EXPLORING THE HEART OF LOGISTICS

Operational Readiness as a Function of Maintenance Personnel Skill Level

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Introduction

Oliver, et al., identified the key logistic and operational factors associated with mission capable (MC) rates.[1] Correlation analysis was performed to identify the key factors associated with MC rates and various logistic factors (such as logistic functions and personnel) and operational factors (such as funding and environment) and their associated interactions. Regression analysis was used to explain and predict F-16 MC rates using quarterly data by flying year. Personnel skill levels, cannibalization, and funding levels were found to be significant factors.

These research findings led to the recognition that the Air Force does not currently have a metric to relate maintenance (MX) personnel skill level to operational readiness. Building upon Oliver's work, objectives of this research are to further investigate relationships between personnel skill level and mission capability, and to develop an associated metric and standard. Specifically, a metric which measures MC rate as a function of MX personnel skill level has been developed. A simple example metric is the number of 5-level personnel per aircraft. Once a metric has been determined, a standard for it can be developed which might be thought of as an objective tied to Air Force operational goals. Relationships between maintenance personnel skill level and multiple utilization and reliability and maintainability (RM) performance measures have also been examined. Finally, we have contributed an effective methodology for producing the results described here.

Article Acronyms

FAMMAS – Funding/Availability Multi-Method Allocation for Spares
FY – Fiscal Year
LCOM – Logistics Composite Model
MC – Mission Capable
MX – Maintenance
NMCM – Not Mission Capable Maintenance
NMCS – Not Mission Capable Supply
PMCM – Partially Mission Capable for Maintenance
RM – Reliability and Maintainability
WUC – Work Unit Code

Background

Headquarters Air Force, Air Combat Command and Air Mobility Command have each been developing models to predict readiness rates such as MC rate, aircraft maintenance production capability, and aircraft availability. The common goal of these models is to augment decisionmaking capability among logistics managers at various levels in anticipation of improved readiness. Oliver expressed concern about total readiness Air Force-wide as characterized by a general decrease in MC rate and increases in total not mission capable for maintenance (NMCM) and total not mission capable for supply (NMCS) rates.[2]

While there are many readiness forecasting models in use, several have gained prominence. The Funding/Availability Multi-Method Allocator for Spares (FAMMAS) is one such forecasting model which makes use of an exponential smoothing algorithm to predict MC rates based on past values.[3] Oliver also notes that while FAMMAS does well predicting MC rate based on inflation, carryover and lead time factors, there are other logistics factors such as maintenance manning and maintenance skill levels, retention, break rates, fix rates, operations tempo, spare parts issues, and RM of aircraft that are not taken into account by FAMMAS.

A second readiness forecasting model which has seen much use is the Logistics Composite Model (LCOM). LCOM uses historical data or engineered estimates to populate a Monte Carlo simulation in order to conduct weapon system capability analyses and determine required support resources for a given weapon system capability.[4] LCOM does not examine issues such as the effect of maintenance personnel skill levels on these forecasts.

The Mission Capable Rate and Aircraft Availability Modeling and Simulation Summit in Washington, DC addressed observations of the General Accountability Office and recognized that a suitable model to predict MC rates and establish suitable goals should contain the following dependent variables:

- MC rate
- NMCM rate
- NMCS rate.

Suitable independent variables should deal with resources, funding, manpower, and programming data.[5] As discussed in the

remainder of this section, manpower has been specifically studied many times in order to both understand it better and quantify its effects more accurately.[6,7,8,9]

Howell studied the effects of personnel skill level on sortie, mission generation, and manpower requirements.[10] Through the use of operational audits, standard times for the completion of tasks related to the maintenance of F-4E aircraft were obtained. These data, along with failure rates obtained through Air Force maintenance databases, were used to populate a maintenance unit simulation through LCOM. Two separate, unconstrained simulation models were run. The first was run using only 3-level maintainers, and the other was run using only 5-level maintainers. Howell's study found that 3-levels produced only 76 percent of sorties produced by 5-levels, and 3-levels took 1.34 times as many man-hours as the corresponding 5-levels. Additional experimentation with a constrained model found 3-levels actually take an average of 1.463 times as long to complete a given task. These results led to suggestions of grouping teams of 3- and 5-level maintainers in more effective ways.

Garcia and Racher examined the effects of skill level differences within LCOM.[11] They noted that 3-level maintainers must frequently accomplish tasks beyond their skill level. As a result, these tasks take significantly longer and contain more mistakes than if they were performed by 5-level maintainers. Since LCOM fails to model this, manning requirements may be understated. The current work provides a methodology to modify LCOM to reflect differing skill levels in the completion of maintenance tasks.

Dahlman and Thaler sought to identify and quantify the value of 5- and 7-level maintainers.[12] Using a ratio of skilled to unskilled maintainers, a correlation analysis was performed to examine the relationship between the ratio and NMCM rates to emphasize the balance between skill and training.

Independent Variables
Number of 3-Level Maintainers Available
Number of 5-Level Maintainers Available
Number of 7-Level Maintainers Available
Number of 9-Level Maintainers Available
Percent of 3-Level Maintainers Available
Percent of 5-Level Maintainers Available
Percent of 7-Level Maintainers Available
Percent of 9-Level Maintainers Available
Number of Crew Chiefs
Number of Total Maintainers Available

Figure 1. Independent Variables

Dependent Variables
MC Rate
Utilization Variables 8-Hour Fix Rate Average Aircraft Inventory Flying Hours Sorties
Reliability and Maintainability Variables CANN Hours Maintenance Reliability TNMCM Hours

Figure 2. Dependent Variables

Methodology

Our methodology consists of performing four analysis tasks for each dependent variable MC rate, four utilization variables and three RM variables.

- Define how variables would be used in the analysis
- Perform correlation analysis between dependent and independent variables
- Construct regression models for each dependent variable
- Select models for each dependent variable

We use quarterly data collected from fiscal year (FY) 1993 through FY00.[13] These data were obtained through the Reliability and Maintainability Information System from the Equipment Inventory, Multiple Status and Utilization Reporting System and Product Performance Subsystem databases. Personnel variable data were acquired from the Personnel Data System. This section gives a detailed description of how each analysis task is performed and the results of each task.

Variable Definition

As our objective is to examine relationships between personnel skill level and readiness, our first task is to select relevant independent (related to personnel skill level) and dependent (related to readiness) variables from Oliver et al.[14] As shown in Figure 1, we identify ten independent variables including the numbers and percentages of 3-, 5-, 7- and 9-level maintainers. Figure 2 contains the dependent variables including MC rate, utilization variables and RM variables. To clarify, the 3-, 5-, 7- and 9-level maintainers represent the availability of each level maintainer to the F-16C/D airframe.

MC rate refers to the percentage of time that aircraft are fully or partially mission capable. Eight-hour fix rate represents the cumulative percentage of Code 3 aircraft breaks recovered within 8 hours of landing. Average aircraft inventory represents the average number of assigned aircraft. Flying hours represent the number of hours flown by all F-16C/D aircraft in each quarter. Sorties are the number of flights recorded for all F-16C/D in each quarter. Cannibalization hours represent the number of hours expended on cannibalization per work unit code (WUC). Maintenance reliability is the number of times a WUC is coded NMCM or partially mission capable for maintenance (PMCM). Total not mission capable maintenance hours are the number of hours recorded for aircraft not being mission capable for maintenance reasons (does not include PMCM hours).

Correlation Analysis

To identify existing linear relationships between independent and dependent variables, Pearson product moment correlation is computed for each independent and dependent variable combination. Variables with correlation coefficients greater than 0.80 are identified as good regression model candidates. Figure 3 contains the results of the correlation analysis. We have also systematically investigated meaningful interaction among the independent variables identified for inclusion in our models.

Dependent Variables	Independent Variables				
	# of Level 3 Maintainers	# of Level 5 Maintainers	# of Level 7 Maintainers	# of Level 9 Maintainers	# of Crew Chiefs
MC Rate	-0.620	0.738	0.835	0.859	0.051
8-hr Fix Rate	-0.530	0.895	0.930	0.873	0.090
Average Aircraft Inv	0.845	-0.540	-0.739	-0.659	0.101
Flying Hours	0.385	-0.323	-0.462	-0.307	0.052
Sorties Flown	0.330	-0.272	-0.368	-0.197	0.114
CANN Hours	0.457	-0.742	-0.813	-0.746	-0.008
MX Reliability	0.626	-0.708	-0.865	-0.793	-0.101
TNMCM Hours	0.618	-0.605	-0.759	-0.770	-0.071
Dependent Variables	**% of Level 3 Maintainers**	**% of Level 5 Maintainers**	**% of Level 7 Maintainers**	**% of Level 9 Maintainers**	**# of Total Maintainers**
MC Rate	-0.838	0.466	0.858	0.847	0.758
8-hr Fix Rate	-0.896	0.623	0.862	0.767	0.905
Average Aircraft Inv	0.778	-0.301	-0.902	-0.639	-0.560
Flying Hours	0.419	-0.068	-0.552	-0.216	-0.359
Sorties Flown	0.350	-0.106	-0.426	-0.086	-0.292
CANN Hours	0.768	-0.441	-0.791	-0.659	-0.769
MX Reliability	0.816	-0.329	-0.931	-0.733	0.750
TNMCM Hours	0.739	-0.278	-0.849	-0.779	-0.640

Figure 3. Correlation Results

Regression Modeling

Regression Model Construction

The first step of our regression modeling is to develop candidate regression models for each dependent variable. In order to find good candidate models, seven distinct regression techniques are identified and conducted as described in Figure 4. Each of these regression techniques is employed separately on two subsets of the independent variables. One subset contains percentages of each level of maintainers, number of crew chiefs, and number of total maintainers. The other subset contains the numbers of each level maintainer, number of crew chiefs, and number of total maintainers. This ensures that the percentages and numbers of each level maintainer are never included in the same model, thereby maintaining independence. Figure 5 contains resulting models from each regression technique for the MC rate dependent variable.

Regression Model Selection

The regression model construction step results in multiple candidate models for each dependent variable. The need arose to select the best model for each dependent variable by examining the linear fit of the models, the efficiency of models, and adherence to model assumptions.

The first step is to examine the linear fit of each candidate model. Any candidate model which does not result in a fit parameter (adjusted R-squared value) of 0.64 or greater was eliminated from further consideration, reducing the number of candidate models from 82 to 60. This criterion determines that no candidate model provides a good fit for flying hours and sorties. This result suggests that factors other than personnel skill level are influencing these two performance measures, and therefore flying hours and sorties are eliminated from further analysis.

The next criterion used to select the final models is model efficiency. Here, efficiency is defined as how well the model fits the data (adjusted R-squared) given the number of variable inputs needed to obtain this fit (independent variable terms).

Technique	Description
Regression 1	Multivariate regression analysis containing all independent variables (no interactions)
Regression 2	Variation of Regression 1 containing only significant independent variables based on p-value of 0.05 or less
Regression 3	Multivariate regression analysis containing only independent variables with a correlation coefficient of 0.8 or higher; Interaction effects with high correlations were included
Regression 4	Variation of Regression 2 containing only significant independent variables and interactions based on p-value of 0.05 or less
Regression 5	Stepwise regression analysis starting with all independent variables (no interactions)
Regression 6	Stepwise regression analysis starting with only two and three way interactions
Regression 7	Combination of Regression 5 and Regression 6; Stepwise regression analysis starting with all independent variables and two and three way interactions

Figure 4. Regression Techniques

Efficient frontiers for each of the six remaining dependent variables are developed by graphing the adjusted R-squared value versus the number of variable terms for each remaining candidate model. Dominant models, or those models that lie on the efficient frontier, are identified as models that achieve better or equal adjusted R-squared values with fewer variable terms. A summary of all candidate models with fit criteria greater than 0.64 is shown in Figure 6. We have identified the most efficient models for each dependent variable, and we have reduced the number of candidate models from 60 to 18.

A summary of the efficiency analysis is given in Figure 7. An abbreviated naming scheme for the candidate models is given by regression analysis technique number and type of skill level

Mission Capable Rate	
Percentage of Maintainers	**Number of Maintainers**
Regression 1: MC rate = $5.24 - 4.54x_{\%3} - 5.30x_{\%5} - 4.01x_{\%7} + 2.75x_{\%9} - 0.000002x_{chiefs} + 0.000001x_{total\ maintainers}$ R-Sq = 84.3%, R-Sq (adj) = 80.5%	**Regression 1:** MC rate = $0.729 - 0.000114x_{\#3} - 0.000134x_{\#5} - 0.000106x_{\#7} + 0.000077x_{\#9} - 0.000002x_{chiefs} + 0.000116x_{total\ maintainers}$ R-Sq = 84.1%, R-Sq (adj) = 80.3%
Regression 2: No variables were significant from Regression 1.	**Regression 2:** No variables have a p-value that are significant.
Regression 3: MC rate = $0.622 - 0.046x_{\%3} + 26.7x_{\%7}x_{\%9}$ R-Sq = 80.9%, R-Sq (adj) = 79.6%	**Regression 3:** MC rate = $0.699 + 8.63E\text{-}8x_{\#7}x_{\#9}$ R-Sq = 74.7%, R-Sq (adj) = 73.9%
Regression 4: MC rate = $0.607 + 27.6x_{\%7}x_{\%9}$ R-Sq = 80.9%, R-Sq (adj) = 80.2%	**Regression 4:** This regression is redundant to Regression 3.
Regression 5: MC rate = $0.347 + 1.27x_{\%7} + 4.89x_{\%9}$ R-Sq = 82.0%, R-Sq (adj) = 80.7%	**Regression 5:** MC rate = $0.792 - 0.000017x_{\#3} + 0.000123x_{\#9}$ R-Sq = 77.3%, R-Sq (adj) = 75.7%
Regression 6: MC rate = $0.639 - 9.43x_{\%5}x_{\%9} + 42.1x_{\%7}x_{\%9}$ R-Sq = 82.5%, R-Sq (adj) = 81.3%	**Regression 6:** MC rate = $0.650 - 6.59E\text{-}9x_{\#3}x_{\#9} + 4.47E\text{-}8x_{\#7}x_{\#9} - 1.29E\text{-}12x_{\#5}x_{\#7}x_{\#9}$ R-Sq = 83.7%, R-Sq (adj) = 82.0%
Regression 7: This regression is redundant to Regression 6	**Regression 7:** MC rate = $1.59 - 4.68E\text{-}5x_{\#5} - 0.00236x_{\#9} + 1.14E\text{-}7x_{\#5}x_{\#9} + 1.85E\text{-}7x_{\#7}x_{\#9} - 8.2E\text{-}12x_{\#5}x_{\#7}x_{\#9}$ R-Sq = 86.6%, R-Sq (adj) 84.0%

Figure 5. Regression Analyses for Mission Capable Rate

Dependent Variables	# of Independent Variable Terms					
	1	2	3	4	5	6
MC Rate		0.802	0.84	0.82		0.805
		0.807	0.813			0.803
		0.739	0.796			
		0.757				
8 Hour Fix Rate	0.813	0.861	0.859	0.847		0.842
	0.861	0.857	0.863			0.84
			0.859			
Average Aircraft Inventory	0.808		0.92	0.932	0.973	0.917
	0.704		0.943		0.982	0.941
					0.973	
CANN Hours	0.649	0.65	0.651		0.746	0.665
		0.649	0.647			0.669
			0.694			
MX Reliability	0.861	0.886	0.891	0.901		0.894
		0.859	0.74			0.898
		0.87				
		0.88				
		0.883				
		0.872				
TNMCM Hours	0.711		0.792	0.776	0.794	0.779
			0.792			0.774
			0.794			0.854

Figure 6. Adjusted R-Squared Values for Efficiency Analysis

data (P for percentage and N for number). For example, a candidate model developed for percentage of skill level data using regression 5 is Regression 5P. Figure 8 presents the efficiency analysis graph for MC rate. Here we can see that candidate models Regression 5P and Regression 7N lie on the efficient frontier as they dominate the other models.

The third criterion used to identify the final models is whether or not the efficient models for each dependent variable meet four common linear regression assumptions.

- The error term, ϵ, has mean zero
- The error term, ϵ, has constant variance
- Errors are not correlated
- Errors are normally distributed

A description of how each of these assumptions is tested is provided in Figure 9.

Figure 10 contains the results of each assumption test for the efficient models. Models that do not meet all four of the criteria were removed from consideration as final recommended models. This decreased the number of candidate models from 18 to 15.

Final Model Identification

A final model is chosen based on the results presented in the previous section. The last criterion enforced in identifying final models is avoiding the use of interaction terms when other model criteria are similar. The final models for the six remaining dependent variables are presented in Figure 11.

Further Investigation

Because none of the constructed models for predicting MC rate capture budget constraints, additional steps are taken to model budgetary effects. The dependent variable flying hours is used as an indicator of budget amounts since the number of flying hours recorded depends partially on budget constraints. The variable of flying hours is defined as the number of aircraft flying hours recorded.[15] Other than the addition of flying hours as an independent variable, the same methodology is followed to estimate new regression models.

The regression procedure outlined in Figure 4 is followed to examine whether the addition of flying hours would result in more descriptive models of MC rate. Upon inspection, all but two of the resulting models do not differ from those previously constructed. The two models that do include flying hours are Regressions 1N and 1P for the percentage data set. The reason flying hours is included in these models is that Regression 1 requires that all independent variables are used.

The models estimated using Regression 1, including flying hours, are not more efficient compared to those excluding flying

Dependent Variable	Efficient Frontier Models
MC Rate	Regression 5, P
	Regression 7, N
8 Hour Fix Rate	Regression 5, N
	Regression 6, P
Average Aircraft Inventory	Regression 3, P
	Regression 5, N
	Regression 6, N
Cannibalization Hours	Regression 3, N
	Regression 5, P
	Regression 7, N
	Regression 6, N
Maintenance Reliability	Regression 2, P
	Regression 2, N
	Regression 4, P
	Regression 7, P
TNMCM Hours	Regression 3, P
	Regression 6, P
	Regression 7, N

Figure 7. Efficient Frontier Models for Each Dependent Variable

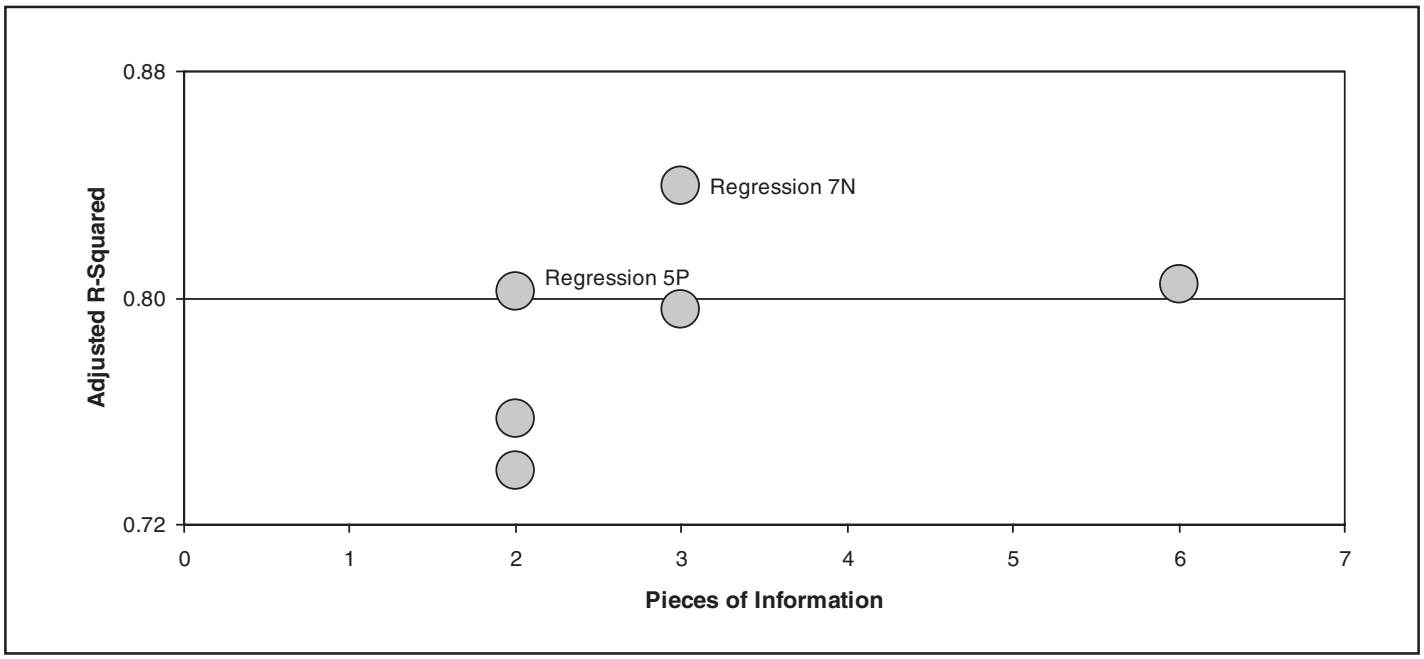

Figure 8. Efficiency Analysis Graph

hours. A conclusion which can be drawn from this analysis is that (assuming flying hours effectively represent budget constraints) models using only personnel skill level are more efficient than models including budget constraints in addition to personnel skill level.

Results

The statistical variability inherent in the regression model and the varying nature of the skill levels require that a range, or interval, be given instead of point estimates to illustrate what is useful about models such as these. Prediction intervals are calculated for each given combination of 7- and 9-level maintainers. A summary of the prediction intervals can be seen in Figure 12. The confidence used to calculate the prediction intervals is 95 percent. When the prediction intervals are compared to point estimates, it can be seen that the intervals provide more combinations of independent variables resulting in the standard MC rate. This result gives decisionmakers more flexibility with personnel levels that might reasonably facilitate the standard for MC rate. The result also gives decisionmakers a considerably more realistic range of values instead of simple point estimates of MC rate.

Figure 12 provides an examination into standards, according to the results reported here, that Air Force should maintain for percentages of 7- and 9-level maintainers to ensure that the expected value for MC rate might not fall below the desired threshold of 84 percent.

Assumption	Test Description
Has zero mean	One-sample t-test where H_o: The sum of the residuals = 0; models failed this assumption if their p-value was less than 0.95.
Has constant variance	The residuals were ordered according to the value of the predicted values of the variable being modeled. The residuals were then halved and a 2-sample t-test was performed where H_o: variances are equal. If the resultant p-value was less than 0.05, it failed this assumption.
Errors are uncorrelated	Each residual (r_j) was compared to the next r_{j+1} residual by computing a correlation value. Correlation coefficients of 0.80 or higher failed this assumption.
Errors are normally distributed	Ryan-Joiner test for normality where p-values less than 0.05 failed this assumption.

Figure 9. Assumption Test Description

Conclusions

There have been shown here systems to formally explore and find relatively good models based on valid assumptions of dependent variables such as MC rate, utilization variables, and RM variables. Independent variables in the study include numbers and percentages of 3-, 5-, 7- and 9-level maintainers, and numbers of crew chiefs and total maintainers available. Our focus has been on the estimation of MC rate as a function of percentages of 7- and 9-level maintainers. With this we have explained 82 percent of the variation observed in MC rate.

Based more specifically on prediction intervals, the user of our model can contemplate combinations of 7- and 9-level

Dependent Variable	Model	1-Sample t test (p-value)	Ryan-Joiner Test (p-value) *(Residual Normality)*	Correlation Coefficient for error terms	2-Sample t test (p-value)
MC Rate	Regression 5, P	1.000	> 0.100	0.48	0.697
	Regression 7, N	1.000	> 0.100	0.198	0.412
8 Hour Fix Rate	Regression 5, N	1.000	> 0.100	-0.241	0.680
	Regression 6, P	1.000	> 0.100	-0.256	0.733
Average Aircraft Inventory	Regression 3, P	1.000	0.070	0.889	0.048
	Regression 5, N	1.000	> 0.100	0.504	0.430
	Regression 6, N	1.000	> 0.100	0.199	0.477
CANN Hours	Regression 3, N	1.000	> 0.100	0.373	0.168
	Regression 5, P	1.000	> 0.100	0.370	0.167
	Regression 6, N	1.000	> 0.100	0.337	0.313
	Regression 7, N	1.000	> 0.100	0.188	0.452
Maintenance Reliability	Regression 2, P	1.000	> 0.100	0.216	0.873
	Regression 2, N	1.000	> 0.100	0.204	0.044
	Regression 4, P	1.000	> 0.100	0.239	0.675
	Regression 7, P	1.000	> 0.100	-0.102	0.429
TNMCM Hours	Regression 3, P	1.000	0.021	0.493	0.816
	Regression 6, P	1.000	0.087	0.151	0.732
	Regression 7, N	1.000	0.050	0.332	0.470

Figure 10. Assumption Test Results

MC Rate (%)	% Level 9				
% Level 7	2.25	2.50	2.75	3.00	3.25
23	72.80 – 77.03	74.02 – 78.25	75.25 – 79.47	76.47 – 80.69	77.69 – 81.91
24	74.11 – 78.25	75.34 – 79.47	76.56 – 80.69	77.78 – 81.92	79.01 – 83.14
25	75.38 – 79.52	76.60 – 80.75	77.83 – 81.97	79.05 – 83.19	80.27 – 84.41
26	76.61 – 80.84	77.83 – 82.06	79.05 – 83.28	80.27 – 84.50	81.50 – 85.73
27	77.79 – 82.20	79.01 – 83.42	80.23 – 84.64	81.46 – 85.86	82.68 – 87.08

Figure 11. Final Models

maintainer percentages and their probable effects on MC rate. For example, we have illustrated six different realistic personnel combinations that should produce MC rates consistent with 84 percent standard for MC rate.

End Notes

1. Steven A. Oliver, "*Forecasting Readiness: Using Regression to Predict Mission capability of Air Force F-16 Fighter Aircraft*," graduate thesis, Air Force Institute of Technology, Wright-Patterson AFB, Ohio, 2001.
2. Oliver, graduate thesis, 2001.
3. Oliver, graduate thesis, 2001.
4. AT&L Knowledge Sharing System, AFMC Logistics Composite Model (2001), [Online] Available: http://akss.dau.mil/software/20.jsp, accessed 9 July 2004.
5. Kirk Pettingill and Constance von Hoffman, "Air Force Mission Capable Rate and Aircraft Availability Model Study," Study Number LM200301600, Air Force Logistics Management Agency, Maxwell AFB, Gunter Annex Alabama, 2004.
6. C.J. Dahlman and D.E. Thaler, "Assessing Unit Readiness: Case Study of an Air Force Fighter Wing," Rand: Santa Monica, California, 2000.
7. R. Garcia and J.P. Racher, "An Investigation into a Methodology to Incorporate Skill Level Effects into the Logistics Composite Model," masters thesis, Air Force Institute of Technology, Wright-Patterson AFB, Ohio, 1981.
8. L.D. Howell, "Manpower Forecasts and Planned Maintenance Personnel Skill Level Changes, Technical Report ASD/TR81-5018, Washington, DC: Air Force Systems Command, 1981.
9. Steven A. Oliver, A.W. Johnson, E.D. White, and M.A. Arostegui, "Forecasting Readiness," *Air Force Journal of Logistics*, Volume 25, No. 3, 1, 29-40, 2001.
10. Howell.
11. Garcia and Racher.
12. Dahlman and Thaler, 2000.
13. Steven A. Oliver, "*Forecasting Readiness: Using Regression to Predict Mission capability of Air Force F-16 Fighter Aircraft*," graduate thesis, Air Force Institute of Technology, Wright-Patterson AFB, Ohio, 2001.
14. Oliver, et al., *Air Force Journal of Logistics*, Volume 25, 2001.
15. Oliver, graduate thesis, 2001.

Dependent Variable	Final Model
MC Rate	$0.347 + 1.27x_{\%7} + 4.89x_{\%9}$ r-sq = 82.0%, r-sq (adjusted) = 80.7%
8-Hour Fix Rate	$0.441 + 0.000040x_{\#7}$ r-sq = 86.5%, r-sq (adjusted) = 86.1%
Average Aircraft Inventory	$760 + 0.0624x_{\#3} + 0.0363x_{\#5} - 0.0736x_{\#7}$ r-sq = 94.9%, r-sq (adjusted) = 94.3%
CANN Hours	$33{,}857 - 2.49x_{\#7}$ r-sq = 66.0%, r-sq (adjusted) = 64.9%
Maintenance Reliability	$24{,}947 - 72{,}293x_{\%7}$ r-sq = 86.6%, r-sq (adjusted) = 86.1%
TNMCM Hours	$-178{,}625 + 41.7x_{\#5} - 0.0366x_{\#7}x_{\#9}$ r-sq = 80.7%, r-sq (adjusted) = 79.4%

Figure 12. Prediction Intervals for MC Rate Within Observed Values

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Be nice to your mother but love your logisticians and communicators.

—Gen Charles A. Horner, USAF

You think out every possible development and decide on the way to deal with the situation created. One of these developments occurs; you put your plan in operation, and everyone says, "What genius…" whereas the credit is really due to the labor of preparation.

—Marshal of France Ferdinand Foch

…instant history [was] invariably shallow history.

—Anthony Cordesman