Evaluating the Economic Viability of 8th Military Police Brigade's Nuclear, Biological, Chemical Reconnaissance Vehicle (NBCRV) Program

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The views and opinions expressed in this paper are those of the author and do not reflect the official policy or position of any agency or individual in the United States military or government.

Abstract

Military Commanders are in the business of producing readiness. Unlike private organizations, in which profit maximization drives most decision making, military units seek to maximize readiness given a budget constraint. The difference might seem nuanced, but if readiness remains un-quantifiable, it can be difficult to discern the most efficient purchases for the Command. The entire funding process creates a zero-sum game; a dollar spent on training aids translates to one less dollar available for maintenance, fuel, and equipment. In order to make better-informed decisions, the Army must place greater emphasis on analyzing data from its accounting systems.

In 2010, Congress mandated that the Army become auditable by 2017.[1] While the Army has yet to pass an audit, its leaders have taken substantial steps to foster a climate of fiscal stewardship. In 2011, the initial wave of the Army's accounting system, the General Fund Enterprise Business System (GFEBS), launched.[2] Global Combat Support System-Army (GCSS-Army) fielding followed in 2013 and established the maintenance system of record. Fast forward to 2020 and mechanics at the motor pool are asked to tie maintenance requests to vehicle serial numbers. When properly documented, this creates time series data on maintenance requirements for specific components within vehicles over multiple years.

In this paper, I attempt to analyze the M1135 Nuclear, Biological, Chemical, Reconnaissance Vehicle (NBCRV) program within 8th Military Police Brigade, stationed at Schofield Barracks, Hawaii. I do so by employing a traditional Bayesian model using expert prior knowledge and three and a half years' worth of real data extracted from GCSS-Army. I model time to failure for three separate major components within the NBCRVs in order to produce estimated readiness levels throughout the year given a budget. I also attempt to answer various questions regarding the effectiveness of funding spent on the NBCRVs, factors affecting component failure rates, and the impact of maintenance on future cost reduction. This paper does not serve as a panacea, merely as a starting point for further investigation and discussion. I find that the minimum budget threshold to ensure long-term NBCRV program success lies between \$150,000 to \$200,000 per Fiscal Year (FY) given FY2020 pricing.

[1] Bill Chappell, "Pentagon Announces First-Ever Audit Of The Department Of Defense," NPR (NPR, December 8, 2017).

[2] Frank Distasio, "Army Business System GFEBS Now Operational Worldwide," (October 26, 2011).

Background and Motivation

The Army uses the Training Resource Model (TRM) to compute costs in prior years in order to justify future budget requests. The entire Planning, Programming, Budgeting, and Execution Process (PPBE) spans five years and outlines the allocation of government funding for the accomplishment of military objectives.[3] While the PPBE process should be deliberate and thought-out, culminating with a Budget Estimate Submission based on actual prior execution, the time requirement to create such a product has the potential to create a lagged effect. If the average lifespan of a durable good falls between 2-3 years, a unit might not feel the burden of a decreased budget until it comes time to pay for a new piece of that equipment once again.

Since 2017, the NBCRV TRM allocation has steadily decreased from $207,172 per vehicle to $54,509 in Fiscal Year 2020 (FY20). Yet, the cost of maintaining specific parts on the vehicles continues to rise. In 2018, a the Chemical, Biological Mass-Spectrometer cost $331,575 with an associated turn-in credit of $240,499—a total cost of $91,076. In 2020, the cost had risen to $367,719 while the credit fell to $170,112—a total cost of $197,607. As the system becomes older and shifts into a legacy status, this gap will only continue to increase. The chart below shows actual costs by year from 2017 through 2020 after accounting for turn-in credits.

Budget vs Actual Costs Based on Training Resource Model

Year	2017	2018	2019**	2020*	2021	2022	2023
Budget Per Vehicle	$ 207.2	$ 172.2	$ 114.0	$ 54.5	$ 55.2	$ 56.7	$ 57.4
Total Budget (x4)	$ 828.7	$ 688.9	$ 456.1	$ 218.0	$ 220.8	$ 226.6	$ 229.7
Credits	$ 83.9	$ 811.2	$ 1,208.1	$ 209.6			
Actual Expense	$ 7.2	$ (462.8)	$ 922.2	$ 874.1	$ -	$ -	$ -

*Data for 2020 incomplete, as of Aug 2020

**2019 Data includes $937 of free parts from PM Stryker

Figure No. 1

Above charts displays funding allocation based on the TRM from 2017-2023 compared to actual expenses (after credits) in those same years. Costs are in thousands of US Dollars.

The NBCRV is a variation of the Infantry Carrier Vehicle, Stryker, outfitted with specialty equipment that allows the Commander to detect an assortment of nuclear, biological, or chemical threats both in the air and on the ground. I used text analysis on the “Description” field of GCSS-Army work order reports to find that three major components required higher levels of maintenance and resulted in a large portion of total work orders performed. These components are the Joint Biological Point Detection System (JBPDS), Chemical Biological Mass-Spectrometer (CBMS), and Remote Weapon System (RWS). Together, they comprise 27.1% of all maintenance work orders over 2017-2020 and a combined 62% of the cost. These are the cost drivers of the entire program. Other expensive items such as engines, transmissions, and the Joint Service Lightweight Standoff Chemical Agent Detector (JSLSCAD) fail at lower rates than the above three components. A model of NBCRV costs over the fiscal year must, at a minimum, take these pieces into account.

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[3] Department of Defense, The Planning, Programming, Budgeting, and Execution (PPBE) Process, DoD Directive 7045.14 (Washington, DC: Department of Defense, 2013).

The chart below shows a detailed breakdown of the number of work orders associated with the NBCRVs by year based on whether or not the work order included any maintenance performed on one of these three systems.

Maintenance Breakdown by Major Component (JBPDS, CBMS, RWS)

Year	Cost Driver	Count	% of Total Work Orders	Cost	% of Total Cost
2017	No	54		$ 88.9	
2017	Yes	4	6.9%	$ 2.2	2.4%
2018	No	107		$ 45.8	
2018	Yes	57	34.8%	$ 302.7	86.8%
2019	No	148		$ 696.0	
2019	Yes	61	29.2%	$ 1,434.3	67.3%
2020	No	73		$ 269.5	
2020	Yes	20	21.5%	$ 55.2	17.0%
All	No	382		$ 1,100.3	
All	Yes	142	27.1%	$ 1,794.3	62.0%

Figure No. 2

Number of work orders and total cost based on maintenance to a major component in terms of cost drivers (JBPDS, CBMS, or RWS).

The 8th TSC G8 and 303rd Explosive Ordnance Disposal (EOD) Battalion both wrote white papers regarding the 8th TSC NBCRV systems.[4] Both papers can be found as an appendix. In the first paper, the G8 concluded that there was "not enough historical evidence that supports a need for an increase budget." The analysis was based on average cost of the NBCRV programs from 2017-2019 and did not take failure rates or the high level of variance in costs from year to year into account. In the 303rd EOD's paper, which spans the years of 2015-2019, they correctly identify the CBMS as a major cost driver of the program, noting that eight systems had been replaced over the same time period. Their work claims that user error is not a factor in the program and that the systems are failing at an appropriate rate of 25%, or one every four years, according to Project Manager Stryker (PM Stryker).[5] [6] [7] Their final recommendation, to increase budgets in FY21, is based only on the likely increased cost of the CBMS system to over $600,000 per new unit. While certainly a problem, the CBMS is only one component of the entire NBCRV; failing to focus on the vehicle as a whole creates the potential for blind spots to

[4] The G8 is the higher headquarters staff section that performs accounting and budgetary functions; 303rd EOD BN is the Battalion-level unit that owns and operates the NBCRV systems.

[5] 303RD Ordnance Battalion (Explosive Ordnance Disposal), "NBCRV Chemical Biological Mass Spectrometer (CBMS)," (official memorandum, Washington, DC: Department of Defense, 2020).

[6] PM Stryker is an Army organization and responsible for the acquisition, development, and sustainment of the Stryker family, per their website.

[7] William Venable, "Project Manager Stryker Brigade Combat Team," Program Executive Office Ground Combat Systems, (2019).

the problem as a whole. In the end, both papers failed to consider the full depth of the problem: that average cost in itself is a poor metric for evaluating vehicle readiness, and that cost is only a function of failure rates. To find a solution, we must better define the problem. By determining failure rates for each cost driver (the JBPDS, CBMS, and RWS) while still accounting for routine costs such as engines, we can help reduce the complexity inherent in the issue and create a model to simulate expected costs and fleet readiness. The next section will focus on the methodology and accompanying assumptions made in order to model NBCRV failure rates for each major component.

Methodology

In order to understand the factors affecting readiness of the NBCRVs, I interviewed maintenance mechanics and our Brigade S4 (Supply and Maintenance Officer) to create the process map below. Dashed lines indicate potential relationships, solid lines show definitive relationships. For example, a CBMS *might* fail in a given year, which would affect cost, turn-in credits, and whether or not a major component failed. As such, the line between CBMS Operability and whether a Major Component Failure occurs or not is dashed. However, a major component failure affects vehicle capability without a doubt, and thus, has a solid line. The crux of the issue therefore comes down to predicting the pace at which the CBMS, JBPDS, and RWS systems fail. Using a simple Bayesian model, I find the time to failure for each component, *j*, on every one of the four vehicles, *v*. Thus, the cost function for any given month can be written:

$$C_m = \sum_{v=1}^{4} \sum_{j=1}^{3} Y_{j,m,v}\left(P_j - W_j\right) + R_m$$

Equation No. 1
Cost function of NBCRV system

Where *C* is the cost of the entire program; *m* is the month; *v* is the vehicle (1-4), *j* is the cost-driving component (1-3, CBMS, JBPDS, and RWS); *P* is the price of the respective components; *W* is the turn-in credit of the respective components; *R* is the price of routine costs; and Y is operability of the *j* components at month, *m*, for each of the *v* vehicles. Or, put more simply, total cost is equal to the sum of the costs of all component failures, less turn-in credits in a given month, plus routine maintenance costs. It follows, then, that readiness is simply the cumulative operability status of the vehicles divided by the total number of vehicles (four). This equation is in the bottom right corner of the process map below.

NBCRV Readiness Process Map

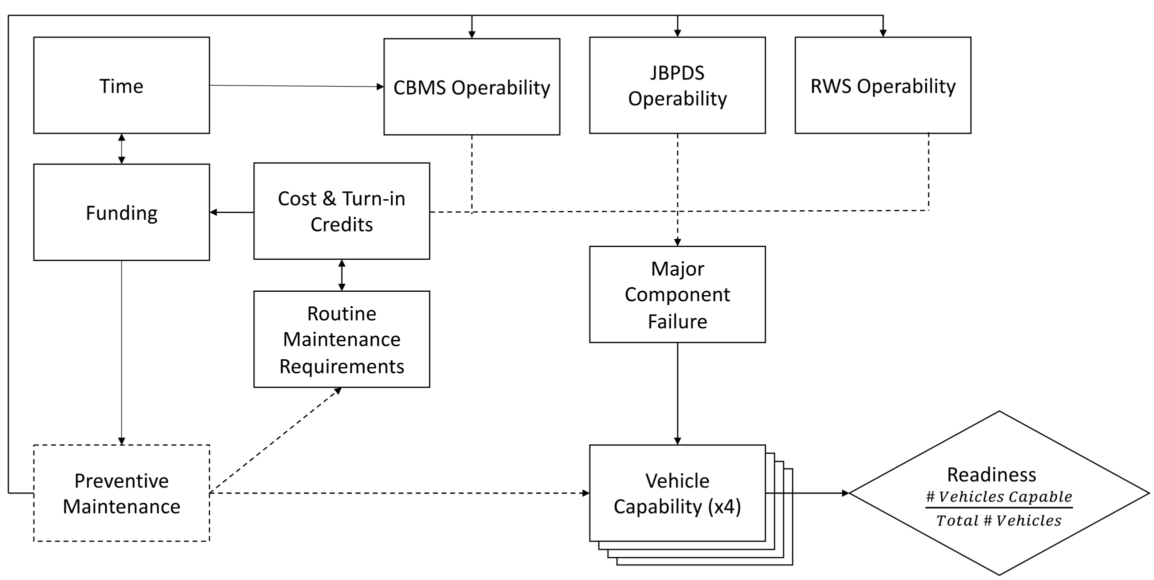

Figure No. 3
Process map of the NBCRV system. The fleet consists of four vehicles, each with routine costs and three cost drivers, the CBMS, JBPDS, and RWS, which combine to determine fleet readiness.

After developing the above chart, I realized that the entire system acts as a network with probabilities of proceeding from one section to the next. Failure rates for the CBMS vary compared to the RWS and JBPDS. However, it's preferable to frame the question in a different light for two reasons. First, failure rates are the true unknown and root cause to determining a vehicle's cost function. Our maintenance technicians only purchase supplies as they need them, so modelling failure rates makes intuitive sense. Secondly, modelling failure rates allows one to examine time as a more continuous variable not confined to a fiscal year. Some of these components function properly for three or more years until they require maintenance. If three components are replaced in one year, we would likely see a dip in total cost over the next one or two years, followed by a spike again in the third and fourth years. If we simply model average cost over some period, we might miss the true cause of the problem which is the failure rate of our cost driving components.

The problem at hand is thus ripe for Bayesian modelling in which prior knowledge is combined with data to produce updated estimates. The most fundamental equation that allows for this possibility is Bayes' Theorem, which states: $Prior * Likelihood\ (Data) \propto Posterior$. To model failure rates for the three major components, I first elicited expert prior knowledge from the maintenance mechanics on their opinion of how long these systems can function without requiring maintenance that would deadline them. I asked them to map out what they might observe if twenty separate CBMS systems all started at once and proceeded until failure. They were instructed to ignore routine maintenance like the replacement of a filter, for example, which would not place the entire vehicle in a deadlined status and affect readiness. I repeated the same process for the RWS and JBPDS. Appendix C shows the distribution of failures according to the mechanics (priors). With the constructed distributions, I then fit a Weibull distribution to the data using maximum likelihood estimation (MLE) for alpha and sigma parameters. I then fit the lognormal distribution to alpha and sigma, respectively, in the Bayesian framework. These are my prior distributions. I use the statistical software, R, for all analysis throughout the entirety of the paper. R utilizes the parameterization of the Weibull:

$$X_{x|\alpha,\sigma} = \frac{\alpha}{\sigma}\left(\frac{x}{\sigma}\right)^{\alpha-1} e^{-\left(\frac{x}{\sigma}\right)^{\alpha}}$$

Equation No. 2
Weibull distribution using the default parameterization in R.

Next, I pulled GCSS-Army maintenance orders from 2017 to 2020 and determined the length of time, for each vehicle, between component failures. Many of the components had zero-dollar work orders associated with them in which minor actions were logged and performed. I made the decision to drop these observations from the data because I was not interested in modelling items without costs. As such, only 28 total observations remained in the dataset: 7 for the CBMS; 14 for the JBPDS; and 7 for the RWS. I further subset these observations into high, medium, and low cost categories. The splitting of observations into discrete categories based on proportions lends itself to the multinomial distribution, which I use to model the sub-component failure within each major system. The JBPDS might have the Biological Agent Warning Sensor (BAWS) malfunction, which costs $160,017, or it could have the fluid collector assembly break and only cost $22,524. The category probabilities are rounded to the nearest 5th percentile for simplicity. The following chart displays the breakdown of costs for each component:

Distribution of Costs across Major Components				
Cost Category		**CBMS**	**JBPDS**	**RWS**
High	Frequency	5/7	2/14	1/7
	Cost	$367,719	$ 160,017	$ 161,642
	Credit	$170,112	$ 98,122	$ 74,705
Medium	Frequency	2/7	10/14	0
	Cost	$ 158,199	$ 22,524	$ -
	Credit	$ -	$ 12,565	$ -
Low	Frequency	0	2/14	6/7
	Cost	$ -	$ 3,515	$ 190
	Credit	$ -	$ -	$ -

Figure No. 4
Breakdown of costs into discrete categories based on level of spending within each component. Observed frequencies are based on real-data from GCSS-Army and used to create probabilities within a multinomial distribution as part of the hierarchical model.

Next, I combine the prior knowledge with the GCSS-Army data to numerically approximate the posterior distribution of each component's failure rate. The goal is to combine the prior knowledge with the likelihood function of our data to create a posterior from which I can make random draws and simulate many years of NBCRV data. For this portion of the investigation, I used Stan, a Bayesian statistical software program that interfaces with R. I decided to use informative priors due to the low number of observations for each component (7, 14, and 7). Figure No. 5 below shows how adding data to our model allows us to update our beliefs about the failure rates of specific components. Plots that display the prior and posterior distributions for the JBPDS and RWS can be found in the Appendix C.

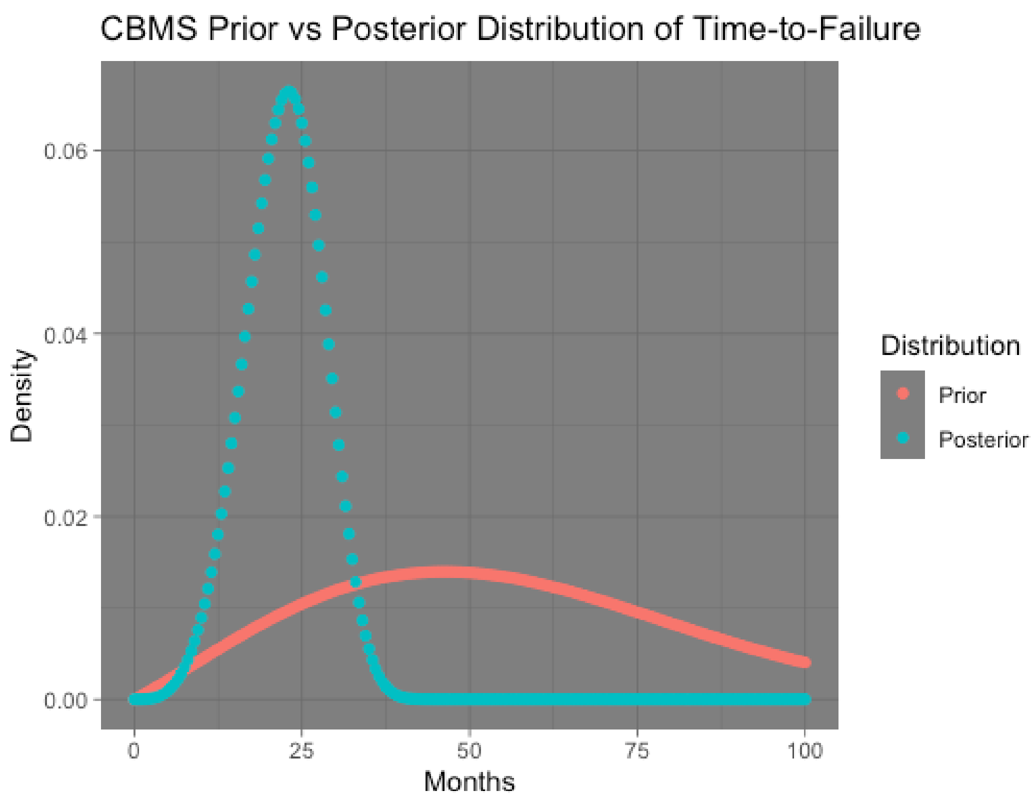

Figure No. 5
Prior and posterior distributions of time until failure for CBMS in NBCRVs based on observed data from 8th MP BDE during 2016-2020.

The final piece involves determining which subcomponent of each cost driver failed at a certain time. At nine months, for example, imagine that the JBPDS malfunctions. Using our previous data, we estimate that there's a 15% chance of it requiring a costly repair, a 70% chance of a somewhat-costly repair, and a 15% chance of a low-cost repair. Over the course of a fiscal year, we can then simulate the number of times in which each component might fail, how costly the failure is, and sum the results. The chart below provides an example of what this looks like for one of the components:

Major Component Failure Map

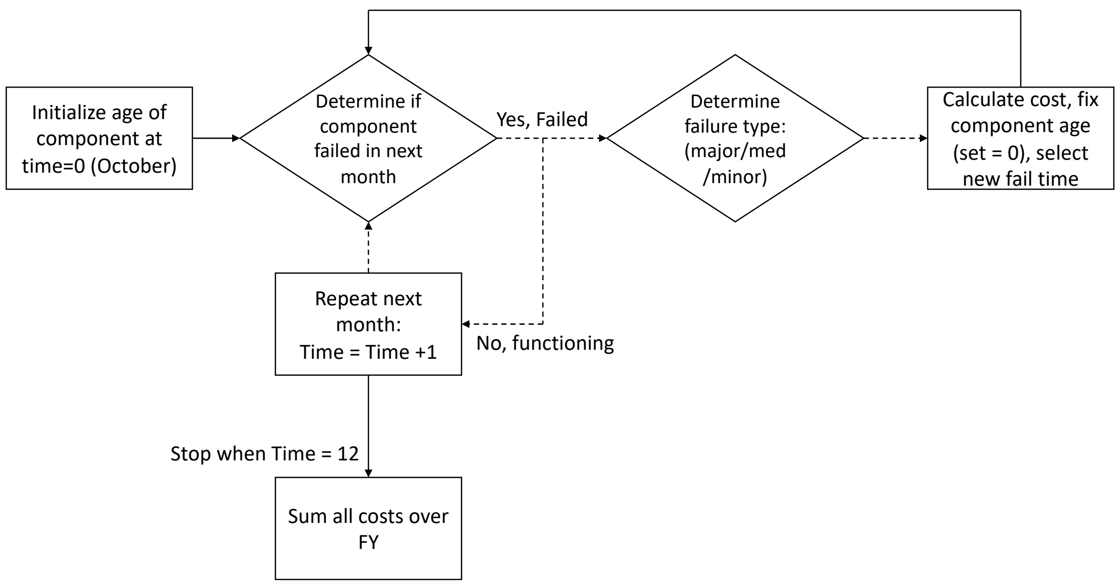

Figure No. 6
Process for single component simulation within a Fiscal Year. This process is recreated for each component (3 times) within each vehicle (4 times) to calculate the total cost of all simulated NBCRV maintenance costs.

After computing each component's respective posterior distribution, the entire simulation can be accomplished using the above process map. In the following section, I explore how the addition of a budget constraint affects readiness, the minimum funding level to allow for consistent functionality over multiple years, the impact of increasing the CBMS cost from $367,000 to $600,000 in FY21, and provide suggestions for further study.

Analysis, Results, and Discussion

This paper serves as a recommendation on the budget required to achieve a desired readiness level throughout a Fiscal Year. By introducing a budget constraint, repairs are no longer performed in the simulation after spending reaches this amount. This might occur in the third month, eleventh, or not at all in a given year. However, after gathering multiple years of simulated data, we can evaluate trends and averages. In order to achieve reasonable long-run NBCRV readiness ratings, the program requires at least $150K per vehicle given FY20 prices. charts below show expected readiness ratings over five distinct funding levels:

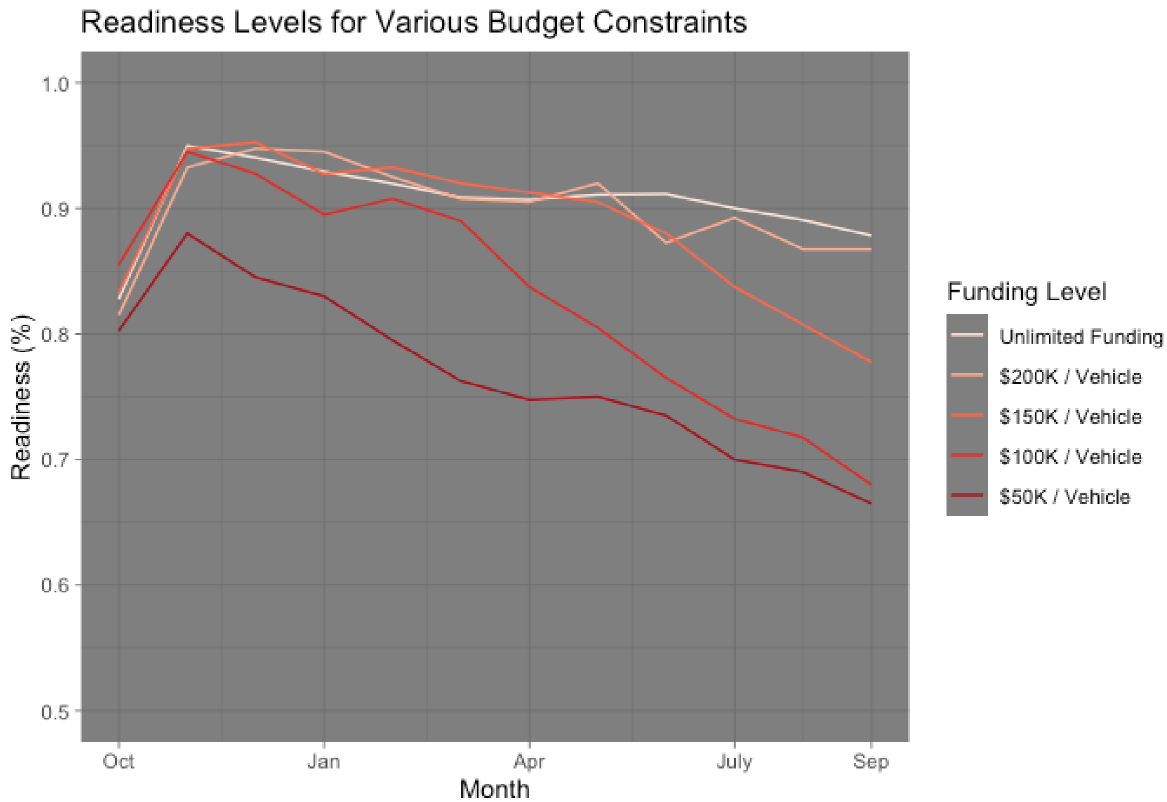

Figure No. 7
Estimated readiness percentages over the Fiscal Year given various budget constraints. The constraint fails to make a large impact in readiness levels until dropping to $150K / vehicle.

Readiness Ratings Given Various Funding Levels		
Funding Level	Average Readiness	Ending (September) Readiness
Unlimited	90.6%	87.8%
$200K / Vehicle	90.0%	86.7%
$150K / Vehicle	88.6%	77.8%
$100K / Vehicle	82.9%	68.0%
$50K / Vehicle	76.7%	66.5%

Figure No. 8
Average and ending expected readiness ratings given budget constraints. Notice no significant drop-off in ratings until funding falls to $150K per vehicle.

From an efficiency standpoint, we lose little readiness when jumping from the 'unlimited' funding scenario to the $200K limit. This is because we observe only 20.5% of the simulated years exceeding $800K, and only break the $1M mark above the 94th percentile. Funding should be based on non-outlier years of data; thus, the expected total value of $641,358 or $160,339.5 per vehicle per year makes a great deal of sense as the starting point for Training Resource Model allocation. We observe another significant decrease in readiness ratings at the $100K per vehicle threshold. At this level, there simply isn't enough funding to preserve the NBCRVs over a single year, let alone multiple years. The jump in readiness at the beginning of the fiscal year is an artifact of the simulation. I chose to randomly select the starting age of each component based on a uniform distribution from zero months to the month corresponding to that component's 50th percentile in time-to-failure. This ensures that *all* of the components are somewhat young and we don't simulate an old broken fleet. Still, the month in which components are the 'oldest' is almost always October in this model. The key is to maintain the fleet above 80% readiness through September without limping into the next year with too many broken components to fix.

To check the convergence diagnostics of each Markov Chain Monte Carlo (MCMC) sampling, I examined traceplots and Gelman-Rubin statistics. Visually, I see no issue with divergence on the traceplots (Appendix D). The GR statistics for the CBMS, alpha and sigma parameters, was 1.0009 and 1.0003; JBPDS was 1.0001 and 1.0004; RWS was 1.0000 and .9999. Acceptable values are considered to be those under 1.1.

The chart below depicts expected total costs over the fiscal year by month with a 95% credible interval. We would expect 95% of the means to fall within this region.[8]

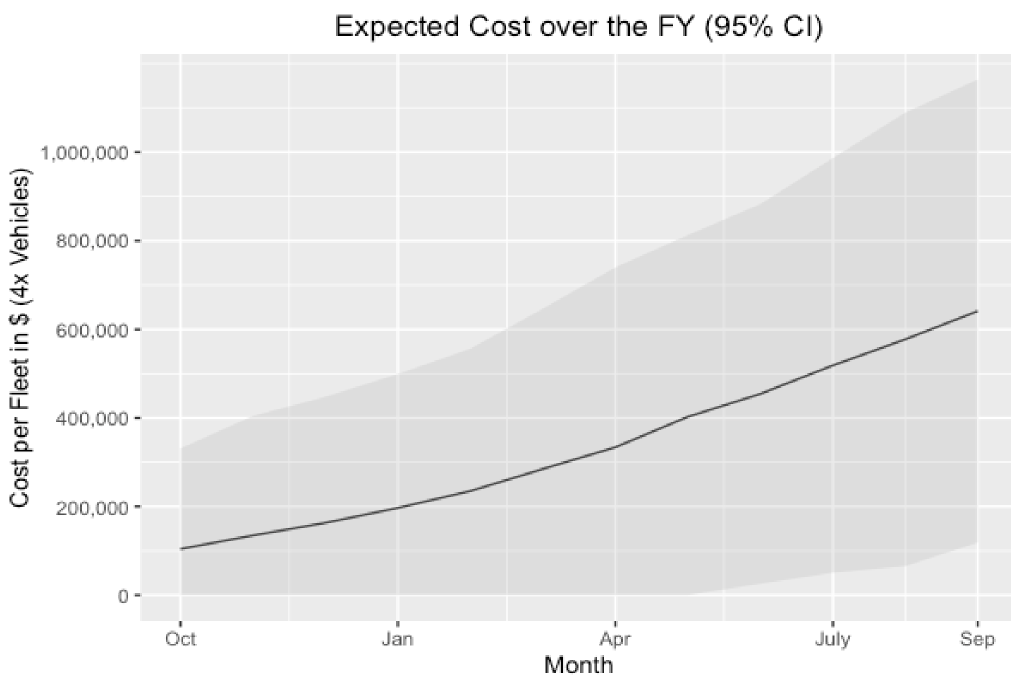

Figure No. 9
Cost to maintain NBCRVs over the FY given an unlimited budget. 95% of simulated years fell between $117,678 and $1,150,383.

[8] Side note: From a frequentist perspective, this statement would not make sense. However, given a Bayesian framework, we can safely state that 95% of the means fall within this region because we are modelling the cost (and its associated mean) as a random variable with its own distribution.

In FY21, should the CBMS cost actually increase from $367,000 to $600,000, and the turn-in credit remain fixed at $170,112, we observe a tremendous impact on expected total cost. The September total mean increases from $641,358 in the first scenario, to $1,013,838 in the second—an increase of $372,480. This also raises the average cost per NBCRV from $253,459.5. Should this price increase take effect, 8th MP BDE would only be able to afford an approximate 71.9% readiness rating through September given an $800,000 ($200,000 / vehicle) total budget.

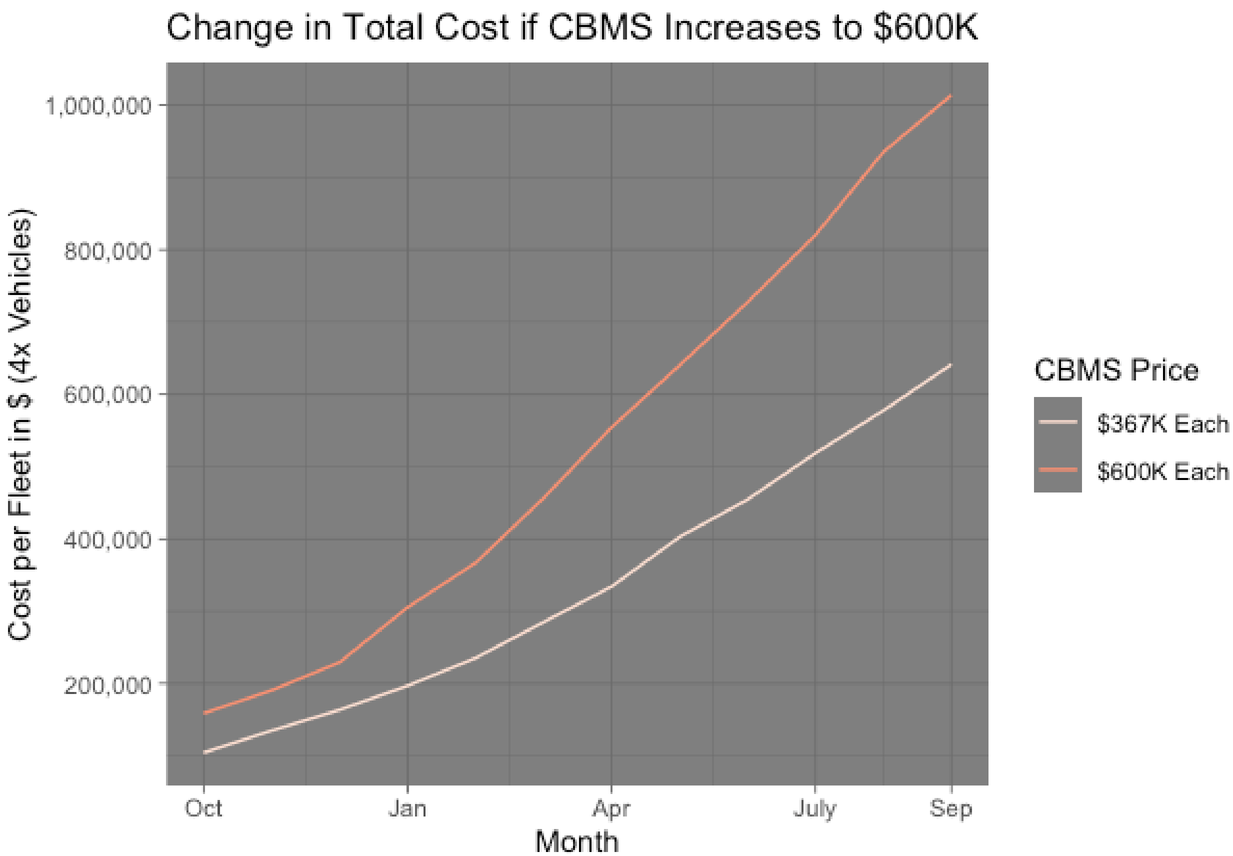

Figure No. 10
Total cost curves by month given separate price points for the CBMS. Price is expected to increase in FY21 from $367,000 to $600,000.

Include the Field Sustainment Representative (FSR) contract for 303rd EOD BN into the equation and it's easy to see how the unit can already spend $1,000,000+ annually on the vehicles. In FY20, 8th MP BDE paid $224,000 for a full-time civilian contractor from General Dynamics to provide expert oversight of the NBCRV maintenance program.

Future NBCRV studies should incorporate budget allotment over the course of a fiscal year as well as turn-in credit lags for broken components. In this model, all credits are returned to the unit in the same month as component failure. While this is not an awful assumption, I do find that 12.6 % of turn-in credits exceed 30 days. Incorporating these pieces would allow for even greater realism in the model. In the final section, I discuss extensions of the NBCRV analysis unrelated to the above simulation.

Conclusion

In conclusion, the primary takeaway is the minimum $150,000 - $200,000 budget requirement for continued NBCRV readiness each year given FY20 pricing. While a Command can certainly get away with a year (or even two) of neglecting maintenance, this is not a formula for long-term program success. Costs will eventually catch up. Even so, this recommendation stems from average results. In reality, we are sampling from only four vehicles in a given year. The variability inherent in such a small sample size lends itself to years with average vehicle costs exceeding $250,000 each or even falling under $50,000 each. As such, the Army should consider a model in which it provides funding only for required maintenance for the vehicles over a year and withhold the remaining funds for major component failures. Then, as components fail across the Army at an average, predictable rate, funding could flow where needed. In 8th MP Brigade, which receives only four million dollars of funding each Fiscal Year, a single CBMS failure accounts for nearly 5% of the budget. The risk of component failure has the potential to wreak havoc on such a small budget. If prices continue to rise, the Command will have no option but to request additional funding or accept the risk associated with not performing maintenance.

Further NBCRV Investigations

In addition to readiness ratings and the cost function I developed above, I found that the G8, Commanders, and other staff sections asked questions about the NBCRVs that no one attempted to answer. These questions are:

1) Are turn-in credits something worth discussing with 8th Theater Sustainment Command (TSC) (our higher headquarters)?
2) Does humidity affect the NBCRVs?
3) Do certain vehicles require more maintenance than others?
4) Does preventive maintenance have an effect on future NBCRV maintenance?

NBCRV Turn-in Credits

Though I mentioned it briefly in the preceding section, turn-in credits are worthy of an entire paper themselves. In FY20, 8th MP BDE (at the time of writing) could potentially lose $170,112 in turn-in credit from a CBMS. The piece was turned in close the end of the fiscal year (July), but if the credit is not returned October 1, 2020, the brigade simply loses this purchasing power. Going forward, we have recommended to the Command to *not* turn in expensive pieces of equipment after June. The plot below shows the distribution of turn-in credit lag, in days, from 2016-2020.

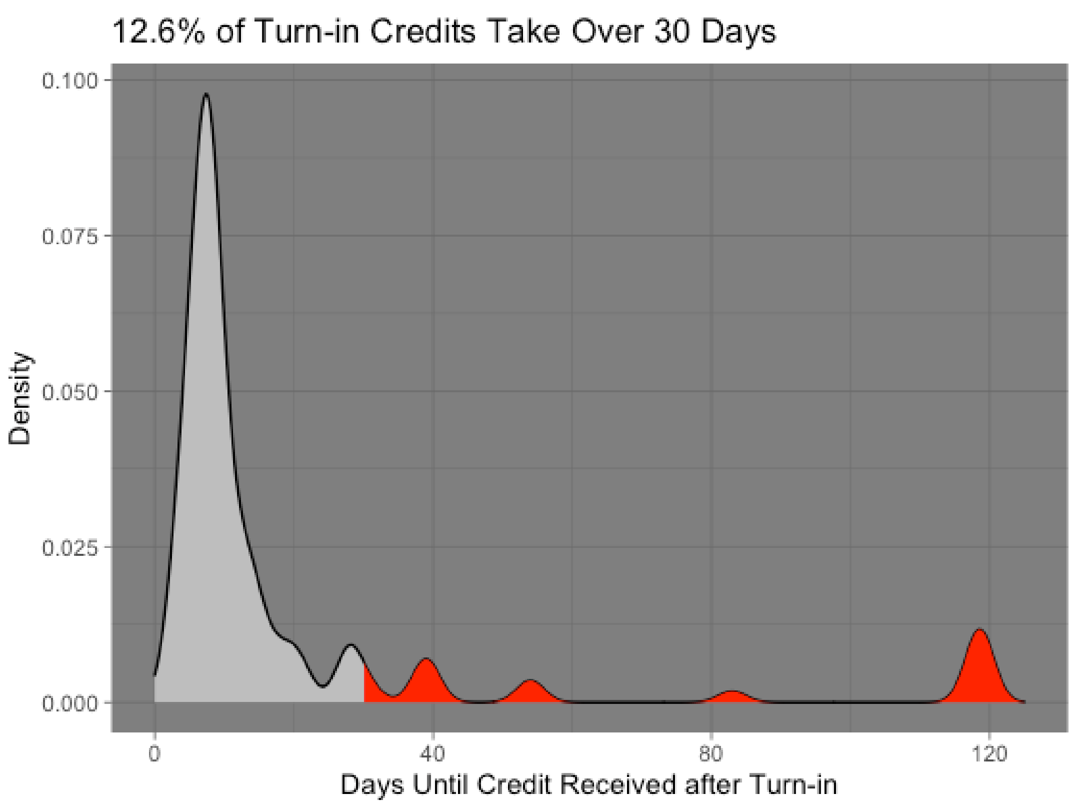

Figure No. 11
Turn-in Credit lag, in days. Data is calculated by determining the number of days between the turn-in date and the credit receipt date.

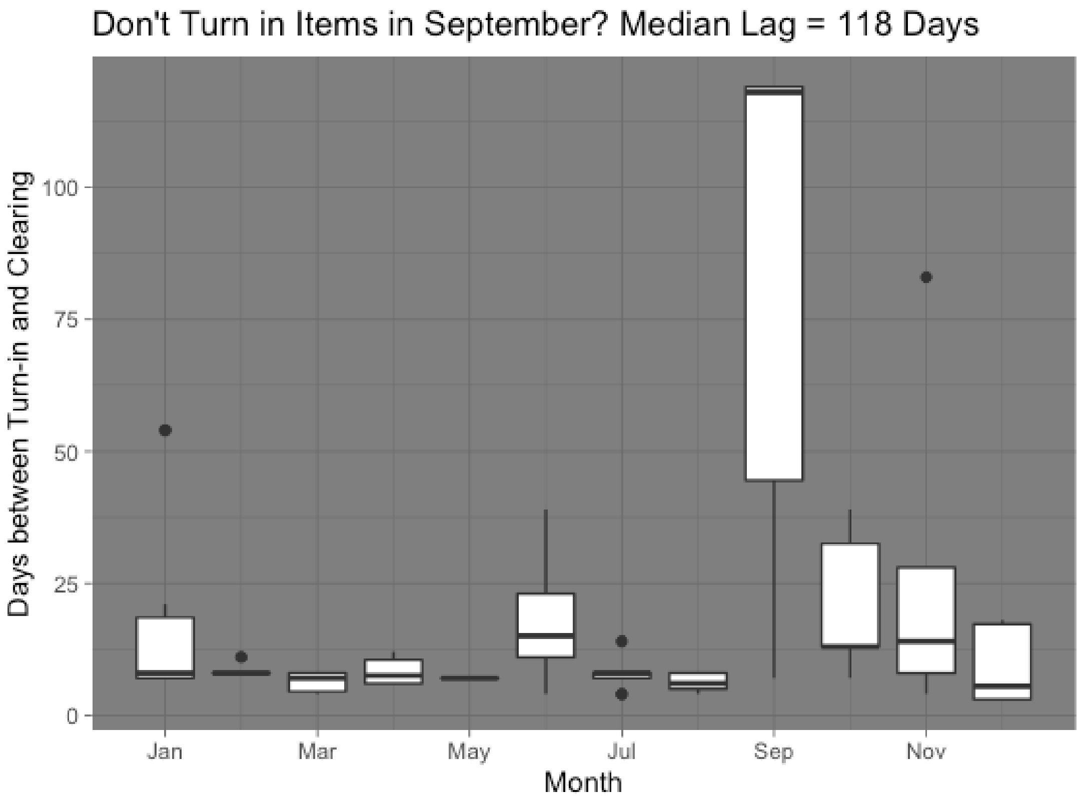

Figure No. 12
Boxplots of turn-in lag by month. September, the last month of the fiscal year, has an average lag of 118 days.

I test whether repair part category, credit value, and month affect the lag time. I find that turn-in month significantly affects lag time, but no relationship exists among the other variables. This relationship was significant at the alpha=.05 rejection level using a generalized linear model with a gamma link function (p-value = 0.028). Items turned in during the month of September experienced a median 118 days until cleared. This data only reflects NBCRV-specific credits.

Does Humidity Affect the NBCRVs?

After hearing this question repeatedly during Command and Staff meetings, I thought perhaps it was worth investigating. The most common refrain I heard was that "humidity has no effect on these components." People would then show the flier from the manufacturer (Appendix E) that states that "Performance is not influenced by relative humidity." Performance and survivability are indeed two separate things. A cellphone might slowly die in a bathroom with high humidity while maintaining its computational performance until breaking.

To analyze the hypothesis, that humidity on Schofield Barracks, Hawaii, has no effect on the survivability of the NBCRV components, I compare failure rates on each major component to the historical humidity levels of each month. Below, a chart outlines JBPDS failure rates by month compared to average humidity levels:

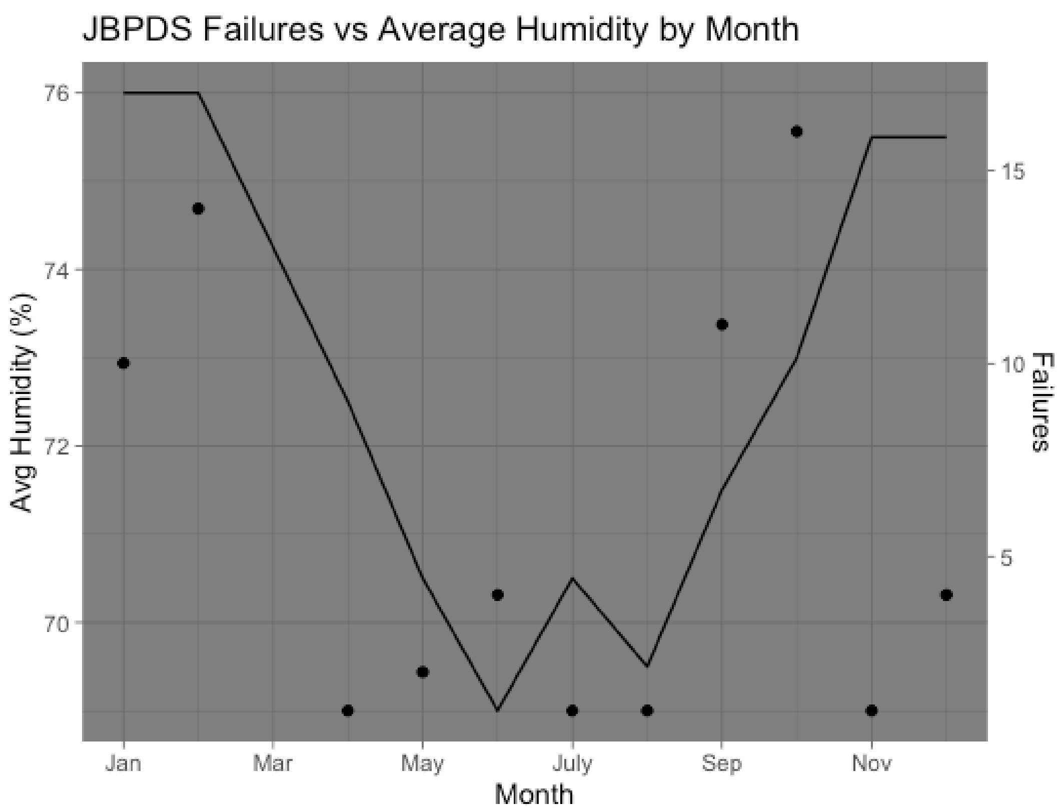

Figure No. 13
Number of failures, by month, for the JBPDS compared to humidity in those same months.

Visually, it would appear that some relationship between humidity and the number of failures for the JBPDS exists. Empirically, I fit two types of models to the data. First, I employ a generalized linear model (GLM) with a binomial link function using JBPDS failure (Yes/No) for each maintenance item and humidity as my dependent variable (n = 524). Before and after controlling for the specific vehicle, I find that there is a weak correlation between humidity and JBPDS failure. Next, I summarize the dataset and fit a GLM with a poisson link function using count data for the number of JBPDS failures in each month. The dependent variable, again, is humidity. I found strong evidence of a correlation in this case. I performed the same analysis using lagged humidity, thinking that perhaps there was a link between humidity in a prior month causing failures in the next. I found no evidence of such a relationship. The regression coefficient estimates, standard error, and associated p-values for the built out models is below:

	Binomial Link Function				**Poisson Link**
	Model 1	Model 2	Model 3	Model 4	Model 5
High Humidity	0.053 (.0295) p = .0671*	0.0501 (.0301) p = .096*			0.2015 (.051) p = .000***
Lagged High Humidity			0.0056 (.0311) p = .857	0.00079 (.0301) p = .98	
Vehicle Control	No	Yes	No	Yes	Yes
AIC	393.5	382.1	396.9	384.9	
N	524	524	524	524	11

* Denotes significance at the .1 level

*** Denotes significance at the .001 level

Figure No. 14
Binomial and Poisson GLM using humidity as a predictor and JBPDS failure as the response. Model 5 fit with summary statistics of the 524 observations in the first 4 models. Summarized data allowed for the use of counts, which can be modeled as a poisson process.

I found no relationship whatsoever between humidity and CBMS or RWS failure rates. The JBPDS relies on water and houses an internal fluid transfer system, so perhaps it is more sensitive to changes in humidity than the other two components. Still, this is only moderate evidence that humidity affects JBPDS failure rates. Data should be compared from other locations using similar techniques to test if the same relationship holds.

Do certain vehicles require more maintenance than others?

I believe this is a tough question due to answer due to the varying levels of emphasis placed on maintenance over time. From the graph below, we can see that the Command made a calculated decision to accept the risk associated with performing little maintenance on the vehicles in 2017. The spike in 2019 may be correlated with the decreased emphasis two years prior. Still, after controlling for differences between years, I run a GLM on the count data given the vehicle number and year. I find that vehicle 121 has a significant coefficient of 0.41, which can be interpreted as a single unit increase in x_j (selecting vehicle 121) translates to an expected maintenance increase of $(e^{0.41} - 1)$ or, 0.51 in a given year. The associated p-value for vehicle 121 is 0.0004. It's difficult to draw any real conclusions from this analysis, as the size of the impact is minimal. The average cost of a single maintenance requirement over the dataset is $5,524. I run the same analysis for each major component and found no relationship between each vehicle and the number of maintenance requirements.

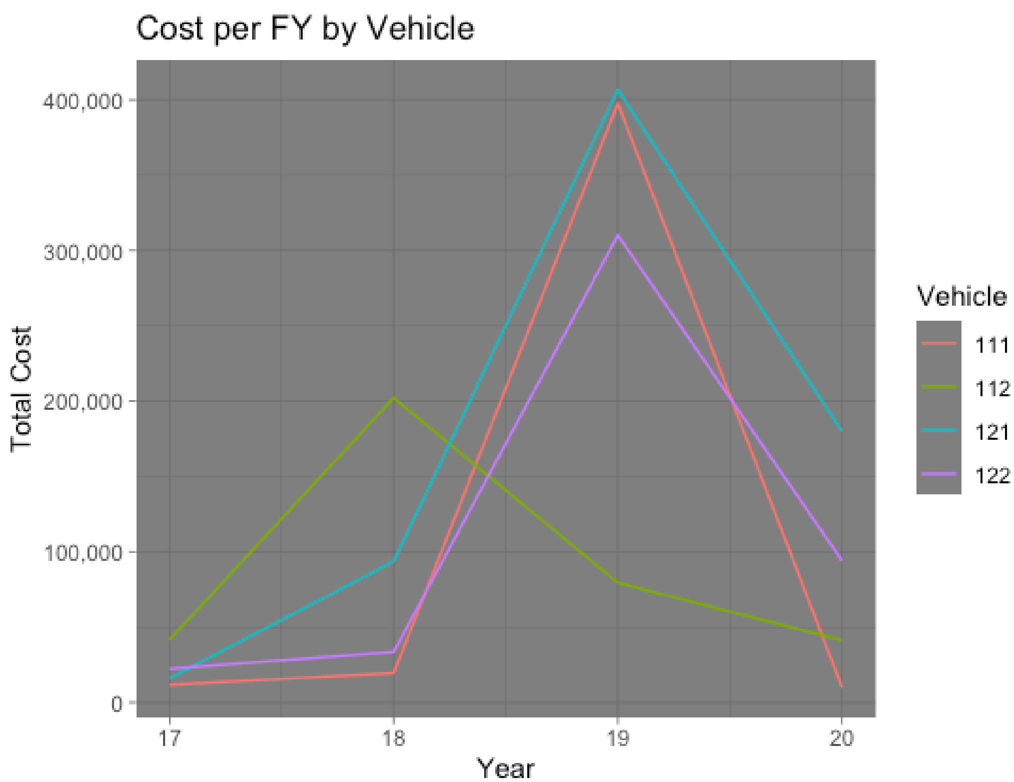

Figure No. 15
Cost for each NBCRV from FY 2017- Feb 2020.

Vehicle	Year	# Maintenance Req's	Total Cost	CBMS	JBPDS	RWS
111	2017	17	$ 11,625.0	0	0	0
	2018	43	$ 19,383.0	3	6	3
	2019	44	$ 397,487.0	1	7	2
	2020	14	$ 9,798.0	0	1	0
112	2017	7	$ 41,440.0	1	0	0
	2018	43	$ 202,170.0	2	8	1
	2019	48	$ 79,372.0	0	8	6
	2020	11	$ 41,181.0	1	3	0
121	2017	22	$ 15,741.0	0	1	0
	2018	44	$ 93,480.0	1	7	1
	2019	69	$ 406,690.0	4	3	5
	2020	44	$ 179,746.0	0	1	0
122	2017	12	$ 22,278.0	0	1	1
	2018	34	$ 33,456.0	2	7	0
	2019	37	$ 310,105.0	1	7	5
	2020	24	$ 93,993.0	0	4	0

Figure No. 16
Summary statistics of maintenance requirements for each vehicle, by year.

Does preventive maintenance matter?

If performed properly, preventive maintenance has the ability to save the Command thousands of future dollars by spending hundreds of current dollars. Below, I examine the effect of preventive maintenance on future maintenance requirements. First, I create a TRUE/FALSE variable that states whether preventive maintenance (in G-Army, this code is PM02) was performed in the prior month. Then, I compare 'treated' months to non-treated while controlling for each vehicle. The findings are interesting: preventive maintenance in the prior month seems positively correlated with the number of work orders performed in
the next month. That is, if preventive maintenance is performed in September, we are likely to find more maintenance issues in October. Intuitively, this could make sense if mechanics are simply identifying a component that requires maintenance during their routine checks. What would be more damning to our mechanics is if preventive maintenance actually correlated with increased costs in the next month. Alas, I find a negative relationship in our model using cost as the response variable instead of maintenance counts, but the correlation is statistically insignificant. From this, I conclude that preventive maintenance does not affect the mean cost of next month's maintenance. However, this does not tell the entire story. If we look at the spread of the costs, we observe twelve instances in which costs exceeded $45,000. All twelve (out of 91) of these observations occur in month's after no preventive maintenance was performed. While the median value in the plot below is negligibly different for each group, the variance is not. I perform an F-test to determine if the variance between the groups is significantly different. Visually, this seems to be the case, but the test provides the quantitative backing. I find the ratio of the variances to be approximately 21.3 and a p-value of 0.0009. So, while preventive maintenance might not have an effect on the average cost of NBCRV maintenance work orders, forgoing it does seem to increase the chances of a major failure occurring. The boxplot and regression estimates for this section can be found on the following page.

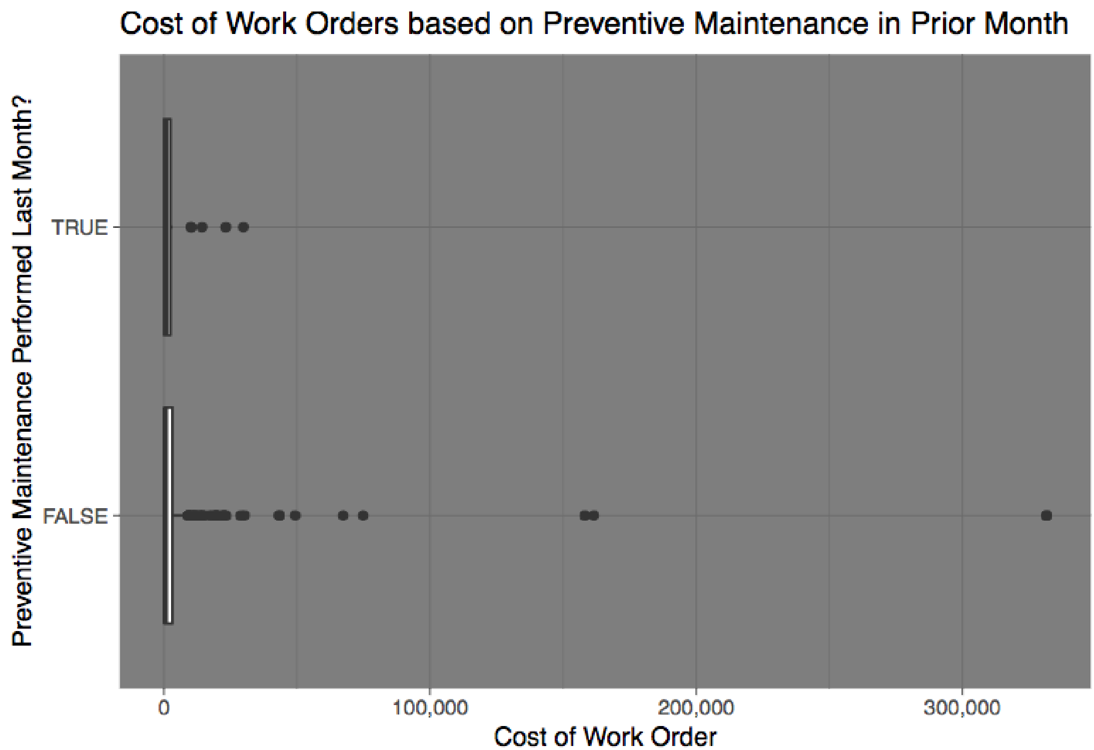

Figure No. 17
Boxplot of maintenance costs based on whether preventive maintenance was performed in the previous month or not. We observe no difference in mean between the groups, but do find a ratio of the variance between groups to be 21.3, significant at the 0.0001 level.

Variable	**Model 1 (Response = Count)**	**Model 2 (Response = Cost)**
Preventive Maintenance	.577***	-9,872.1
	(.178)	(20,127.5)
Vehicle 112	0.169	2,588.8
	(.189)	(17,282.8)
Vehicle 121	.148	11,394.1
	(.177)	(16,054.5)
Vehicle 122	-0.023	5,520.2
	(.194)	(16,795.4)
Intercept	.778***	17,616.80
	(.131)	-11,330.30
N	91	91

*** Denotes significance at .001 level

Figure No. 18
Two separate regression models fit using preventive maintenance as the independent variable. I model count and sum of maintenance requirements in the next month.

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I would like to thank LTC Nicholas Clark for his assistance in editing my Stan Code. His contributions and mentorship were invaluable in the production of this paper.

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Appendix A

INFORMATION PAPER

APTS-8TSC-RM 9 April 2020

SUBJECT: Funding Analysis for Nuclear Biological Chemical Reconnaissance Vehicles (NBCRVs)

1. Purpose: To provide the 8th Military Police Brigade (MP BDE) leadership with relevant funding information and recommendations related to the ongoing decrease of NBCRV Training Resource Model (TRM) funding.

2. Facts:

a. The 8th MP BDE, 71st Chemical Company, is the sole unit authorized NBCRVs island-wide. The unit possesses four NBCRVs that provide nuclear, biological, chemical detection, and surveillance to give commanders battlefield visualization. In March 2016, the 25th Infantry Division's Stryker Brigade Combat Team converted into an Infantry Brigade Combat Team. This transition crippled the 8th MP BDE, because of its reliance on the Stryker Brigade for sustainment level maintenance and Field Service Representative (FSR) support. Since the conversion, 8th MP BDE implemented a new maintenance plan that relies solely on its Soldiers and a contracted FSR to provide operator and maintainer level support.

b. As displayed in the chart below, funding for NBCRVs has significantly trended downward. Though funding has decreased exponentially, there is not enough historical evidence that supports a need for an increased budget. Both Fiscal Year (FY) 17 and FY18 were years of surplus, leaving FY19 the sole year of over execution.

	FY17	FY18	FY19
Budget	$ 828,688.00	$ 688,909.00	$ 456,056.00
Actuals	$ 88,381.00	$ -153,607.00	$ 1,181,492.00
Difference	$ 740,307.00	$ 842,516.00	$ -725,436.00

*Negative actuals amount in FY18 due to funding earned from equipment turn-in credits.

c. From FY17 to present, the 8th MP BDE has requested the help of an FSR to assist with NBCRV maintenance. The subsequent chart exhibits the costs associated with FSR assistance.

FY17	FY18	FY19
$ 24,934.00	$ 26,112.00	$ 195,570.00

d. Consistent FSR support for 8th MP BDE started during FY19. Collectively, the data shown is indicative of the onsite FSR conducting enhanced Preventative

Maintenance Checks and Services (PMCS) in an attempt to improve the overall readiness of vehicles that have generally maintained a 50% Operational Readiness (OR) rating.

3. Recommendation: The 8th MP BDE should enlist the help of qualified personnel to assist in the maintenance of NBCRVs. Military personnel need to be properly trained and qualified to maintain the equipment they possess. Educating military personnel will allow the unit to withdraw from the current FSR contract, thereby increasing buying power and freedom of action for the 8th MP BDE Commander. Relevant information for the NBCRVs will be reviewed yearly to further assess the funding impact on overall readiness.

SSG Shantell Butler/ (808) 437-1708

Approved by: LTC James Weaver

Appendix B

Subject: (U) 303D Ordnance Battalion (Explosive Ordnance Disposal) NBCRV Chemical Biological Mass Spectrometer (CBMS)

EXECUTIVE SUMMARY

(U) From FY15-19 the BN replaced eight CBMS systems and currently has two NBCRVs dead-lined for the same component. The BN was initially concerned that the failure rate might be attributed to an operator and/or maintainer training gap. However, the BN confirmed via PM Stryker and contracted FSR that operators and mechanics conduct all operational employment, PMCS, and maintenance procedures IAW the TM and that the failure rate for the CMBS is consistent with the DA fleet average of 25% per FY (60 CBMS failures per 247 NBCRVs since FY18).

EXECUTION

Purchase History/Pattern (2015-2019)

(U) As of FY19, the BN replaced eight CBMS systems. Additionally, two NBCRVs are currently dead-lined for the CBMS for a total of ten CBMS failures from FY2015 – present. The total cost for CBMS replacement alone has totaled $3.7M in addition to other routine maintenance costs.

(U) The cost driver of the NBCRV maintenance is the CBMS at $367K per system and is projected to increase to $600K in FY21. PM Stryker indicates FY21 CBMS cost increase is due to new CBMS production as the legacy CBMS systems became inviable for refurbishment.

Maintenance

(U) The Contracted FSR and PM Stryker verified the Unit (71st CM CO) conducts operations and maintenance IAW TM 9-2355-326-13&P, *Operator Manual for Stryker Nuclear, Biological, and Chemical Reconnaissance Vehicle.* Based on the assessment from Contracted FSR and PM Stryker; the CBMS failure rate is not attributed to the Unit's NBCRV operation, PCMS, and/or maintenance procedures and is consistent with DA NBCRV fleet averages.

Cost of CBMS

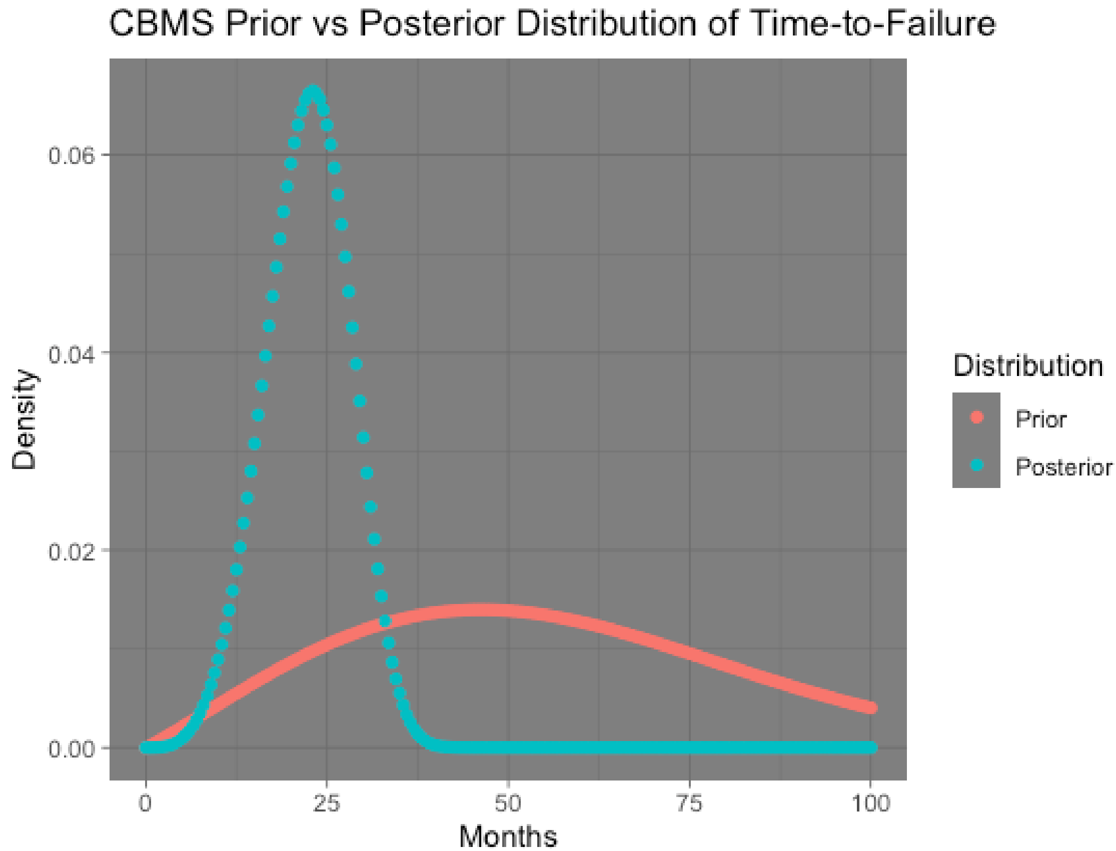
(U) Legacy CBMS replacement cost is $367K with an unserviceable turn-in credit of $170K (Unit Cost of $197K). It is currently more cost effective to purchase the CBMS vice individual subcomponents to the system. For example, a Mass Spectrometer Electronics Module, NIIN: 015685021 (a subcomponent of the CBMS) costs $305K and has an unserviceable turn-in credit of $31K (Unit Cost of $274K). Replacing the CBMS has historically proven the most cost and time effective TTP.

(U) As the CBMS cost is projected to increase to $600K in FY21 it may become more cost effective to replace CBMS subcomponents. However, this practice typically results in significantly longer downtime and will incur higher average annual costs than historic CBMS replacement. Additionally, the BN's anecdotal experience with replacement of CBMS subcomponents tends to result in ordering multiple subcomponents as different fault codes present with the replacement of previous subcomponents resulting in extended NBCRV downtime and significantly higher costs.

END STATE

(U) Recommend FY21 budget reflect the anticipation of increased NBCRV maintenance costs to reduce negative impact to NBCRV Operational Readiness Rates and overall budget predictability. As the CBMS is projected to increase 100% in FY21 the realized cost of NBCRV maintenance will likely increase in kind.

Appendix C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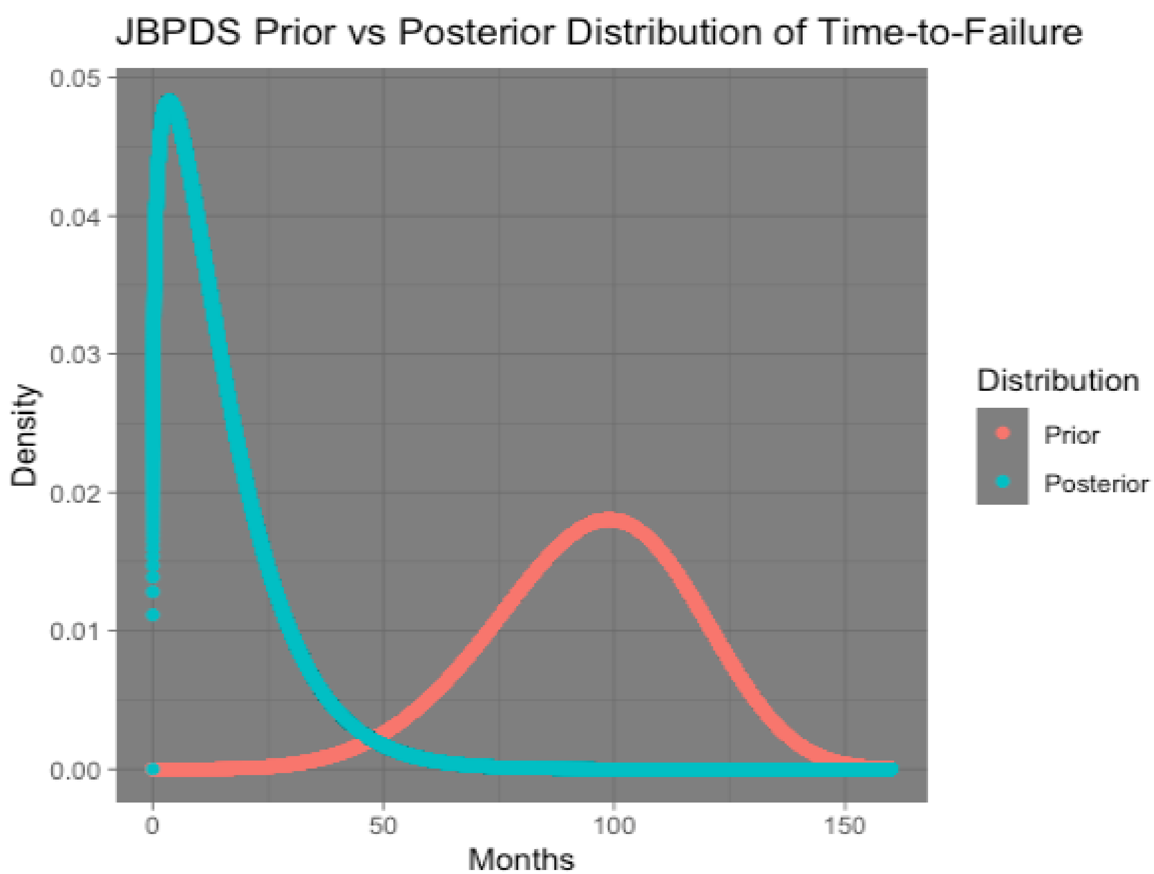
Months
Distribution
Prior
Posterior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Months
Distribution
Prior
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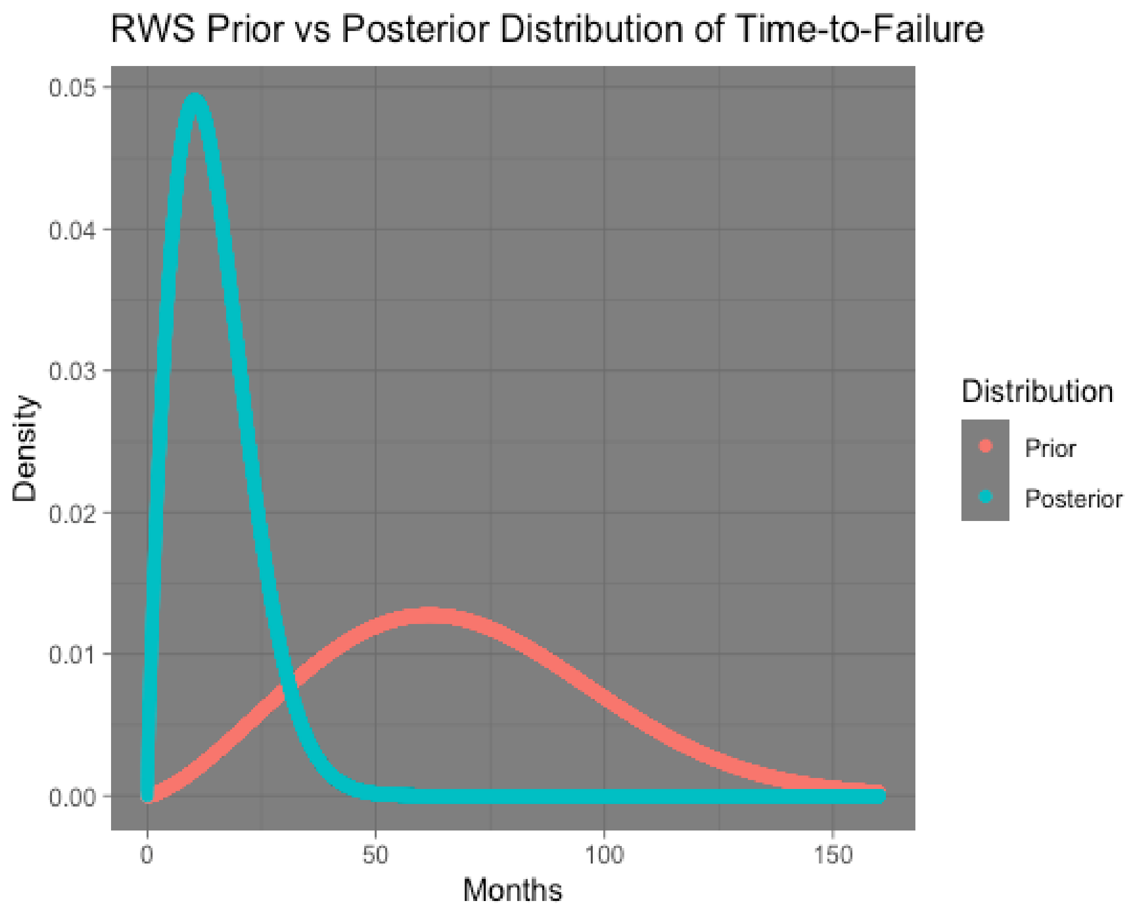
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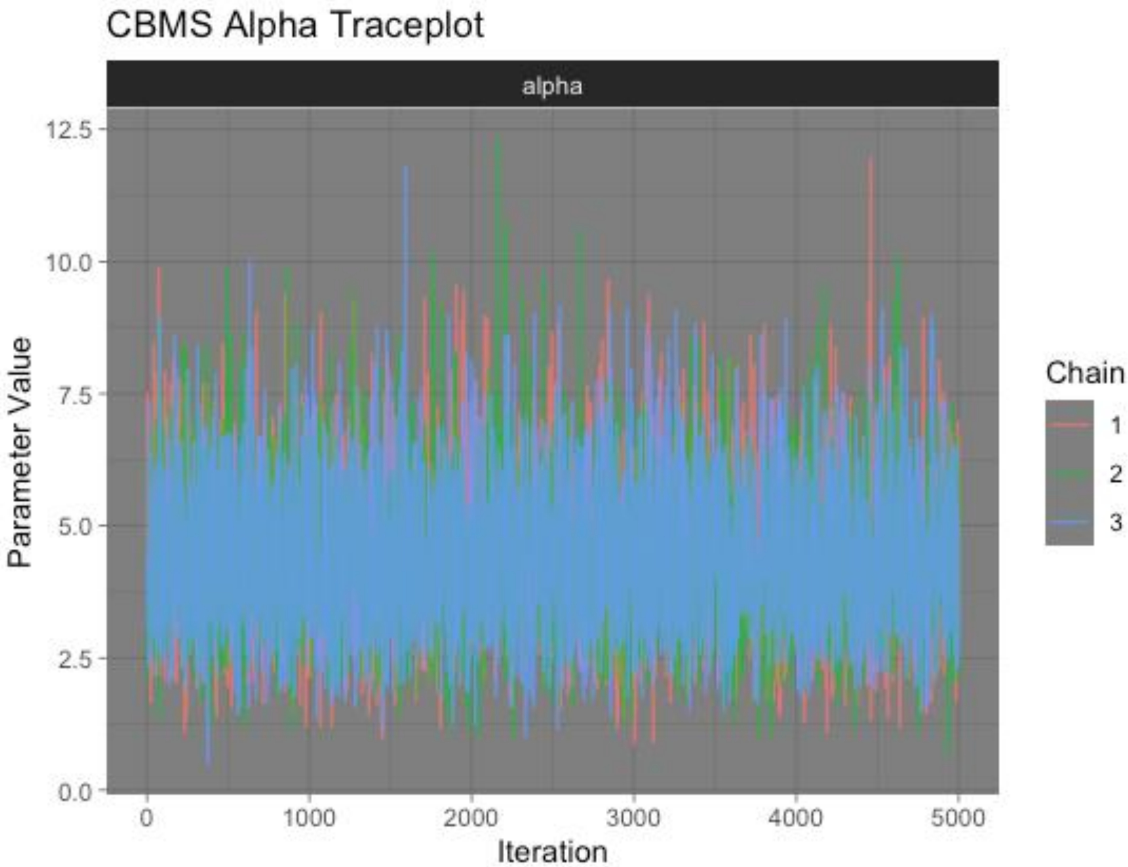
Months
Distribution
Prior
Posterior

Appendix D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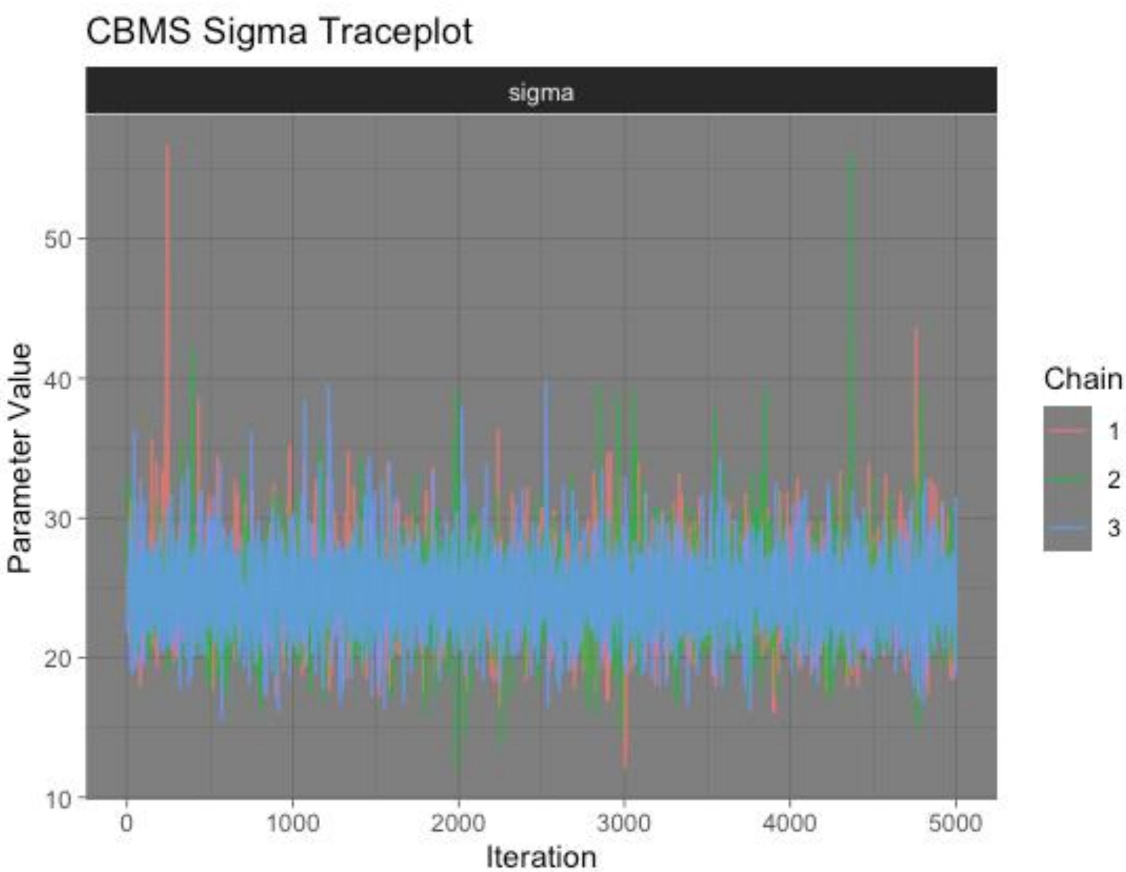
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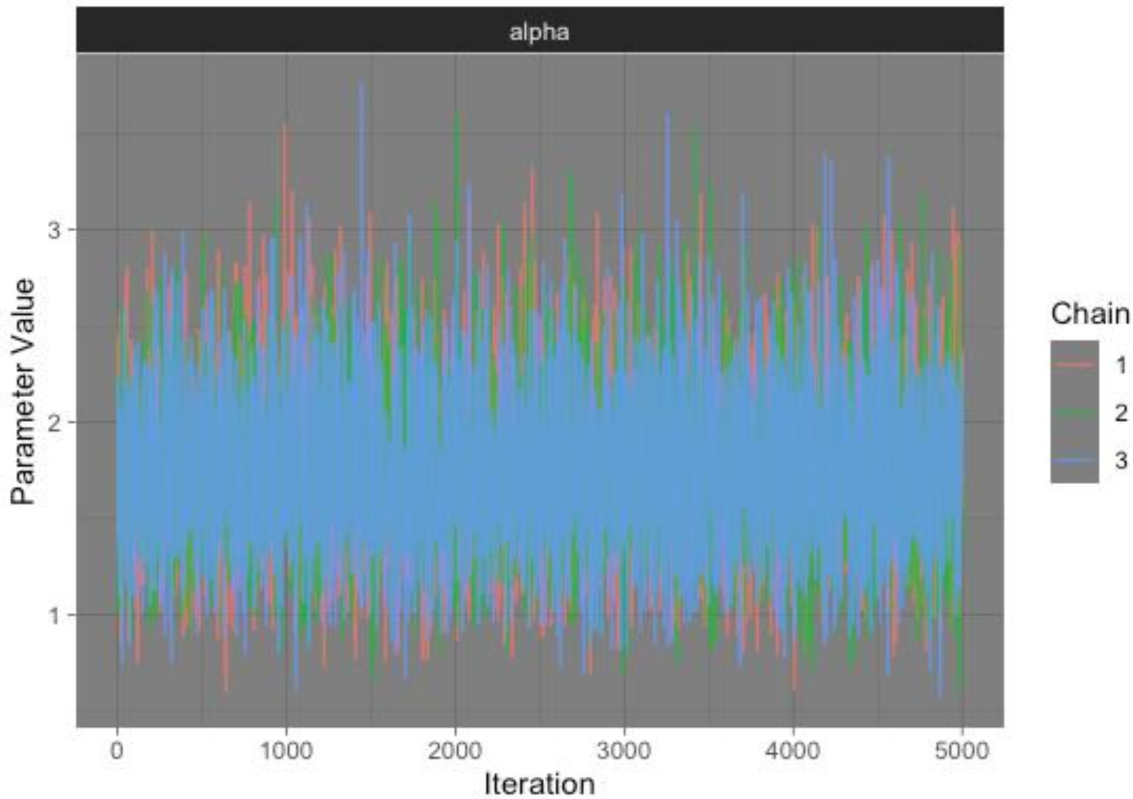
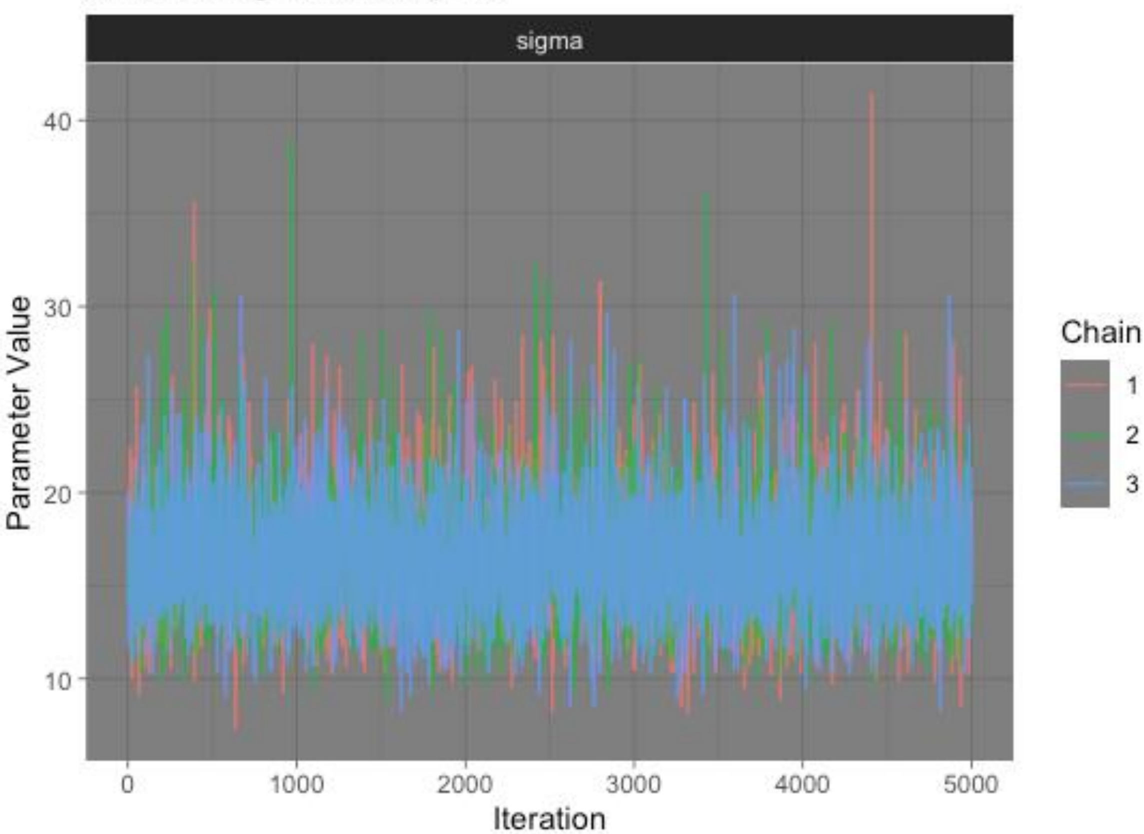
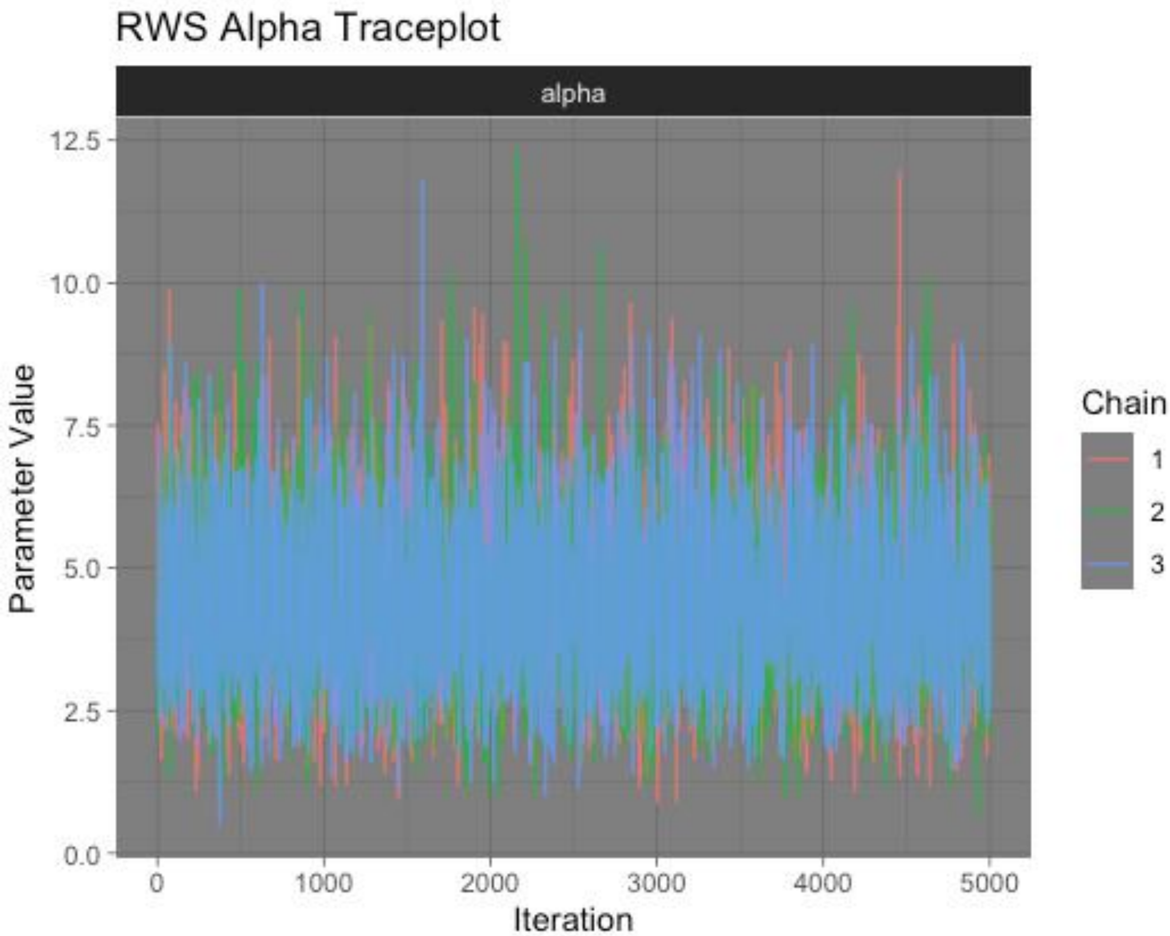
JBPDS Alpha Traceplot



JBPDS Sigma Traceplot

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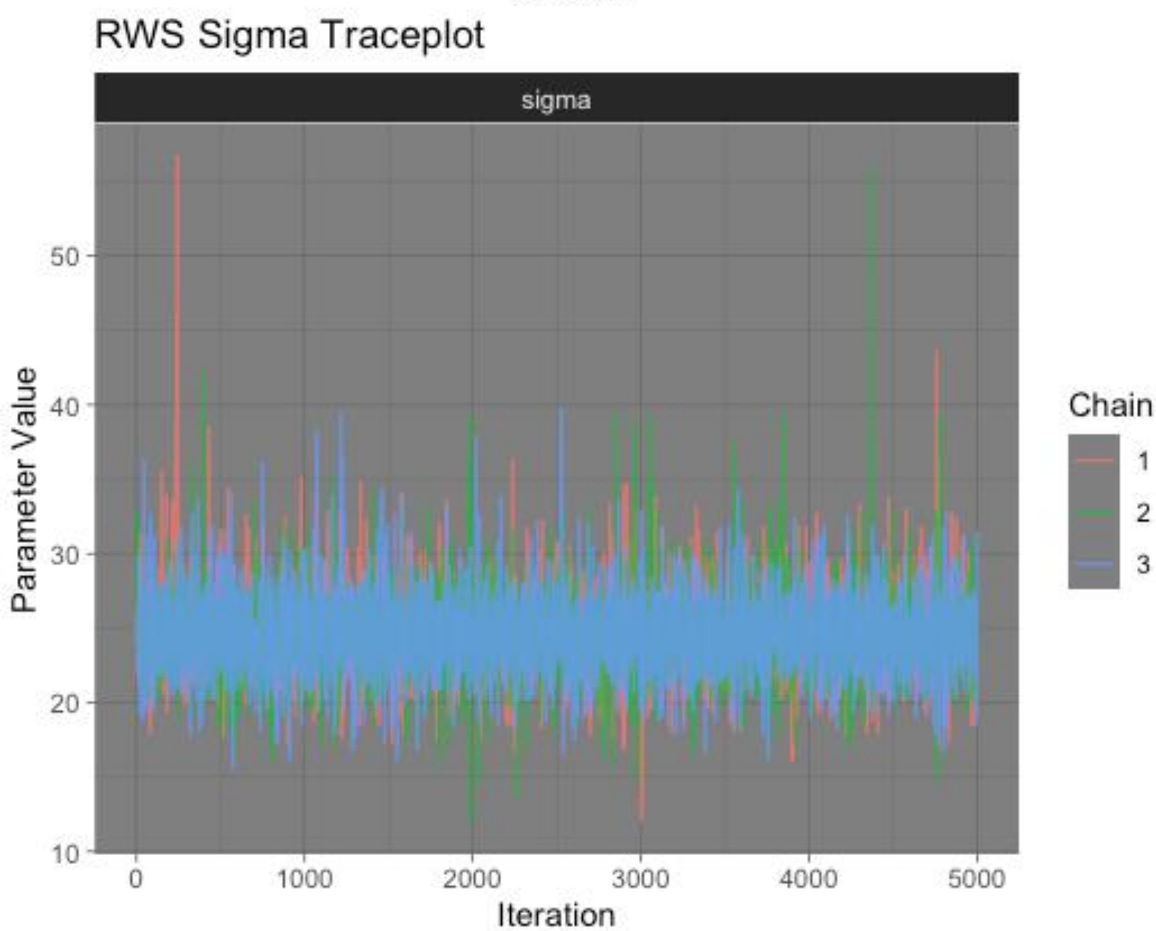
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Appendix E

GLOBAL CBRN DETECTOR MARKET SURVEY

Hamilton Sundstrand Corporation - Chemical Biological Mass Spectrometer/Chemical Biological Detection System (CBMS/CBDS)

GENERAL DESCRIPTION:

The CBMS is a mass spectrometer for the detection of liquid Chemical Warfare Agents (CWAs) on the ground from a moving military reconnaissance vehicle via a ground sampling system. The CBDS version adds an air sampler and pyrolysis module to enable the detection of Biological Warfare Agents (BWAs) via an air intake. In either mode, the system operates continuously and autonomously, reporting alarms both on a display screen and electronically.

TECHNICAL DESCRIPTION:

CWA detection employs direct ion trap mass spectrometric with MS/MS capability for the analysis of the vapor molecules. BWA detection concentrates aerosols during a collection period and pyrolyzes the accumulated material, and then the composite mass spectrum is analyzed for patterns indicating the presence of target BWAs.

CONTACT INFORMATION

Hamilton Sundstrand Corporation
2771 N. Garey Ave
Pomona, CA 91767
POC: Gary R. Stewart
909-593-3581 Ext. 4499

COST

- $180,000-$240,000/system
- $0.1/analysis

Tier Selection

Final tier assignment is based on overall product score.

● Top Tier ◓ Second Tier ○ Third Tier
◒ Fourth Tier ● Bottom Tier

RANKINGS

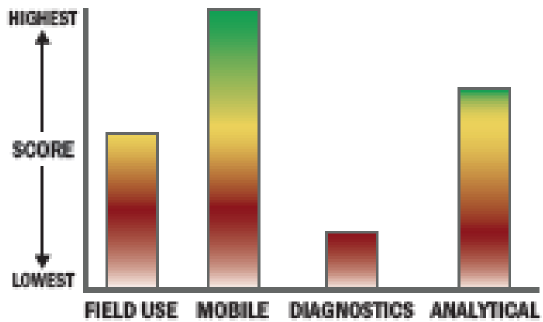
	Biological	Chemical	Radiological
FIELD USE System	◒	●	N/A
MOBILE Laboratory	◒	●	N/A
DIAGNOSTIC Laboratory	◒	◒	N/A
ANALYTICAL Laboratory	◒	◒	N/A

Survey Source

Vendor Supplied Information

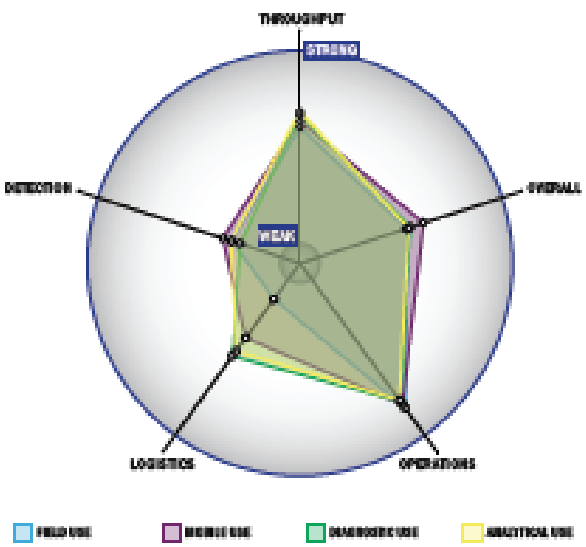
Scoring Analysis

System scores are compared across the four scenarios and ranked from highest to lowest.



Impact Chart

The Impact Chart is a spider graph representing specific categories and designed to give the reader a visual depiction of how a particular system is expected to operate across the four different scenarios. The score for each of the seven categories is presented as the percentage of the total possible score. Higher category scores extend the spokes of a graphic toward the outer edge of the chart. The area graphed for each of the four scenarios relates to how well the system performed in that scenario. Graphics for each of the four scenarios are super-imposed for ease of comparison.



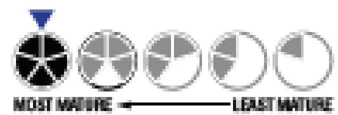
Evaluation Criteria

Throughput:

- Between 2 and 15 minutes for detection
- Multiple samples, multiple tests/sample per run
- 348-98 samples every 2 hours
- The system or device is currently fully automated
- Device or system is intended for multiple detection assays
- 3 solutions, buffer, eluents, and/or reagents
- 1 component
- Greater than 20 minutes is required for set-up
- 1-2 steps are required for detection

Logistics:

- More than a day of training and significant technical skills are required
- Approximately the size of a home dishwasher
- More than 50 kg
- Wired connections are available
- System or device requires multiple outlets or a dedicated circuit breaker



Operations:

- Can be used from < -21 °C to > 42 °C (All temperatures)
- Performance is not influenced by relative humidity
- Between 1 to 3 years shelf life
- Greater than 10 years expected life
- Results can be viewed in real-time
- The system or device is currently fully autonomous
- The system software is closed and not available for modification
- The system hardware is closed and not available for modification

Detection:

- Less than 10 µL
- Good specificity. System has a consistently low level of false alarms (2-5%)
- Spore lysis not necessary for detection by system
- $1x10^{3}$ mg/m^{3}
- System could be adapted to identify aerosolized chemical agent
- System currently can identify liquid chemical agent