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ASSESSING THE SUCCESS OF THE ARMY HMMWV INTEGRATED LOGISTICS PLAN

by

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March 2011

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Acquisition costs of Departement of Defense (DoD) weapon systems are of major concern due to their enormous annual expense. In fact, $165B was spent by DoD on acquisition in 2008. However, another budget component, Product Support, costs the government an additional $132B annually. DoD has stated that the preferred method for providing this life-cycle sustainment is Performance Based Logistics (PBL), and 20% of all programs now use that method of support. PBL's goal is to provide maximum readiness at reasonable costs.

Unfortunately, evaluation of the success of these PBL contracts is difficult, because of the large number of metrics and vast differences among weapon systems. Several studies have attempted to do so, but they have not used DoD-prescribed metrics for evaluation. This research attempts to use two of the five DoD-prescribed metrics to analyze the PBL contract for the Army High Mobility Medium Wheeled Vehicle (HMMWV) Integrated Logistics Plan (ILP). These two are Cost Per Unit Usage (CPUU) and Operational Availability.

This statistical analysis found that the ILP does not appear to be decreasing cost or increasing Operational Availability for the Army HMMWV program. Further study using the other three DoD metrics is recommended.

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ASSESSING THE SUCCESS OF THE ARMY HMMWV INTEGRATED LOGISTICS PLAN

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ABSTRACT

Acquisition costs of Department of Defense (DoD) weapon systems are of major concern due to their enormous annual expense. In fact, $165B was spent by DoD on acquisition in 2008. However, another budget component, Product Support, costs the government an additional $132B annually. DoD has stated that the preferred method for providing this life-cycle sustainment is Performance Based Logistics (PBL), and 20% of all programs now use that method of support. PBL's goal is to provide maximum readiness at reasonable costs.

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This statistical analysis found that the ILP does not appear to be decreasing cost or increasing Operational Availability for the Army HMMWV program. Further study using the other three DoD metrics is recommended.

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TABLE OF CONTENTS

I. INTRODUCTION 1
- A. BACKGROUND 2
- B. ANALYSIS 3
- C. SUMMARY OF FINDINGS 3
- D. ORGANIZATION OF THIS THESIS 4

II. LITERATURE REVIEW 5
- A. PRODUCT SUPPORT ASSESSMENT TEAM 5
- B. GOVERNMENT ACCOUNTABILITY OFFICER 10
- C. RAND CORPORATION 11
- D. ARMY MATERIEL SYSTEMS ANALYSIS ACTIVITY (AMSAA) 12
- E. DEFENSE ACQUISITION UNIVERSITY 12
- F. CONCLUSION 13

III. DATA ISSUES 15
- A. UNITED STATES ARMY 15
  - 1. Operating and Support Management Information System (OSMIS) 15
  - 2. Logistics Integrated Database (LIDB) 22
- B. UNITED STATES MARINE CORPS 24
  - 1. Visibility and Management of Operating and Support Costs (VAMOSC) 24
- C. SUMMARY 29

IV. ANALYSIS 31
- A. COST PER UNIT USAGE 31
  - 1. Summary Statistics 35
  - 2. CPUU by Year of Manufacture 41
  - 3. CPUU by Year of MACOM 43
  - 4. Statistical Testing 46
  - 5. Mixed Effects Model 50
- B. OPERATIONAL AVAILABILITY 51
- C. CONCLUSION 55

V. SUMMARY AND RECOMMENDATIONS 57

APPENDIX: DATA CORRECTION 61
- A. SERIAL NUMBERS 61
  - 1. WON Data 61
  - 2. Usage Data 61
  - 3. Combining the Serial Number Data 62
- B. USAGE DATA 62
  - 1. Cost 63

LIST OF REFERENCES 65

INITIAL DISTRIBUTION LIST 67

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LIST OF FIGURES

Figure 1: Sustained Readiness Improvement versus Time for Two Weapons Systems and Their Baseline Index 9
Figure 2: Operational Availability for Two Weapons Systems Over Time 9
Figure 3: Army HMMWV CPUU for M998 and M1097 from 1996 to 2000 17
Figure 4: Army HMMWV Count for M998 and M1097 Models from 1993 to 2009 19
Figure 5: Army HMMWV Cost Per Unit for M998 and M1097 from 1996 to 2009 21
Figure 6: Histogram of Work Order Numbers for 2000–2009 23
Figure 7: USMC HMMWV Inventory Levels for 1998 to 2008 26
Figure 8: USMC HMMWV Cost Per Unit for 1998 to 2008 28
Figure 9: Mean Usage per Year 32
Figure 10: Boxplot of Log of Usage for M998 excluding all values of zero from original data 33
Figure 11: Boxplot of Log of Usage for M1097 excluding all values of zero from original data 34
Figure 12: 5% Trimmed Mean CPUU by Quarter from FY2004 to FY2009 37
Figure 13: M998 Trimmed Mean CPUU from 2004–2009 38
Figure 14: M1097 Trimmed Mean CPUU from 2004–2009 39
Figure 15: Year-by-Year boxplot of Log(CPUU) for M998 40
Figure 16: Year-by-Year boxplot of Log(CPUU) for M1097 41
Figure 17: M998 CPUU by Year of Manufacture before and after ILP Implementation 42
Figure 18: M1097 CPUU by Year of Manufacture before and after ILP Implementation 43
Figure 19: Histogram of M998 Log of CPUU Difference (2004 vs. Post-ILP Years) 47
Figure 20: Mean Operational Availability of Vehicles by Quarter 52
Figure 21: Comparison Histogram of Operational Availability for M998 Vehicle 54

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LIST OF TABLES

Table 1: SRI for Two Different Weapons Systems 8
Table 2: Number of Vehicles with Established Mileage Per Year..................... 31
Table 3: CPUU Before and After ILP Implementation 35
Table 4: CPUU Counts and Percentages for Cost Ranges 36
Table 5: CPUU Comparison by MACOM 45
Table 6: M998 Two-Year Comparison Test Results... 49
Table 7: M1097 Two-Year Comparison Test Results....................................... 49
Table 8: Operational Availability Comparison by MACOM 53

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LIST OF ACRONYMS AND ABBREVIATIONS

A_0	Operational Availability
AMSAA	Army Materiel Systems Analysis Activity
BCA	Business Case Analysis
CPU	Cost Per Unit
CPUU	Cost Per Unit Usage
CSV	Comma Separated Value
DoD	Department of Defense
FMC	Fairbanks Morris Corporation
FMTV	Family of Medium Tactical Vehicles
GAO	Government Accountability Office
HEMTT	Heavy Expanded Mobility Tactical Truck
HMMWV	High Mobility Multi-Purpose Wheeled Vehicle
ILP	Integrated Logistics Plan
LEAD	Letterkenny Army Depot
LIDB	Logistics Integrated Database
LCM	Life-Cycle Management
MACOM	Major Army Command
MMA	Maine Military Authority
MTVR	Medium Tactical Vehicle Replacement
NCCA	Naval Center for Cost Analysis
OEM	Original Equipment Manufacture
OPTEMPO	Operational Tempo

O&S	Operating and Support
OSMIS	Operating and Support Management Information System
PBL	Performance-Based Logistics
PSAT	Product Support Assessment Team
PSM	Product Support Manager
RECAP	Recapitalization
RRAD	Red River Army Depot
SCM	Sustained Cost Management
SRI	Sustained Readiness Improvement
TOC	Total Ownership Costs
TSV	Tab Separated Value
USAMC	United States Army Materiel Command
USD AT&L	Under Secretary for Defense for Acquisition, Technology and Logistics
VAMOSC	Visibility and Management of Operating and Support Costs
WON	Work Order Number
YOM	Year of Manufacture

EXECUTIVE SUMMARY

Acquisition costs of DoD weapon systems are of major concern due to their enormous annual expense. In fact, $165B was spent by Department of Defense (DoD) on acquisition in 2008. However, another budget component, Product Support, costs the government an additional $132B annually. DoD has stated that the preferred method for providing this life-cycle sustainment is Performance Based Logistics (PBL), and 20% of all programs now use that method of support. PBL's goal is to provide maximum readiness at reasonable costs.

In October 2009, President Obama signed the Fiscal Year 2010 National Defense Authorization Act. This act contained a provision entitled "Life-cycle Management and Product Support" requiring that: (1) the Secretary of Defense issue comprehensive guidance on Life-cycle Management (LCM), and on the development and implementation of product support strategies for major weapon systems; (2) each major weapons system be supported by a Product Support Manager (PSM); and (3) each PSM position be performed by a properly qualified member of the armed forces or full-time employee of the DoD. Product support and sustainment thus became a high priority for DoD.

Since 1999, the DoD has been transforming to a system that places more emphasis on readiness outcomes. Performance-Based Logistics (PBL) has been named the preferred method of life-cycle sustainment. PBL has allowed partnerships between government and industry to be formed. These partnerships are designed to bring together the best of the public and private sectors in order to provide DoD with maximum readiness at reasonable costs.

The Army has been working through this transformation in life-cycle sustainment. Specifically in 2006, it implemented an Integrated Logistics Plan for the recapitalization (RECAP) program for High Mobility Medium Wheeled Vehicle (HMMWV) vehicles. This created a partnership with AM General to provide parts to Army Depots conducting the RECAP of HMMWVs. This study analyzes the

Cost Per Unit Usage (CPUU) and Operational Availability (A_0) of the Army HMMWV. The CPUU and Operational Availability were analyzed over a six year period from 2004 to 2009.

The primary goal of this thesis was to conduct a comparison of different support strategies on a weapon system. Data was collected from the Army Logistics Integrated Database (LIDB) and Operating and Support Management Information System (OSMIS). This study focused on the M998 and M1097 models, which are two of the models that went through the RECAP process. The data for the usage (mileage) of the HMMWV's contained numerous anomalies and was missing numerous odometer readings. This made computing the CPUU difficult, as we had to make several corrections to the usage data under assumptions that we determined to be reasonable based on the usable data.

Ultimately, we found that the ILP does not appear to be providing any costs savings or increased Operational Availability since its implementation. The CPUU had an upward trend over the six-year period and the pre-ILP cost was found to be cheaper than the post-ILP cost. The Operational Availability was consistent at 90% to 95% across this same time period. The major finding in this study was that the data available to conduct these type of studies is poorly maintained. The amount of missing and anomalous data does not allow analysts to confidently draw conclusions. It is recommended that DoD invest time and money in data collection and database organization in order to provide analysts with accurate and complete data.

Studies such as this can provide valuable information to key decision makers within the DoD. However, in order to provide that valuable information, analysts need to be provided with complete and accurate data. Providing our warfighters with the best weapons systems at reasonable costs to the taxpayer is a key issue in the United States. It is critical that DoD analysts be provided with cost and availability information to allow them to make accurate estimates of weapons system support.

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I. INTRODUCTION

Acquisition costs of DoD weapon systems are of major concern due to their enormous annual expense. In fact, $165B was spent by DoD on acquisition in 2008. However, another budget component, Product Support, costs the government an additional $132B annually. (U.S. Department of Defense, Deputy Under Secretary of Defense for Logistics and Materiel Readiness, 2009, p. 6) DoD has stated that the preferred method for providing this life-cycle sustainment is Performance Based Logistics (PBL), and 20% of all programs now use that method of support. PBL's goal is to provide maximum readiness at reasonable costs.

For years product managers managed components of readiness as discrete units. In other words, they bought and stocked parts, systems, and sub-systems, and shipped them to units as necessary. Since 1999, the DoD has been evolving to a system that places more emphasis on readiness outcomes. Performance-Based Logistics (PBL) is the "poster child" of this strategy. PBL has allowed partnerships between government and industry to be formed. These partnerships were designed to bring together the best of the public and private sectors in order to provide DoD with maximum readiness at reasonable costs. While this strategy has been declared as the preferred means of life-cycle support (U.S. Department of Defense, 2007, p. 7), fewer than 20% of all weapons systems are using this strategy. PBL has been criticized as simply being "contracted logistics." Many have questioned the cost-effectiveness of this strategy. The Government Accountability Office (GAO) has conducted two separate studies on PBL and has yet to find any conclusive evidence that PBL contracts are saving the government money. Other studies have indicated increased levels of availability. Fewer people have raised questions concerning this metric than with cost. Lawmakers, DoD administrators, and our Military

Commanders need to be able to look at the costs and availability together to determine if these types of support strategies are the future of weapon systems life-cycle sustainment.

A. BACKGROUND

In 2005, an Integrated Logistics Plan (ILP) was developed in an attempt to increase readiness for the Army HMMWV. Two production lines, Letterkenny Army Depot (LEAD) in Franklin County, Pennsylvania, and Red River Army Depot (RRAD) in Bowie County, Texas, were chosen for the program. This was expanded to include Maine Military Authority (MMA) in Aroostook County, Maine, in May of 2006. (Smith, 2009, p. 6) The idea behind the ILP was to move the “point of sale” to the “point of use” by having the supplier deliver the parts and having minimal government intervention in the supply chain. AM General was awarded a $200 million contract to provide parts for the HMMWV recapitalization program at the two Army Depots.

The overall strategy of the program was to optimize support to the warfighter, which is also the overall goal of the DoD policy on weapons system support. Additionally, this partnership was expected to save the Army money on Operations and Support (O&S) costs. The contract with AM General was renewed in 2008. The Army has reported an overall savings of $4,520 and $3,414 per vehicle at LEAD and RRAD, respectively. Considering the large number of HMMWV’s the Army has in its inventory, this is a substantial savings to the DoD. Army Material Systems Analysis Activity (AMSAA) reported an overall savings of over $800,000 for FY06. (Chapman, 2007)

The Army and other services continue to modify their maintenance strategies to try and find ways to increase availability and save costs. Each of these strategies needs to be analyzed to determine effects on costs and availability and to give decision makers a basis for their future plans.

B. ANALYSIS

The key metrics of this study were Cost Per Unit Usage and Operational Availability. The years 2004–2005 were used as a baseline, since these were the two years of data prior to the ILP being put in place. Then the years 2006–2009 were compared to the baseline to determine if there were any costs savings or increased Operational Availability. We also looked at the trends across the entire time frame to determine what the CPUU and Operational Availability were doing over time. All the analysis was conducted in R (R Development Core Team, 2010) and Microsoft Excel (Excel, 2007).

The largest portion of our time was spent handling the data. In particular, the usage data required substantial repairs due to missing and anomalous data. The serial numbers for the vehicles also required several repairs mostly due to obvious entry errors. Once the data was corrected and put in a usable format, we used several different strategies to examine the effects of the ILP. For instance, the metrics were categorized by Major Army Command (MACOM) to eliminate the possibility that some of the smaller commands had too much leverage on the data. We used statistical tests to determine if the differences between the time periods were statistically significant. The data was broken down by quarters and analyzed to determine trends over the course of the study period. Ultimately, all the analyses led to similar conclusions.

C. SUMMARY OF FINDINGS

The Cost Per Unit Usage (CPUU) was found to have a rising trend over the time period studied. When comparing the two time periods, pre-ILP and post-ILP, the study determined that the pre-ILP CPUU was less expensive. Several different analyses were conducted and all of them came to the same two conclusions: the Army HMMWV ILP is not saving the DoD money, and the Operational Availability has not increased.

The Operational Availability was studied in a manner similar to that of the CPUU. We found that over the period studied, the Operational Availability showed a very slight downward trend. However, the decrease was insignificant and Operational Availability never dropped below 90% during the time-period studied.

In conducting these analyses, the major finding was that the data was inconsistent and missing numerous values. Specifically, the usage data, which was vitally important to studying the CPUU, was missing monthly entries and had numerous obvious errors, such as a monthly reading being lower than the previous monthly reading. Problems like this caused difficulty and lots of data had to be eliminated or corrected in order to conduct the analysis.

D. ORGANIZATION OF THIS THESIS

This thesis describes the analytical methodology, findings, and recommendations for achieving long-term product support for the Army HMMWV. Chapter II of this thesis provides a brief synopsis of the different reports and analyses that were read while conducting this study. Chapter III provides an in-depth discussion of the different data sources used and, more importantly, the problems encountered with the data. The analysis approach, methodology, and resulting models are present in Chapter IV. Finally, Chapter V closes the report by drawing conclusions and making recommendations for a successful future of the HMMWV and other DoD weapons systems.

II. LITERATURE REVIEW

Since the inception of Performance-Based Logistics, a number of studies have examined its performance. The Government Accountability Office (GAO) has conducted two separate analyses of PBL's, one in 2005 and one in 2008. (U.S. Government Accountability Office, 2005, 2008) The RAND Corporation has also done studies on PBL, as have many other analysis organizations, including the U.S. Army Materiel Systems Analysis Activity, the Office of the Under Secretary of Defense, independent industry, and academia. (RAND Corporation, 2008; Chapman, 2007; U.S. Department of Defense, Deputy Under Secretary of Defense for Logistics and Materiel Readiness, 2009). But few of these studies have examined the DoD-prescribed metrics for their analysis.

A. PRODUCT SUPPORT ASSESSMENT TEAM

The most recent high-level study conducted on Performance-Based Logistics was released by the Under Secretary of Defense for Acquisition, Technology and Logistics (USD AT&L) in November of 2009. This report was created by a working group of military, civilian DoD, industry, and academic analysts designated as the Product Support Assessment Team (PSAT). While the report was very broad and covered more topics than just costs and availability, one of the major findings was: "Performance-based product support strategies consistently deliver improved materiel readiness, but assessing the true cost of both traditional and performance-based strategies is difficult, if not impossible, given current financial systems." (U.S. Department of Defense, Deputy Under Secretary of Defense for Logistics and Materiel Readiness, 2009, p. 9) The major issue the PSAT had with this analysis was that the data for the cost analysis was either unavailable or inconclusive. Furthermore, across the services, there was no standard way of tracking costs.

Another interesting finding from this report was the fact that acquisition and sustainment communities do not have shared goals and are funded separately. (U.S. Department of Defense, Deputy Under Secretary of Defense for Logistics and Materiel Readiness, 2009, p. 26) For example, acquisition organizations have traditionally purchased weapons systems from the lowest bidder. While this may provide savings for the procurement portion of the life span of the system, it may, in turn, incur more Operation and Support (O&S) costs later in the life-cycle. If the acquisition groups and logistical support groups worked more cohesively and had common goals, life-cycle cost savings could be more easily achieved. In many cases, more costs up front could lead to large savings in O&S costs over the life span of the system. PBL contracts force the acquisition and logistic organizations to work together and come to agreement on some common goals.

The PSAT was asked to conduct the analysis on analogous systems. In other words, they grouped systems by mission capability, such as land assault (AAV, Bradley, Stryker, M1 FOV, and M1 Abrams), land transport (FMTV, MTVR, HEMTT, HMMWV (Army), and HMMWV (USMC)), etc. However, comparing different systems, produced by different companies and at different stages in their life cycles, is problematic. Ideally, a single system could be examined both with PBL in place and without. For example, a lower cost per unit usage for the HMMWV than for the MTVR might suggest that the former's maintenance plan is more efficient. However, the MTVR might be inherently more expensive to maintain, perhaps because parts cost more or because the vehicles are used differently. The PSAT used two primary indexes for grading the systems: Sustained Readiness Improvement (SRI) and Sustained Cost Management (SCM). The SRI is a binary metric that was calculated by taking the average availability change of all systems within a category as the baseline. An individual system earned a value of one for any year in two distinct ways. First, a system scored a one if it experienced an increase in availability from one year to the next. Second, a one was also scored if the system decreased in availability at a rate less than the average availability change for that category. Otherwise, a zero was scored for that year. The average of the ones and zeros over the period study produced the SRI. (U.S. Department of Defense, Deputy Under Secretary of Defense for Logistics and Materiel Readiness, 2009, p. 83) The SCM was calculated using a similar method except that Cost Per Unit Usage (CPUU) was used for each system and in order to earn a one, the system's cost had to decrease from year to year or increase at a rate smaller than the average CPUU change. An example of why this could be a problem is shown in Table 1.

The PSAT found numerous flaws within DoD that needed to be corrected and made several suggestions on how improving this process could be implemented. It also pointed out that this would require strong leadership, open-mindedness, a reform-driven DoD-Congressional partnership, and a collaborative DoD-Industry relationship. (U.S. Department of Defense, Deputy Under Secretary of Defense for Logistics and Materiel Readiness, 2009, p. 12)

Table 1 shows how the SRI used by PSAT could give a false indication that two systems are performing at a similar level. Consider two systems with Availability, as shown in Table 1.

System 1:	Year 1	Year 2	Year 3	Year 4	Year 5	Year 6	Year 7	Average	Readiness improvement	
Availability	80%	79%	78%	79%	78%	77%	78%	78%	+	4
% Change		–1%	–1%	+1%	–1%	–1%	+1%			
Score		0	1	1	0	1	1		-	2
										67%
System 2:	Year 1	Year 2	Year 3	Year 4	Year 5	Year 6	Year 7	Average	Readiness improvement	
Availability	74%	75%	60%	63%	65%	64%	65%	67%	+	4
% Change		+1%	–20%	+5%	+3%	–2%	+2%			
Score		1	0	1	1	0	1		-	2
										67%
Average	77%	77%	69%	71%	72%	71%	72%			
% Change		0%	–11%	+3%	+1%	–1%	+1%			

Table 1: SRI for Two Different Weapons Systems

So, according to the PSAT results, both systems receive a grade of 67%; however, clearly system #1, which has an overall average of 78% availability, is the better system. A graph of the corresponding Sustained Readiness Improvement and the Operational Availability are shown in Figure 1 and Figure 2.

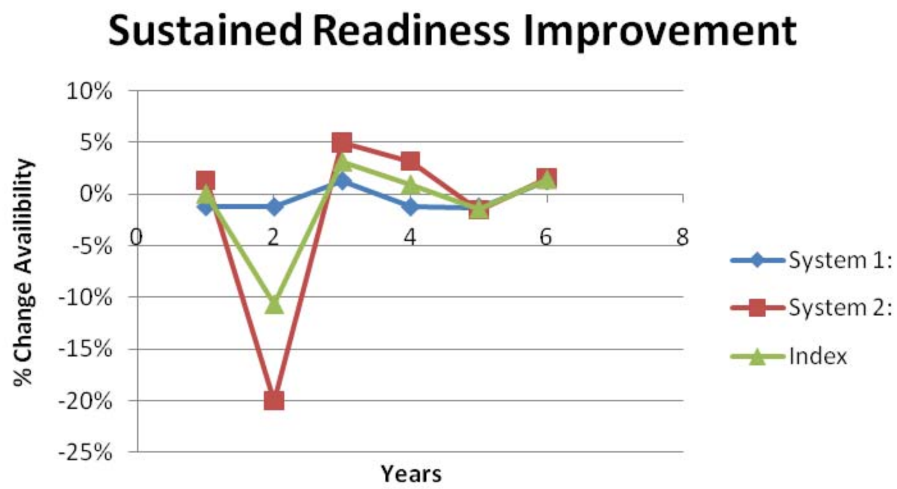

Figure 1: Sustained Readiness Improvement versus Time for Two Weapons Systems and Their Baseline Index

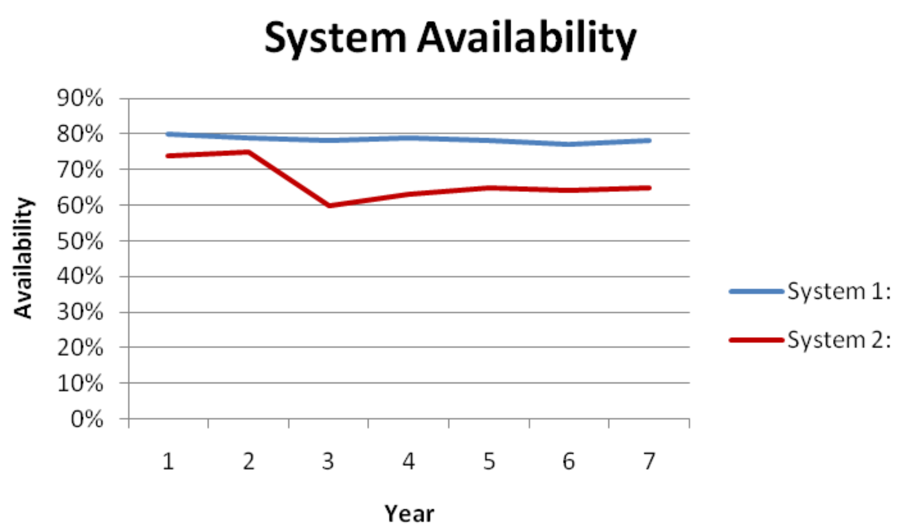

Figure 2: Operational Availability for Two Weapons Systems Over Time

B. GOVERNMENT ACCOUNTABILITY OFFICER

The GAO has released two reports regarding Performance-Based Logistics. (U.S. Government Accountability Office, 2005, 2008) These reports reach similar conclusions. The GAO found that while DoD guidance states that program offices should use business case analysis (BCA) to guide decision making regarding PBL contracts, the services are not consistent and in many cases simply did not conduct a BCA.

In the 2005 study, only one of the fifteen program offices reviewed actually updated the BCA in accordance with DoD instruction. One of the two major recommendations in this report to the DoD was "to reaffirm DoD guidance that program offices update the business case analysis following implementation of a performance-based logistics arrangement and develop procedures, in conjunction with the military services, to track where program offices that enter into those arrangements validate their business case decisions consistent with DoD guidance." (U.S. Government Accountability Office, 2005, p. 12) Three years later, of the 29 PBL arrangements the GAO studied, about half of them either did not use a business case analysis or were unable to provide documentation of one. (U.S. Government Accountability Office, 2008, p. 5) Clearly, the problem with business case analysis has not been fixed. It may be that the guidance for these business case analyses needs to be revised or perhaps the program offices are not appropriately equipped to conduct them. This is an area that still needs to be addressed and corrected in order for studies such as this to make any substantial conclusions regarding the effectiveness of PBL contracts.

The GAO also found in both reports that the data used to evaluate these contracts is not sufficient to draw conclusions. A common belief identified in these reports was that a fixed cost contract would always be cheaper than a traditional contract and therefore the program offices did not bother tracking costs. The program offices also acknowledged limitations in their own information systems in providing reliable data to monitor contractor cost and performance. Furthermore, they stated that they had more confidence in the contractors' systems than in their own regarding accuracy and completeness. (U.S. Government Accountability Office, 2005, pp. 9–10) According to the 2008 report, this same problem persisted. It stated, "Program managers often lacked detailed and standardized cost data." (U.S. Government Accountability Office, 2008, p. 32) We encountered this same lack of data problem as well, and an entire chapter of this study has been dedicated to the different problems encountered. Ultimately, the DoD has to lay down and enforce the standards established in order to track this data accurately and completely.

C. RAND CORPORATION

In 2008, the RAND Corporation released a study conducted on the Army HMMWV recapitalization (RECAP) program. As with the current study, the RAND study was performed at the vehicle level. The key objectives of the study were to assess the effects of age on costs and availability, develop a tool that determines optimal RECAP times, and demonstrate how the tool can be used to produce recommendations. (RAND Corporation, 2008) While RAND's analysts were not as interested in cost per unit usage as this study is, they did determine that the optimal replacement point for the M998 occurred at age 12, yielding an average cost per mile of $5.53 over the lifetime of the vehicle. (RAND Corporation, 2008, p. xiii)

As with all the other studies, RAND found numerous problems with the data. Since their study was based on age, the Year of Manufacture (YOM) was important data. About 5% of the data they collected did not have a YOM, or it contained a YOM that was obviously incorrect. The usage data was even worse. In order to put some realistic maximum limitations on this, they capped the usage at 3,000 miles per month. With this restriction, over 24% of the data had missing or invalid usage elements. RAND used simple imputation to replace these missing values. Another issue RAND faced lay in the part order data. Their data contained part orders that were not true HMMWV parts, and therefore those were excluded. (RAND Corporation, 2008, p. 57) Fortunately, RAND's data set was large enough that even with these problems, they were able to conduct a thorough study and develop a model for determining the optimal age for RECAP.

D. ARMY MATERIEL SYSTEMS ANALYSIS ACTIVITY (AMSAA)

The Army Materiel Systems Analysis Activity (AMSAA) conducted a study on the HMMWV ILP and released a report in October of 2007. This study was conducted for Headquarters Army Materiel Command and included five different performance metrics. These performance metrics were: Stockout Rate, Turnaround Time, Code G Vehicle Rate, Customer Wait Time, and Quality Defect Rate. There were also four cost metrics: Repair Parts Cost, Supply Chain Operating Cost, Investment/Other Additional Cost, and Inventory Holding Cost. According to this study, the cost savings to the government from the inception of the ILP in January of 2006 to December of 2006 was approximately $800,000. (Chapman, 2007, p. 33). The performance of the program conveyed consistent improvement according to AMSAA. The major recommendations that AMSAA had upon conclusion of their study all centered around data collection. They found that the data for the baseline assessment was not available, that adequate time to conduct the baseline data collection was not permitted prior to the performance based agreement (PBA) being negotiated, and that baseline metrics needed to be established prior to the PBA being written. As with all other studies that were reviewed, the lack of data or inaccuracy of data was a major hurdle to overcome.

E. DEFENSE ACQUISITION UNIVERSITY

In order to gain insight into Performance-Based Logistics, the "PBL Guide" provided by Defense Acquisition University was reviewed along with the governing DoD instruction, 5000 series. According to DoD Instruction 5000.01, program managers "shall develop and implement performance-based logistics strategies that optimize total system availability while minimizing costs and logistics footprint." This is interesting to note, considering that, as previously stated, only 20% of current weapons systems are under a PBL contract. According to the "PBL Guide" and many other reports, the preferred method of product support strategy is performance-based logistics. (Defense Acquisition University, 2005, p. vii)

The "PBL Guide" offers information for program managers to use as they shift to this new strategy. It offers guidance on developing a team, determining performance outcomes, supply chain management strategy, and awarding contracts, along with many other topics. Additionally, this guide provides information on the five primary metrics for PBL contracts: 1) Operational Availability, 2) Operational Reliability, 3) Cost per Unit Usage, 4) Logistics Footprint, and 5) Logistics Response Time. Also presented in this guide book are several success stories of PBL contracts and a section on best practices determined from these success stories.

F. CONCLUSION

In conclusion, many different studies were reviewed and one resounding conclusion consistently appeared. The data that was available to conduct cost and performance analysis is limited and of dubious quality. Because of this, the ability of the different teams to provide substantial and conclusive results was very limited. Furthermore, they were unable to study the DoD prescribed metrics for PBL contracts. In the case of the PSAT study, the scope of the study was extremely large and made an attempt to compare analogous systems. Unfortunately, while these systems are similar, they have their differences as well, and therefore it is hard to make exact comparisons. Ultimately, to determine if PBL contracts are working, analysts will have to study systems that have used both methods of life-cycle support. This allows for a fair comparison amongst the two methods. Also, the metrics prescribed by DoD should be the focus of these future studies. The bottom line is that in order to conduct a thorough and significant analysis, there must be accurate and complete data available.

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III. DATA ISSUES

A major difficulty in this study in assessing the metrics for the HMMWV is the inconsistencies found in the data. There are many obvious errors that were found within the data sets. This problem was discussed in Chapter II. The data collection process requires drastic improvement. Studies such as this are only as good as the data they can use. This chapter discusses the problems in the data that was obtained on the HMMWV for both the U.S. Army and U.S. Marine Corps.

A. UNITED STATES ARMY

The metrics studied for the HMMWV were Operational Availability and Cost Per Unit Usage (CPUU). These metrics were explored on the M998 and M1097 models, which are the two models for which the Army ILP was originally written. The data was collected from Operating and Support Management Information System (OSMIS) and the Logistics Integrated Database (LIDB). The data collected from OSMIS provided a summary of quarterly costs for each Major Army Command (MACOM) and we were able to capture data from 1993 to present. LIDB provided a detailed look at costs broken down by individual Work Order Numbers (WONs). LIDB also provided usage data for each vehicle by serial number. The Operational Availability data in LIDB is reported by each Unit Identification Code (UIC) that maintains that particular style of vehicle and is recorded monthly. All data collected from LIDB included the years 2000 to 2009. However, due to minimal data recorded between 2000 to 2003, only 2004 to 2009 were analyzed.

1. Operating and Support Management Information System (OSMIS)

The data collected from OSMIS had numerous anomalies that had to be studied closely to determine why they occurred or whether the data was simply incorrect. For instance, 10% of the line items in the OSMIS data contained zeros in the Activity (amount of usage) field. This typically would cause the Cost Per Unit Usage, which is the sum of all the costs for a vehicle divided by the miles traveled, to be infinite. However, these values were recorded as zero. This clearly is an error because there were reported costs for those years and therefore the vehicles had presumably been used. It should be noted that most of these zeros fell in the time frame from 1993–1998. Furthermore, the maximum CPUU during the time frame studied was $16.4 billion. Approximately 10% of the reported CPUU values were over $10.00 per mile. Such a vehicle operated for 1200 miles per year would cost around $12,000 dollars per year; over the course of a 15-year life span, O&S costs would be around $180,000 dollars at that rate. That does not include the purchase price. From these observations of the CPUU reported in OSMIS, we decided that this 10% of the data was defective and therefore needed to be removed. A plot of average CPUU for Army HMMWV is shown in Figure 3.

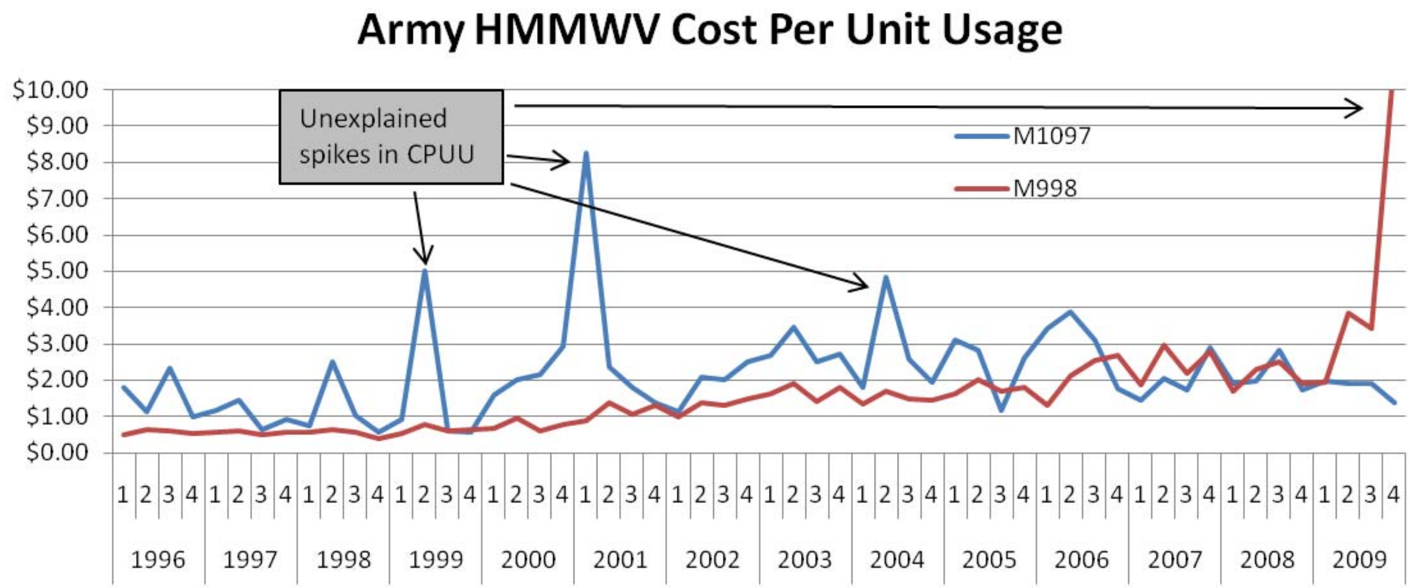

Figure 3: Army HMMWV CPUU for M998 and M1097 from 1996 to 2000

The CPUU for the M998 is much more consistent than that of the M1097 and this can probably be attributed to the fact that there are substantially more M998 vehicles than M1097 vehicles for most of the years studied. One last interesting note for the CPUU is the drastic spike in 2009 for the M998 model and in 1999 and 2001 for the M1097 model.

Another example of the inconsistencies lay in the number of HMMWV's reported in OSMIS that are displayed in Figure 4. This type of study requires a large number of vehicles in order to ensure accurate results. In the final data sets used for the study, there were ample vehicles, but the point of this paragraph is to show inconsistencies in the data. Note, the drastic change in the reported number of M998 models between Quarter 4 of 1998 and Quarter 1 of 1999. This drop was over 30,000 vehicles. While there is no clear explanation for this, it could possibly be attributed to some vehicles being re-designated to a different model number due to an upgrade or addition to the vehicle. Numerous calls and emails yielded no other possible conclusions from the Program Manager and AMC. For example, if a new communication system is installed on a vehicle, it is re-designated from M1097 to M1097A1. Also notable in this graph is the spike in numbers for the M1097 during 1998 followed by a drop in 1999. While the drop is not nearly significant as that for M998 in 1999, there is another substantial drop between Quarters 1 and 2 in 2006 for the M998 model. This is when the ILP first began. One trend that is clear from this graph is the rise in numbers of M1097 models and decrease of M998 models beginning in 2006.

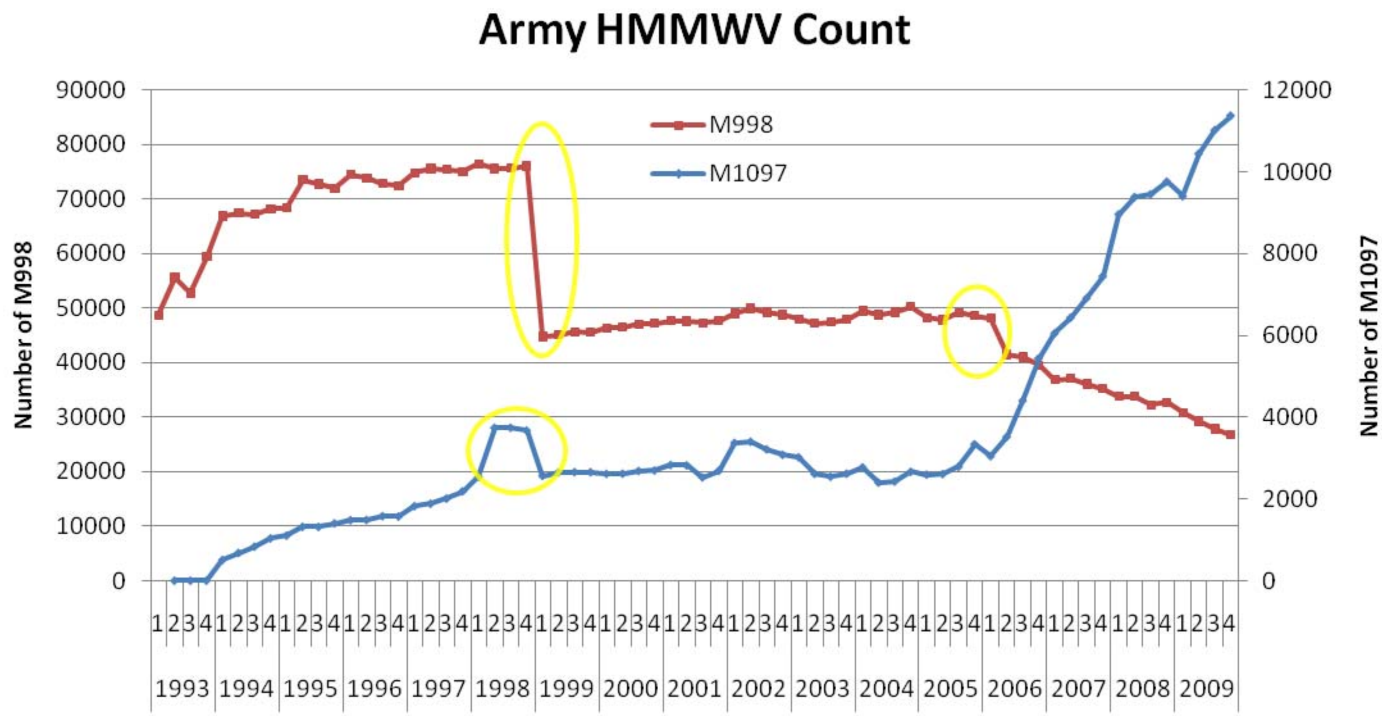

Figure 4: Army HMMWV Count for M998 and M1097 Models from 1993 to 2009

The final area of interest from the OSMIS data was the Cost Per System/Unit (CPU). CPU is the total O&S costs for an individual system. While this was not one of the primary metrics studied, the data was observed initially just to see how it coincided with the Cost Per Unit Usage. It seems that these two metrics should have some similarities especially over such a large sample size. The graph of the CPU is displayed in Figure 5. While there appears to be a rising trend across the entire time frame, it is also easy to see the large spikes from quarter to quarter. Furthermore the increases and decreases do not coincide with the increases and decreases in the CPUU graph in Figure 3.

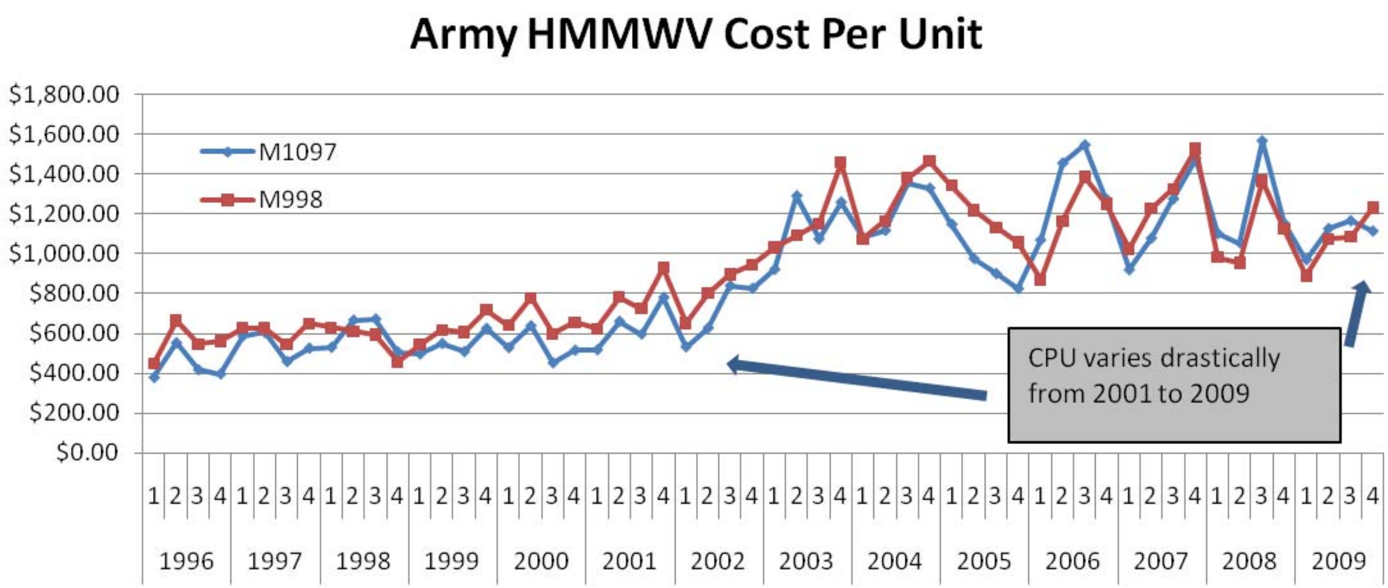

Figure 5: Army HMMWV Cost Per Unit for M998 and M1097 from 1996 to 2009

While there appears to be no consistency in this data, the two models do seem to follow similar trends. In other words, CPU for the M998 and M1097 models appear to be rising and falling at the same time. From 2000 to 2007, the range of CPU for M998 was $779.52 to $1528.49. This is a significant range, particularly considering that all these values have been adjusted to FY 2011 dollars.

2. Logistics Integrated Database (LIDB)

The Logistics Integrated Database contained vehicle level data that was much more useful. Data on both cost and Operational Availability was obtained for the years 2000–2009. Although this was by far the best data we were able to obtain, it still had some significant problems. First, the cost data for these years had 268,348 Work Order Numbers with 294 of those being duplicates. However, the categorical data had only 264,492 WONs with 59 duplicates. Costs associated with a WON that did not exist in the categorical data raised some concern. Without a WON in the categorical data, it was impossible to determine which serial number those costs could be associated with.

The next major problem with this data was the fact that the first four years of the data contained very few WONs. That left us with only two-years' worth of data to establish the baseline before the ILP was implemented. A histogram of the number of WONs by year is shown in Figure 6. In 2000, there were two WONs in the data; in 2001 only one; and there were sixteen in 2002. These numbers are not visible in the graph due to the scale. The important conclusion is that prior to 2004, WONs were not being tracked or entered, and therefore, these years cannot be used for any significant analysis.

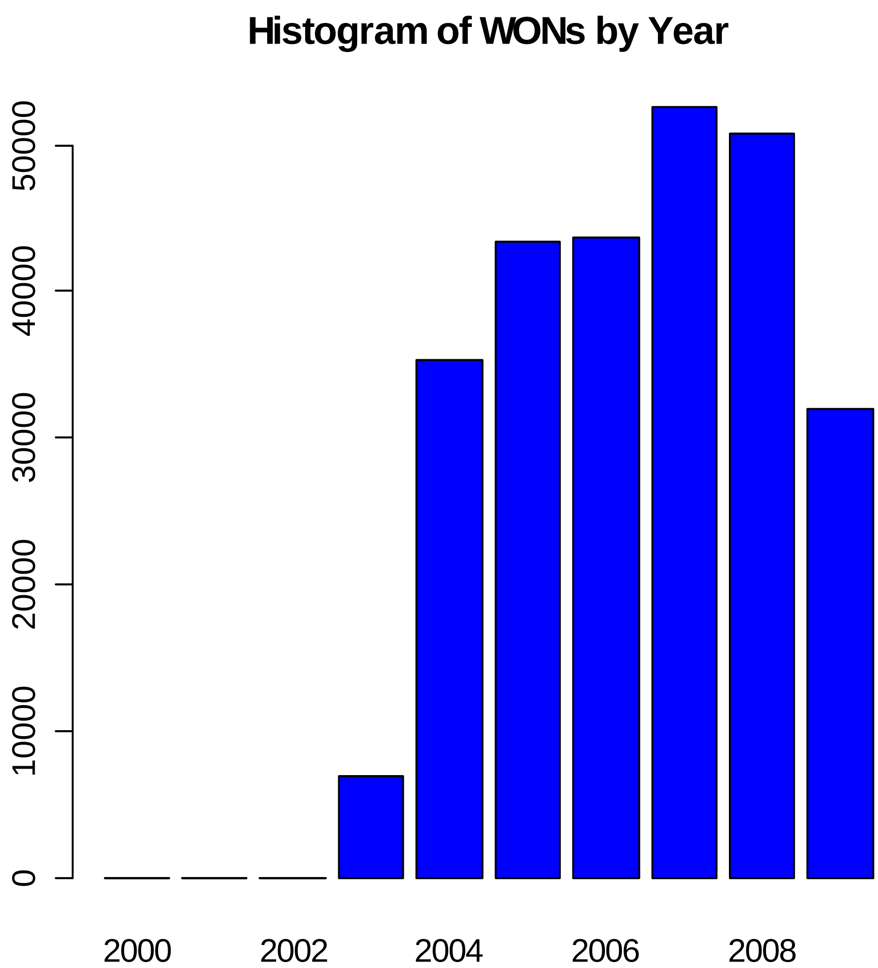

Figure 6: Histogram of Work Order Numbers for 2000–2009

Finally, of the over 250,000 work orders associated with costs, over 12,000 of them had a zero in the total work order cost field, and over 26,000 of them were missing the serial number for the vehicle. Slightly fewer than 140,000 of them had valid six-digit serial numbers (before we implemented correction algorithms). Ultimately, this was the best we were able to collect and after corrections to serial numbers, that is detailed in Appendix A, we used just under 180,000 WONs for this study.

B. UNITED STATES MARINE CORPS

1. Visibility and Management of Operating and Support Costs (VAMOSC)

The metrics studied for the USMC HMMWV were the same as with the Army: Operational Availability and Cost Per Unit Usage. The Marine Corps data was gathered from the Navy Visibility And Management of Operating and Support Cost (VAMOSC) database at the Naval Center for Cost Analysis (NCCA). Data was gathered on eight different models of the HMMWV. The years from 1998 to 2008 were available for download; however, some of the models did not appear in all of these years. The data obtained was summary statistics by model and year. There were 88 different combinations of model and year obtained. As with the Army data, several anomalies were noted upon initial collection of the data.

The most significant problem with this data set was the fact that the “OPTEMPO” or usage was reported for both deployed and regular units; however, the inventory was only reported for the entire fleet of that particular model. This makes it difficult to determine the average usage per vehicle, which is needed to determine the cost per unit usage. Furthermore the units for the OPTEMPO were inconsistent and in many cases not documented. Of the 88 organizations listed in line items for regular (non-deployed) vehicles, 77 of them were reported in miles per year, five were reported in hours per year, and six were left blank. For the deployed units, 35 were reported in miles per year, one was reported in hours per year, and 52 were left blank. The 52 that did not report could be attributed to that particular vehicle style not having any deployed vehicles for that particular year. Based on these numbers and various conversations with Marines who have dealt with HMMWV’s in the past, it is believed that the correct unit is in miles per year.

As with the Army, the Marines’ inventories or counts were another significant problem area. Of the 88 line items gathered from VAMOSC, only 73% included an inventory; however, all 88 included at least one of the five different cost fields included in the data. A graph of the inventories is included in Figure 7, and while the drastic drops seen in the Army data are not as evident here, there are several oddities that raise concerns. For instance: for the D1125 model for years 2005 to 2007, the inventory varied from 669 to 1175 to 854. A similar problem occurred for the D0187 model during the same years; the inventory varied from 17 to 357 to 74. For FY-2009, no inventories were reported for any model. In summary, the USMC data was not analyzed for this thesis due to the lack of vehicle level data.

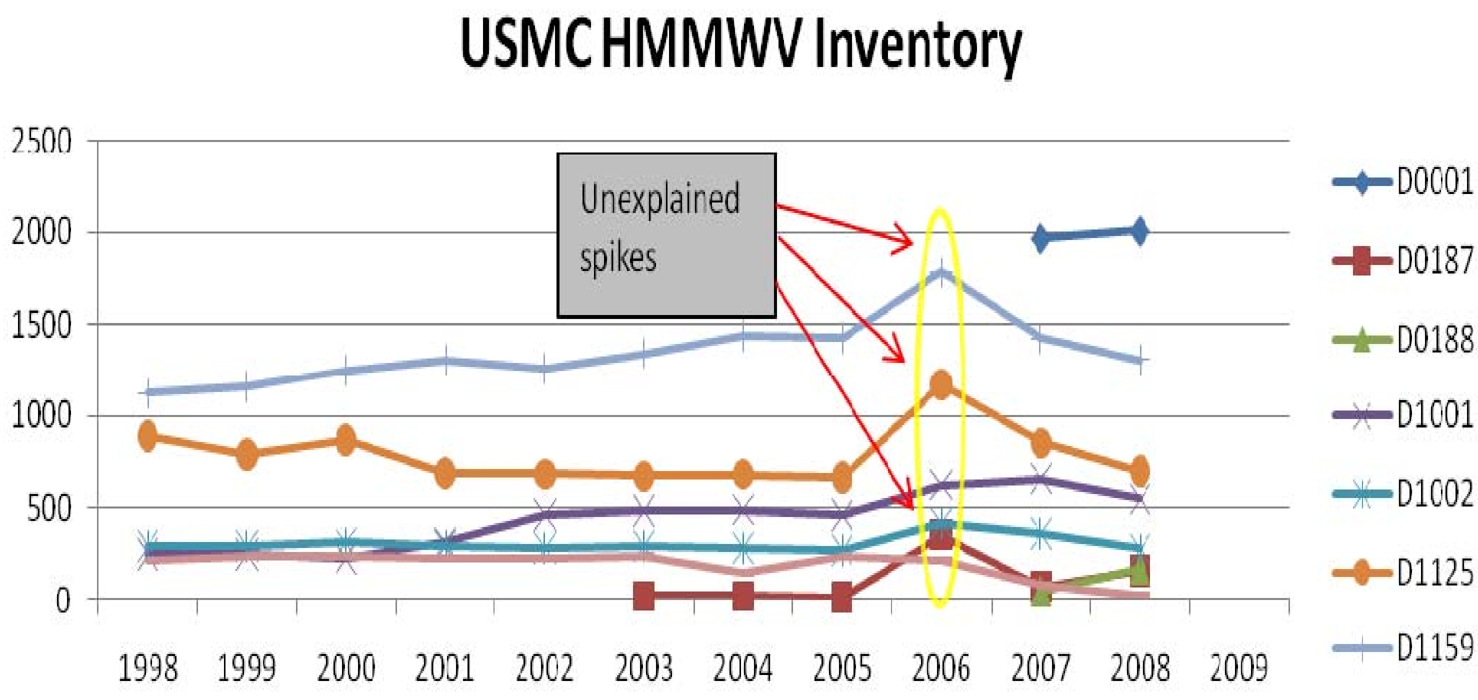

Figure 7: USMC HMMWV Inventory Levels for 1998 to 2008

The final observation from this data was the Cost Per Unit (CPU). The most interesting observation in this area was with the D0187 model. Over the course of 6 years, the CPU data varied drastically and was more than 5–7 times higher than the other models' average in 4 out of 6 years. A graph of the CPU is shown Figure 8, and the anomaly that occurred with D0187 is clear to see. There is also a trend beginning in 2005 that shows an increase in CPU.

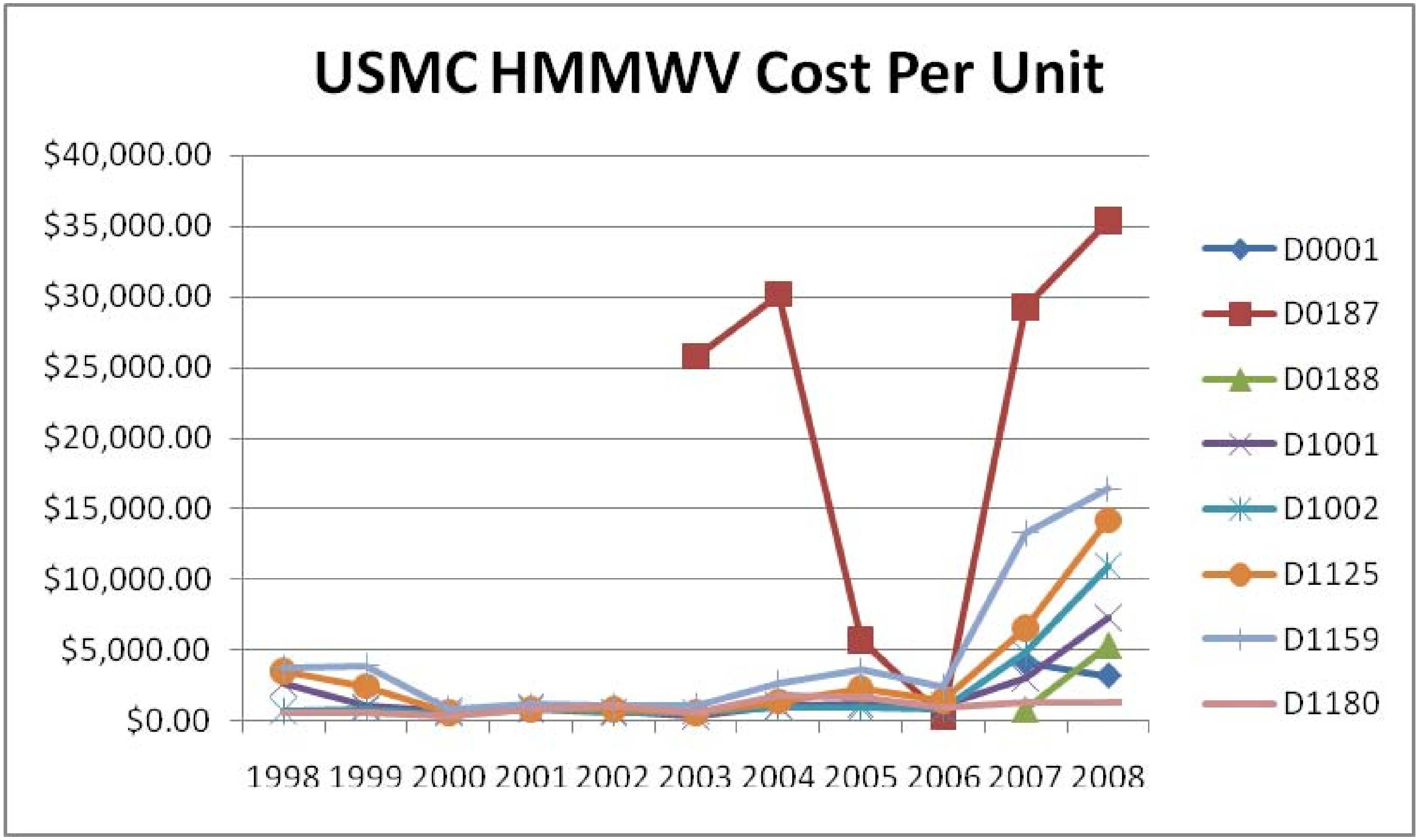

Figure 8: USMC HMMWV Cost Per Unit for 1998 to 2008

C. SUMMARY

Data obtained from the Army and Marine Corps was full of anomalies. From unexplained drops in inventory to differences in Cost Per Unit of over $25,000, the data contained many inconsistencies. While there is plenty of data available on weapons systems from the various databases across the services, it appears there needs to be some quality control implemented at the entry level. For maintenance issues, jobs are typically entered into the system by personnel of rank E-5 and below and then reviewed by Non-Commissioned Officers and again by Officers. Unfortunately, this review process is not correcting the multitude of errors and needs to be revised across the services. Perhaps with new technology available, the multiple entry points could have drop-down menus and the ability to warn the user of a faulty input. Ultimately, for DoD to conduct thorough and, more importantly, conclusive studies, we recommend that the issues addressed above regarding the data be corrected.

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IV. ANALYSIS

The analysis focused on two of the six metrics used to measure PBL's: Cost Per Unit Usage (CPUU) and Operational Availability. We examined the Cost Per Unit Usage over time to determine if any cost savings could be attributed to the ILP. Operational Availability was studied to find any trends before and after the inception of the partnership with AM General. All the analysis was conducted in R and Excel 2007 using the data gathered from the Army LIDB. Due to the large number of missing data points, some of the data had to be repaired and those repairs are documented in Appendix A.

Two different models from the Army were studied, the M1097 and M998. Over 45,000 vehicles were used for this study, 33,761 M998s and 14,832 M1097s. The data covered the years 2004 to 2009. After repairs and deletions, we had nearly 128,000 work orders for M998's and 41,000 work orders for the M1097's.

A. COST PER UNIT USAGE

The cost per unit usage was difficult to study because the usage data was missing multiple values and had countless anomalies. After repairs to the data, there was still variability. The mean usage per year per was 914 miles for M1097 and 1,242 for the M998. A table of the number of vehicles having a certain level of usage for a year is shown in Table 2. There were over 28,000 times when a vehicle recorded zero usage for the year. The average vehicle usage decreased over the period studied. A plot of both models' average yearly usage is shown in Figure 9.

Miles of Usage	**0**	**1-1,000**	**1,001-5,000**	**5,001-10,000**	**>10,000**
M998	20,547	26,640	21,362	2,515	851
M1097	8,001	11,999	5,673	570	254

Table 2: Number of Vehicles with Established Mileage Per Year

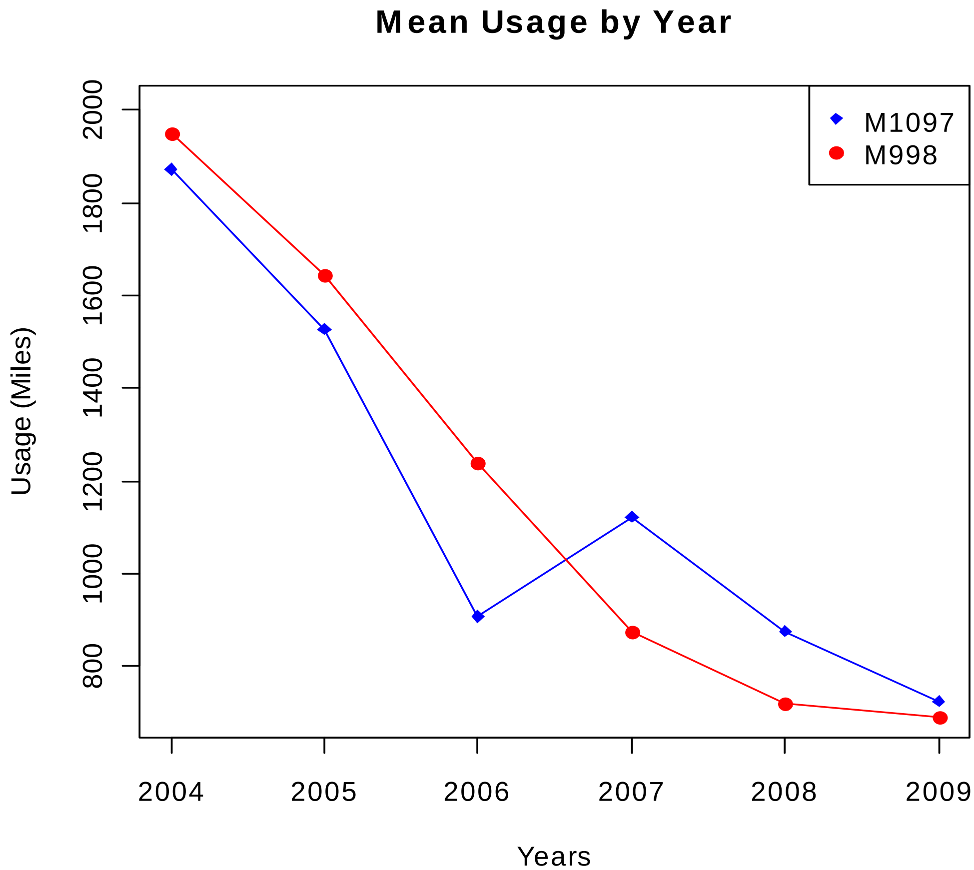

Figure 9: Mean Usage per Year

A boxplot of the log of the usage is provided in Figure 10 and Figure 11 for the M1097 and M998, respectively. We chose the log of the usage value because the spread of the values was so large it would have been difficult to display otherwise. Note that in these plots values of zero were excluded. This eliminated from between 9% to 42% of the data for any given year. The percentage of zero values is shown below the year in parentheses. Notice that the percentages increase over time. These plots indicate a downward drift in the usage of the period studied.

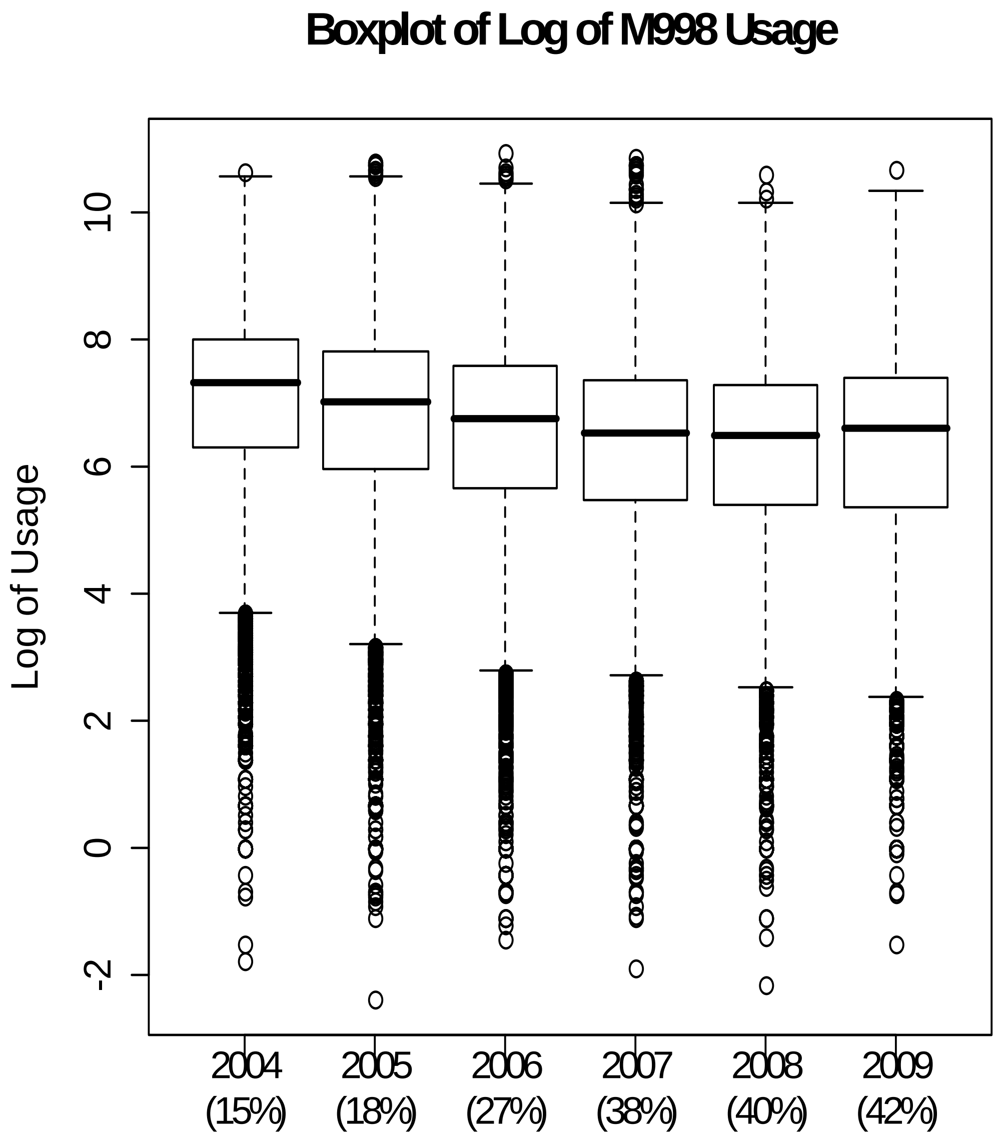

Figure 10: **Boxplot of Log of Usage for M998 excluding all values of zero from original data**

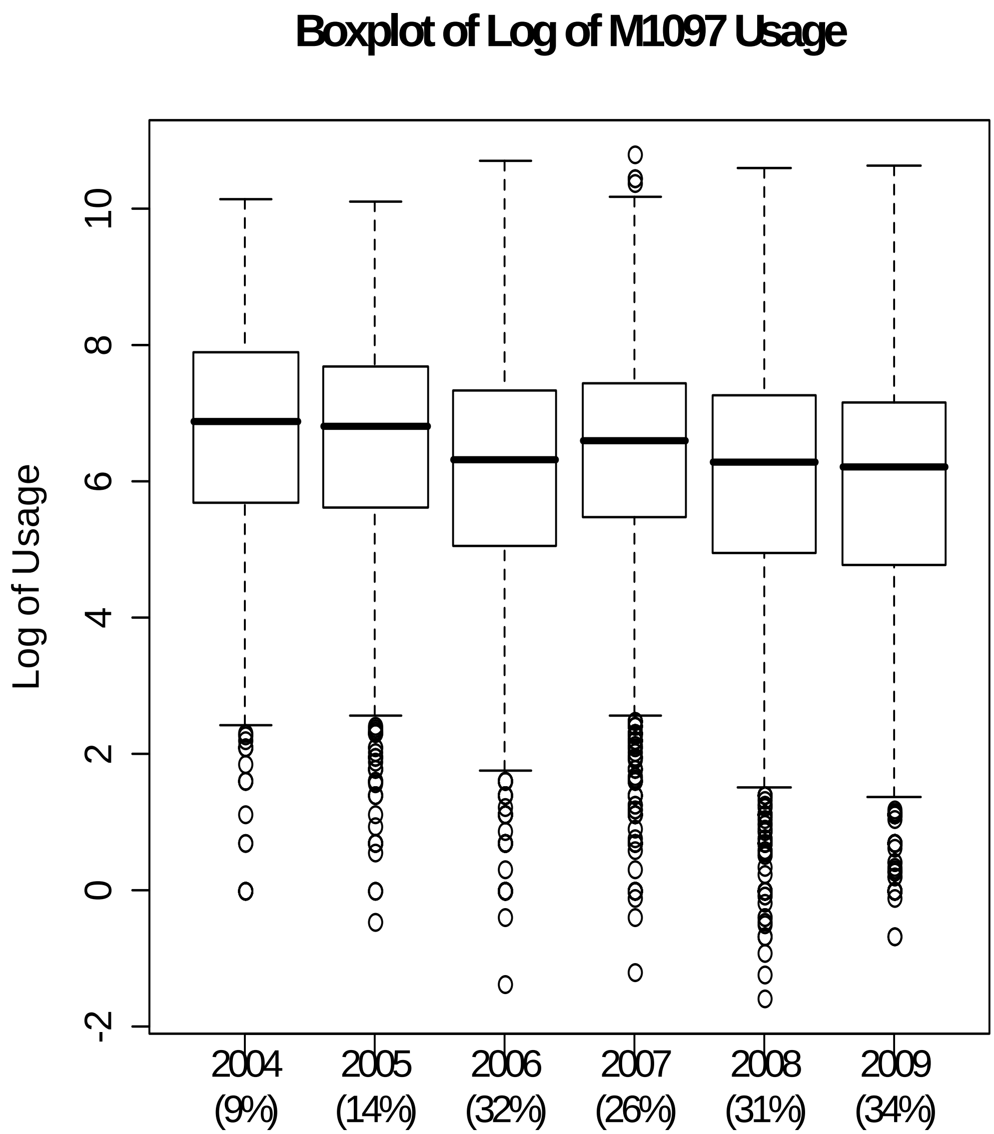

Figure 11: **Boxplot of Log of Usage for M1097 excluding all values of zero from original data**

Despite the problems with the usage data, we examined the CPUU for both vehicle models. The goal was to use the years prior to the implementation of the ILP as a baseline and then observe how the metric changed with respect to the baseline after implementation.

All CPUU values discussed in this chapter account for inflation and are displayed in Fiscal Year 2011 dollars. The adjustments were made in accordance with the Naval Center for Cost Analysis using the Operations and Maintenance Army Appropriations index. (Naval Center for Cost Analysis, 2010)

1. Summary Statistics

Table 3 summarizes the CPUU before and after the ILP was implemented. The year 2006 is excluded in column three to eliminate the possibility of the CPUU being skewed in that year due to initial start-up costs for the program. However, notice that when 2006 is included, the CPUU was actually lower. We conjecture that when the program initially started, there were still parts on the shelves at the depots that had been procured through the old system, and the technicians were using these despite the fact that AM General was under contract to provide the parts. The key takeaway is that the CPUU in 2006 cannot be accurately represented and should be viewed cautiously when trying to draw conclusions about the ILP's success (or lack thereof).

	2004-2005	**2006-2009**	**2007-2009**
M998	$98.14	$111.19	$119.02
M998 5% Trim	$5.72	$10.44	$11.63
M1097	$80.32	$107.56	$111.75
M1097 5% Trim	$6.21	$8.39	$8.81

Table 3: CPUU Before and After ILP Implementation

Based on these averages, the overall CPUU for both units appears to be rising over time. We used the 5% trimmed means because there were a small percentage of very large values that had significant influence on the CPUU values. The distribution of the CPUU values is shown in Table 4.

Model & Years		CPUU FY11$						
		$0.00-$5.00	$5.01-$10.00	$10.01-$50.00	$50.01-$100.00	$100.01-$1000.00	>$1000.00	NA's
M998	Count	33633	4864	6502	1402	2224	850	20547
	%	68%	10%	13%	3%	4%	2%	
M998 2004-2005	Count	15894	2006	2438	481	792	356	4643
	%	72%	9%	11%	2%	4%	2%	
M998 2006-2009	Count	17739	2858	4064	921	1432	494	15904
	%	64%	10%	15%	3%	5%	2%	
M1097	Count	10441	2033	3183	885	1190	369	8001
	%	58%	11%	18%	5%	7%	2%	
M1097 2004-2005	Count	1006	127	234	64	58	20	225
	%	67%	8%	16%	4%	4%	1%	
M1097 2006-2009	Count	9435	1906	2949	821	1132	349	7776
	%	57%	11%	18%	5%	7%	2%	

Table 4: CPUU Counts and Percentages for Cost Ranges

Figure 12 displays the 5% trimmed average CPUU for both vehicle models for each quarter over the period studied. Again, it is clear that the CPUU appears to be rising with time.

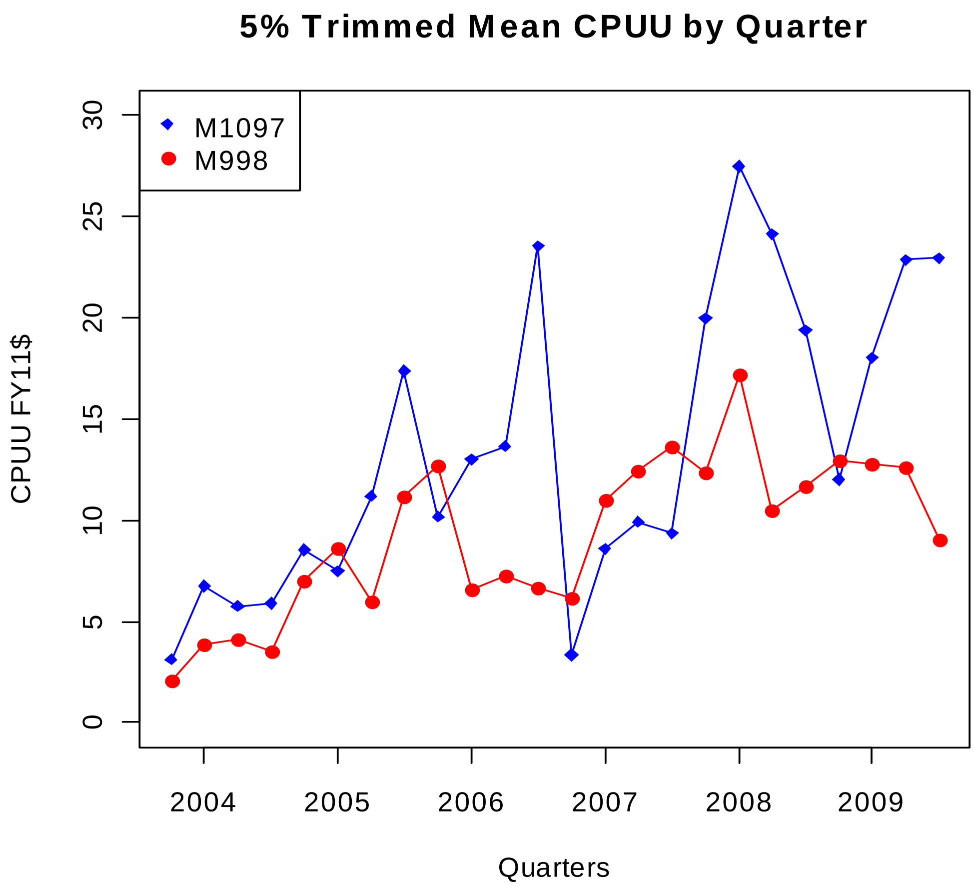

Figure 12: 5% Trimmed Mean CPUU by Quarter from FY2004 to FY2009

Notice that there are several large spikes in the CPUU, especially for the M1097 vehicle. In the second quarter of fiscal year 2008, there was a large jump for both models. This graph displays how inconsistent this metric is and we believe that is attributable to variability in the usage data.

While the quarterly data was not very conclusive, we were able to see a better trend when using the yearly averages. Figure 13 and Figure 14 display the yearly averages with a trim level of 2%, 5%, and 10%. Notice that in 2006 the CPUU increased for both vehicles with the exception of the 2% trimmed mean for the M998 vehicle. As previously mentioned, this was expected as a response to increased start-up costs. The following year, 2007, the CPUU dropped for the M1097, indicating that the program may have been achieving some cost savings. However, the following two years were higher and indicate that the CPUU was growing with time. We need to point out that over time the average usage for these vehicles decreased, as shown in Figure 9. So, for routine maintenance that is based on time, not mileage, the CPUU would be driven up. This could explain why an increase in the CPUU is seen during the period of study.

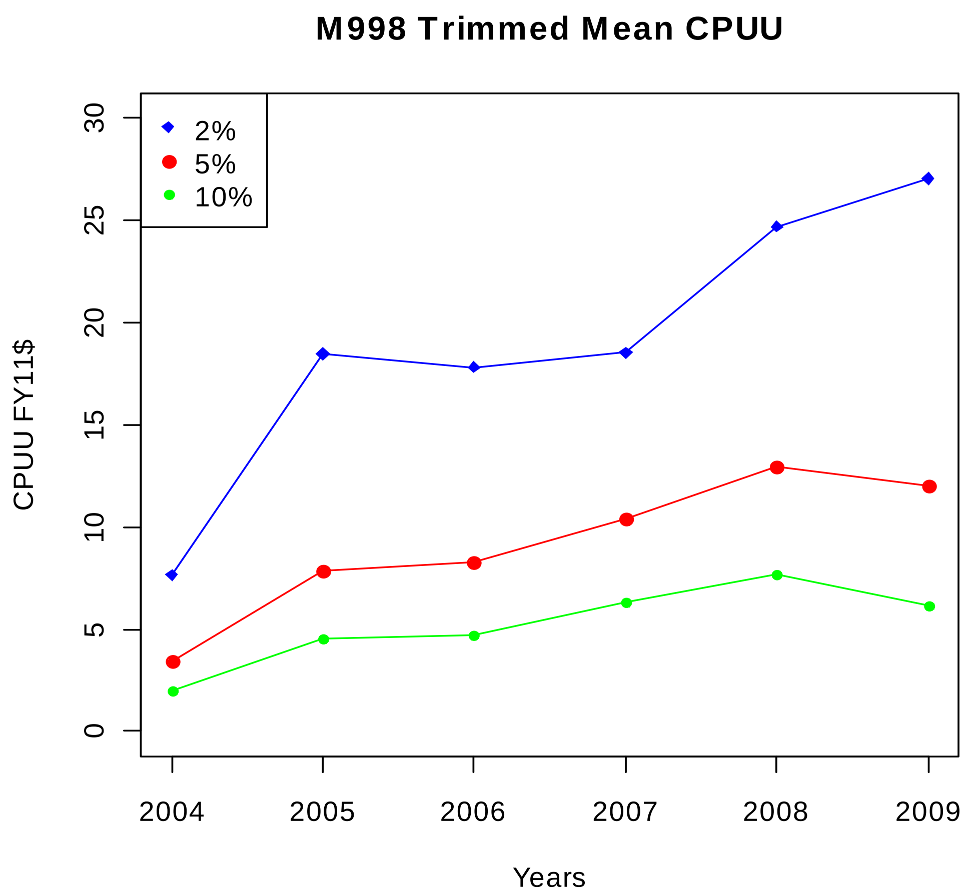

Figure 13: M998 Trimmed Mean CPUU from 2004–2009

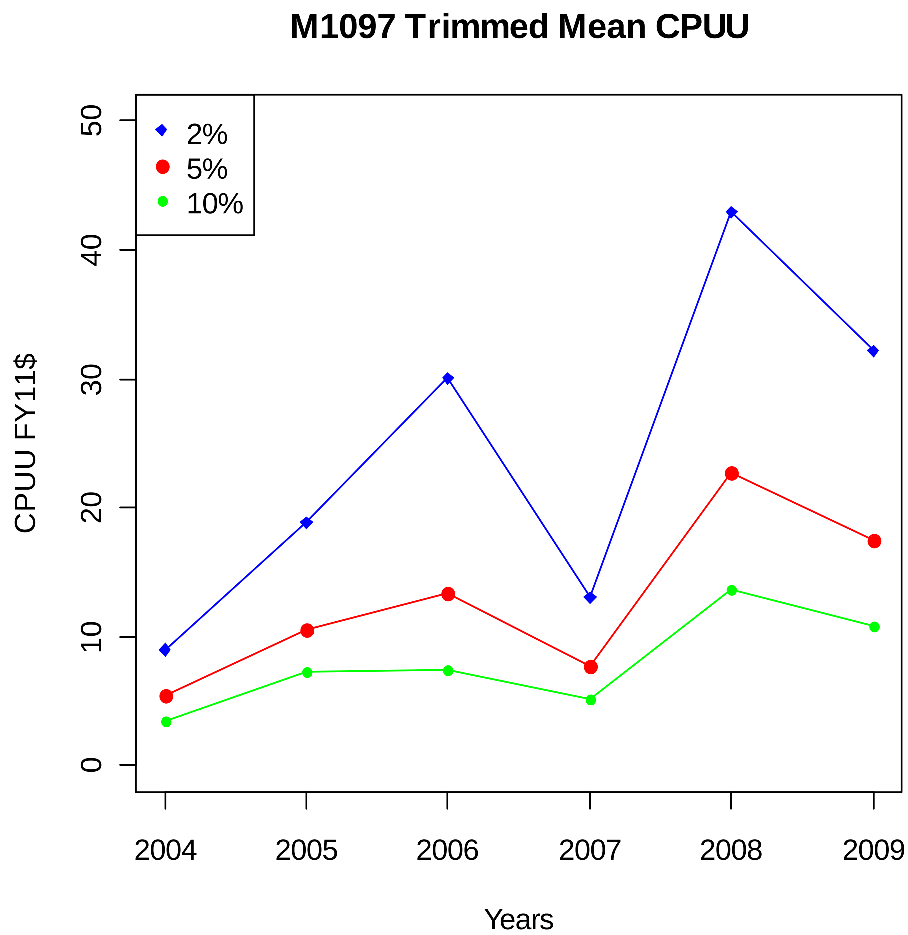

Figure 14: M1097 Trimmed Mean CPUU from 2004–2009

Additionally, we looked at the boxplot of each year's CPUU values side by side. Looking at the raw data, it was hard to gather any useful information because there was such a large number of outliers and the ranges of values were from $0.00 to nearly $300,000. To make this a more readable plot, we plotted the log of the CPUU. The plots for both models are shown in Figure 15 and Figure 16. Again, notice the upward drift over the period studied. While this does not indicate any huge shift in costs, it clearly shows that the costs are rising over time, and that there is no cost savings that can be attributed to the ILP. This may have happened regardless of the ILP, but there is no way to determine that.

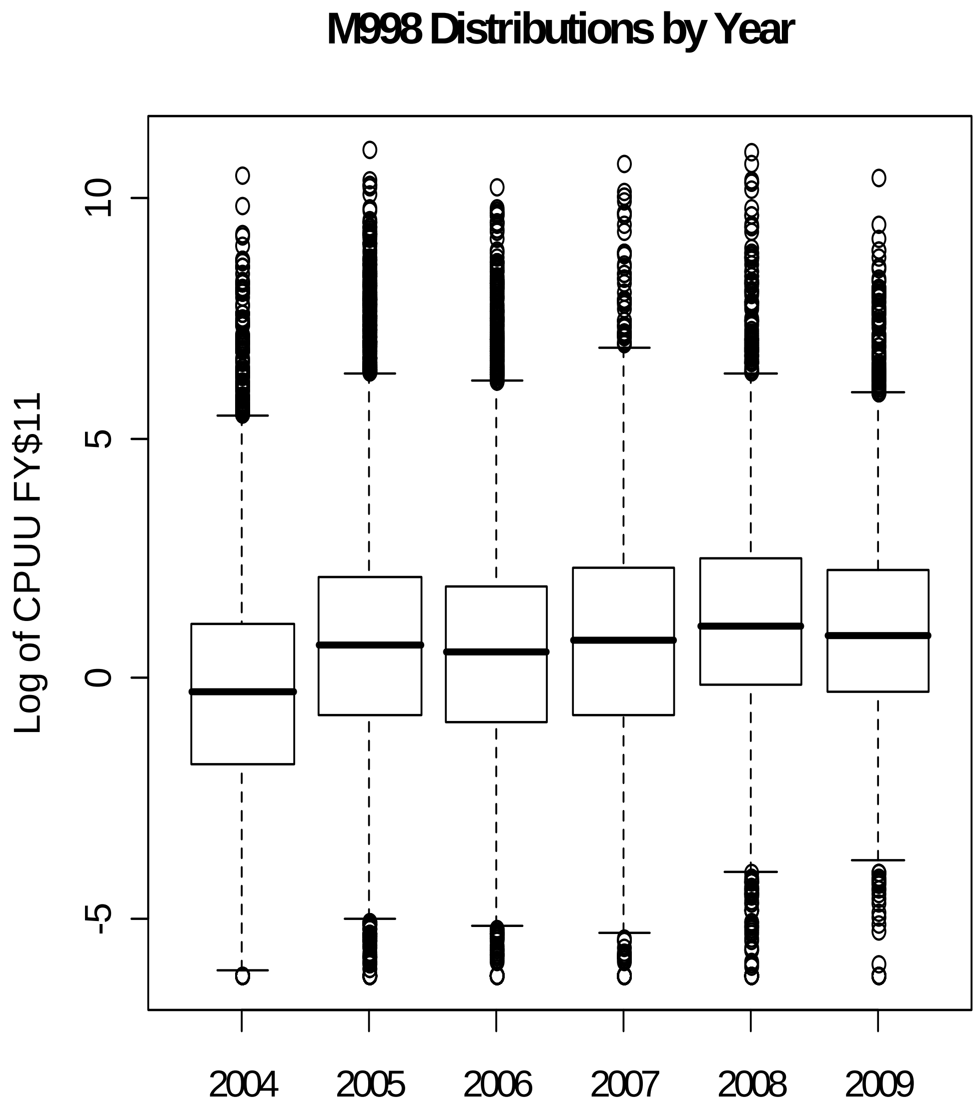

Figure 15: **Year-by-Year boxplot of Log(CPUU) for M998**

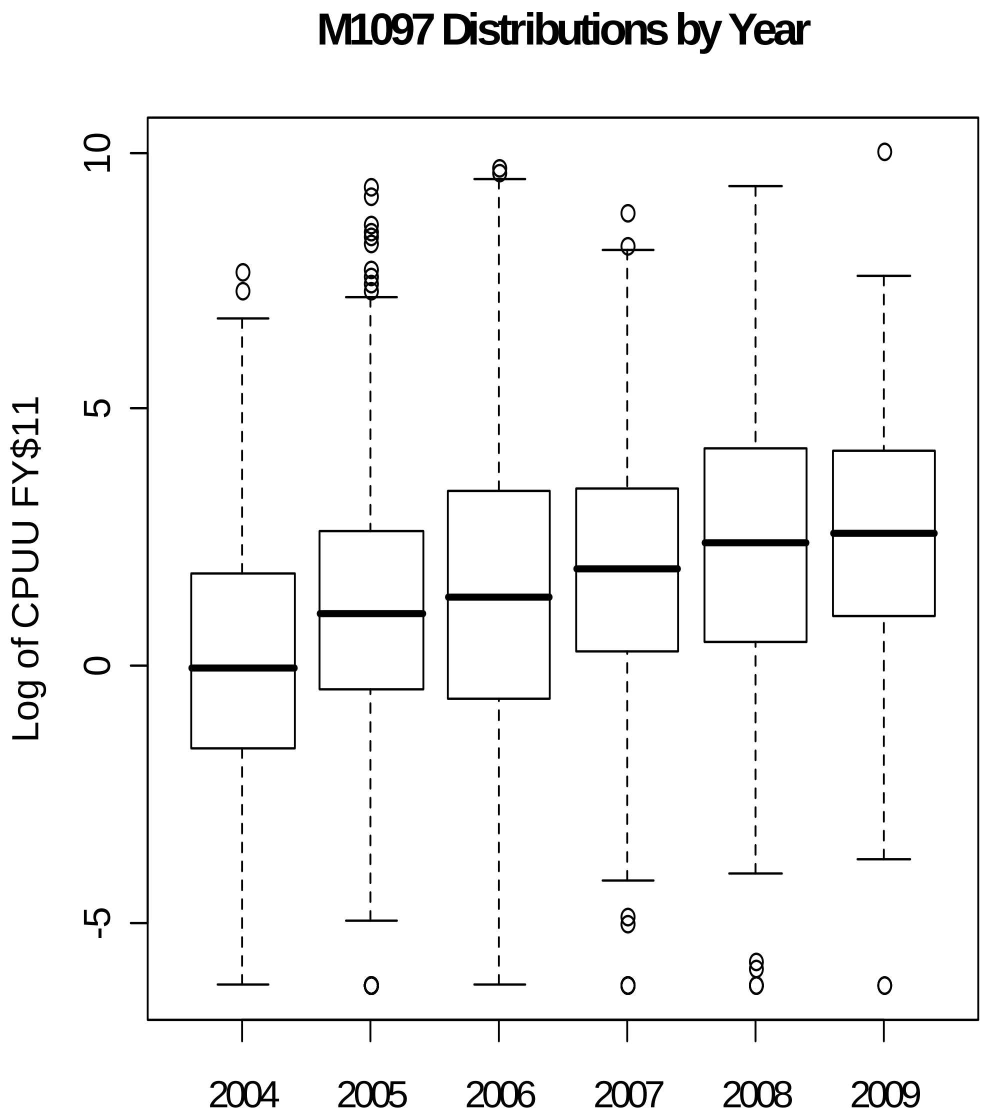

Figure 16: Year-by-Year boxplot of Log(CPUU) for M1097

2. CPUU by Year of Manufacture

Next, we looked at the CPUU based on the Year of Manufacture (YOM). Prior to examining this, we expected to see some trends in the data because as a vehicle gets older we expect it to need repair more often than a newer vehicle. This is not, however, what we observed from the data. The later model vehicles had more variability and their CPUU was higher. This may be attributed to newer parts being more expensive, the price of labor rising, or new technology. Plots of the two models' CPUU based on YOM are displayed in Figure 17 and Figure 18. Notice that the pre-ILP CPUU values are lower for most years. Although these are 10% trimmed means, large spikes in the CPUU values are still visible. The one value that is not displayed on the M1097 chart was over $280 per mile. The values after the implementation of the ILP have less variability but are generally higher than those values prior to the ILP.

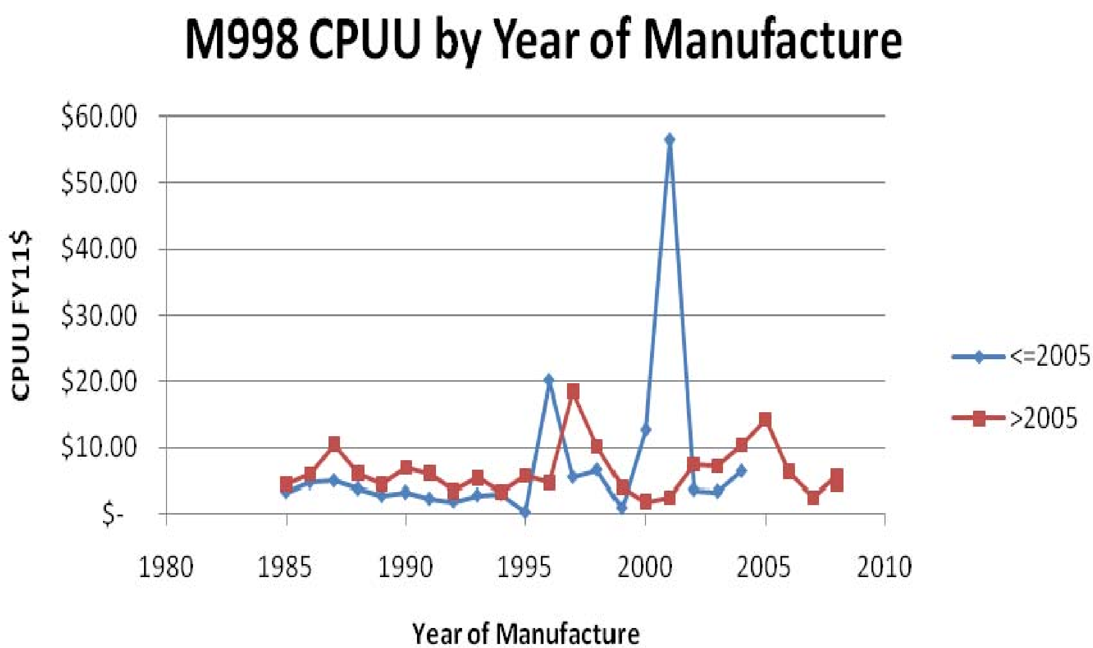

Figure 17: M998 CPUU by Year of Manufacture before and after ILP Implementation

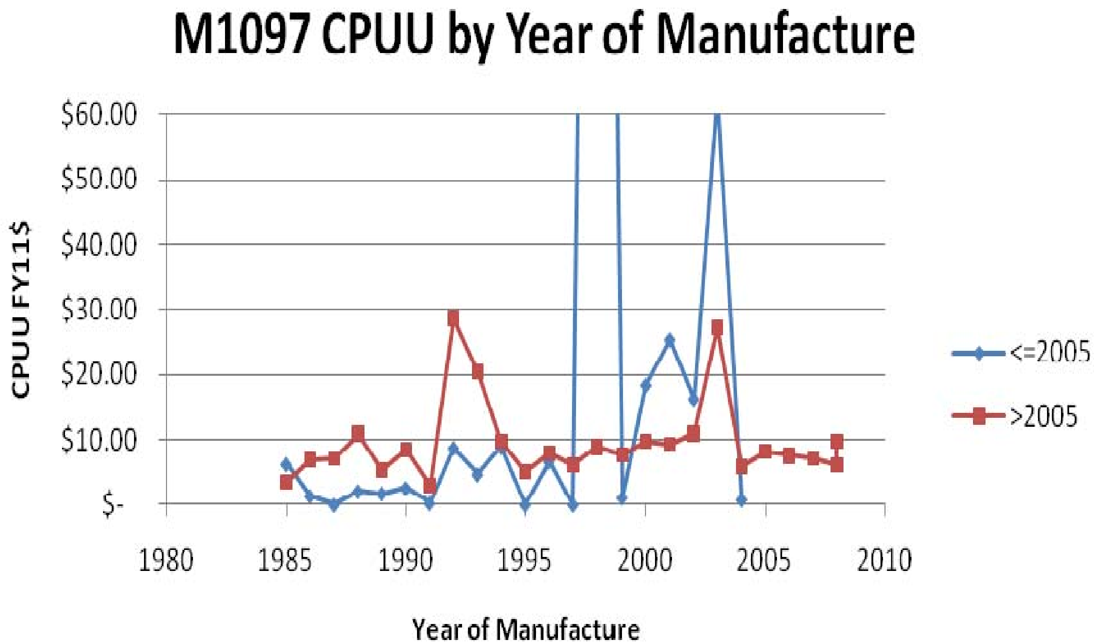

Figure 18: M1097 CPUU by Year of Manufacture before and after ILP Implementation

3. CPUU by Year of MACOM

Next, we looked at the CPUU for each Major Army Command (MACOM). Two of the MACOMs, Forces Command (FORSCOM) and National Guard Bureau (NGB), owned 70% of the vehicles studied. The remaining 30% of vehicles were distributed among 15 other MACOMs. Again, we attempted to compare the CPUU before and after the implementation of the ILP. The results were the same as in the previous analyses. The CPUU for 2004 and 2005 was cheaper than for 2006 to 2009. For the FORSCOM and NGB MACOM's, the CPUU was 1.5 to 2.25 times larger after the implementation of the ILP than it was before. Again, we used a 10% trimmed mean to eliminate the influence of some of the unusually large values. A summary of our findings is shown in Table 5. A score of one was assigned for those MACOM's in which the pre-ILP CPUU was lower than the post-ILP. A zero was scored for the opposite. The percentages at the bottom of the “Score” columns represent the proportion of vehicles that belonged to a MACOM in which the costs went up. This indicates that the CPUU has risen since the inception of the ILP.

MACOM	M998						M1097				
	Sample Size	%	<=2005	>2005	Score		Sample Size	%	<=2005	>2005	Score
EUSA	1471	2.0%	$ 2.41	$ 13.20	1		201	0.8%	$ 1.75	$ 34.13	1
FORSCOM	30643	42.6%	$ 5.04	$ 11.24	1		16548	62.5%	$ 8.08	$ 11.74	1
IMCOM	446	0.6%	$ 3.65	$ 4.06	1		672	2.5%	$ 1.50	$ 24.06	1
MDW	16	0.0%	$ 9.72	$ 1.57	0		1	0.0%	NA	$ 0.02	NA
NETCOM	417	0.6%	$ 4.23	$ 10.61	1		188	0.7%	$ 12.21	$ 36.85	1
NGB	15227	21.2%	$ 1.85	$ 2.73	1		2778	10.5%	$ 1.16	$ 2.15	1
TRADOC	3281	4.6%	$ 1.02	$ 2.44	1		327	1.2%	$ 2.26	$ 2.69	1
USACIDC	34	0.0%	$ 42.88	$ 280.27	1		0	0.0%	NA	NA	NA
USAIMA	34	0.0%	$ 10.97	$ 9.23	0		0	0.0%	NA	NA	NA
USAMC	53	0.1%	$ 2.81	$ 36.31	1		1414	5.3%	NA	$ 29.36	NA
USARC	11943	16.6%	$ 3.74	$ 4.66	1		2251	8.5%	$ 4.62	$ 3.87	0
USARCENT	179	0.2%	$ 2.41	$ 22.64	1		0	0.0%	NA	NA	NA
USAREUR 7A	4917	6.8%	$ 2.67	$ 5.63	1		440	1.7%	$ 4.42	$ 5.65	1
USARPAC	2286	3.2%	$ 5.43	$ 7.83	1		1117	4.2%	$ 2.05	$ 23.09	1
USARSO 6A	114	0.2%	$ 0.01	$ 0.99	1		0	0.0%	NA	NA	NA
USASOC	534	0.7%	$ 2.64	$ 7.15	1		541	2.0%	$ 12.03	$ 5.16	0
USINSCOM	295	0.4%	$ 10.71	$ 9.86	0		19	0.1%	$ 5.37	$ 6.23	1
TOTAL	71890				**99.52%**		26497				**84%**

Table 5: CPUU Comparison by MACOM

These analyses revealed that the CPUU has risen over the six-year period studied. Additionally, comparing the baseline years, 2004–2005, to the post-ILP years, 2006–2009, we noticed the baseline years' CPUU values are consistently lower.

4. Statistical Testing

It is important that we point out that for this study we had the entire population of Army HMMWV's for which data was available. Therefore, strictly speaking, there is no call for the testing of statistical hypotheses, in which data from a sample is used to draw inferences about parameters of a population. However, it may be reasonable to consider the set of yearly HMMWV observations as if they were a sample from a larger, hypothetical population of possible observations. In this way, the observed data can serve as a sample from this larger population, which may represent future observations on these (or other) vehicles, and hypotheses about this population (and in particular whether it has changed) can be tested.

In order to have a more robust test, we looked at only those vehicles containing values for the CPUU in both time periods. Specifically, we looked at two-year comparisons. There were eight different combinations of two-year comparisons. Vehicles that had zero usage for a given year but had associated costs for that same year, had a N/A value for CPUU. We eliminated those vehicles that had a N/A for the CPUU value in either year. We then conducted the t-test on the difference of the log of the CPUU for both time periods. The log was used because the assumptions of Normality required for the t-test was not plausible for the original data. However, after transforming the data using the logarithmic function, the data appears Normal for both models. This is displayed in Figure 19 for the M998 vehicle. While not every year combination for each vehicle is shown, each of the plots are similar to those in Figure 19.

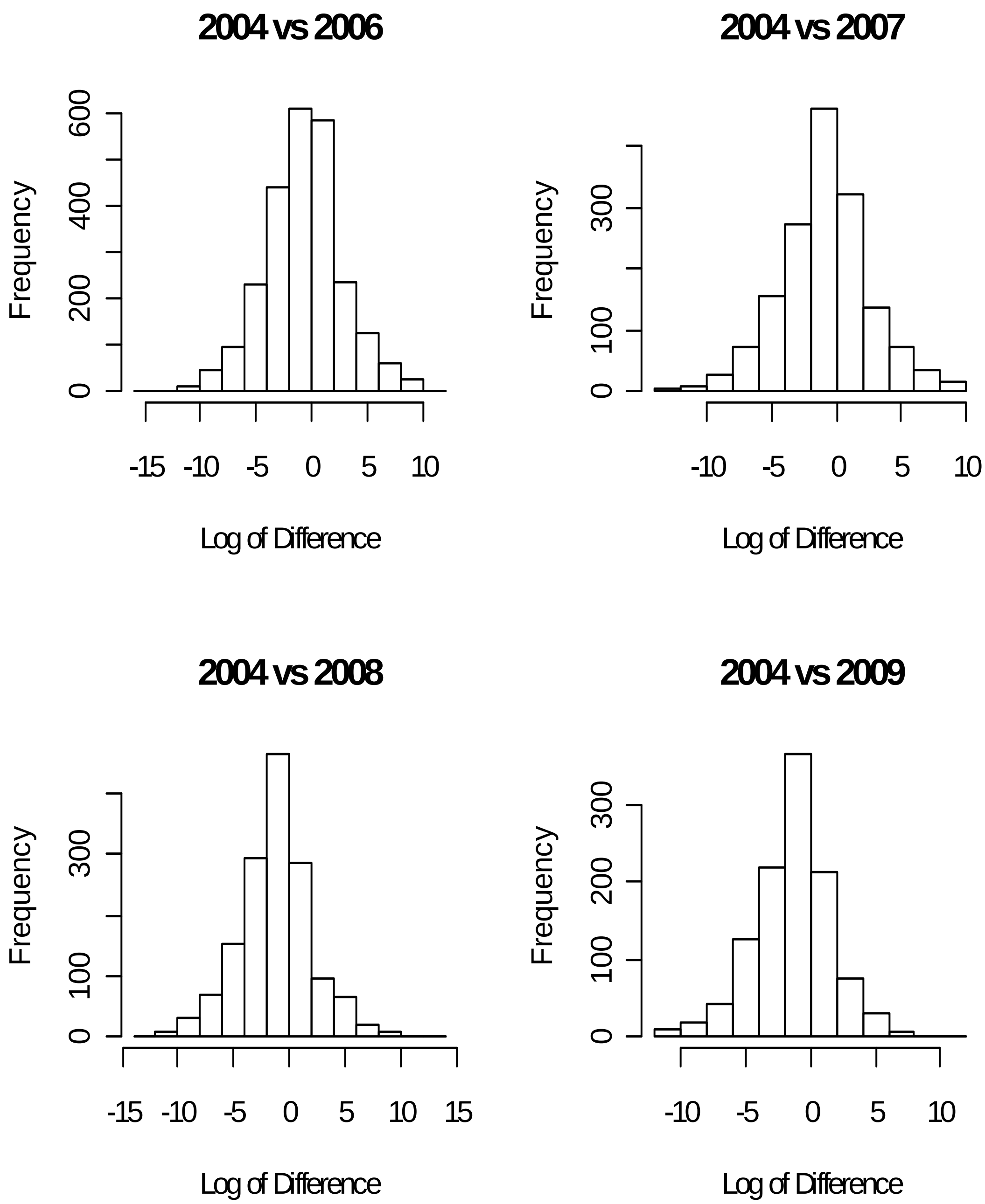

Figure 19: Histogram of M998 Log of CPUU Difference (2004 vs. Post-ILP Years)

We also conducted the Wilcoxon test. For this test, the null hypothesis is the same as the t-test: the average change in CPUU between the two years being compared is equal to zero. We conclude from this test that the difference in means is different and that the pre-ILP years are cheaper. Additionally, we conducted the Chi-Squared test to ensure consistency in our results. For the Chi-Squared test, the null hypothesis is that the percentage for which the difference between CPUU values is less than zero is equal to 50% (there are as many vehicles that had a higher CPUU Pre-ILP as there were that had a higher CPUU Post-ILP). The final column in Table 6 and Table 7, True-p, is the percentage of vehicles that had a higher Pre-ILP CPUU than the Post-ILP CPUU. For both models in nearly every instance, this value is less than 50%, which indicates that in most cases, the CPUU was lower prior to implementation of the ILP. These results confirm that on average the Pre-ILP CPUU is lower than the Post-ILP CPUU. Table 6 and Table 7 contain the results of all three tests for both models.

	T-Test				Wilcoxon			Chi-Squared		
	Ha = Difference in means is NOT zero				Ha = Difference in means is NOT zero			Ha = True p is not equal to 0.5		
	Log(Old-New)				Old-New			Old>New		
	T-stat	Df	P-value	Result	V	P-Value	Result	Chi^2	P-value	True-p
04 vs 06	-9.96	2468	2.20E-16	Reject	1139967	2.20E-16	Reject	64.80	8.28E-16	0.42
04 vs 07	-10.43	1581	2.20E-16	Reject	414444	2.20E-16	Reject	109.92	2.20E-16	0.37
04 vs 08	-14.87	1502	2.20E-16	Reject	307282	2.20E-16	Reject	196.90	2.20E-16	0.31
04 vs 09	-15.50	1114	2.20E-16	Reject	168809	2.20E-16	Reject	181.61	2.20E-16	0.30
05 vs 06	0.55	4404	5.84E-01	Fail	4883129	2.92E-01	Fail	2.01	1.57E-01	0.51
05 vs 07	-1.31	3030	1.91E-01	Fail	2112927	4.09E-04	Reject	11.17	8.31E-04	0.47
05 vs 08	-10.83	2646	2.20E-16	Reject	1354358	2.20E-16	Reject	104.53	2.20E-16	0.40
05 vs 09	-7.43	1606	1.70E-13	Reject	515748	2.50E-12	Reject	49.49	1.99E-12	0.41

Table 6: M998 Two-Year Comparison Test Results

	T-Test				Wilcoxon			Chi-Squared		
	Ha = Difference in means is NOT zero				Ha = Difference in means is NOT zero			Ha = True p is not equal to 0.5		
	Log(Old-New)				Old-New			Old>New		
	T-stat	Df	P-value	Result	V	P-Value	Result	Chi^2	P-value	True-p
04 vs 06	-7.45	178	3.80E-12	Reject	2874	8.50E-14	Reject	41.31	1.29E-10	0.26
04 vs 07	-7.26	101	8.22E-11	Reject	630	2.68E-11	Reject	38.91	4.34E-10	0.19
04 vs 08	-7.37	106	4.02E-11	Reject	888	5.05E-10	Reject	23.36	1.34E-06	0.26
04 vs 09	-5.33	64	1.35E-06	Reject	382	6.51E-06	Reject	13.85	1.98E-04	0.26
05 vs 06	0.22	333	8.30E-01	Fail	26001	3.50E-01	Fail	0.00	1.00E+00	0.50
05 vs 07	-0.19	198	6.20E-02	Fail	7655	8.80E-03	Reject	8.04	4.57E-03	0.40
05 vs 08	-4.25	182	3.43E-05	Reject	5344	1.84E-05	Reject	10.58	1.14E-03	0.37
05 vs 09	-3.44	129	7.93E-04	Reject	2672	2.30E-04	Reject	11.70	6.25E-04	0.35

Table 7: M1097 Two-Year Comparison Test Results

5. Mixed Effects Model

The final piece of our analysis involved using a mixed effects ANOVA model. (Galwey, 2006) In this model, the response is CPUU. The effect of year is "fixed" in that the levels of year are known in advance, but the effect of vehicle is "random" in that we envision (at least hypothetically) the observed vehicles acting as a random sample from a larger population of possible vehicles. This approach allows us to consider every observation for every vehicle, instead of simply comparing years two at a time, while adjusting for variability among vehicles. As with the statistical testing, we used the log of the CPUU because the assumption that the errors are Normal was not plausible for the original data, but for the log, this assumption was valid.

Specifically, the model proposes that

$$C_{ij} = \mu + y_j + V_i + \epsilon_{ij},$$

where

μ = intercept,

y_j = jth year effect (fixed),

V_i = ith vehicle effect (random, assumed N(0, σ_V^2), and

ϵ_{ij} = error (assumed iid N(0, σ_ϵ^2))

The null hypothesis of interest is that the year effects are identically zero (that is, that overall average CPUU has remained constant across years). This model was implemented using the lme4 package in R. (Bates, 2010) That package does not directly provide *p*-values for the *F* test associated with that null hypothesis, but it is possible to compare two nested models. We compared the above model to a similar model that included vehicle but excluded year. The resulting *p*-value was smaller than .01, leading us to reject the null hypothesis of constant average CPUU and to conclude that the average CPUU value has changed with time. The same conclusion is reached when comparing the two models' AIC values. Since the model that included the year had a smaller (that is, better) AIC than the one without, we reject the null hypothesis.

To examine the effect of the ILP more directly, we built a third model in which the year was represented by a two-level factor denoting the pre-ILP (2004-2005) and post-ILP (2006-2009) years. We can then examine the null hypothesis of no effect of the ILP. In the comparison of this model to the baseline (vehicle-only) model, we observe a slightly smaller AIC, and the p-value associated with that null hypothesis was less than .01, suggesting that the imposition of the ILP had a significant effect on average CPUUs. Based on our previous analysis and this test, it is safe to conclude that the ILP is not providing any cost savings to the DoD.

B. OPERATIONAL AVAILABILITY

The availability data collected from LIDB was not broken down by vehicle like the cost and usage data. Instead, it was broken down by Unit Identification Number (UIC), Location, and MACOM. Each UIC reported a Mission Capable (MC) percentage on the 15th of every month. This is the metric we used for this study.

First, we looked at the Operational Availability versus the calendar quarter. This showed a fairly constant rate until the latter part of 2007 when there were noticeable reductions in the Operational Availability rate. For the M998 vehicle, we see a slight increase in readiness until that point in 2007 when the rate drops about 2%. The M1097 falls 10% between the 2nd quarter of FY2007 and the 2nd quarter of FY2008. They both appear to level out near 89-90% by the end of 2009. It is clear that something occurred in 2007 to cause a drop in readiness. It is also clear that the Operational Availability rates prior to the ILP implementation were higher than those after. These results are displayed in Figure 20. The surge in Iraq occurred in 2007, and this could have had some effect on this metric. Also, as documented in Chapter III, the number of M1097 vehicles increased between 2006 and 2009. An increase in vehicles without an increase in logistical support could have driven the average Operational Availability down.

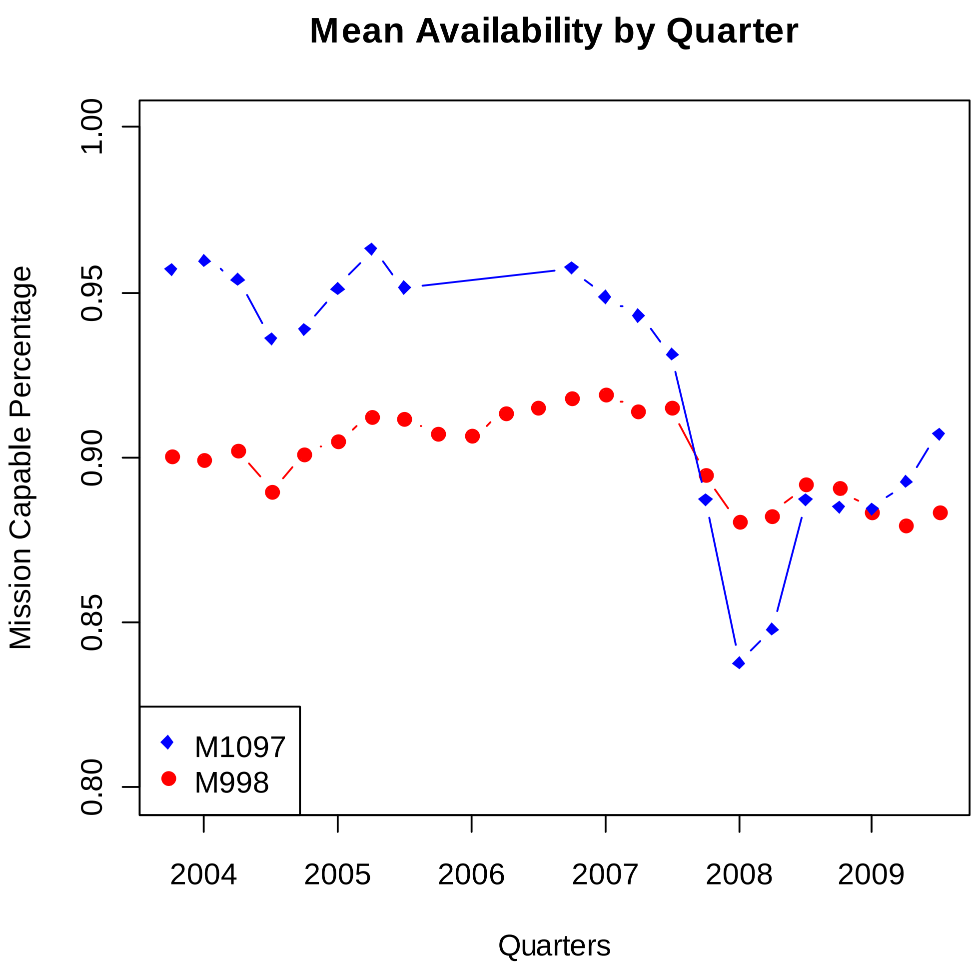

Figure 20: Mean Operational Availability of Vehicles by Quarter

As in the CPUU analysis, we looked at the Operational Availability by MACOM before and after the implementation of the ILP. The results were not as conclusive as with the CPUU. While the post-ILP Operational Availability numbers were on average lower than those from before, Operational Availability for the two MACOM's that own the majority of the vehicles remained fairly constant. In the case of the M998 at FORSCOM there was a 3% increase, indicating an improvement since the ILP implementation. But, Army Materiel Command (USAMC) had large drops in Operational Availability for both vehicle models. Considering that AMC owned less the 10% of the M1097s and less than 1% of the M998s, this large drop does not lead us to any conclusions. A summary of the results are presented in Table 8.

MACOM	M998				M1097		
	<=2005	>2005	Score		<=2005	>2005	Score
EUSA	92.84%	94.96%	1		94.54%	92.68%	0
FORSCOM	89.62%	92.49%	1		95.22%	96.53%	1
IMCOM	NA	94.35%	NA		NA	99.86%	NA
MDW	93.67%	99.31%	1		98.41%	99.50%	1
NETCOM	94.60%	94.32%	0		97.67%	96.50%	0
NGB	89.90%	90.77%	1		95.54%	95.43%	0
OSD	97.82%	97.21%	0		NA	100.00%	NA
USACIDC	94.65%	96.10%	1		100.00%	99.59%	0
USAIMA	84.25%	100.00%	1		97.05%	99.99%	1
USAMC	88.95%	65.31%	0		83.24%	69.09%	0
USARC	NA	90.43%	NA		NA	95.47%	NA
USARCENT	NA	95.72%	NA		NA	94.03%	NA
USAREUR 7A	92.13%	89.52%	0		94.34%	97.17%	1
USARPAC	92.43%	93.18%	1		95.01%	90.69%	0
USARSO 6A	NA	93.25%	NA		NA	97.08%	NA
USASOC	96.67%	97.48%	1		98.28%	99.08%	1
USINSCOM	93.62%	94.61%	1		94.30%	95.85%	1
Averages	92.39%	92.88%			95.30%	95.21%	
Final Score Percentage			**0.67**				**0.55**

Table 8: Operational Availability Comparison by MACOM

Histograms for the Operational Availability of the M998 vehicle before and after implementation of the ILP are displayed in Figure 21. Plots of the M1097, while not shown here, displayed similar results. Based on these plots and the results from above across MACOMs, the Operational Availability does not appear to change in any significant manner. In fact, it appears to hold relatively constant between the 90-95% range. This has been the DoD unwritten standard for weapons systems Operational Availability.

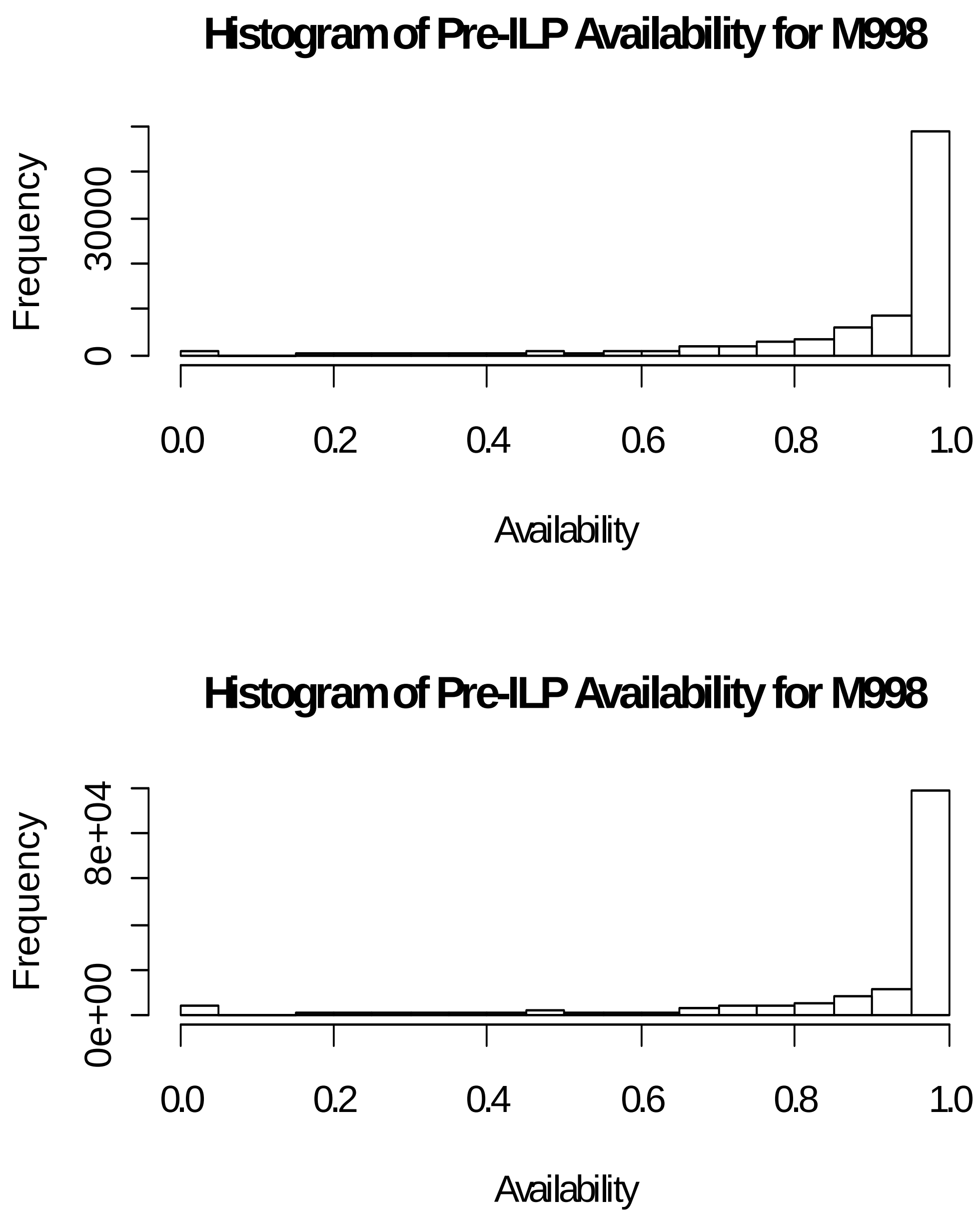

Figure 21: Comparison Histogram of Operational Availability for M998 Vehicle

C. CONCLUSION

This study analyzed two of the DoD-defined metrics to determine if the HMMWV ILP was functioning better than the traditional maintenance plan. Several different approaches were taken to view the performance of the program using the CPUU and Operational Availability. There appeared to be an increase in cost and no significant change in Operational Availability, over the six-year period studied. Hypothesis testing was conducted on the metrics for the two time periods, and it revealed that there was, indeed, a statistically significant difference between the two time periods for CPUU. To further confirm this, a year-to-year comparison was conducted as well and the results were confirmed. A mixed effects model was built, and it was determined that the year had a significant relationship with the CPUU. On average, the CPUU prior to implementation of the ILP is lower than the CPUU after; however, it cannot be determined that the ILP is the cause of this decrease. The only conclusive statement that can be made is that the ILP has not provided the DoD with cost savings.

The accuracy of the data was an area of concern for the writer and much time and effort was exhausted to correct it. However, there is still doubt as to its complete validity. Since the metric studied was based on the usage data, there could be inherent errors in these results.

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V. SUMMARY AND RECOMMENDATIONS

The Department of Defense has claimed that Performance-Based Logistics is the preferred method of Life-Cycle Support for weapons systems. This approach was implemented in an effort to increase availability while decreasing costs. Unfortunately, based on the results found in this study, neither of these results appears to have occurred in the case of the Army HMMWV ILP.

Four principal conclusions were found in the course of this study:

1. CPUU had an upward trend from 2004 to 2009;

2. CPUU was lower before the ILP and higher after the ILP implementation;

3. Operational Availability showed no significant trend from 2004 to 2009; and

4. Operational Availability experienced no significant change due to the ILP.

The CPUU rose continuously over the time period studied. While there were some drops in certain quarters, the overall trend was upward. While unadjusted costs are expected to grow over time, this study accounted for inflation and still a rise in costs was observed. Additionally, when the two time periods were compared, the time period before the ILP was determined to have a smaller CPUU than the post-ILP time period. This was found through several different analyses and confirmed using statistical hypothesis testing. Again, we point out that the CPUU is driven by the usage data, which we found to be a major area of concern in this study. However, every effort was made to use that data that was available and correct obvious errors in a logical manner. The CPUU rise was subtle and could be attributed to rise in costs over time. It could also be attributed to the fact that usage went down over this same time period. If there are time-related maintenance requirements, then the CPUU would be driven up because the maintenance is still conducted regardless of the usage. The costs of the HMMWV program could have seen a similar (or even greater) rise even if the ILP had not been in place.

While the CPUU rose over the study period, the Operational Availability did not show any change. While there appears to be a slight drop in the latter portion of 2007, this decrease was minute and the overall Operational Availability remained above 90% throughout the period studied. The slight drop could have been attributed to other things such as, perhaps, the surge in Iraq in 2007. This metric remained relatively constant for both models studied until that time frame, at which point a decrease was seen. Even after the decrease, both models were maintaining nearly 90% Operational Availability, which is the unwritten minimum throughout the DoD. While the DoD wants to achieve cost savings, as well as availability increases, the availability metric is of higher importance. Operational Availability is the key for our warfighters to be able to conduct their missions successfully. Regardless of costs, if weapons systems are not available for use, we will have many things to be concerned about other than costs.

While these conclusions are important, the primary finding in this study was that the data to conduct an analysis of PBLs is simply not accurate enough. In order to give decisions makers a tool to plan for future Life-Cycle Sustainment of weapons systems, analysts need sufficient and accurate data that can be used to analyze the DoD prescribed metrics. The key problem encountered in this study was the usage data obtained from the Army LIDB database. Missing values and obvious errors were rampant in the data. While we went to great efforts to correct these errors, this could still have an effect on the outcome.

The Army LIDB is an improvement from the past and has the capability to provide all the necessary data for analysts to conduct studies such as this. However, the inputs into this database are clearly in need of refinement. Most likely, these errors are being committed at the lowest level, which is when the maintenance man goes out to take the monthly reading and enters it into the computer. There needs to be more quality control on this process. The best solution would be for the Army to develop electronic tracking of the data, and have a system similar to the Navy's remote monitoring system being installed on ships. This system allows the watchman to simply plug in a hand-held device to a piece of equipment and the operating parameters are automatically uploaded. The Army could develop a similar device such that each time it is plugged in to a vehicle, the current odometer reading is uploaded, thus preventing any human error.

The original plan for this study was to use the LSD-41/49 Class diesel engines, as well as the HMMWV, to examine the effect of ILP. The Navy made a shift in diesel maintenance practices on the LSD-41/49 Class ship in the past decade after one ship failed to deploy and three other ships deployed but were essentially ineffective. (Caccese, 2007, p. 4) The basic idea behind this new practice, Diesel Readiness System, was to increase Operational Availability and reduce costs. These goals would be accomplished through a one-time base line assessment, followed by more proactive (vice reactive) maintenance schedules. Some of the major changes would include automated collection of machinery history logs, standardized repair requirements, new failure and costs metrics, off-ship lube oil analysis, and program management for business rules. (Caccese, 2007, p. 6)

While the DRS program has made improvements over the previous diesel maintenance program, it would be interesting to see if a Performance-Based Logistics (PBL) contract with the Original Equipment Manufacturer (OEM) would produce even more costs savings for the Navy. Fairbanks Morris Corporation (FMC) and Northrop Grumman have offered to establish such a partnership for the LSD class ship. The offer has never come to fruition; however, FMC was contacted and asked about a possible maintenance plan for these engines. FMC was kind enough to release some figures on what they would have charged the Navy for a 30-year maintenance program, which would require the engines to be maintained at 90% Operational Availability or better.

One of the key topics of concern amongst Navy brass is Total Ownership Costs (TOC) for diesel engines. In our study, the TOC was going to be the metric of interest for the LSD 41/49 Class ship. Unfortunately, there was not enough data or historical information to accurately calculate the TOC in the time allotted. Therefore, the diesel engine was abandoned and the study was narrowed down to the Army HMMWV only.

While the Navy is developing monitoring systems, as mentioned previously, its database is years behind that of the Army's. The Navy and Marine Corp Visibility and Management of Operating and Support Costs (VAMOSC) database contains a myriad of data, but gives summary statistics instead of weapon system level data. It is important for the analysts to have data that is at the weapon system level. Furthermore, VAMOSC is difficult to use. The queries are not intuitive and have too many options that leave the user unsure about the type of report he or she is producing. Additionally, it is difficult to export the data into a Comma Separated Value (CSV) or some other format that is commonly used by analysts. So, the Army and Navy need to collaborate and share their strengths when it comes to data collection and storage. This would provide analysts with accurate data that in turn could provide decision makers sound decision-making tools for future planning of weapons systems life-cycle sustainment. That the data was dirty and missing came as no surprise, as many of the studies reviewed had similar findings, as documented in Chapter II.

There are ample opportunities for future studies on Performance Based Logistics. The DoD has prescribed five metrics: 1) Operational Availability, 2) Operational Reliability, 3) Cost per Unit Usage, 4) Logistics Footprint, and 5) Logistics Response Time. This thesis addressed Operational Availability and CPUU, but follow on studies could address the other metrics. Furthermore, other platforms under PBL contracts could be studied using the same metrics, any combination of the others, or all five of them.

APPENDIX: DATA CORRECTION

This appendix discusses various refinements we made to improve the quality of the data for our analysis.

A. SERIAL NUMBERS

1. WON Data

The serial number data for several WONs from LIDB required some correction. Based on the RAND study, the data from LIDB, and emails from Army Materiel Command, it was determined that a valid serial number was a three- to six-digit number (Neal, 2010; RAND Corporation, 2008, 56). Originally, this data contained 88,036 unique serial numbers from 264,554 WONs. In our data, 2,092 serial numbers were entered along with their corresponding registration number separated by either a slash or a dash. The registration number was removed from those entries. There were 582 entries that contained only the registration number. We replaced this with the corresponding serial number for each vehicle. There were 2,116 entries which had a valid six-digit number either preceded or followed by another character. These characters were removed leaving only the six-digit number. We removed 20,513 entries because the serial number entry was unable to be repaired or it had not been entered. After these repairs and eliminations, 72,394 unique serial numbers remained for analysis.

2. Usage Data

The serial number entries in the usage data gathered from LIDB was in great condition and only required a few eliminations. For the M998 model, the original data had 566,240 line items from the years 2000 to 2009. From these line items we found 48,266 unique serial numbers. We eliminated 204 of these entries due to registration numbers not corresponding to serial numbers. For example, the registration number was recorded as being the same for multiple serial numbers. We were left with 48,062 serial numbers for the M998 model. For the M1097 model, the exact same process for elimination was used resulting in an original unique set of serial numbers of 25,349 being reduced to 25,055.

3. Combining the Serial Number Data

Using the serial number lists created from each of the two data sets, we created a master list. The two models combined had 72,394 serial numbers from the WON data and 73,117 from the usage data. A total of 52,147 numbers appeared in both lists. Of that, 35,590 were M998s and 16,584 were M1097s. This resulted in 142,186 WONs for M998 and 46,430 WONs for M1097. From the original WON data, we eliminated 29% of the line items from the repair, elimination, and matching of the serial numbers across both data sets.

B. USAGE DATA

The vehicle odometer data gathered from LIDB had a large number of missing values and other errors, such as double entries that did not correspond, and unusually high readings from one month to the next. First, any values that were over 300,000 were removed. The data was then cut into 50,000 mile categories across all the years, 2000–2009, for each vehicle. Each reading was assigned a category between one and six (0-50,000=1, 50,001–100,000=2, etc.). Next, the mode of these categories for each individual vehicle was determined. Values that fell in the mode of the categories plus or minus one increment were kept. For example, if a vehicle had a mode of three, then all values that were assigned a category of two, three, or four were retained. All others were marked as “N/A.” This same process was repeated for each year with the cuts being reduced to 8,000. The process was repeated once more for each quarter using a 3,000 mile cut. This process eliminated the cases where we had anomalies in the month-to-month readings. In cases where there were multiple entries for one vehicle for a single year, the entries were merged. If one entry had a value for a particular month and the other entry did not, then the value was retained. If there were multiple different entries for a single month, then the maximum entry was retained. Next, we looked through each reading for a single vehicle and if the previous months reading was higher than the current months reading, the current months reading was replaced with “N/A.” We calculated the actual usage by subtracting the n+1 month from each month assuming that the readings were taken on the final day of each month. Because of the eliminations, we used simple imputation to fill in gaps in the data. Then, the sum of the monthly data was calculated for each vehicle for each year.

1. Cost

The cost data was associated with each individual WON, and therefore, needed to be summed in order to determine total costs for a vehicle for each year studied. Using the remaining WON data after the serial number corrections, we built a new database that contained the sum of the costs for each vehicle for each year. We also counted the number of WONs for a particular vehicle for each year and included that information in the new database. The primary metric studied, CPUU, was calculated by dividing the total cost for a vehicle for the year by the total usage for that year. These values were then adjusted for inflation and converted to FY11$. The Operations and Maintenance Army Appropriations index was used for this adjustment. (Naval Center for Cost Analysis, 2010)

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