.

4.1.1 Status quo or "as is" state

To execute this COA, the research team used the pre-existing makerspace at the Mickelsen Library in its current state (current space configuration, equipment, etc.). The team familiarized itself with the space operation, gathered historic data, and collected new data over an 8-month period. The team then analyzed the data in detail and developed a business case.

4.1.2 Enhancement of current space and increase marketing and awareness activities

To execute this COA, the research team conducted a market survey of the current state of makerspaces to gather information on makerspaces within public communities, universities, libraries, and military installations. Based on the findings of the market research and existing subject matter experience, researchers assessed the functional and operational capabilities and limitations of the makerspace at the Mickelsen Library (Fort Bliss) to identify the best equipment to be purchased and installed to enhance the pre-existing makerspace. The team coordinated procurement and installation of new equipment with onsite personnel and developed the best configuration for the enhanced space. After performing the enhancements, researchers gathered historic data and collected new data over an 8-month period. The team then analyzed the data in detail and developed a business case.

4.2 Selection criteria

4.2.1 Alignment to mission

Makerspaces are collaborative workspaces typically located in schools, libraries, or other public/private facilities for making, learning, exploring, and sharing technical (and non-technical) ideas and skills.* Implementation of this growing program on Army installations aligns with the Army lines of effort (Modernization, Readiness, Reform, and People) at the time of the study. The operation of sophisticated new technologies that will enable the Army to meet its future military needs requires a higher level of technical understanding. To employ such new technologies to best advantage, it is imperative that the Army modernize the workforce by developing current and future warfighters' and civilians' technical skills. Although this work focused on the use of the makerspace program in the MWR environment, makerspaces could also be set up as non-MWR makerspaces intended to teach technical skills to support mission-critical tasks, such as DPW functions.

4.2.2 Support to personnel and community

In addition to modernizing the workforce by enhancing their technical skills, makerspaces also promote hands-on learning on critical 21st century skills in STEM, which is important not only for the workforce but for the entire Army community. As part of the selected alternative, ERDC-CERL provided the installation of the equipment and certification training to makerspace staff and users.

Finally, although this report does not attempt to quantify "quality of life" considerations associated with the makerspace, researchers acknowledge that many characteristics associated with makerspaces have the potential to enhance quality of life for installation personnel, and that these characteristics are important and a significant objective of MWR activities.

4.2.3 Modernize infrastructure

Implementing a makerspace program within the Army requires creation of a space suitable of supporting equipment, classes, and events targeted to create awareness and provide a test environment of new capabilities and or technologies. Early tests and awareness are imperative for the Soldiers

* https://www.makerspaces.com/

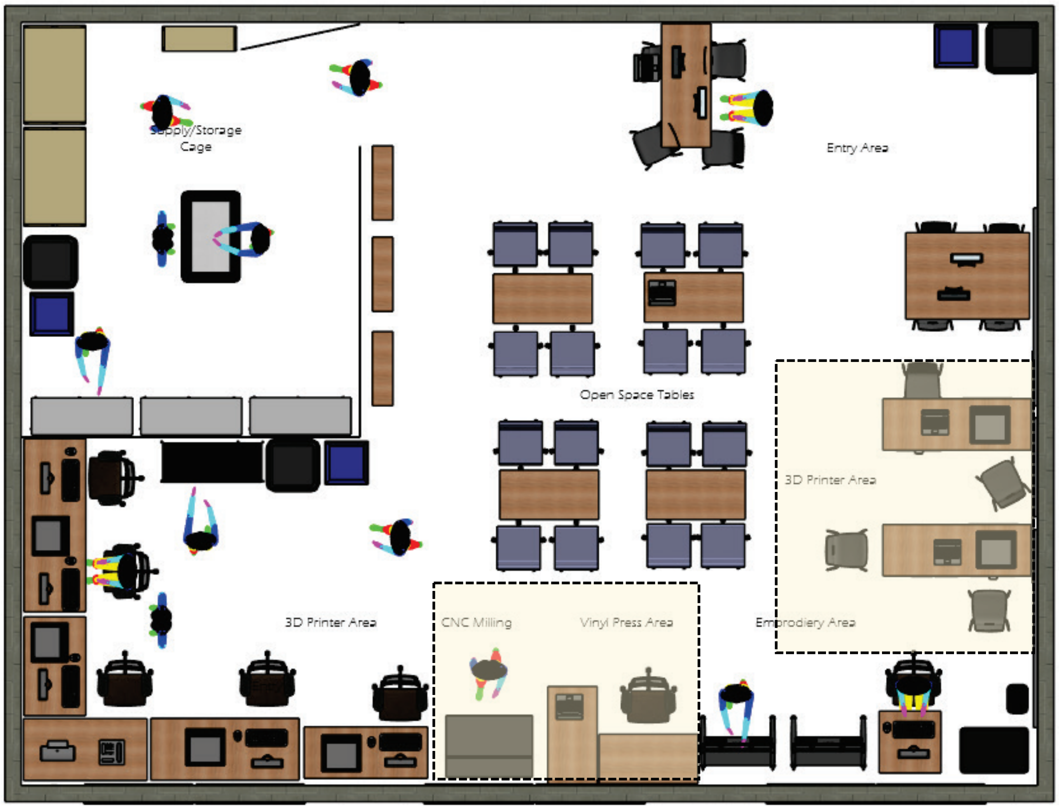
and community to familiarize themselves with assets, programs, and/or technologies potentially on the path to enterprise adoption.

The selected alternative allowed ERDC-CERL personnel to engage in strategic discussions with the Fort Bliss Makerspace staff regarding the desired technology that would benefit the space considering the space limitations, safety issues (limited power tools and saws), personnel skills, and fit with existing community. This discussion along with findings derived from market research resulted in procurement and installation of the equipment listed in Table 4-1. (See Appendix B for makerspace market research findings.) This equipment, along with re-configuration of the pre-existing space, provided a better makerspace environment suitable for demonstration (Figure 4-1). Appendix C describes the Fort Bliss Makerspace enhancement in detail, with supporting photographs and diagrams.

Table 4-1. Additional equipment provided by ERDC-CERL.

Item	Type	Qty	Capability
3D scanner	Sense – Next Generation	2	Scan real objects to re-create or to custom fit designed objects
3D printer	Lulzbot Taz 6	2	Additive manufacturing of a wide breadth of polymer materials
CNC	ShopBot Desktop w/1.1HP Spindle & Full Enclosure (DT3 Model 2018)	1	Subtractive manufacturing & etching
Laptop Computer	Dell Laptop	2	3D printer, CNC, and scanner operation
Furniture	Workbenches & supply storage	n/a	Support 3D printing equipment placement and onsite storage for tools and materials
Supplies	CNC Bits (general, router, sign makers, plotter pen, diamond drag engraving bit kits, etc.), wood for CNC (maple, plaque, etc.), 3D Printer supplies (filament, replacement parts, etc.)	n/a	Support operation and usage of equipment

Figure 4-1. New layout design (boxes added to highlight new areas).



4.2.4 Enable information sharing

This study and early demonstration of Makerspace in the Army MWR environment supported information sharing at the selected makerspace, and formed the basis for many marketing activities to promote awareness of the makerspace and the two competition engagement programs organized as part of this work.

4.2.5 Deliver return of investment

The selected alternative included a cost-to-revenue evaluation of the makerspace within the MWR environment. This analysis was based on the framework used by the MWR environment and defined by the Defense Logistics Agency Instruction (DLAI) 7303, which categorizes its various program types as

- Category A – Mission Sustaining,
- Category B – Basic Community Support, or
- Category C – Revenue Generating (DLA 2009).

Appendix A provides further information on MWR Makerspace program category types. This categorization determines the operational purpose of the program and the type of funding to be used in supporting the program. The makerspace program types used in the demonstration are purposely defined to align with DLAI 7303 for program/operational definitions of Category A, Category B, and Category C programs. All types are considered MWR assets and would be required to operate according to MWR requirements, rules, and instructions pertaining to the category in which they operate.

Additionally, as discussed in section 4.2.2 , the makerspace provides a host of intangible and non-revenue-generating benefits. The facility provides opportunities for military, civilians, and their dependents to improve their knowledge and skills associated with STEM type activities. These skills expand their abilities to provide services and enhance their career development both within and outside the Army environment. While these benefits are difficult to quantify (and are not the focus of this project), they are expected to greatly outweigh the economic costs of operating such spaces and add to the program's return on investment (ROI).

5 Risk Assessment & Mitigation Strategies

When considering risks that may affect the success of a makerspace operation, it is important to first consider the likelihood of a particular risk event occurring and the impact of that event. This analysis considers the factors associated with risks to the operation and sustainability.

Analysis of the risk associated with makerspaces, regardless of the category type of makerspace, must account for various vulnerabilities associated with the space. This analysis categorizes those vulnerabilities as organizational and operational risks, and adversity risk (not further considered here).

5.1 Acquisition risk

5.1.1 Technical risk

In this project, organizational risk is a top-level type of risk that includes risks associated with all aspects of an organized entity. In this context, organizational risk refers to the risk to successful operation based on how and where within the MWR environment the space is organized, set up, and operated. Factors impacting the organization are how it is organizationally established (e.g., its management hierarchy, funding, and reporting chain-of-command, etc.) and where it is physically and operationally required to function. Although the spaces are owned and operated by MWR in all cases, funding, reporting, metrics, and operation will differ across the three types of makerspaces (see Tables 6-10, 6-11, and 6-12, pp 30-31).

In addition to the successful operation of the space, selection of the appropriate equipment represents a technical risk when implementing a makerspace program. During initial meetings with the library staff, researchers found that the pre-existing 3D printers in the space were not adequate, despite being a widely known brand. This was in part due to the makerspace not having a choice in their selection. This issue often arises in the government due to acquisition processes and information technology (IT) restrictions, which can result in the selection of less-than-ideal equipment (i.e., 3D printers). Machine-based requirements are often specified during a purchase; however, the quality of the printing is determined not only by these requirements but the interaction between the software and machine. As such, the pre-existing 3D printers had limited usage due to the quality of the prints, size, speed, limitations on materials, and software limitations.

5.1.2 Operational risk (cost and business risks)

Operational risk refers to the chance of a loss due to the organization's day-to-day operations (Spacey 2015a). Such risks typically result from a breakdown of processes and/or the management of exceptions that are not addressed by normal business operations. For example, the Fort Bliss Makerspace was adversely impacted when the library experienced burst pipes that closed the adult book section. Another example is the disruption caused when four employees left the Fort Bliss Makerspace (for various reasons) during the 8-month demonstration period; two of these four individuals left within 3 months of being hired. Fort Bliss personnel indicated that it is rare for an individual to remain on staff for more than a year given the transient nature of installation populations. The more commercial traits the space takes on within its operational procedures, the greater the risk of failure and/or loss of revenue. Factors that impact the operation are hours of operation, types of equipment within the space, physical layout of the space, and safety and associated hazards that vary with the type of space. For evaluating the risks associated with these types of makerspaces, the above vulnerabilities have been combined into the following risk events:

- equipment failure
- loss of personnel/staff
- insufficient funding and/or revenue.

Note that more than one of these risk events could co-occur, amplifying the negative impacts of the individual events. During this demonstration period, combinations of these events occurred (described in section 2.3, chapter 3, and illustrated in Figure 6-2) causing door count reduction.

Table 5-1 lists risk fractions for the three MWR category types of makerspaces, where high, medium, and low values are represented, respectively, as H, M, or L. Each event is assigned a risk fraction. The value in the numerator represents the likelihood of an event and the value in the denominator represents the impact of such an event. Therefore, there are nine potential fractional representations of "risk" in which H/H is the worst case (i.e., very likely to happen and high impact) and L/L is best case, i.e., the least likely to occur and low impact. Risk fractions were organized into an ordinal scale (lowest to highest: L/L, M/L, L/M, H/L, M/M, L/H, H/M, M/H, H/H) and color coded to denote overall risk level (Green= L/L, M/L, L/M; Yellow= H/L, M/M, L/H; Red= H/M, M/H, H/H).

Table 5-1. Risk fractions for Category Type A, B and C makerspaces.

Event	Makerspace Category Type		
	A	B	C
Equipment Failure	L/L	M/M	H/M
Loss of Staff/Personnel	H/L	H/M	H/H
Insufficient Funding and/or Revenue	L/L	M/L	M/H

As discussed, because the military installation's population (the employee pool from which staff are typically hired) can be characterized as transient/mobile, it is anticipated that the greatest risk to all three types of makerspaces will be the loss of staff and personnel. Although the likelihood is high, the expected impact to long-term viability due to an event is low, medium, and high at a Category Type A, B, and C facility, respectively. Note that the greatest risk fraction across all three types is the loss of personnel from a Category Type C facility because of the increased technical functionality of equipment in the space. Equipment in a Category Type C space, due to its increased capabilities, requires more training, and at a higher level, than required at a Category Type A or B facility. High employee turnover in a Category Type C facility thus has the greatest potential for adverse impact due to potential downtime of equipment while new employees are hired and trained, which may result in loss of revenue.

5.2 Adversary risk

Adversary risk, i.e., the risk that any technology deployed onto an Army installation could be subject to attack or exploitation by a future adversary, was not assessed on this project.

5.3 Mitigation strategies

This section provides potential mitigation plans for each of the above highest risk scenarios. An MWR Category type C makerspace is the type of space with the highest likelihood to experience an event with the highest impact. Table 5-2 lists and describes the risks and their associated mitigation plan. The identified mitigation is intended to reduce the probability and/or the impact of the adverse risk event. Although the steps to mitigate risk listed in Table 5-2 cannot absolutely prevent organizational or operational failures, they do present practical steps to reduce the likelihood of failures in the most vulnerable areas, i.e., those with the greatest potential to occur and highest associated impact.

Table 5-2. Risks and steps to mitigate risk.

Risk	Steps to Mitigate Risk
Untimely loss of trained staff	Seek personnel that are trained, committed and "all in" to expand the knowledge, skills and abilities of their patrons. Provide training to a second individual as the backup so there is no interruption of operation for each technology within the makerspace. Produce training videos to capture instructional/training requirements to minimize knowledge loss and training costs.
Insufficient funding and/or revenue	Identify funding (Non-Appropriated Funds/Appropriated Funds [NAF/APF]), source of funding and operational metrics to ensure sustainability of the space and its objectives. Build the above metrics into standard operating procedures of the space.
Equipment failure	Obtain extended warranties and required maintenance agreements with all equipment. Ensure routine maintenance is built into standard operating procedures of the space.

6 Return on Investment

6.1 Quantifiable and nonquantifiable benefits

6.1.1 Quantifiable benefits

6.1.1.1 Cost-to-revenue ratio

To evaluate the demonstration period in MWR categories, the cost-to-revenue ratio was calculated. As summarized in Table 6-1, expenditures were $3,276.94 and revenue was $885 during the monitoring period from 31 October 2018 to 15 December 2018, over which detailed operating costs were collected. Using these figures, approximately 27% of the costs to operate the space were covered by revenue generated from the patrons using the space. The cost-to-revenue ratio decreases to 17.72% using projected annual costs and actual revenue.

This indicates the Fort Bliss Makerspace cost-to-revenue ratio met the 15% threshold for a Category A makerspace according to DLAI 7303. This in turn means that makerspaces, such as the one at Fort Bliss, can operate successfully as a Category A MWR asset. The 27% cost-to-revenue ratio falls below the threshold of 35% required for Category B and the 50% threshold required for Category C. Furthermore, longer term analysis would be necessary to make a definitive business case to determine what types of MWR facilities (i.e., libraries, theaters, gyms, etc.) are suited for makerspaces as this number is heavily influenced by the individual parameters of the space (e.g., hours, number of programs, etc.).

Table 6-1. Overall costs versus revenue (*denotes estimated values).

	Monitoring Period (31 Oct – 15 Dec 2018)		2018 Annual (Estimated)	
Item	**Cost**	**Revenue**	**Cost**	**Revenue**
Labor	$2,250.00		$18,000.00	
Materials	$756.16*		$6,000.00*	
Lighting	$18.29		$146.33	
Equipment	$47.06		$373.41	
Heating/Cooling	$205.43*		$756.92*	
Total Operating	**$3,276.94**		**$25,276.66**	
Total Revenue Generated		**$885**		**$4,479**

6.1.1.2 Operational costs

Operational costs for the makerspace are identified and analyzed in three distinct categories: labor, materials, and energy. Researchers also collected data on the revenue generated by the Fort Bliss Makerspace. Each of these categories is described in more detail below.

6.1.1.2.1 Labor cost

The space is open from 1300-1730, Tuesday through Friday, and 1100-1800 on Saturday. This level of operation requires 25 work hours per week (60% full-time equivalent [FTE]) to maintain a physical presence at all times during open hours. Requirements for the job are general hobby-type skills and interests with a desire to learn, assist, and teach as required. This results in an annual cost of approximately $18,000, given the individual can fill the other 40% of their funded FTE by performing additional MWR duties.

6.1.1.2.2 Material cost

During the space's operation, it is estimated that the cost required for materials, supplies and routine maintenance ranges between $500 - $1,000 per month; however, researchers determined that the average cost per month is closer to $500. Comprehensive data for material costs had not been tracked at daily or monthly intervals but were taken as average costs over the time period when resupply was required. Consumables for the equipment purchased as part of this demonstration cost $1,854.74. Most of this was the cost of consumables for the CNC in the form of tooling ($1,118.88) over the entire 8-month demonstration period. Even though these are considered to be "consumables," if properly cared for, they will have a 5- to 10-year life expectancy.

6.1.1.2.3 Energy cost

The total annual energy cost for the makerspace was calculated to be $1,276.66 for electricity, lighting, and heating. Electrical usage was measured in the space to calculate the amount of total energy consumption. Since the space did not have an independent meter, equipment had to be installed and the data were analyzed to evaluate this information. Consumption costs due to energy consumption include lighting, general electrical usage, and heating/cooling requirements.

Lighting in the space is provided by 48 Philips F32T8, 25W lamps across 24 fixtures. Electrical usage by the lights is assumed to be equal to the hours of operation (i.e., 25 hours per week). Lighting consumed by the makerspace is calculated using 48 bulbs rated at 25W each or 1.2kW total. Given that the lights are on 25 hours per week for 52 weeks each year and electrical costs are $0.0938/kWhrg, the annual cost of lighting is

1.2 x 25 x 52 x $0.0938 = $146.33 per year

Electrical usage by the equipment within the space is measured using 12 25A current transformers and three Elite Pro portable power meters manufactured by Dent Instruments. On 24 November 2018, usage data were retrieved from the meters. These meters were installed on 31 October 2018 and remained connected until 15 December 2018. Intermediate data were collected on 24 November 2018. The three meters were connected to 12 breakers (four breakers each) within the power panel and set to monitor electrical usage within the makerspace. Figure 6-1 provides the layout of relationships between the breakers, outlets, and equipment connected to the outlets. Table 6-2 lists a breakout of the space's equipment electrical usage per outlet for the 6.5-week monitoring period, from 31 October 2018 through 15 December 2018. Note that outlets 3, 12, and 20 have no equipment continuously plugged in; however, energy was still consumed by various temporarily used pieces of equipment.

Figure 6-1. Breakers, outlets, and equipment connectivity layout.

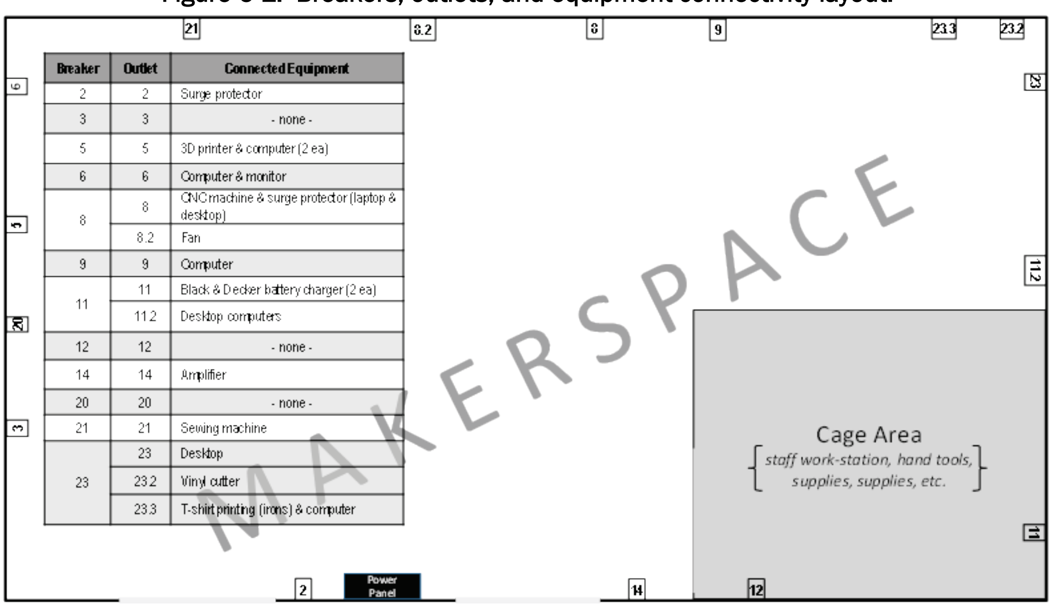


Table 6-2. Electrical consumption 31 Oct – 15 Dec 2018.

Breaker	Outlet	Equipment	Usage (kW-hrs)	Cost
2	2	Surge Protector	0.644838	$0.06
3	3	—none—	1.240836	$0.12
5	5	3D Printer & Computer (2ea)	141.552	$13.28
6	6	Computer & Monitor	41.5355	$3.90
8	8	CNC Machine & Surge Protector (laptop & desktop)	87.2306	$8.18
	8.2	Fan		
9	9	Computer	33.71742	$3.16
11	11	Black & Decker battery charger (2ea)	46.97461	$4.41
	11.2	Desktop computers		
12	12	—none—	47.06834	$4.41
14	14	Amplifier	5.517737	$0.52
20	20	—none—	1.483061	$0.14
21	21	Sewing machine	7.166946	$0.67
23	23	Desktop computer	87.595186	$8.21
	23.2	Vinyl cutter		
	23.3	T-shirt printing w/computer		
		TOTAL	**501.7271**	**$47.06**

Electrical consumption by the makerspace equipment totaled 501.73 kWhr at $0.0938/kWhr = $47.06 for the duration of the 31 October to 15 December 2018 monitoring period. The estimated annual cost for electricity being consumed by the equipment is $373.41. Additionally, the total annual cost for electricity and lighting is estimated at $519.74.

No heating and cooling measurements were made as there were no baseline data for comparison, nor was there a method (within the scope of this project) to obtain such data. Therefore, heating and cooling estimates were obtained using the space's physical characteristics, heating degree days, cooling degree days, and standard engineering practices and principles to calculate the general energy consumption for the space. Researchers used a natural gas price of $3.19 per cubic feet of natural gas (Natural Gas Local 2020) to derive an estimate of $205 for heating and cooling requirements for the makerspace during the monitoring period 31 October 2018 to 15 December 2018. Fort Bliss uses only natural gas for heating, which is required only during cooler months, from October through mid-April; this amounts to an estimated $756.92 spent annually on natural gas.

6.1.1.2.4 Revenue generated

Revenue generated by the makerspace was captured as a monthly lump sum amount for the period from May 2017 –Dec 2018 (Table 6-3).

Table 6-3. Participants and Revenue (May 2017 - Dec 2018).

Month	# of Participants	Amount Collected
May-17	16	$256.00
Jun-17	6	$90.00
Jul-17	25	$360.00
Aug-17	27	$300.50
Sep-17	43	$404.00
Oct-17	19	$304.00
Nov-17	28	$370.00
Dec-17	18	$247.00
Jan-18	32	$440.00
Feb-18	21	$341.00
Mar-18	37	$410.00
Apr-18	24	$351.00
May-18	22	$179.25
Jun-18	23	$249.25
Jul-18	42	$535.50
Aug-18	21	$329.00
Sep-18	33	$287.00
Oct-18	27	$472.00
Nov-18	40	$548.00
Dec-18	31	$337.00
TOTAL	**535**	**$6,810.50**

From July 2018 through 15 December 2018, revenue was captured based on the following areas within the makerspace; 3D printing, Painting, Crochet/Knitting/String Art, Embroidery, Pyrography, Sewing and Miscellaneous. Table 6-4 and Table 6-5 list a breakout by these areas for that time.

Table 6-4. Revenue by functional area within the makerspace (Jul-Sep18).

Area	July 2018		August 2018		September 2018	
	# of Participants	Amount Collected	# of Participant s	Amount Collected	# of Participants	Amount Collected
3D Printing	13	$55.50	3	$19.00	12	$37.00
Painting	24	$455.00	17	$305.00	18	$235.00
Crochet/Knitting /String Art	–	–	–	–	–	–
Embroidery	–	–	–	–	–	–
Pyrography	5	$25.00	–	–	–	–
Sewing	–	–	–	–	–	–
Miscellaneous	–	–	1	$5.00	3	$15.00
TOTAL	42	$535.50	21	$329.00	33	$287.00

Table 6-5. Revenue by functional area with the makerspace (Oct-Dec18).

Area	October 2018		November 2018		December 2018	
	# of Participants	Amount Collected	# of Participants	Amount Collected	# of Participants	Amount Collected
3D Printing	10	$27.00	18	$204.00	14	$102.00
Painting	11	$190.00	15	$295.00	10	$200.00
Crochet/Knitting/String Art	–	–	–	–	–	–
Embroidery	–	–	–	–	–	–
Pyrography	–	–	–	$25.00	7	$35.00
Sewing	–	–	–	–	–	–
Miscellaneous	6	$255.00	2	$24.00	–	–
TOTAL	27	$472.00	35	$548.00	31	$337.00

6.1.1.2.5 Annual estimates

Yearly estimates for cost and revenue were based on the operational costs during the demonstration period and revenue for 2018. Projected costs were based on available data, including engineering judgment as necessary, to achieve estimates given the standard operating procedures within the makerspace environment. Table 6-6 lists overall costs and total revenue generated for the makerspace for both the monitoring period from 31 October 2018 to 15 December 2018, and estimated annual projected costs.

Table 6-6. Overall costs versus revenue (*denotes estimated values).

Item	Monitoring Period (31 Oct – 15 Dec 2018)		2018 Annual (Estimated)	
	Cost	Revenue	Cost	Revenue
Labor	$2,250.00		$18,000	
Materials	$756.16*		$6,000*	
Lighting	$18.29		$146.33	
Equipment	$47.06		$373.41	
Heating/Cooling	$205.43*		$756.92*	
Total Operating	**$3,276.94**		**$25,276.66**	
Total Revenue Generated		**$885**		**$4,479**

As shown, expenditures were $3,276.94 and revenue was $885 during the monitoring period from 31 October 2018 to 15 December 2018, during which detailed operating costs were collected. Using these figures, approximately 27% of the costs to operate the space were covered by revenue generated from the patrons using the space. The cost-to-revenue ratio decreases to 17.72% using projected annual costs and actual annual revenue.

6.1.2 Nonquantifiable benefits

6.1.2.1 Enhance quality of life for installation personnel

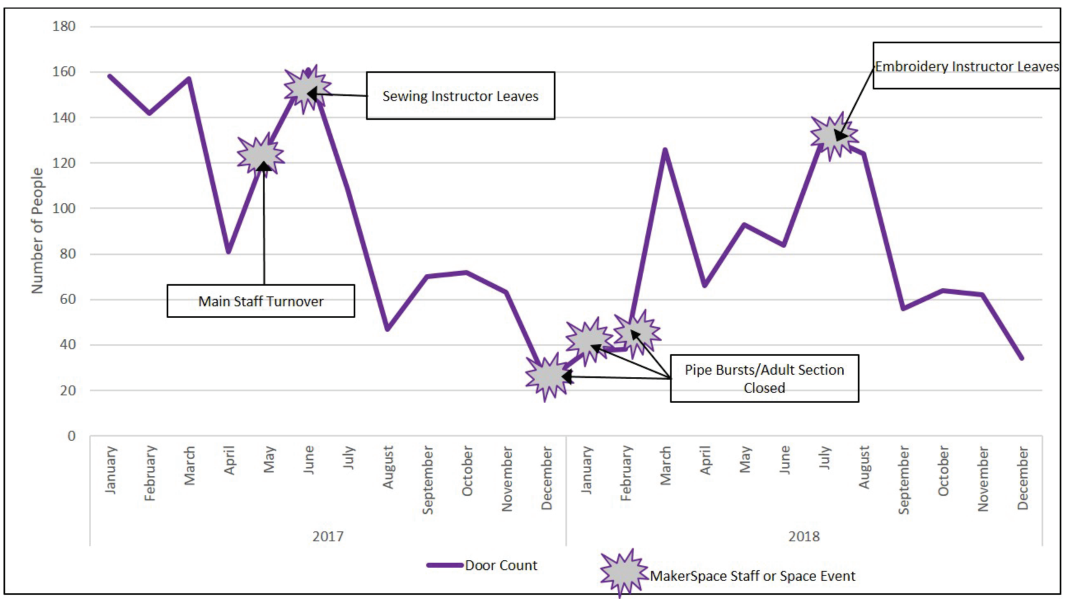
All makerspace Category Types, A, B, and C, provide Soldiers, civilians, retirees and their dependents with increased knowledge, skills, and abilities. Most of these outcomes are difficult to quantify beyond the costs discussed in the above paragraphs. However, many positive outcomes result from providing these types of facilities on military installations. By definition, the MWR environment focuses on quality of life programs and services. The impact these programs and services have on the quality of life for Soldiers, civilians, retirees, and their dependents is qualitative in nature. Therefore, no attempt was made to assign quantitative values to the qualitative considerations within this demonstration and analysis. Inclusion of subject matter experts on assessments for quality of life in future studies could provide valuable metrics of impact of quality of life.

6.2 Costs and benefits comparison

Researchers evaluated the impact of the additional equipment on the makerspace and its usage trends. Results are presented as graphical and tabular summary statistics. Overall results indicate that 3D printer usage, procured as part of the selected COA, is trending upward while overall use of the makerspace is trending downward, suggesting that the 3D printer is becoming the main attraction for the makerspace.

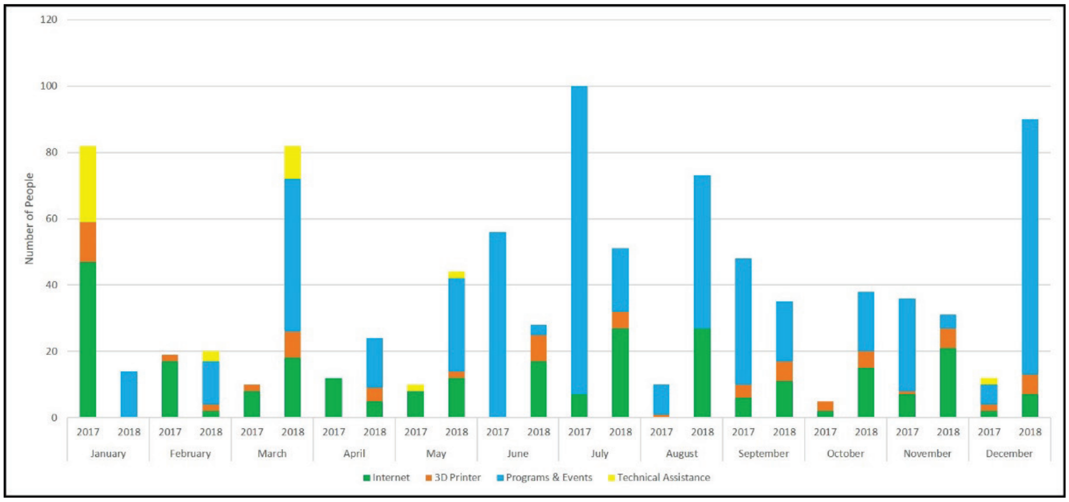
Due to the interconnectivity of the library and the makerspace, events that impacted library patronage also impacted makerspace usage. For the duration of the study period, the Mickelsen Library underwent a major radio frequency identification (RFID) conversion and removed 30% of the physical collection. From December 2017 to February 2018, the adult section of the library was closed due to several burst pipes. From March 2018 through September 2018, purchases of new materials to the collection were limited. Based on daily door counts, all these events are associated with a negative impact on makerspace patronage (Figure 6-2). The loss of key makerspace staff also affected daily door counts due to loss of programming and content available within the space.

Figure 6-2. Door counts for makerspace.



In addition to daily door counts of those accessing the makerspace, staff tracked how many people were using certain areas of the makerspace, including the number of people who used the internet, used the 3D Printer, requested technical assistance, or attended a scheduled program or event. Figure 6-3 shows the monthly patronage totals by usage area for the activities tracked by the makerspace staff. The activities with the highest attendance data are: (1) programs and events, (2) Internet, (3) 3D printers, and (4) Technical assistance.

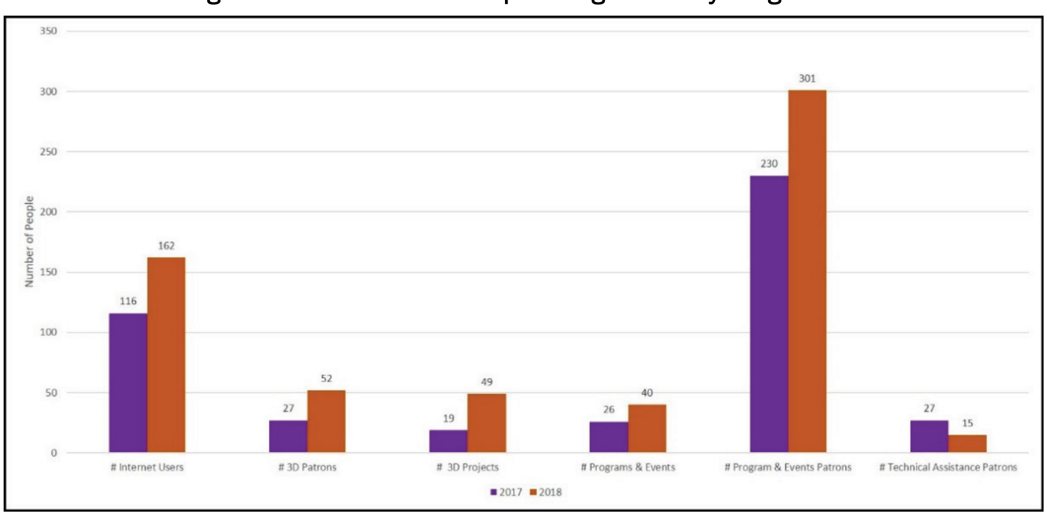
Figure 6-3. Patronage by usage area.



A comparison of Figure 6-2 to Figure 6-3 reveals that the difference in the door count is encompassed by people who are not represented as participating in the identified activities. This includes children engaged in supplemental activities like the LEGO board (e.g., there were 158 people who used the makerspace in January 2017, but only 84 people used the internet, the 3D printer, requested technical assistance, or participated in a program or event).

Figure 6-4 shows the 2017 and 2018 yearly totals for each usage area. In addition to the number of people using each space, the graphic also includes the number of 3D printer projects and the number of program and events that occurred each year. Figure 6-4 clearly shows that the number of both 3D printer patrons and 3D printer projects increased in 2018.

Figure 6-4. 2017 and 2018 patronage totals by usage area.



Usage statistics for the 3D printer indicate a significant increase in the use of the 3D printer in 2018 (Table 6-7). Even as the usage rate for the overall makerspace declined, from a little over one person in the space per hour open to one person for every hour and 15 minutes the space was open in 2017 and 2018 respectively, the 3D printer usage rate increased. The rate for usage of the 3D printer increased from 2% of patrons in 2017 to 6% of patrons in 2018, reflecting a 300% increase in usage. Specifically, the total number of 3D printer patrons in 2018 increased 93% and the number of 3D printer projects increased 158% over the same period, even though the total number of patrons of the makerspace decreased by 24.3% in 2018 and the total hours open decreased by 1% (12 hours).

Table 6-7. Usage statistics.

Category	2017	2018
Total # of Hours Open	1,148	1136
Total # of Patrons	1,210	916
Makerspace Usage Rate	1.05 person/hour open	0.80 person/hour open
Busiest Month	June (161 patrons)	July (132 patrons)
Slowest Month	December (24 patrons)	December (34 patrons)
Total # 3D Printer Patrons	27	52
Total # 3D Printer Projects	19	49
3D Printer Usage Rate	2% of Patrons	6% of Patrons
Busiest Month for 3D Printer	January (12 patrons; 2 projects)	March (8 patrons; 9 projects)
Slowest Month for 3D Printer	April/July (0 patrons; 0 projects)	January/August (0 patrons; 0 projects)

ERDC researchers installed high quality 3D printers in the makerspace in May 2018. A comparison of the usage statistics for the 3D printer year over year for the period between 1 May and 31 December indicates an even greater increase in usage trends in 2018 (Table 6-8). There were only 11 patrons and 13 projects during this timeframe in 2017, and 38 patrons and 32 projects in 2018. This represents a 245% increase in 2018 of 3D printer patrons and 146% increase in the number of 3D printer projects, despite a 3.4% decline in overall patronage of the makerspace during this timeframe (Table 6-8). The significant increase in 3D printer usage in 2018 following the installation of high quality 3D printers, especially when compared to the 3D printer usage over the same time period in 2017, strongly suggests that the high quality 3D printers had a positive effect on the makerspace (Figure 6-5). Additionally, the 3D printer and the internet are the only usage areas that show an increasing usage trend from May 2017, when high quality 3D printers were installed, through December 2018 (Figure 6-6). In summary, this indicates the 3D printer is becoming the main draw of the makerspace.

Table 6-8. Summary usage statistics 1 May – 31 December 2017 vs. 2018.

Year	# Patrons	# Hours Open	# 3D Patrons	#3D Projects
1 May–31 Dec 2017	672	769	11	13
1 May–31 Dec 2018	649	761	38	32

Figure 6-5. 3D Printer patronage trends.

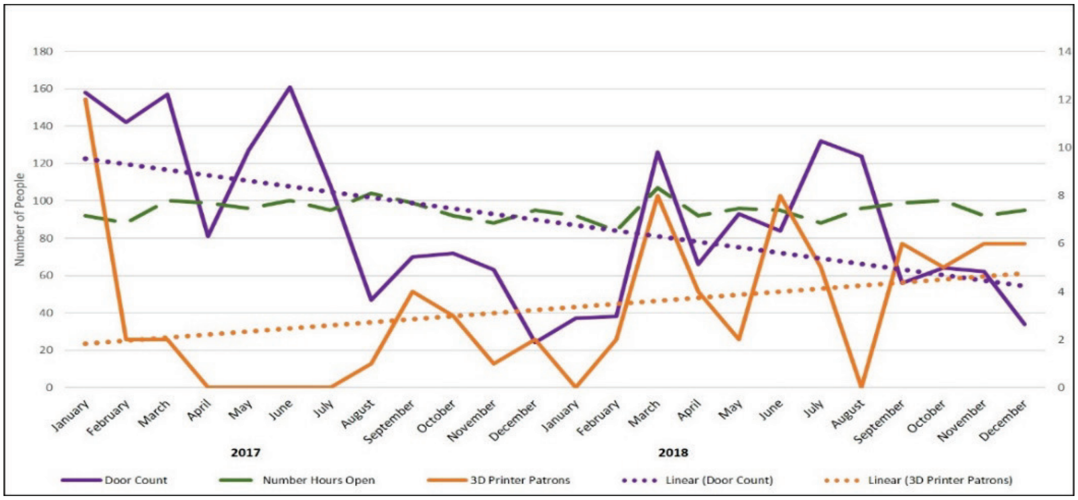
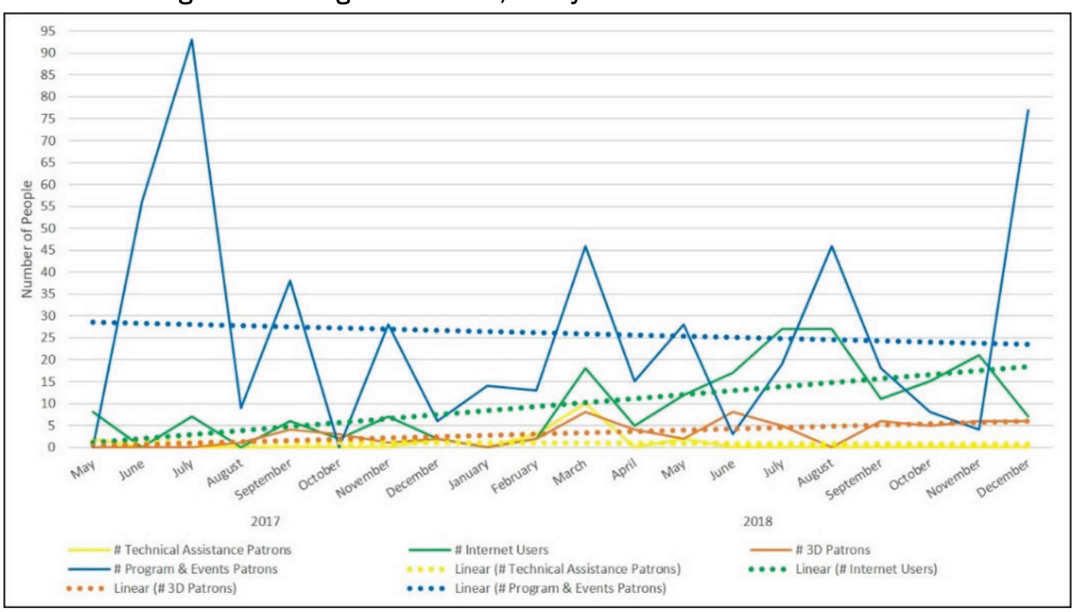


Figure 6-6. Usage area trends, 1 May 2017 –31 December 2018.



6.3 Bill payers, offsets, or tradeoffs

As stated in section 4.2.5 , the makerspace program types discussed in this demonstration are purposely defined to align with DLAI 7303 for program/operational definitions of Category A, Category B, and Category C programs. All Category A, B, and C programs are funded differently in terms of the amount of Non-Appropriated Funds (NAF) and APF programmed and acquired for operational purposes. Category A makerspaces receive a maximum of 85% of total funding from APF, leaving little revenue required from NAF. Category B makerspaces receive a maximum of 65% APF funding, after which the remaining 35% would have to come from NAF sources. Category C makerspaces are provided “limited” APF funding, thereby making it vulnerable, based on its ability to generate revenue for sustainment (DoD 2009). The operational definition/purpose for makerspaces operating in each MWR environment used on this project were those stated in DLAI 7303 (DLA 2009).

Each type of makerspace can be characterized by categories and factors that define its configuration. The categories include objective, feature, and cost. Factors within the objective category are purpose, definition, operation, and reporting. The features category includes equipment, capabilities, products/results, space, requirements, and metrics. The cost category is defined by funding, implementation cost factors and annual operating cost factors. Table 6-9 lists these relationships within each of the three alternatives.

Table 6-9. Characteristics of Category Type A, B and C makerspace.

Category	Factor
Objective	Purpose
	Definition
	Operation
	Reporting
Feature	Equipment
	Capabilities
	Products/results
	Space
	Requirements
	Metrics
Cost	Funding
	Implementation cost factors
	Annual operating cost factors

For the purposes of this analysis, the MWR requirements will be used to govern funding, operation, and reporting. The categories and factors, including their values, are based on information and experiences taken from the Fort Bliss demonstration. Tables 6-10, 6-11, and 6-12 list the three makerspace types and describe how they differ according to the categories and factors of each.

Table 6-10. Category Types of makerspaces and their objectives.

Category	FACTOR	MAKERSPACE Category Type		
		Category A	Category B	Category C
Objective	Purpose	Mission Sustaining	Basic Community Support	Revenue Generating
	Definition	Promotes the physical and mental well-being of the workforce	Satisfies the physiological and psychological needs of the workforce	Produces locally generated income which supports the overall MWR program inventory with NAF
	Operation	Business	Business + 4hrs	Business + 6hrs + Saturday
	Reporting	Annual Funding Usage Program execution	Annual Funding Usage Program execution	Annual Funding Usage Program execution

Table 6-11. Category Types of makerspaces and their features.

Category	Factor	MAKERSPACE Category Type		
		Category A	Category B	Category C
Feature	Equipment	Crafting supplies, artwork supplies, screen printer & materials, sewing machine, embroidery machine & supplies	Crafting supplies, artwork supplies, sewing machine, embroidery machine & supplies, Lulzbot® & materials, CNC machine & materials	Crafting supplies, artwork supplies, screen printer & materials, embroidery supplies, Lulzbot® & materials, CNC machine and materials, laser cutter and materials, raspberry pi(s), Arduino®, desktop computer w/Adobe® Studio Software Suite, video & photo (w/studio & lighting) equipment
	Capabilities	Arts & Crafts Screen printing Embroidery Sewing	Arts & Crafts Screen printing Embroidery, Sewing 3D printing CNC	Arts & Crafts Screen printing Embroidery, Sewing 3D printing CNC, Laser cutting Digital Media
	Products/Results	Crafts T-Shirts, hats Other clothing and apparel	Crafts T-Shirts, hats, clothing, apparel Lulzbot products (3D printed goods) CNC products (engraved, cut, etc.)	Crafts T-Shirts, hats, clothing, apparel Lulzbot products (3D printed goods) CNC products & Laser cutting products (engraved, cut, etc.) Electronics products Photo/video/graphic design
	Space Requirements	500 – 1000 ft^2	1000 – 1500 ft^2	2000 – 3000 ft^2
	Metrics	Revenue/usage Funding (APF/NAF) Quality of Life	Revenue/usage Funding (APF/NAF) Quality of Life	Revenue/usage Minimize APF
	Operational Staff	0.5 FTE	1.5 FTE (varied skills)	2.5 FTE (varied skills)

Table 6-12. Category Types of makerspaces and their costs.

Category	Factor	MAKERSPACE TYPE		
		Category A	Category B	Category C
Cost	Funding	85% minimum APF	65% minimum APF	Limited APF
	Implementation Cost Factors	Low Space: $20,000 Equipment: $10,000 Materials: $4,000 **Total: $34,000**	Med/Low Space: $45,000 Equipment: $33,000 Materials: $8,000 **Total: $86,000**	Med Space: $95,000 Equipment: $49,000 Materials: $11,000 **Total: $155,000**
	Annual Operating Cost Factors	Low Space: $9,000 Equipment: $1,000 Materials: $3,000 **Total: $13,000**	Med Space: $22,000 Equipment: $6,000 Materials: $10,000 **Total: $38,000**	Med/High Space: $48,000 Equipment: $12,000 Materials: $12,500 **Total: $72,500**

6.4 Second and third order effects

It is important to note that, although there are many physical differences, as well as objectives, requirements and operation of makerspaces, two major factors are considered important to their contribution in the success (or failure) of a makerspace as a commonality between the MWR Category Types. These two factors are (1) the space's physical layout and location and (2) the personnel operating the space. Although these factors were fixed for this project, researchers understand they should be considered by decisionmakers during implementation of the program across the enterprise.

6.4.1 Physical space

As in the case of the Fort Bliss Makerspace, the layout and location (i.e., physical address) of the space is expected to play a role in the attendance and ability to support equipment. Layout of the space should be conducive to group learning, supervision, and support of the various technologies within the space. Location of the space should be noticeable and convenient to installation personnel. Location (the physical address of any business or operation) has a tremendous impact on the marketability and potential patronage regardless of the type of business. Convenient access and visibility of the makerspace should directly correlate with increased usage of the makerspace. For example, locating the makerspace near other recreation or leisure-based facilities, with high traffic visibility, such as malls, gyms, swimming pools, or movie theaters, would likely improve usage of the space. When makerspaces are located out-of-sight and out-of-the-way, such as in a basement in a facility located on the edge of the installation, it may reduce awareness and/or patronage of the space.

6.4.2 Personnel

The number and capabilities of personnel hired to operate the makerspace play a critical role in the potential success of the space. Employees' background, interest, knowledge, skills, and abilities are paramount to the user experience. Patrons require assistance, direction, and instruction while using the space. It is detrimental to their user experience if they get the sense they are simply being "left on their own"; this resulting sense of isolation (or alienation) is counterproductive and can potentially fuel an unnecessary and invalid distaste for the specific apparatus or technology in general.

7 Results, Recommendations, and Conclusion

7.1 Results of analysis

Analysis of usage trends and patrons of the enhanced makerspace at Fort Bliss showed that the selected COA, which included investment on additional equipment, had a positive effect on the pre-existing program. During the demonstration period, trends reflected a 245% increase in 2018 of 3D printer patrons and a 146% increase in the number of 3D printer projects, despite a 3.4% decline in overall patronage of the makerspace. High quality 3D printers were part of the additional equipment procured for enhancement of the space (Table 4-1).

It was also found that the highest revenue comes from hosting classes, even though the cost vs. revenue for each program is unknown based on data received from Fort Bliss. For daily operation, support staff labor is mainly devoted to attendance and monitoring. Programs/events could be increased to take full advantage of the labor allocated to this space. Increased programs would increase labor costs due to greater staff participation but would also create the potential to place the makerspace into a higher category if the programs yield more revenue.

Overall, analysis of this early demonstration indicates that the Fort Bliss Makerspace had a positive impact and its cost-to-revenue ratio met the 15% threshold for a Category Type A makerspace according to DLAI 7303. This indicates that makerspaces, such as the one at Fort Bliss, can operate successfully as a Category Type A MWR asset. The operational and organizational risks identified with the Fort Bliss Makerspace can be mitigated in future implementations of installation makerspaces.

7.2 Recommendations

The project team recorded several observations throughout the demonstration project that may be helpful for future implementation of makerspaces on military installations. For ease of understanding, these observations are categorized as: General Makerspace, Location, Data Collection & Recording, Setup, Intent of Space, and Usage Trends.

7.2.1 General Makerspace

Observation: Makerspace success depends on its purpose (see Intent of Space below).

Recommendation: Before setting up a makerspace, determine the makerspace type, purpose, and operation. This affects the expectations of the space and defines the needed capabilities

Observation: One of the greatest challenges for makerspaces on installations is finding and retaining properly trained employees and maintaining interest with a highly transient population. Installation populations are highly transient, leading to a high turnover of staff and patrons. Staff members rarely stay a year or more.

Recommendation: This is a known challenge. Plan on staff and patron turnover. Implement transition plans for periods that have high fluctuation in personnel. Train all staff members on all equipment, so that capabilities are not lost when a staff member leaves. Plan high effort marketing events during times of patron turnover (example: if rotations are every 6 weeks, hold a marketing event every 6 weeks).

Observation: Generating interest in the makerspace within the MWR library environment is difficult and met with marginal success. Typical outreach is done through MWR Facebook and Twitter pages. The number of followers of these pages represent a small fraction of the Fort Bliss supported population and are more likely to already know about the library and makerspace. This outreach may not be reaching a large number of potential new patrons. Participation of new patrons was greater when outreach was done in the mall setting (the first of its kind for the makerspace).

Recommendation: Expand outreach to general Fort Bliss communication methods to reach the portion of the Fort Bliss population currently unaware of the on-post library or makerspace. Outreach may also be increased by using a larger set of social media platforms. Increase outreach in the mall and other high visibility settings bringing equipment onsite.

Observation: Makerspace patrons within the MWR library environment generally fall within the military and military dependent category and are typically focused on “arts and crafts.”

Recommendation: Engage with local groups to increase this participation. To expand patron type, engage with champions within the installation to get direct involvement of civilians, Soldiers, and DPW staff. Coordinate and set up poster in areas such as the Machine Shop and DPW facilities to expand user base. Open during business hours for a short time period to allow for military-specific projects and encourage the local military to use the space for their tasks.

7.2.2 Location

Observation: Generating interest in the makerspace within the MWR library environment is difficult and met with marginal success. Several people during the activity awareness event were unaware of not only the makerspace, but also of the library and its location. The level of involvement in this awareness activity (48 participants over 2 days at lunchtime) also indicates that placing the makerspace in an area with high traffic may yield more utilization.

Recommendation: At Fort Bliss, the library may not be an ideal location for the makerspace and should be relocated OR the library is not in an ideal location and that a change of location for the library (and makerspace) may increase their use. Implementation of makerspaces should be in areas with higher traffic and visibility areas.

Recommendation: The use of mobile makerspaces should be established before committing to a permanent location. This would allow for evaluation of suitable installations and locations on installations for makerspaces. Similarly, different equipment sets can be used to gauge interest and to test their capabilities to support the facility. It is recommended that future work address this evaluation stage, which should precede makerspace implementation.

7.2.3 Data collection and recording

Observation: In this demonstration, historic baseline data specifically related to the type, amount, and resolution (gathered within relevant categories) did not exist due to a lack of reporting requirements before demonstration.

Recommendation: Initiate and require data collection at all makerspaces.

Observation: Recording of attendance and utilization information can be problematic.

Recommendation: Establish clearly defined data gathering protocols and provide standardized data collection form. Also, install automated door counters (e.g., turnstile machines) and have a separate entrance for staff. Install equipment or software (e.g., OctoPrint) that automatically records hours of use, numbers of individual jobs, and/or materials used for computers and equipment in the space.

Observation: Financials are currently hard to separate from overall library costs and do not have a high level of resolution when not required. Certain activities within the makerspace that require supplies, such as the 3D printing or painting, collect fees on a per-project basis to offset the costs of operating the makerspace. The library provided monthly summaries of funds collected, including the number of participants who used features in the space requiring payment and the amount of funds collected.

Recommendation: Have all existing and future makerspaces begin keeping financials separate from other entities. These records should include setup costs. Keep financials as detailed as possible including the specification of consumable cost vs. revenue by activity area. When hosting programs, each program needs to include cost and revenue per participant and overall.

Observation: Electrical metering allowed for a high level of precision in cost for the space but was found to cost a minimal amount per month. The cost to heat and cool the space had to be estimated due to lack of collection methods.

Recommendation: When installing a makerspace, install a separate meter for gas and electric for recordkeeping purposes for operational costs. This is more effectively done in a new space. Additional meters that record usage per device can be installed to give high level of detail for how much operational costs for each device.

7.2.4 Setup

Observation: To take full advantage of the available space, worktables should be selected based on size of equipment and should have self-contained storage capabilities. This allows for new equipment to be added to the space with minimal impact to the existing capabilities.

Recommendation: Conduct detailed planning before purchasing furniture and equipment. This needs to include the full operating space for every piece of equipment to properly support the equipment and work area required to support activities with the equipment.

Observation: Not all equipment is created equal, even with the same contract specifications. During the initial meeting, the staff noted that the pre-existing 3D printers in the space were not adequate, despite being a widely known brand. As such, the pre-existing 3D printers had limited usage due to the quality of the prints, size, speed, limitations on materials, and software limitations. Similarly, to ensure that the CNC mill was a high-quality piece of equipment, the U.S. Marine Corps (USMC) provided suggestions based on Fort Bliss's space requirements to ensure success in the space.

Recommendation: Select 3D printers that have high recommendations in makerspaces (examples: Lulzbot, Ultimaker, Prusa, etc.) that are easy to use and accommodate a widespread amount of: non-proprietary materials, print size, quality prints, and user-friendly software (similar to Slic3r and Cura). This may require adequate justification depending on approved venders at the time. When adding new equipment seek advice from existing makerspaces (commercial or other) and subject matter experts before purchase.

7.2.5 Intent of Makerspace

Observation: Desired MWR type needs to be determined before setup as the built-in characteristics (categories and factors) inherent to each type will be critical to successfully designing, implementing, and operating makerspace.

Recommendation: Determine the role, functionality, and bottom-line impact of any makerspace (regardless of its characteristics, operational intent, and definition of success) before its design, to ensure successful implementation and operation. Base design on the actual details of the designated or desired location. Design makerspaces with identified purposes, using a specified physical infrastructure, tailored to the geographical location.

Observation: When considering Soldier-focused or operational makerspaces within a military installation environment, the type of installation (i.e., readiness, training, sustainment, etc.) will determine the spaces categories and factors that drive the makerspace's operation and capabilities. Quantifiable cost savings would be most apparent in a "manufacturing" makerspace, e.g., the space being implemented at the Rock Island Arsenal. The additive manufacturing capabilities and makerspace environment can allow for the workforce to become familiar with and use modern technology to improve existing processes.

Recommendation: As noted above, a “one-size-fits-all” design should not be used in setting up makerspaces on military installations if Soldier participation is desired, as this design should be tailored to the specific skillsets and needs of the specified installation. Identify and address implications to Soldiers’ Military Occupational Specialty (MOS) and post military career from engagement with an operational makerspace.

Recommendation: Conduct a business case analysis of an operational makerspace established outside of the MWR framework that focuses on technical skills and supporting mission-critical tasks, including DPW functions.

7.2.6 Usage trends

Observation: The ranking of highest attendance is (1) Programs and events, (2) Internet, and (3) 3D printers. The largest revenue generated is also from Programs and events.

Recommendation: Place a large emphasis on programs and events when setting up or maintaining a makerspace. Increase emphasis on 3D printing capability and hold classes to teach users how to be successful when 3D printing (e.g., to reduce waste). The other areas should conduct outreach activities to increase use. For example, on in the use of equipment like the vinyl cutter and press could easily be done as an outreach activity due to its ease of use. Such outreach activities could bring in new patrons.

Observation: Labor accounts for approximately 62% of the operational costs. The use of volunteers to staff the makerspace could greatly offset the cost of operations. Providing free usage of the space and materials to volunteers in exchange for their time, knowledge, and instructional efforts would benefit both the individual and the makerspace. The highest revenue comes from hosting classes; however, data received from Fort Bliss indicates that cost vs. revenue for each program is unknown. For daily operations, support staff labor is expended mainly on attendance and monitoring.

Recommendation: To take full advantage of the labor allocated to this with space, programs/events could be increased. An increase in programs would also increase the level of effort required from the staff during their existing labor hours, but has the potential to place the makerspace into a higher category if the programs are designed to yield more revenue for the cost.

7.3 Conclusion

Researchers concluded that makerspace Category Type A, Category Type B, and Category Type C all provide increased knowledge, skills and abilities for Soldiers, civilians, retirees and their dependents, and can contribute to an improved quality of life. Specifically, the Fort Bliss Makerspace demonstration usage trends indicate that enhanced makerspaces with high quality equipment have a positive impact on Soldiers. The business case analysis determined that the Fort Bliss Makerspace fits the criteria of, met the 15% cost-to-revenue ratio threshold for, and can operate successfully as a Category Type A (Mission Sustaining) program asset.

7.4 Value proposition

Industry has already adopted the technologies found in makerspaces as current and pragmatic ways of doing business. It is suggested that the Army study the advantages and disadvantages of adopting these new technologies as organic capabilities via pilot studies in installation/operational environments.

The Fort Bliss Makerspace pilot demonstration indicates that makerspaces implemented across the Army enterprise have the potential to make a positive impact on Soldiers, family members, and installation personnel. Makerspaces are also capable of operating as a Category Type A MWR asset and may be able to operate as Category Type B and Type C MWR assets if the recommendations made in this report are followed. Specifically, it is recommended that future implementations of makerspaces on military installations be located more prominently within the installation, perhaps on a mobile platform, and that they expand hours of operation to include times that are convenient to Soldier's schedules. It is anticipated that doing so will significantly improve the revenue-generating potential that will make makerspaces a more viable MWR asset across the Army.

Furthermore, if the Army establishes future makerspaces outside of the MWR framework, these non-MWR makerspaces have the potential to focus more on teaching technical skills and support mission-critical tasks, including DPW functions. Doing so could place makerspaces in a mission context in which they could become part of a training program used to upskill Soldiers to meet job requirements. As a result, the value proposition of makerspaces would expand from simple financial payback and quality of life enhancement to include risk reduction for achieving mission objectives.

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Acronyms and Abbreviations

Abbreviation	Term
APF	Appropriated Funds
CERL	Construction Engineering Research Laboratory
CNC	Computer Numerical Control
COA	Course of Action
DLA	Defense Logistics Agency
DLAI	Defense Logistics Agency Instruction
DPW	Department of Public Works
ERDC	Engineer Research and Development Center
FTE	Full-Time Equivalent
IMCOM	U.S. Army Installation Management Command
IT	Information Technology
MIT	Massachusetts Institute of Technology
MOS	Military Occupational Specialty
MWR	Morale, Welfare, and Recreation
NAF	Non-Appropriated Funds
RFID	Radio Frequency Identification
ROI	Return On Investment
STEM	Science, Technology, Engineering, and Math
USAG	U.S. Army Garrison
USMC	U.S. Marine Corps

Appendix A: MWR Makerspace Program Category Types

MWR uses a framework defined by Defense Logistics Agency (DLA) Instruction (DLAI 7303) to categorize its various program types as either a Category A – Mission Sustaining, Category B – Basic Community Support or Category C – Revenue Generating (DLA 2009). This categorization determines the operational purpose of the program and the type of funding to be used in supporting the program. The makerspace program types developed in this section are purposely defined to align with DLAI 7303 for program/operational definitions of Category A, Category B, and Category C programs. All types are considered MWR assets and would be required to operate according to MWR requirements, rules, and instructions pertaining to the category they are operating within.

All Category A, B, and C programs, as described above, are funded differently in terms of the amount of NAF and APF programmed and acquired for operational purposes. A Category A Makerspace would receive a minimum of 85% of its total funding from APF, leaving little revenue required from NAF. Category B Makerspace funding would be a minimum of 65% APF funding, after which the remaining 35% would have to come from NAF sources. A Category C Makerspace is provided "limited" APF funding, thereby making it vulnerable, based on its ability to generate revenue for sustainment (DoD 2009).

The operational definition/purpose for makerspaces operating in each MWR environment, according to DLAI 7303, and for the purposes of this project, are (DLA 2009):

- Category *A – Mission Sustaining*. Programs that promote "physical and mental well-being of the workforce (i.e., Physical Fitness Facilities; Parks and Picnic Areas; and Playing Courts and Fields)." The Fort Bliss Makerspace is operating as a Category Type A makerspace, in a Category Type A environment, due to its connection to the Mickelsen Community Library.
- Category *B – Basic Community Support*. Programs satisfying "the physiological and psychological needs of the workforce (i.e., Child Development Center; Youth Service Programs; Information, Ticketing,

and Registration Programs; Swimming Pools; Bowling Centers; and Automotive Craft Skills Development Centers)."

- Category *C – Revenue Generating*. Programs that "produce locally generated income, which supports the overall MWR Program inventory with NAF (i.e., Food, Beverage, Entertainment and Theme Facilities; Snack Bars; Lodging Facilities; Golf Courses; and Equipment Rentals)."

The purpose of each program type is to "support mission readiness and effectiveness; support recruitment and retention of quality personnel; provide leisure time activities that support a quality of life commensurate with generally accepted American values; promote and maintain the mental and physical well-being of authorized personnel; foster community pride, solider morale, family wellness and promote esprit de corps" (DLA 2009).

To further define general operational characteristics of the three types of programs, consider the following example. A facility/program providing Aquatic Training: Category A would be swimming programs associated with Service member training; Category B would include recreational swimming programs; Category C would be considered an aquatics center. Similarly, a library is a Category A due to the support of mental well-being for the workforce, while supporting their daily tasks and hosting children's programs; this contrasts with a formal book store that would operate as a Category C, the purpose of which is to generate revenue. Each Category (A, B, and C) receiving varied amounts of funding.

Each type of makerspace can be characterized by categories and factors that define its configuration. The categories include objective, feature, and cost. Factors within the *objective* category are purpose, definition, operation, and reporting. The *features* category includes equipment, capabilities, products/results, space, requirements, and metrics. The *cost* category is defined by funding, implementation cost factors and annual operating cost factors. Researchers used this framework to define makerspaces that meet the definition for MWR Category Type A, B and C assets.

Appendix B: Makerspace Market Research

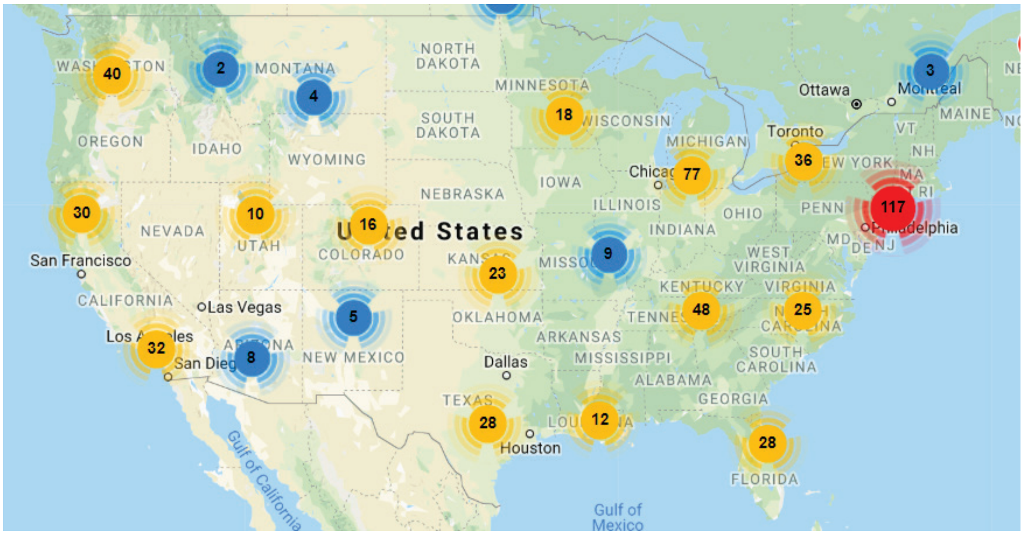
B.1 Civilian Makerspaces

Makerspaces are collaborative workspaces typically located in schools, libraries, or other public/private facilities for making, learning, exploring, and sharing technical (and non-technical) ideas and skills.* Over the past decade, makerspaces have become more available, with over 14 times as many makerspaces as in 2006 (Lou and Peek 2016). Equipment within a makerspace is used by children, adults, hobbyists, and entrepreneurs to learn, develop, and increase their knowledge, skills, and abilities for creating, designing, prototyping, and manufacturing. Typical makerspaces with dedicated space provide 3D printers, laser cutters, CNC (Computer Numerical Control) machines, soldering irons, sewing machines, hand tools, and crafting supplies for use within the facility. Critical thinking skills, self-confidence, and entrepreneurship are encouraged and enhanced by individuals as they participate in electronics, 3D printing, 3D modeling, coding, robotics, and woodworking.

Makerspaces, or "hackerspaces," across public communities, universities, and libraries have been established across the United States and have published suggestions for successful makerspaces (Figure B-1). Part of the organization of makerspaces across the world has been through *Make* magazine. The creators of the Maker Faire events across the U.S. Makerspaces are often community-operated and not-for-profit organizations. The longevity of these makerspaces has often depended on the community, which handles challenges such as those associated with the culture of the space, availability of personnel, cost, space, and liability. For-profit makerspaces and FabLabs can be difficult to maintain. The most well-known for-profit makerspace was TechShop, which filed for bankruptcy and closed in 2017 (Su 2017, Woods 2017, Smith 2017).

* https://www.makerspaces.com/

Figure B-1. Makerspaces in the continental United States listed on the Makerspace registry.



Source: *Make* (2018).

Individual makerspaces may be outfitted with a wide variety of equipment. *Make* magazine's *Makerspace Playbook* (Hlubinka et al. 2013) recommended makerspace guidelines and equipment (Figure B-2). This overall generic list offers helpful suggestions to those wishing to configure a new space. The *Makerspace Playbook* list reflects equipment commonly used across many makerspaces. Note that specific locations may have brand preference for various technology, activity focus areas, and individual makerspaces may have activities that have a wide range from child-friendly to more technical adult spaces (UWM 2020, Sufficient Space 2017, Lawrence University 2020, Smith System 2020, Hughes 2015, FormaSpace 2016, Schwartz 2020).

Figure B-2. Makerspace suggested equipment list from the “Makerspace Playbook.” (Source: Hlubinka et al. 2013).

Reusable Tools List

JOINING
- staple gun
- hot glue gun
- hot glue gun
- pop riveter
- box rivets
- big sewing needles
- paint brushes (1" and 3")
- straight pins
- splice set
- tap and die (SAE + Metric)

MECHANICAL
- screwdriver set (precision)
- screwdriver set (big)
- allen (SAE + metric)
- claw hammer
- mallet
- combination wrench
- ratchet set
- joint pliers (channel locks)
- miter box
- PVC pipe cutter
- socket set
- driver bits
- hollow-shaft nut drivers

ELECTRONICS
- Arduino
- LilyPad
- soldering iron
- soldering tips
- crimper tool
- wire cutter
- wire stripper
- diagonal cutter
- solder sucker
- digital multimeter
- solder tip tinner
- 1/2 size breadboard
- third hand
- tweezers
- solder
- heat gun

CUTTING
- hole saw
- metal file(s)
- file card
- chisel/rasp set
- tin snips
- box knives
- X-acto knife
- scissors
- drill bits
- sanding block
- hacksaw
- wood-saw
- block plane
- deburring tool
- countersink
- awl
- cutting mat
- hand-crank (rotary) craft drill

FIXTURING
- vise
- C-clamps
- bar clamps
- needlenose
- locking pliers
- adjustable wrench
- binder clips
- locking pliers

BATTERIES / POWER
- AA NiMH and charger
- AA NiMH
- 9V battery clip
- 4 AA battery holder
- 3 AA battery holder
- 2 AA battery holder
- alligator clips

TEXTILE/SOFT CIRCUIT
- Fabric scissors
- pinking shears
- seam ripper
- cloth tape measure
- sewing needles
- iron
- embroidery needles
- needle threader
- snap setter
- Serger

STORAGE TOOLS
- containers
- labels
- camera
- broom
- dust pan and broom
- Shop Vac

POWER TOOLS
- jigsaw (electric)
- sewing machine
- drill
- extension cord
- Dremel

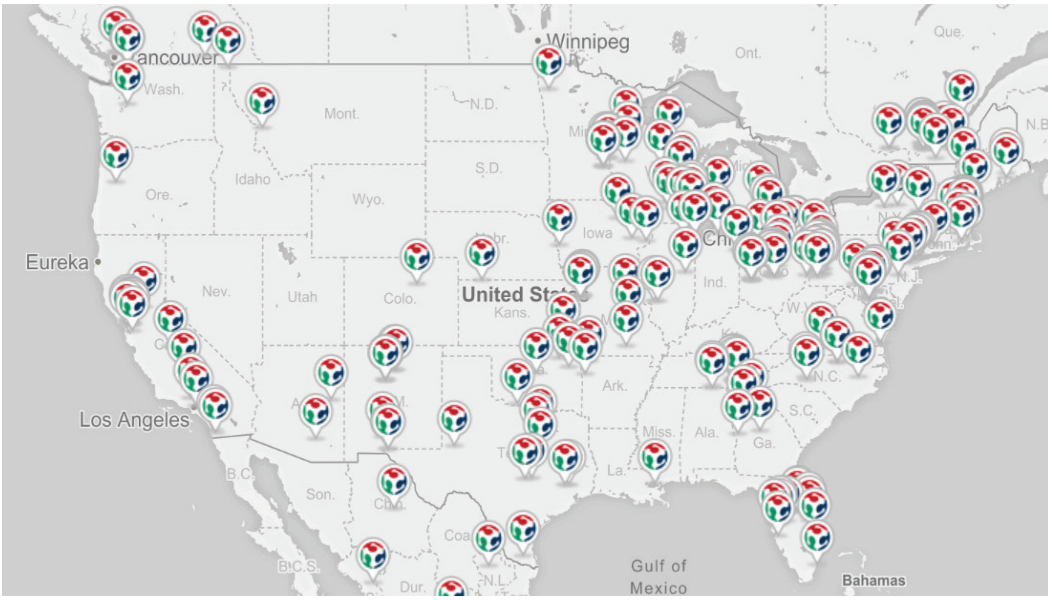
EXTENSION
- 3D printer
- CNC mill
- laser cutter
- circular saw
- orbital sander
- table saw
- hot wire foam cutter
- plastic bender

ETC
- tool box
- workbench
- saw horses
- CNC router

Massachusetts Institute of Technology (MIT) and the MIT Media Lab have broadly influenced the FabLab community by jumpstarting “Fablabs” through the MIT course, “How to Make (Almost) Anything” (MIT 2020), by establishing the Fab Foundation (2019) (an organization for coordinating FabLabs), and by supporting the continued work of Neil Gershenfeld (2006). The Fab Foundation has recommendations for starting new FabLabs from budgets, equipment, layouts, and more (Fab Foundation 2019). These recommendations are followed by many FabLabs around the country (Figure B-3).

This research effort found that the MIT list of suggested equipment (Google Sheets 2020) was helpful in the selection of equipment to give the existing Fort Bliss Makerspace more fabrication capabilities. This list provides a good starting point for those wishing to create a more technical fabrication space with a dedicated staff. The Fab Foundation also suggests useful recommendations and layouts for a Mobile FabLab (Fab Foundation 2019), which may be useful to military installations wishing to gauge interest in creating a FabLab at their location without making a heavy resources commitment.

Figure B-3. FabLabs in the continental United States associated with the Fab Foundation. (Source: Fab Labs 2018).



B.2 Military Makerspaces

Throughout the military there has been a widespread amount of activity to get modern fabrication technology to the forces. This includes implementation of modern fabrication methods (including 3D printers and CNCs) on Navy ships to produce parts on demand, producing lightweight aircraft parts for the Air Force, integration with construction shops within the U.S. Marine Corps, and standing up an Army center of excellence for Additive Manufacturing at Rock Island Arsenal to enhance production lines. There are many accounts of these facilities benefiting the military due to co-location with the MOS that uses them. However, the integration of military makerspaces for widespread personnel use has varied by force.

To determine what location would best support a makerspace, the U.S. Marine Corps (USMC) has taken an alternative approach to traditional makerspaces by setting up mobile makerspaces. This allows the USMC to not only try out locations before a permanent setup, but to deploy these makerspaces to remote locations. This mobile approach was implemented due to the Marine Corps noting that the location of the makerspace is the key to success. The USMC's experience was a model for outlining equipment needs for this demonstration. The USMC has implemented makerspaces to help train its personnel through two major efforts: Tactical Manufacturing (TacMan) and Expeditionary Fabrication (xFab). The USMC basic kit, TacMan, includes Lulzbot Taz 6 3D printers, industrial 3D printers, 3D scanners, laptops, Desktop CNC mill/router/lathe, and a laser cutter. The more advanced kit, xFab, contains these items plus the addition of a large-format 3D printer and a 5-axis CNC mill/router/lathes. The TacMan kit, which is tailored to an organizational level and scalable to any unit, was chosen as the initial template for guiding this research. The xFab kit was not chosen due to its cost, to the level of required training for this equipment, and to safety considerations (since the Fort Bliss Makerspace is intended as a child-friendly space).

At the time of this research, makerspaces are permanently operating within the boundaries of only three Army installations: Fort Bliss, Texas; Fort Knox, Kentucky; and U.S Army Garrison (USAG) Kaiserslautern, Germany. The Army makerspaces are implemented through the MWR library and differ by space allocation, equipment, hours, staff, and guidance by location. The Fort Knox location has a 3D printer, Sprout computer, robots, virtual reality headset and an audio/video editing laboratory. The Kaiserslautern Makerspace has similar capabilities. The only known location with over 1200 sq ft of fully dedicated space and wide subset of equipment for a makerspace is at Fort Bliss, Texas (Knott 2017). This allows the Fort Bliss Makerspace to support more technical equipment than other spaces located within the libraries, since sound, power, and ventilation requirements can be tailored to this separate space. Fort Hood is currently in the process of creating two dedicated spaces for makerspaces, one dedicated for children and one for adults from converted storage rooms, no bigger than 10 ft x 10 ft.[*] Furthermore, as of March 2019, over six Army installations have provided "pop-up" makerspace activities to incorporate things like Snap Circuits® and Makey Makey to teach participants introductory technical skills:

- Joint Base Lewis McChord, WA (https://jblm.armymwr.com/view-event/steam-makerspace/2625765/31845)
- Ansbach, Germany (https://ansbach.armymwr.com/calendar/event/open-stem-lab-ages-5-and/2758145/29357?fbclid=IwAR2o8JXTS_0zm5hJD8E2OFx8L7eRrSMKRO65gfUWt8T0F3tw_QR6Bw0FQ90)
- Fort Sill, OK (https://sill.armymwr.com/calendar/event/makerspace-adults/2856268/28159; https://sill.armymwr.com/calendar/event/makerspace-kids/2856818/34265)
- Fort Lee, VA (https://lee.armymwr.com/calendar/event/makerspace-making-your-own-technology/2918956/33052)

[*] e-mail communication with Rachel Arizaga, Fort Bliss Librarian, 14 March 2019.

- Benelux-Brussels, Belgium (https://brussels.armymwr.com/calendar/event/makerspace-meet/2915499/35991)
- Hohenfels, Germany (https://hohenfels.armymwr.com/calendar/event/makerspace-mystery-class/3003386/24675)

Note that these are not dedicated spaces. Additionally, many military and civilian personnel and their dependents have access to commercial makerspaces at locations across the country.

Appendix C: Fort Bliss Makerspace Site Enhancements

ERDC-CERL personnel visited the Fort Bliss Makerspace in February 2018 to assess the space and document available equipment and current capabilities in the facility (Figure C-1). During this visit, ERDC-CERL personnel and Fort Bliss Makerspace staff discussed the desired technology that would benefit the space; considerations for desired technology included space limitations, safety issues (limited power tools and saws), personnel skills, and fit with existing community. Discussions during the site visit elicited a list of equipment (Table C-1) to be acquired and delivered to the space. A laser cutter was also considered beneficial for the space but was not included in the final list due to space limitations, safety issues, and concerns regarding regular required training.

Figure C-1. Equipment available in the makerspace before demonstration.

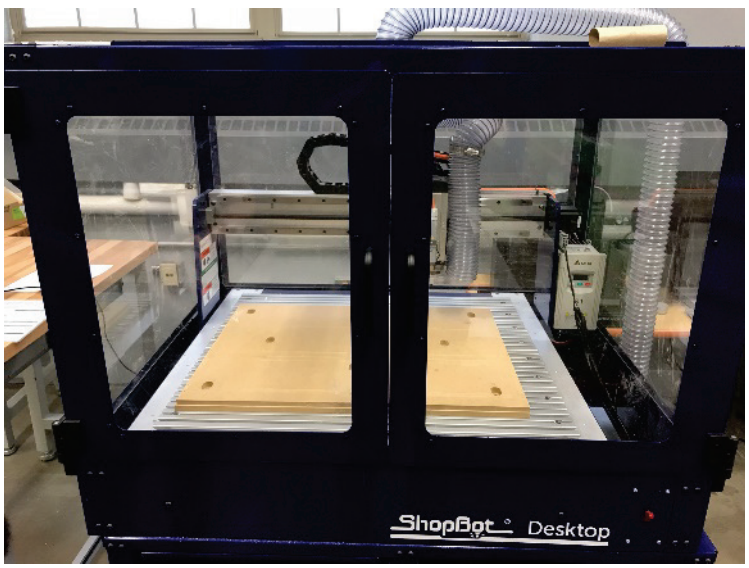
Table C-1. Additional equipment provided by ERDC-CERL.

Item	Type	Qty	Capability
3D scanner	Sense – Next Generation	2	Scan real objects to re-create or to custom fit designed objects
3D printer	Lulzbot Taz 6	2	Additive manufacturing of a wide breadth of polymer materials
CNC	ShopBot Desktop w/1.1HP Spindle & Full Enclosure (DT3 Model 2018)	1	Subtractive manufacturing & etching
Laptop Computer	Dell Laptop	2	3D printer, CNC, and scanner operation
Furniture	Workbenches & supply storage	n/a	Support 3D printing equipment placement and onsite storage for tools and materials

Item	Type	Qty	Capability
Supplies	CNC Bits (general, router, sign makers, plotter pen, diamond drag engraving bit kits, etc.), wood for CNC (maple, plaque, etc.), 3D Printer supplies (filament, replacement parts, etc.)	n/a	Support operation and usage of equipment

Personnel from ERDC-CERL and manufacturer representatives provided training to the makerspace staff and one potential power user, as well as the initial setup of all additional equipment. ERDC-CERL and makerspace staff participated in certification training for the ShopBot CNC (Figure C-2). This training allowed all certified personnel to train and certify additional operators for the ShopBot system to create a pattern of longevity for the use of the equipment. All these manufacturing related technologies require some degree of technical knowledge, skills, and abilities.

Figure C-2. ShopBot Desktop CNC mill.



The addition of Lulzbot 3D printers into the makerspace environment increased the 3D printer utilization (see Section 6.2, for a detailed description of utilization rates). During the initial meeting, the staff noted that the pre-existing 3D printers in the space were not adequate, despite being a widely known brand. This was in part due to the makerspace not having a choice in this selection. This issue often arises in the government due to acquisition processes and IT restrictions, which can result in the acquisition of less-than-ideal equipment (i.e., 3D printers). Machine-based requirements are often specified during a purchase; however, the quality of the printing is determined not only by these requirements but by the interaction between the software and machine. As such, the pre-existing 3D printers had limited usage due to the quality of the prints, size, speed, limitations on materials, and software limitations.

Going forward, it is recommended to incorporate 3D printers that have high recommendations in makerspaces (examples: Lulzbot, Ultimaker, Prusa), that are easy to use and that accommodate a widespread amount of non-proprietary materials, print size, quality prints, and user-friendly open-source software (similar to Slic3r and Cura). This may require having adequate justification for alternate vendors depending on the approved vendors at the time.

To accommodate the additional technology, the Mickelsen Library Staff and ERDC-CERL researchers maximized the space by re-configuring the floor plan. ERDC-CERL researchers assessed and measured the current makerspace area. Key space components and elements, such as the receptacles, lighting fixtures and switches, storage cage area, doors, and windows were documented (Figure C-3). Other elements such as tables and chairs were also documented and added to a digital Autodesk Revit® model developed by ERDC-CERL researchers. The layout shows the flow of patrons and equipment in the space "as is," to assess the flow of the work space (Figures C-4 and C-5).

The rearranged space had to account for the addition of over 100 sq ft of new equipment, tables, and tool cabinets, plus additional required offset distances for all areas in makerspace. The largest physical change to the space was the addition of the ShopBot Desktop CNC mill due to its unique requirements (Figure C-3). The ShopBot Desktop CNC mill required (1) a footprint of approximately 3.6 ft x 2.6 ft on a rolling cart to make the space more fluid, (2) close proximity to a laptop and work area, (3) a separate electric outlet, and (4) space to operate and roll the machine out for cleaning and maintenance, (5) additional tables with a sturdy base to support the 3D printing activities, and (6) two tables with four tool chests added to the space to hold the associated tools and supplies for the equipment.

Figure C-3. Makerspace with doors, receptacles and dimensions.

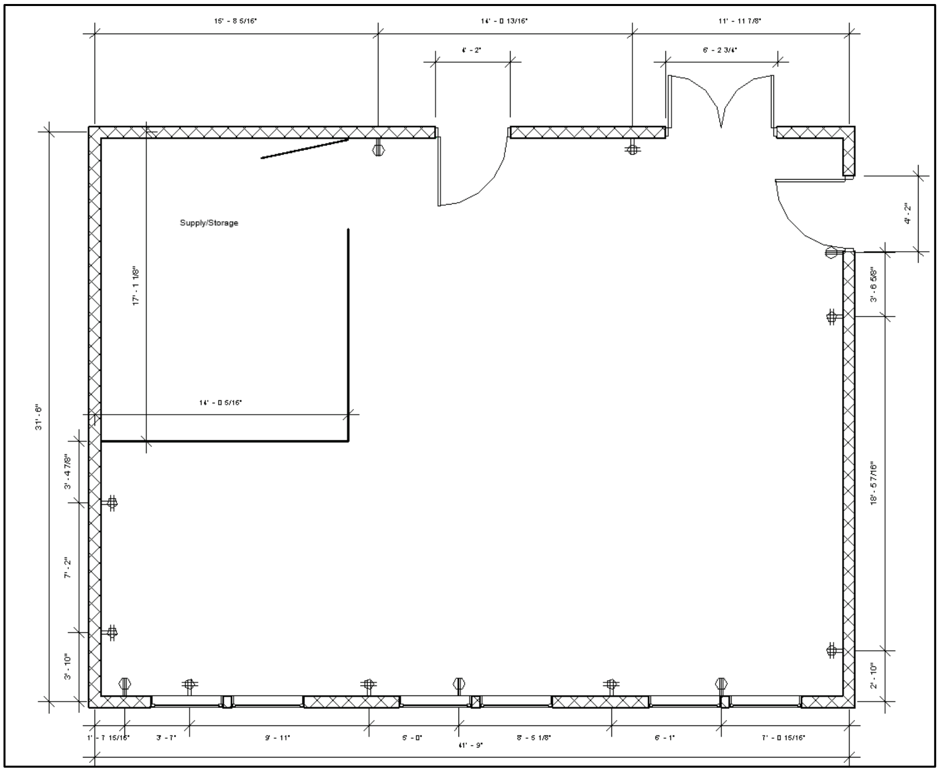
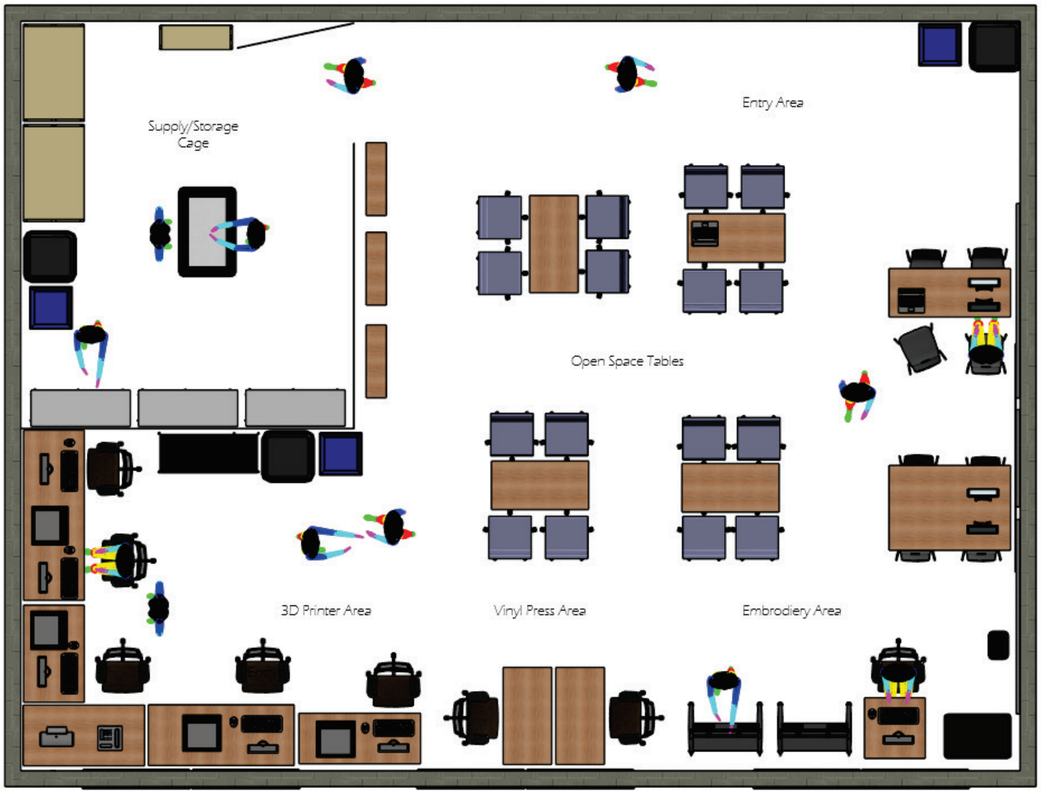


Figure C-4. Rendition of the makerspace: Isometric view.

Figure C-5. Rendition of the makerspace – Original Layout: top view.



Mickelsen Library staff worked with the ERDC-CERL team to create a spatial design to accurately fit all the equipment and elements into the space by introducing a minimal impact on the space (Figures C-6 and C-7). While the open-space work area takes up most of the room, it was not modified as this area hosts the classes and programs for the makerspace, which is the major source of the revenue. The additional worktables added into the room were selected based on size and self-contained storage capabilities to minimally impact the existing equipment and capabilities as a result of this detailed planning. The vinyl press area was modified for use of either CNC activities or for the vinyl press. The added equipment to the space is denoted in the yellow boxes (in Figure C-6). The new layout provides enough space around each piece of equipment to maintain requirements for accessibility and safety, while allowing the space to be tailored to large groups.

Figure C-6. New layout design (boxes added to highlight new areas).

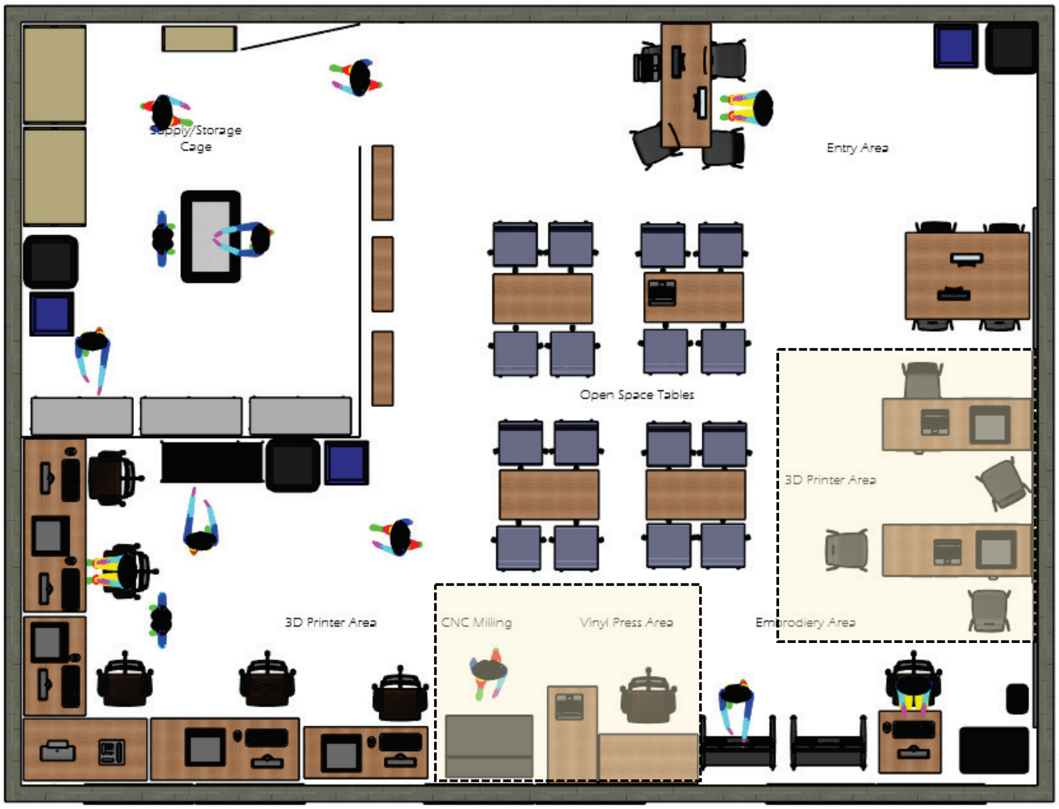
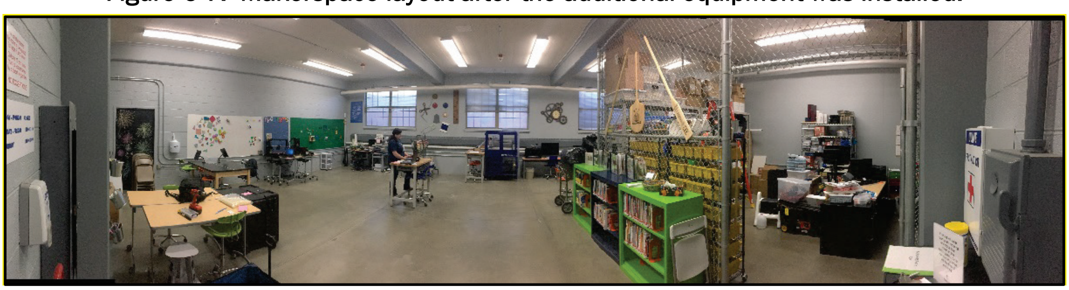


Figure C-7. Makerspace layout after the additional equipment was installed.



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14. ABSTRACT
This work demonstrated the implementation of makerspaces, collaborative workspaces that provide hands-on learning to help prepare the future workforce with critical 21st century applied-technology skills. Researchers from the U.S. Army Engineer Research and Development Center, Construction Engineering Research Laboratory (ERDC-CERL) enhanced and evaluated the pre-existing makerspace at Fort Bliss, Texas to demonstrate the value of a makerspace within the military Morale, Welfare, and Recreation (MWR) environment. The 8-month pilot demonstration, conducted from May to December 2018, focused on investigating program characteristics such as usage trends, optimal locations, equipment, and personnel access. Results from the demonstration indicated that enhanced makerspaces with high quality equipment had a positive Soldier impasct. The business case analysis determined that the Fort Bliss Makerspace fits the criteria of, met the 15% cost-to-revenue ratio threshold for, and can operate successfully as, a Category Type A (Mission Sustaining) program asset.

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