EXPEDITIONARY AIRFIELD SURFACE SOLUTIONS:
A COST-BENEFIT ANALYSIS

GRADUATE RESEARCH PROJECT

Eric L. Hitzfeld, Major, USAF

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Eric L. Hitzfeld, MS

Major, USAF

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Eric L. Hitzfeld, MS

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Committee Membership:

Col Jason Anderson, Ph.D.

Chair

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Abstract

The purpose of this research is to examine the procurement and transportation costs of AM-2 airfield matting in relation to an emerging technology, biocement. Biocement formation involves a process found in natural soil and marine bacteria, where urea and calcium chloride are converted into a naturally-produced cement. BioMASON is a commercial company that is harnessing this process to conduct the rapid construction of airfield taxiways, ramps, and runways. As our near-peer adversaries continue to challenge our flexibility and resolve, any technology that could provide a more agile and cost-effective capability to meet similar results is paramount. Upon completion of this review, readers will understand the benefits of this technology and its expeditionary application in austere locations as well as any potential cost benefits to the Air Force.

Acknowledgments

I would like to express my sincere appreciation to my faculty advisor, Colonel Jason Anderson for his guidance, eternal patience, and support throughout the course of this research project. His insight and experience were instrumental and greatly valued. To the men and women of the Air Force Research Lab, thank you for sharing your research and work with me. I wish you luck going forward and am excited to see the possibilities you will enable someday. To my fellow Airmen (military and civilian) at HQ USAFE-AFAFRICA and DLA, you gave me the tools and insight to accomplish this and I cannot thank you enough. Furthermore, I would like to thank my daughters for being patient while I spent many hours working on this instead of time with you. Being your father is the best job I could ever have. Most importantly, I would like to thank my wife for her constant support, encouragement, and patience during this entire program and with the Air Force's demands on my schedule. I love you.

Eric L. "Hitz"feld

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**EXPEDITIONARY AIRFIELD SURFACE SOLUTIONS:
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I. Introduction

Background

In November 2020, in response to a Presidential order to remove all U.S. military forces from Somalia no later than January 15, 2021, European Command (EUCOM) gave U.S. Air Forces Africa (AFAF) the order to expand Manda Bay, Kenya as necessary to absorb the aircraft and forces that needed a new home (Anna, 2021). Accompanied with the demand for additional lodging, food, medical care, security, and communications infrastructure was a sudden emergency for a parking ramp large enough to house the newly orphaned aircraft. Planners at USAFE had limited options in east Africa: Camp Lemonnier, Djibouti (CLDJ) and Manda Bay. The ramp at CLDJ was a hub of activity and parking was already a serious concern. Manda Bay was not as busy, but the ramp space was already saturated with a plethora of aircraft from multiple military branches. With approximately two months until the deadline, it was not possible to source and transport the mass amount of equipment and supplies needed to build a ramp using traditional paving methods. There were contractors in Kenya that could do the job, but not in that time-frame and for a premium cost. A quick, short-term solution was needed to give EUCOM and AFAF options.

With very few options available, the decision was made to work with the Defense Logistics Agency (DLA) to source airfield matting (AM-2), a portable, puzzle-piece system that could be flown in, unpacked, and assembled. There were immediate challenges that presented themselves. It required a large amount of labor, equipment, tools, and specialized hardware. This hardware connected the panels together and anchored them into the soil. Much of that hardware that wasn't in stock and had to be sourced globally. Getting that hardware to a remote location in Kenya proved to be difficult and time-consuming. There are a variety of national stock numbers (NSNs) and several warehouses were exhausted of their supply and AFAF's ability to track shipments was a challenge; coming from multiple origins such as Pennsylvania, California, Bahrain, Italy, and Djibouti (Pinney, 2021). As the hardware arrived in random sized shipments, every available Airman, Marine and Soldier worked together to assemble the matting. Each panel weighs approximately 150 pounds and requires several personnel to place each piece to ensure it is properly aligned, anchored, and attached (Naval Air Systems Command, 2018). With the clock ticking, every shipment was quickly utilized to assemble every piece of square footage available. When time is limited, the military needs solutions that are cost-effective, easily procurable, and simple to install. Are there emerging technologies that could also accomplish the mission and meet some of those objectives? Biocement is a new technology that turns ordinary dirt into a dense, hardened surface using minimal supplies and equipment. It can be used as a runway and a parking ramp. It can also turn a large plot of dirt into an airfield for vertical take-off and landing operations (BioMASON, 2022).

Objective

This graduate research project (GRP) will examine the costs and benefits associated with the procurement and transportation of airfield matting and biocement. Additionally, it will cover the functions of each, their history, associated costs and benefits and the challenges any organization would face implementing either of them. Upon reading this GRP, the reader should be able to answer, is biocement a good alternative to AM-2 matting with regards to procurement and transportation costs?

II. Literature Review

The purpose of this chapter is to provide basic information about what a cost-benefits analysis is. Additionally, there will be information about the origins of airfields and runways. Finally, the history, current use and primary parts of AM-2 and the ingredients of biocement will assist in understanding the nexus between the two and how each one can provide an expeditionary option for logisticians and tacticians as they deliver solutions to combatant commanders responsible for austere areas of operations.

Airfields - Runways & Ramps

Essentially, airfields are comprised of a runway, taxiways, parking ramps, air traffic control tower and often a terminal or passenger processing area. Aircraft need paths to navigate off the runway and onto their parking spot. In August 1909, the Wright brothers convinced the Army to invest in their first aero plane thus requiring a place to park it and an air strip to operate on. By October 1909, the first military airfield at College Park, Maryland, home to the now University of Maryland just outside of Washington D.C., was cleared of brush and obstacles and a rudimentary hangar was constructed (Founding of the College Park Airport , 2022). While airfields have evolved significantly in over 100 years, the bare necessities exist; you need a place to park, take off and land. That is no different for the U.S. Air Force (USAF) when establishing a presence in a foreign country. According to the Lemay Center's Agile Combat Employment Doctrine, posture "establishes a deterrent to conflict by being strategically predictable, but operationally unpredictable" (Curtis E. Lemay Center, 2021, p. 5). This means establishing locations within an area of operation quickly. There are multiple types of airfields; initial, temporary, and semi-permanent. Under initial airfields there are drop zones, extraction zones and expedient airfields. Their surfaces can be improved and unimproved and have a life expectancy of six months maximum (HQDA, 2016). Semi-permanent are for sustained use and are built using the highest standards of concrete and asphalt construction and can sustain most weather conditions for an extended period (HQDA, 2016). This GRP will focus on temporary airfields, usable for 6-24 months and are designed for heavy airlift. Temporary runways are constructed of temporary matting, concrete, or bituminous asphalt (HQDA, 2016).

Runways enable combat and special-mission aircraft, but especially heavy airlift and aeromedical evacuations to ensure the safe arrival or departure of forces and the enabling of vital supply-chain networks. When establishing an airfield, consideration must be given to the strength and durability of the surface the aircraft will operate. While there are airfields all over Europe that are accessible to the USAF and the Department of Defense (DoD), other theaters face significant challenges; such as the Pacific and Africa. The austere nature of these theaters illustrates the challenges associated with acquiring the supplies and equipment required to build a durable and effective airfield. This requires the DoD to utilize creative solutions.

Airfield Matting

Expedient surfacing systems, also known as airfield matting, have been used since the 1940s, and AM-2 is a variant that was initially used in the 1960s (Garcia & Hoffman, Determination of Structural Properties of Airfield Matting, 2019). Before AM-2 can be placed, the subsurface dirt must be exposed, flattened, and conditioned using several heavy-duty vehicles: a bulldozer, pneumatic roller and vibratory steel-wheel compactor (Garcia, Fisher, Rushing, & Tingle, 2016). Each panel is approximately 1.5 inches thick and 2 feet by 12 feet. A single 6061-T6 aluminum alloy extrusion is used to manufacture each panel and has end connectors welded to the 2-foot ends along with male and female hinge-type connectors on the 12-foot sides as displayed in Figures 1 and 2 (Garcia, Fisher, Rushing, & Tingle, 2016). There are also 6-foot-long panels that aid in arranging an even pattern (Garcia, Fisher, Rushing, & Tingle, 2016).

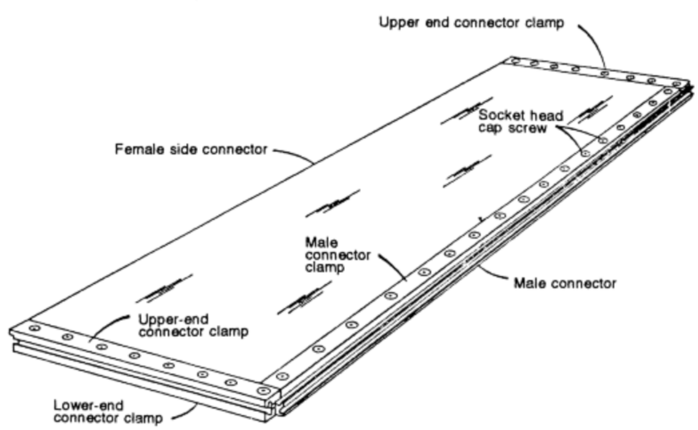

Figure 1. AM-2 Panel

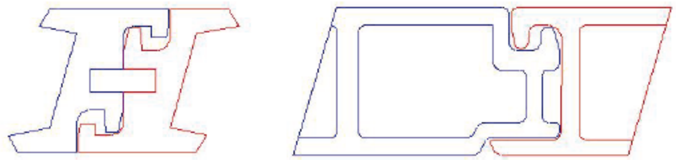

Figure 2. Overlap/Underlap and Male/Female Hinge Connectors

There are several varieties of hardware required to install AM-2. The Maltese cross is a ground anchor that requires heavy equipment to drive it into the ground as an anchor. Then a pin stake is required to attach the anchor to a universal edge clamp. Finally, a safety tie wire is used to secure the pin stake with the edge clamp locking bars. Only the locking bars are included in the packaging for AM-2. The remaining four types of hardware are sold separately. There are three variants of packaging used to transport AM-2 as seen in Table 1 below: F44, F71 and F72. (DLA Troop Support, 2020). Of those packages, only the F71 and F72 are listed in the Naval Air Systems Command (NAVAIR) technical manual (TM). A typical installation crew consists of a 16-man crew: a supervisor, alignment man, pry bar man, and six two-man teams to move the mats from the pallet to the point of installation and install it (Naval Air Systems Command, 2018).

Table 1. AM-2 Airfield Matting Packages

Package Variant	Components	Weight	Surface Area (square feet)
F44	16 panels (12x2 ft) 4 panels (6x2 ft) Locking Bars	2,750 lbs	432
F71	18 panels (12x2 ft) Locking Bars	2,880 lbs	432
F72	18 Panels (6x2 ft) Locking Bars	1,475 lbs	216

Each package variant is airworthy and ready to be palletized on 463L pallets. The F44 and F71 packages contain 12-foot-long panels that require a two-pallet train. Due to their weight, they can only be stacked two high and two wide. The F72 packages are about half the weight and can utilize a single pallet, but are also stacked two high and two wide. A variety of aircraft sizes and types can depart and land on AM-2 and an even larger number of aircraft can park on it. For instance, all fighter aircraft can land on it, but C-5 Galaxies cannot. However, if there is an existing runway and AM-2 is only used as a parking ramp, C-5s can taxi, turn, and park on it (DLA Troop Support, 2020).

Biocement

Imagine a world beneath your feet where bacteria are responsible for turning soil into cement. Certain species of soil like Sporosarcina pasteurii and Bacillus megaterium are known for "producing ammonia, which in turn, causes calcium carbonate to precipitate. This has been studied extensively as a promising method of ground improvement and microbial induced calcium precipitation (MICP) has been shown to produce significant enhancement in the mechanical properties of soils, both at small scale and in field tests" (Dade-Robertson, et al., 2018, p. 2). BioMASON is a company that is hoping to reduce the carbon footprint of traditional concrete materials. "Its patented technology, inspired by nature's production of coral, uses bacteria to create calcium carbonate that stitches together grains of aggregate or sand at ambient temperatures. Biocement is a planet-friendlier alternative to traditional Portland cement, which requires high energy to bake in a hot kiln and emits substantial carbon dioxide into the air" (Teater, 2022, p. 1).

In 2018, the Blue Horizons Program at Air University began working with BioMASON to duplicate tests typically conducted in a lab on a 2,500 square-foot patch of dirt in Durham, North Carolina. The results were very promising and led to more research involving the Air Force Research Lab (AFRL) and the Defense Advanced Research Projects Agency (DARPA) with the intent to test it using actual military aircraft (Ripple, 2019). On August 3, 2021, a crew of Navy Seabees (Construction Battalion) watched an HH-60S land on an improved dirt landing pad that they had built just days prior. The products they used and their specific quantities were designed by BioMASON, in concert with DARPA and AFRL, who work on different biocement application systems with the intent of building expeditionary landing zones (Neal, 2021).

Figure 3. HH-60S lands on a BioMASON-improved landing pad.
Photo by Petty Officer 3rd Class Kevin Neal (NMCB11)

The main ingredients used to create these bio-runways are urea, calcium chloride, bacteria, and water; fresh or saltwater. Once the bacteria are introduced to the urea and calcium ions, the bacteria hydrolyze the urea molecule, leaving carbonate at the cell membrane. Then carbonate ions combine with calcium ions to form calcium carbonate crystals on the cell membranes. The final step is when the progressive crystal formations entomb the bacteria cells (Patterson & Hung, 2022). Urea is a primary ingredient in fertilizers and products like diesel exhaust fluid (DEF). Urea can be derived from non-biological starting material and is also a "naturally occurring molecule that is produced by protein metabolism and found abundantly in mammalian urine" (American Chemical Society, 2021, p. 1). Its role in DEF will be discussed later regarding limitations to using biocement. Calcium chloride "dissolves exothermally in water and is highly hygroscopic. These properties make it useful for applications such as removing water from gases and liquids, melting ice on roadways, maintaining a liquid layer on road surfaces for dust control, and preparing aqueous solutions with low freezing temperatures" (American Chemical Society, 2008, p. 1). Most people recognize it as an ingredient in snow and ice melting salts, but current testing uses the purer form to maintain scientific controls. There may come a time when this common product found on many military bases could be sourced as an ingredient in growing biocement (Patterson & Hung, 2022).

III. Methodology

Introduction

To gather the data needed for this GRP, there were several sources used. First, Web Federal Logistics Information System (WebFLIS) was searched to discover who managed certain supply stocks. From there, prices were gathered from those sources

(ILS-S or DLA). A specific square footage was chosen to examine the requirements for AM-2 and biomason. Then the quantity of AM-2 and biocement ingredients were gathered. Based on the weight of the cargo, Air Mobility Command (AMC) has set rates. Multiple spreadsheets were built to communicate the overall procurement and transportation costs. The future research section will discuss areas that should be pursued to further evaluate the pros and cons of each option. This chapter will further discuss what cost-benefit analysis (CBA) is, different types of CBA, and how the data was collected.

Cost-benefit Analysis

"A cost-benefit analysis (CBA) is the process of comparing the projected or estimated costs and benefits (or opportunities) associated with a project decision to determine whether it makes sense from a business perspective" (Stobierski, 2019, p. 1). Essentially, how will a project benefit or suffer from specific decisions or policies?

There are several different types of CBAs. First, *ex ante*, or prospective cost-benefit analysis, to identify the pros or cons associated before a decision or project is chosen. Another is e*x post*, or retrospective cost-benefit analysis, for capturing the hind-sight view of decisions already made or projects that have already been completed. Then there is analysis performed during a lengthy project where performing a CBA afterwards could produce inherent risk by not having data in a timely manner that could alter current projects or policies. This is called *in medias res* (Boardman, Greenburg, Vining, & Weimer, 2018).

It is not unreasonable to perform a CBA on AM-2 or biocement differently. In a study performed on assessing road safety measures, a total of 18 policies or methods were examined. Of them, nine were performed ex ante and the other nine, ex post. In cases where assumptions were required due to limited data or data from related instances but not directly tied to that safety measure, ex ante was used. Ex post was the most effective regarding measures containing policies or infrastructure that already existed (Yannis, Gitelman, Papadimitriou, Hakkert, & Winkelbauer, 2008). There is a lot of data for AM-2 since it has been used by the military for approximately 80 years. However, there is much context to each scenario. For instance, in the circumstances regarding Manda Bay, Kenya, due to the rapidly emerging nature of that requirement, AFAF and DLA sourced every piece of AM-2 that was closest to eastern Africa (Pinney, 2021). The amount of AM-2 matting and hardware in the various warehouses was disproportional. Some warehouses shipped cargo containing a small amount of hardware and the costs associated were substantially different in comparison with larger quantities that moved as whole packages (Pinney, 2021). This very well could be studied ex post, but due to the infancy of biocement, there isn't any similar data for comparison. This GRP will put both options on equal footing to provide a baseline by using identical sourcing and destination data. This will produce a best-case scenario in which neither alternative will have an advantage based on fluctuating or disproportionate stock levels.

Data Collection

When researching what products can be ordered, a good starting place is the ISO Group website to search through key phrases, NSNs and product catalogs. Their database gives historical context and can illustrate whether a particular product was purchased by the USAF in the past, has an active contract with routine distribution or was discontinued. For instance, urea broth (NSN 6505-01-130-5005) was originally in the supply ordering system in 1982 but has not been ordered in over 5 years. It only had one supplier in the past and as of today, there are zero suppliers (ISO Group, 2022). Fortunately, this was not the type of urea needed for this research. But it demonstrates the level of detail this site offers. This website was used to find the specific NSNs for urea and calcium chloride that have current sourcing in the supply system. Both are available for purchase within the USAF supply chain. Prices were gathered using WebFLIS by entering in the queried NSNs and gathering the verified sources of supply. It was determined that DLA was the source of supply for AM-2 kits (F71 & F72). Additionally, DLA is the source for all but one NSN of AM-2 hardware, locking bars. They can be purchased through GSA but they are also included in the F71 and F72 kits. One hardware kit is included in the analysis because the other pieces of hardware are not included in the kits. A request was submitted to the DLA liaisons to AFAF for an AM-2 fact sheet (DLA Troop Support, 2020). It provided all the NSNs that also matched what was in WebFLIS. AM-2 is reusable and could be available in the supply system, requiring only transportation costs, but it has a limited lifecycle and the intent of this GRP is to examine the procurement costs of brand-new materials to establish a baseline of both alternatives. However, it would be simple to deduct the procurement costs of brand-new AM-2 to observe any potential advantages to either option.

The U.S. Transportation Command (USTC) sets the costs for the movement of all goods across air, land, and sea. To calculate the transportation costs, this GRP used the

FY22 Channel Rates & Guidance published by AMC. This document breaks down passenger and cargo costs to include aeromedical evacuation patients, mail, excess baggage, and pets. To calculate the price per pound, this document provides tariff costs categorized in weight break rates (WBR) based on port of embarkation (POE) and port of debarkation (POD) zones (AMC, 2022). As mentioned before, the origin and destination used in this GRP are the same for AM-2 and biocement. POE 1 is the CONUS and POD 12 is Africa. These prices are only for channel cargo. There is another section in AMC's guide that covers additional legs outside channel routes called Special Assignment Airlift Missions (SAAM). They have a different calculation based on cost per flying hour from origination to destination and includes the aircraft's return to home station (AMC, 2022). SAAMs are much more expensive than channel missions and are often avoided by military branches unless ground transportation is not feasible or the mission priority is too high. The channel tariff rates will be used in the transportation analysis section.

Cost-Benefit Analysis Application

The data used in this GRP focuses on the financial cost to the USAF when faced with the decision to purchase AM-2 or biocement. It focuses on the transaction cost economics theory, where the unit of analysis uses a single transaction (Williamson, 2010). This theory defines a transaction as an economic exchange of a good or service from a provider to a separate user (Pint & Baldwin, 1997). Using this construct, this GRP will evaluate the single transactions of purchasing each product. Then it will add the cost of transporting those items. These costs are often the first questions answered by logisticians. While there is a lot of research that has been performed by engineers to evaluate the strength and durability of AM-2, logisticians are concerned with the procurement and transportation. The data available to determine these costs have been available for the entire time that AM-2 has been a common tool used by the USAF, even if it has changed over time based on multiple variables. This GRP will examine the single transaction costs for AM-2 and biocement using ex ante data. There will also be a section to discuss future research that could reveal other benefits or challenges associated with AM-2 or biocement.

IV. Analysis

Introduction

This chapter will illustrate how the collected data was calculated. As described in the methodology, most of the tables combined data for AM-2 and biocement using simple multiplication and addition. Each table will be described in detail to ensure clarity of how the total procurement and transportation costs were calculated.

Procurement

The procurement cost for AM-2 and biocement was calculated based on 50,000 square feet. That is a space of 250 feet by 200 feet. Since the square footage of the panels isn't evenly divisible by 6 or 12, the only lengths AM-2 is available in, there will be a minor amount of excess space. With each row being 2-feet wide, the width of the ramp is evenly divisible. The most common pattern used is the brick-work-pattern and it maximizes the use of 12-foot panels. It requires at least one 6-foot panel per row (Naval Air Systems Command, 2018). This requires 100 6-foot panels. At 18 panels per F72 kit, it requires six kits. Those panels account for 1,200 square feet of ramp space. The remaining 48,800 square feet is divided by 432 square feet to determine it will require 113 F71 kits. Each F72 kit covers 216 square feet. Table 3 calculates the amount of square footage for each kit and multiplies that by the number of kits to ensure it adds up to enough square footage. In Table 3 below, there is just enough square footage left over.

Table 2. AM-2 Matting Requirement

	Area (sq ft)	# of kits	Total Area (sq ft)
F71	432	113	48816
F72	216	6	1296
Required Ramp Space	50000	N/A	**50112**

Biocement is currently under testing by AFRL and BioMASON. In August 2022, engineers and scientists were at Tyndall AFB conducting more testing outside of a laboratory. Some of the information regarding the formula is proprietary, especially when discussing the specific type of bacteria used and the exact quantity used. A general formula was provided for the purpose of this GRP; 50,000 pounds of urea and 100,000 pounds of calcium chloride for a 50,000 square-foot area. There is also approximately 100 pounds of bacteria required as well (Patterson & Hung, 2022). The pricing of that bacteria has not been provided at this time. The Integrated Logistics System – Supply (ILS-S) interface provides the dimensions of each product. Urea (NSN 6505-00-560-7204) is sold in 1-pound bottles and can be shipped 12 bottles per box. Calcium chloride (NSN 6810-01-220-9194) is sold in 50-pound bags, boxed individually. This information is useful later when calculating the transportation costs. As Table 4 below shows, urea is more expensive than calcium chloride. One pound of urea is 21 cents cheaper than 50 pounds of calcium chloride. When compared by weight, urea is $1,114.50 per 50 pounds compared to the $22.50 for calcium chloride. Larger quantities of urea exist, but not in the USAF supply system. It could be possible to contract with a urea manufacturer to decrease the price per pound and ship the product in a more efficient type of packaging. Based on the formula provided by AFRL, the number of units required multiplied by the cost per unit is totaled at $1,159,500. Using the data from Table 3, the number of units required multiplied by the cost per unit provides a total of $1,1734,789. Overall, AM-2 is $575,289 more expensive to procure.

Table 3. Procurement Costs of AM-2 and Biocement

	Units	Unit Type	Cost	Required Qty	Total Cost
F71	1	Kit	$ 14,829.73	113	$ 1,675,759.49
F72	1	Kit	$ 8,827.32	6	$ 52,963.92
Hardware	1	Kit	$ 6,065.91	1	$ 6,065.91
					$ 1,734,789.32
Urea	1	Pound	$ 22.29	50000	$ 1,114,500.00
Calcium Chloride	50	Pounds	$ 22.50	2000	$ 45,000.00
					$ 1,159,500.00

Transportation Costs

The first step is to determine the dimensions and weight of AM-2 crates and biocement ingredients. These items are very different in size. For instance, a single F71 kit does not fit on a pallet and requires two pallets. Biocement ingredients are much smaller and one pallet can hold many boxes of those ingredients. Before using AMC's WBRs to calculate transportation costs, it must be determined if the customer will be charged based on the actual weight of the cargo, or the dimensional weight. Table 4 below shows how to calculate the dimensional weight. The cargos dimensions are multiplied together, divided by 1,728 inches, and rounded to the nearest whole number. Then it is multiplied by 10 pounds. This is the dimensional weight. If this amount if larger than the actual weight, this number is multiplied against the WBR instead (AMC, 2022). None of the shipments in this chart had a dimensional weight greater than their actual weight as is calculated in Table 4.

Table 4. Dimensional Weight Calculations

Type of Product	*Multiply all 3 measurements (inches) Length x Width x Height*			*Total Dimensions (inches^3)*	*Divide by 1,728 inches*	*Round to nearest whole number*	*multiply by 10 lbs*	
	L	W	H					
F71	146.4	30	30	131760	76.25	76	760	**2880**
F72	74.4	30	30	66960	38.75	39	390	**1475**
Hardware Kit	74.4	30	30	66960	38.75	39	390	**1775**
Urea*	92.8	75.2	77.5	540838	312.99	313	3130	**9935**
Calcium Chloride*	100	68	49.5	336600	194.79	195	1950	**9935**
Biocement ISU	108	88	91	864864	500.50	501	5010	**10000**
**Palletized*							Dimensional Weight	**Actual Weight**

Once it is determined that the actual weight will be used, AMC's guide shows how many dollars to charge per pound of cargo, shown in Table 5 (AMC, 2022).

Table 5. AMC Weight Break Rates

Dept of Defense Channel Cargo Tariffs (Dollars per Pound)							
POE	POD	Zone to Zone	0 - 439 pounds	440 - 1099 pounds	1100 - 2199 pounds	2200 - 3599 pounds	3600+ pounds
1	2	1 - 2	1.572	1.413	1.259	1.099	0.967
1	3	1 - 3	1.247	1.121	0.998	0.871	0.767
1	4	1 - 4	2.704	2.432	2.166	1.890	1.664
1	5	1 - 5	3.844	3.456	3.078	2.687	2.365
1	6	1 - 6	1.676	1.508	1.343	1.172	1.032
1	7	1 - 7	3.084	2.773	2.470	2.155	1.898
1	8	1 - 8	6.601	5.936	5.287	4.614	4.062
1	9	1 - 9	2.054	1.847	1.645	1.436	1.264
1	10	1 - 10	3.190	2.868	2.555	2.229	1.963
1	11	1 - 11	3.461	3.113	2.772	2.419	2.130
1	**12**	**1 - 12**	**5.372**	**4.831**	**4.302**	**3.755**	**3.306**

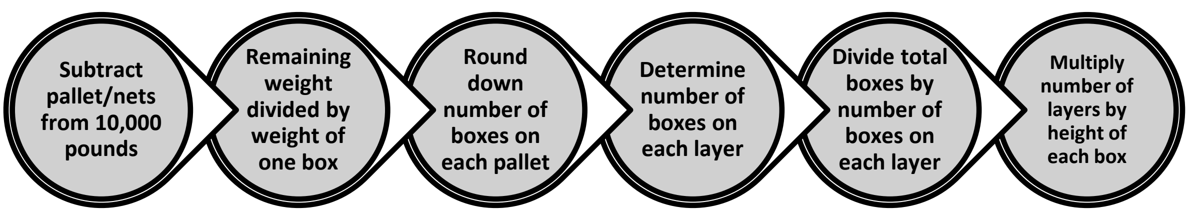

Figure 4. Calculation for Palleted Biocement Ingredients

To calculate the weight of each pallet containing biocement ingredients, it is required to determine the number of boxes that can fit on a pallet. Figure 4 explains the calculation that determines how many boxes fit on a single pallet. Each 463L pallet with a full set of nets weighs 355 pounds. Subtract that from the maximum weight per pallet position: 10,000 pounds (AMC, 2022). Then divide the remaining weight by the weight of one box and round down to the nearest number. That provides the total number of boxes that the pallet can hold by weight capacity. Then determine the number of boxes that fit on each level by dividing the length and width of a pallet by the length and width of one box. For example, a box of urea contains twelve, one-pound bottles in a single box that measures 11.6 inches by 9.4 inches. The usable space of a 463L pallet is 104 inches by 84 inches (AMC, 2022). Dividing each pallet length and width by the length and width of a box of urea determines how many fit along the length and width of the pallet, or 8 by 8 boxes, for 64 total boxes on each layer. Then divide the total number of boxes by the number of boxes on each level. Then multiply the number of layers by the height of one box, 7.1 inches. That gives the final measurement of the pallet height, 75.33 inches. Since that is less than the maximum height of 96 inches per pallet, we know the pallet has reached its maximum weight rather than its maximum cubic space. Then we use the dimensions of the entire pallet to determine the cost per pallet. These calculations are displayed in Tables 6 and 7.

Table 6. Calculation for Pallet Dimensions and Weight (Urea)

Pallet	Minus Pallet & Nets	# of Boxes Divided by Box Weight (14.2 lbs)	# of Boxes on Pallet (Rounded Down)	# Boxes on One Level (Rounded Down)	Total Boxes Divided by # of Boxes per Layer (64 Boxes)	Multiplied by Height of Boxes (7.1 Inches)
10000	9645	679.23	679	104" / 11.6" = 8 84" / 9.4" = 8 64 total boxes per layer	10.61 Layers of Boxes	75.33 Inches Tall

Table 7. Calculation for Pallet Dimensions and Weight (Calcium Chloride)

Pallet	Minus Pallet & Nets	# of Boxes Divided by Box Weight (50 lbs)	# of Boxes on Pallet (Rounded Down)	# Boxes on One Level (Rounded Down)	Total Boxes Divided by # of Boxes per Layer (16 Boxes)	Multiplied by Height of Boxes (4 Inches)
10000	9645	192.90	192	104" / 25" = 4 84" / 17" = 4 16 total boxes per layer	12.00 Layers of Boxes	48.00 Inches Tall

Using the WBRs in Table 5, Table 8 multiplies them against the weight of AM-2 and biocement increments. For instance, an F72 kit weighs 1,475 pounds. That is in the 1100-2199 WBR category, which costs $4.302 per pound. There is a total of six kits needed for a total of 8,850 pounds. When that is multiplied by the WBR price of $4.302, it will cost $38,072.70 for all six kits to ship from CONUS to Africa.

Table 8. Transportation Costs (according to zones 1 - 12)

Type of Cargo	Cargo Weight	Multiplied by WBR Cost	Multiplied by # of Increments	Total Cost
F71 Kit	2880	3.755	113	$ 1,222,027.20
F72 Kit	1475	4.302	6	$ 38,072.70
Hardware Kit	1775	4.302	1	$ 7,636.05
				$ 1,267,735.95
Urea	9645	3.306	6	$ 191,318.22
Calcium Chloride	9645	3.306	11	$ 350,750.07
Equipment ISU	10000	3.306	1	$ 33,060.00
				$ 575,128.29

The calculations in Table 8 show that AM-2 is $692,607.66 more expensive to transport. As illustrated in Table 9, to procure and transport brand new AM-2 airfield matting it costs $1,347,125.27 more than biocement.

Table 9. Cost Comparison of AM-2 and Biocement

Cost is for materials/services required for 50,000 square feet of completed surface

	AM2 Matting	**Biocement**
Procurement Cost	$ 1,734,789.32	$ 1,159,500.00
Transportation Cost	$ 1,267,735.95	$ 495,900.00
Total	**$ 3,002,525.27**	**$ 1,655,400.00**

Assumptions/Limitations

There were several assumptions made to conduct this GRP. First, the amount of surface area and the type of soil that is conducive with this formula. The sandier the soil, the more biocement ingredients that are needed, but requires less time to cure. The higher the clay content, the less material needed, but with a longer cure time (Patterson & Hung, 2022). As mentioned before, if the materials require transport beyond the POD, ground transportation is needed. This GRP calculated the transportation cost based off major ports for POE/POD. There is currently a small list of equipment that is needed to distribute the biocement mixture. A large plastic tub with a portable heating device that can achieve 86° F is needed to grow the bacteria prior to distributing it on the ramp surface. A hydro seeder can be used to saturate the surface with the urea and calcium chloride. Then that same hydro seeder can spray the bacteria onto the saturated surface (Patterson & Hung, 2022). This equipment is not in the USAF supply system but is often available locally at most POE/POD locations. To account for that, it is assumed the equipment could all fit within an ISU 90. Additionally, AM-2 and biocement share some similar types of vehicles and equipment needed to level the surface and compact it as dense as possible, such as a bulldozer and a pneumatic roller (Naval Air Systems Command, 2018). These items are common at most major bases and often more remote bases under construction. It is assumed that they would be available for either purpose. Due to the infancy of biocement, it is possible that employees of BioMASON would be on site but that over time this work would be performed entirely by Air Force personnel. The information presented has some limitations. The current prices of the AM-2 kits or biocement ingredients are subject to change, especially with rapidly changing global economies. For instance, urea is a main ingredient in some fertilizers. Due to Russia's invasion of Ukraine in early 2022, nearly 15% of the global supply of fertilizer has been removed from the global market (Jones & Nti, 2022). This could have a major impact on the price of urea and the availability of it for non-agricultural purposes. This is a limitation that could have a lasting impact as prices and scarcity increase worldwide (Jones & Nti, 2022).

Biocement is currently in testing and there hasn't been enough evidence to demonstrate its capability to endure consistent operations beyond a hypothesis. Furthermore, there is potential that biocement could repair itself or be repaired with additional applications (Patterson & Hung, 2022). This will require more testing in and out of the laboratory and it is not recommended to make operational decisions based on this information until further tests have been conducted to validate this data.

Future Research

There is a lot of opportunity to further study areas that are not covered in this GRP. First, as mentioned before, the current urea NSN used in this GRP is not an efficiently packaged product and would create a lot of waste at the site with tens of thousands of plastic bottles. It is likely that a company could be contracted to source it in larger containers or possibly in liquid form. Furthermore, researchers at AFRL believe it is possible that DEF could be used instead of pure urea (Patterson & Hung, 2022). This is a product that is already in the DoD supply chain, but only available to the Navy and Army. The USAF could work with item managers to add it to our current supply chain and further research could discover potential savings to significantly reduce the overall cost.

Another prospect worth researching is the impact of disproportionate stock levels across the enterprise. If only 10% of the needed AM-2 is in Europe, 40% is in the CONUS and the other 50% is in the Pacific, transportation costs will be much more than forecasted here. Shipments won't be easily consolidated. For example, F71 kits require two pallets tied together where the kits can be stacked two wide and two high. If a two-pallet shipment is only filled with one or two kits, it wastes available space and is less efficient, driving up the cost and potentially requiring a channel extension if the source of supply is not a major POE. This could be applied to biocement as well, especially with the global impacts of the fertilizer market.

More research could be performed on entire transportation costs to include other airlift options like SAAMs and surface movement to include ships and ground transportation, such as commercial and organic, military trucking.

Implications and Conclusion

If AFRL, BioMASON and other military branches can continue their research, they could reveal that biocement can support a plethora of platforms. Additionally, it could require minimal equipment, personnel, and supplies. However, their research could establish that AM-2 is the best option we currently have. If biocement is not durable enough to fully support operations, the cost savings will not be enough. Further researching AM-2 and biocement can provide decision makers at the Pentagon, Air Force Materiel Command, Pacific Air Forces, U.S. Air Forces in Europe, and Air Forces Africa with another option to enable the rapid mobility of forces to austere locations. Upon examining the data contained in the GRP, biocement is less expensive to procure and transport than AM-2 and the USAF should continue to study the benefits of biocement. By furthering AFRL's efforts, biocement may be an expeditionary and agile capability to explore.

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14. ABSTRACT
The purpose of this research is to examine the procurement and transportation costs of AM-2 airfield matting in relation to an emerging technology, biocement. Biocement formation involves a process found in natural soil and marine bacteria, where urea and calcium chloride are converted into a naturally-produced cement. BioMASON is a commercial company that is harnessing this process to conduct the rapid construction of airfield taxiways, ramps, and runways. As our near-peer adversaries continue to challenge our flexibility and resolve, any technology that could provide a more agile and cost-effective capability to meet similar results is paramount.

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Col Jason R. Anderson, AFIT/ENS	(937)255-6565, ext 4326 (NOT DSN) (jason.anderson@afit.edu)

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