

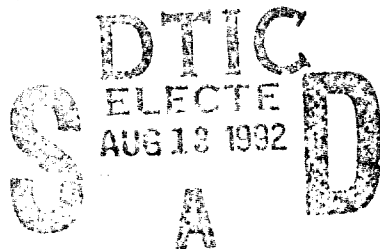
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MULTIPLE FORECASTING TECHNIQUES FOR FUELS



June 1992

OPERATIONS RESEARCH AND ECONOMIC ANALYSIS OFFICE



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**MULTIPLE FORECASTING
TECHNIQUES FOR
FUELS**

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June 1992

Eugene E. Matysek, Jr.

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FOREWORD

The Operations Research and Economic Analysis Office, Directorate of Resources Management, Defense Fuel Supply Center, was tasked with evaluating the multiple forecasting model developed in Multiple Forecasting Techniques, Defense Logistics Agency (DLA) Operations Research and Economic Analysis Office Study DLA-91-P90053, as a predictor of fuel requirements.

The authors of this paper are indebted to the authors of Multiple Forecasting Techniques for their pioneering work in the use of these techniques and for sharing computer programs and other insights into the problems of multiple forecasting.

We are also indebted to the Inventory Management Division, Directorate of Supply Operations, Defense Fuel Supply Center, for their assistance in formulating the initial concepts of this study and for their assistance in acquisition of data.


ROGER C. ROY
Assistant Director
Policy and Plans

EXECUTIVE SUMMARY

Defense Management Review Decision (DMRD) 901 (Reduce Supply System Costs) led the Defense Logistics Agency (DLA) to institute a study under the auspices of the Requirements Forecast Working Group (RFGW) on the use of multiple forecasting techniques to forecast demand for items. The initial work, done at DLA Operations Research and Economic Analysis Management Support Office (DLA-DORO), was applied to construction, electronics, general, industrial, and medical commodities. These commodities are all managed within the Standard Automated Materiel Management System (SAMMS). This initial study showed the potential for inventory safety-level reductions of \$42 million. RFGW requested an extension of this methodology to fuels, which is managed using the Defense Fuel Automated Management System (DFAMS).

This study examines the operation of the multiple forecasting model on fuel sales data and demonstrates improvements in forecast accuracy gained through the use of the multiple forecasting technique. More accurate forecasts of demands at Defense Fuel Supply Points and other customer locations will allow DFSC to better support them by lower-cost fuel movements, fewer emergency shipments and fuel purchases, and perhaps lowered inventory levels resulting from reduced safety level requirements. This report recommends that the Fuels Multiple Forecasting Model developed here be used on a test basis by DFSC.

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SECTION 1

INTRODUCTION

1.1 BACKGROUND

The Defense Management Review Decision (DMRD) 901 (Reduce Supply System Costs) led the Defense Logistics Agency (DLA) to institute a study under the auspices of the Requirements Forecast Working Group (RFGW) on the use of multiple forecasting techniques to forecast demand for items. The initial work, done at DLA Operations Research and Economic Analysis Management Support Office (DLA-DORO), was applied to construction, electronics, general, industrial, and medical commodities. These commodities are all managed within the Standard Automated Materiel Management System (SAMMS). This initial study showed the potential for inventory safety-level reductions of \$42 million. RFGW requested an extension of this methodology to fuels, which is managed using the Defense Fuel Automated Management System (DFAMS).

1.2 PURPOSE

The purpose of this study is to evaluate the operation of the multiple forecasting model on DFSC fuel sales data and to evaluate the criteria used to select the optimal forecasting techniques within the model.

1.3 OBJECTIVES

The objectives of this study are:

(1) Evaluate the forecasting techniques used and the model results for useability by inventory managers.

(2) Provide recommendations for implementation of the Multiple Forecasting Model at DFSC.

1.4

SCOPE OF STUDY

(1) Data was gathered from DFAMS.

(2) Only sales of fuels procured under bulk fuel purchasing contracts were forecasted.

(3) Only those forecasting methods included in the original Multiple Forecasting Techniques study (DLA-91-P90053) were considered in this study (see Section 2.1).

(4) Data was consolidated at the Defense Fuel Supply Point (DFSP) or Department of Defense Activity Address Code (DODAAC) level.

SECTION 2

METHODOLOGY

2.1 DESCRIPTION OF THE MULTIPLE FORECASTING MODEL

DLA's Multiple Forecasting Model is based on the premise that one forecasting technique will prove to be best when tested over a given set of actual data points and the same technique will be best when used to generate the forecast for future points. The model uses 20 quarters of data; 12 quarters for initialization; the next 4 quarters to test the various forecasting techniques; and then the last 4 quarters to evaluate the results of the selected forecasting technique against a forecast of demand currently available in SAMMS.

The forecasting techniques tested by the model include:

- (1) Four Quarter Moving Average
- (2) Eight Quarter Moving Average
- (3) Lagged moving average based on autocorrelations
- (4) Single exponential smoothing with $\alpha = 0.1$
- (5) Single exponential smoothing with $\alpha = 0.2$
- (6) Double exponential smoothing with $\alpha = 0.1$
- (7) Double exponential smoothing with $\alpha = 0.2$
- (8) Adaptive response single exponential smoothing
- (9) Adaptive response exponential smoothing with a smoothed α
- (10) Holt's double exponential smoothing
- (11) Winter's triple exponential smoothing with $\alpha = 0.1$
- (12) Winter's triple exponential smoothing with $\alpha = 0.2$
- (13) Simple linear regression
- (14) Last demand
- (15) Year ago demand
- (16) SAMMS Double exponential smoothing with $\alpha = 0.2$
- (17) Conditional probability model based on clustering
- (18) Nonlinear regression

DLA's Multiple Forecasting Model used three different measures of error in selecting the appropriate forecasting technique:

- Mean absolute deviation (MAD), the average of forecasting errors
- Mean squared error (MSE), the average of squared forecasting errors
- Total absolute error (TAE), the difference between the sum of the forecasts and the sum of demands

The model then used the modified index of predictive efficiency (MIPE), a relative measure that compares two forecasts, to evaluate the selected forecasting techniques against the forecast in SAMMS.

The DLA model used Theill's bias proportion to eliminate any forecasting technique that exceeds a threshold limit.

2.2

FUELS MULTIPLE FORECASTING MODEL

Using DLA's Multiple Forecasting Model as a guide, a similar model, the Fuels Multiple Forecasting Model, was created using a LOTUS spreadsheet. The Fuels Multiple Forecasting Model uses 20 quarters of data in the same way as the Multiple Forecasting Model. Twelve quarters are used to initialize the model. Four quarters of data are used to test the fifteen forecasting techniques to determine which technique to select as the "best" for the particular data set. Finally, the last 4 quarters of data are used to test the advantages of using the chosen forecasting method against an existing forecast.

2.3

FORECASTING TECHNIQUES

The forecasting techniques tested by this model include:

- (1) Four Quarter Moving Average
- (2) Eight Quarter Moving Average
- (3) Lagged moving average based on autocorrelations
- (4) Single exponential smoothing with $\alpha = 0.1$
- (5) Single exponential smoothing with $\alpha = 0.2$
- (6) Double exponential smoothing with $\alpha = 0.1$
- (7) Double exponential smoothing with $\alpha = 0.2$
- (8) Adaptive response single exponential smoothing
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- (10) Holt's double exponential smoothing
- (11) Winter's triple exponential smoothing with $\alpha = 0.1$
- (12) Winter's triple exponential smoothing with $\alpha = 0.2$
- (13) Simple linear regression
- (14) Last demand
- (15) Year ago demand

2.4

FORECASTING TECHNIQUE COMPARISONS

It must be noted that there are three fewer forecasting techniques used in the Fuels Multiple Forecasting Model than in the Multiple Forecasting Model. The SAMMS model was deemed to be extraneous to the DFAMS commodity. The conditional probability model was excluded because the data from DFAMS did not have the large number of null values characteristic of the SAMMS data. The nonlinear regression method is merely regression using a logarithmic transformation of the data.

2.5

SELECTION OF BEST TECHNIQUE

The choice of the "best" forecasting technique for a data set was based on the same two criteria as the Multiple Forecasting Model: bias and accuracy. The bias measure was set at the 0.2 threshold

as in the Multiple Forecasting Model. Any forecasting technique whose bias proportion exceeded this threshold was rejected. The accuracy measures used were the MAD, MSE and the TAE. The "best" forecasting technique was the one that was both unbiased and highly accurate. In the event accuracy measures prescribe different forecasting techniques, the model defaults to the technique with the lowest MAD.

In the determination of the relative advantages of the Fuel Multiple Forecasting Model over the existing forecast in DFAMS, the MIPE plays a key role. This index compares the two forecasts via a ratio of TAEs for the forecasts.

SECTION 3

DATA

3.1 QUARTERLY SUMMARY OF SALES

The Fuels Multiple Forecasting Model was evaluated against quarterly summary of sales data by receiving activity taken from DFAMS. The DFAMS report shows four quarters of demand, the previous year's demand, and a forecast of the next year's demand. The reports for the fiscal years 1985 through 1990 were used. Fiscal year 1991 was excluded because of the possibility of distortion due to Desert Shield/Desert Storm demand.

3.2 SELECTION OF TEST SAMPLES

The model was tested on a sample of data from the targeted years. A randomized choice of locations for each of the major product types was made. Major product types were: Navy Distillate Fuel Oil (DFW), Regular Grade Diesel Fuel Oil (DF2), Navy Distillate Fuel Oil (F76), and Aviation Turbine Fuels (JP4, JP5, and JP8). Together these product types account for over 90 percent of DFSC business.

A total of 29 locations were selected for testing. The breakout by product type was:

<u>Product</u>	<u>Number of Locations</u>
DFW	2
DF2	3
F76	6
JP4	9
JP5	8
JP8	1

In one case, a location chosen as a JP4 test bed converted to JP8 usage during the 5 year period. In this case, the data strings for the commodities were combined and the model operated on the complete string.

SECTION 4

ANALYSIS

4.1 PERFORMANCE OF THE FUELS MULTIPLE FORECASTING MODEL

4.1.1 FORECASTING TECHNIQUES SELECTED

The frequency of forecasting technique selection for the test data by the Fuels Multiple Forecasting Model was as follows:

<u>Forecasting Technique Selected</u>	<u>Frequency</u>
Holt's double exponential smoothing	11
Last demand	4
Year ago demand	3
Lagged moving average based on autocorrelation	2
Double exponential smoothing, $\alpha = 0.1$	2
Adaptive response single exponential smoothing	2
Winter's triple exponential smoothing, $\alpha = 0.1$	1
Double exponential smoothing, $\alpha = 0.2$	1
No Method (see Section 4.1.2)	3

4.1.2 BIAS

In three cases the Fuels Multiple Forecasting Model rejected all of the forecasting methods because the bias proportions exceeded the 0.2 threshold. In all three cases these were locations where fuel use changed suddenly and radically from one year to the next.

4.2 COMPARISON OF THE MODEL WITH THE CURRENT FORECAST

Of 29 locations tested, the Fuels Multiple Forecasting Model outperforms the forecast on the DFAMS report in 21 cases. In 2

cases the report forecast was closer to the actual data, and in 3 cases the accuracy measures were inconclusive (split between the two forecasts). Overall percentage improvements in accuracy measures for the Fuels Multiple Forecasting Model over the DFAMS report forecast are: MAD, 24.1 percent; MSE, 22.0 percent; and TAE, 45.6 percent.

Results are similar using the MIPE; the Fuels Multiple Forecasting Model outperforms the forecast on the DFAMS report in 21 cases, while the DFAMS report is better in 5 cases.

4.3 COMPARISON OF THE MODEL WITH THE COMMERCIAL PACKAGE

To establish some model validity with respect to a commercially available forecasting package, the data was run through the forecasting package called AutoCast. This comparison was done using a non-seasonal, constant-level, exponentially smoothed model from AutoCast. The package is capable of other options, but for this investigation, this model was chosen as the most likely, generic model. In this comparison, the Fuel Multiple Forecasting Model proved more accurate 15 times, AutoCast was more accurate 7 times, and the results were mixed 4 times. The results were similar using the MIPE. The index for the Fuels Multiple Forecasting Model was best 19 times versus 7 times for AutoCast.

SECTION 5

RESULTS

5.1 CONCLUSIONS

The multiple forecasting technique often provides a more accurate forecast than either the current system or the AutoCast model.

5.2 BENEFITS

More accurate forecasts of demands at DFSPs and other customer locations will allow DFSC to better support them by lower-cost fuel movements, fewer emergency shipments and emergency fuel purchases, and perhaps lowered inventory levels resulting from reduced safety level requirements. Certainly the ability to accurately forecast demands would give DFSC the ability to challenge annual requirements submissions; especially when those requirements differ significantly from the Fuels Multiple Forecasting Model.

5.3 RECOMMENDATIONS AND SUGGESTIONS FOR FURTHER RESEARCH

Specific recommendations stemming from this project are the following:

- The customer, Inventory Management Division, Directorate of Supply Operations, DFSC-OI, use the Fuels Multiple Forecasting Model on a test basis.
- An effort should be made to determine if the alpha values used in the exponential smoothing techniques were the best possible.
- Other forecasting techniques should be considered for inclusion into the model. The Box-Jenkins technique was

used at DFSC with some success several years ago and should be reconsidered.

- As in the DLA Multiple Forecasting Techniques study, an investigation be made into the effects of implementing this model as a dynamic forecasting model, allowing the forecasting technique to change for each quarterly forecast.

APPENDIX A
EQUATIONS

APPENDIX A

EQUATIONS

The following is a mathematical representation of the forecast accuracy measures, bias measures, and forecasting techniques referred to in this report.

A-1.1 FORECAST ACCURACY MEASURES

A-1.1.1 MEAN ABSOLUTE DEVIATION (MAD)

$$MAD = \frac{\sum_{t=1}^n ABS(A_t - F_t)}{n}$$

where: F_t = forecast for time t
 A_t = actual demand for time t
 n = number of time periods

A-1.1.2 MEAN SQUARED ERROR (MSE)

$$MSE = \frac{\sum_{t=1}^n (A_t - F_t)^2}{n}$$

where: F_t = forecast for time t
 A_t = actual demand for time t
 n = number of time periods

A-1.1.3**TOTAL ABSOLUTE ERROR (TAE)**

$$TAE = ABS \sum_{t=1}^N (A_t - F_t)$$

where: F_t = forecast for time t
 A_t = actual demand for time t
 n = number of time periods

A-1.1.4**MODIFIED INDEX OF PREDICTIVE EFFICIENCY
(MIPE)**

$$MIPE = 100 * \left[\frac{E_s - E_m}{\frac{1}{2} (E_s + E_m)} \right]$$

where: E_s = TAE of basic forecast
 E_m = TAE of model forecast

A-1.2**BIAS MEASURE**

$$U = \left[\frac{\bar{A} - \bar{F}}{RMSE} \right]^2$$

where: $\bar{F}$ = average forecast
 $\bar{A}$ = average actual demand
RMSE = square root of the MSE

A-1.3 FORECASTING TECHNIQUES

A-1.3.1 BASIC NAIVE

$$F_{t+1} = X_t$$

A-1.3.2 SEASONAL NAIVE

$$F_{t+1} = X_{t-3}$$

A-1.3.3 FOUR QUARTER MOVING AVERAGE

$$F_{t+1} = \frac{\sum_{i=t-3}^t X_i}{4}$$

A-1.3.4 EIGHT QUARTER MOVING AVERAGE

$$F_{t+1} = \frac{\sum_{i=t-7}^t X_i}{8}$$

A-1.3.5 LAGGED TWO QUARTER MOVING AVERAGE

Lagged two quarter moving average determines if there is any relationship between quarters two, three, or four intervals apart. Autocorrelations are computed for these lags and a ninety-five percent confidence interval is used to establish significance. Decision rules are:

- If the second autocorrelation is positively significant then:

$$F_{t+1} = \frac{(X_{t-1} + X_{t-3})}{2}$$

- If the third autocorrelation is positively significant then:

$$F_{t+1} = \frac{(X_{t-2} + X_{t-5})}{2}$$

- If the fourth autocorrelation is positively significant then:

$$F_{t+1} = \frac{(X_{t-3} + X_{t-7})}{2}$$

- If none of the above are true then:

$$F_{t+1} = \frac{(X_t + X_{t-1})}{2}$$

A-1.3.6

SINGLE EXPONENTIAL SMOOTHING

$$F_{t+1} = \alpha X_t + (1 - \alpha) F_t$$

A-1.3.7**DOUBLE EXPONENTIAL SMOOTHING**

$$\begin{aligned}
S'_t &= \alpha X_t + (1 - \alpha) S'_{t-1} \\
S''_t &= \alpha S'_t + (1 - \alpha) S''_{t-1} \\
a_t &= 2S'_t - S''_t \\
b_t &= \left[\frac{\alpha}{(1 - \alpha)} \right] (S'_t - S''_t) \\
F_{t+m} &= a_t + b_t m
\end{aligned}$$

where: S' = single smoothed quantity
 S'' = double smoothed quantity
 α = smoothing parameter
 m = length of forecasting horizon

A-1.3.8**HOLT'S DOUBLE EXPONENTIAL SMOOTHING**

$$\begin{aligned}
S_t &= \alpha X_t + (1 - \alpha) (S_{t-1} + b_{t-1}) \\
b_t &= \delta (S_t - S_{t-1}) + (1 - \delta) b_{t-1} \\
F_{t+m} &= S_t + b_t m
\end{aligned}$$

where: S = smoothed quantity
 b = trend component
 α = smoothing parameter
 δ = smoothing parameter for trend
 m = length of forecast horizon

A-1.3.9

WINTER'S TRIPLE EXPONENTIAL SMOOTHING

$$S_t = \frac{\alpha X_t}{I_{t-L}} + (1 - \alpha) (S_{t-1} + b_{t-1})$$

$$b_t = \delta (S_t - S_{t-1}) + (1 - \delta) b_{t-1}$$

$$I_t = \frac{\beta X_t}{S_t} + (1 - \beta) I_{t-L}$$

$$F_{t+m} = (S_t + b_t m) I_{t-L+m}$$

where: S = smoothed quantity
 b = trend component
 I = seasonal component
 α = smoothing parameter
 δ = smoothing parameter for trend
 β = smoothing parameter for seasonality
 m = length of forecasting horizon

A-1.3.10

TRIGG-LEACH ADAPTIVE RESPONSE RATE EXPONENTIAL SMOOTHING

$$e_t = X_t - F_t$$

$$E_t = \beta e_t + (1 - \beta) E_{t-1}$$

$$M_t = \beta |e_t| + (1 - \beta) M_{t-1}$$

$$\alpha_t = \left| \frac{E_t}{M_t} \right|$$

- Lagged α Trigg-Leach Model:

$$F_{t+1} = \alpha_{t-1} X_t + (1 - \alpha_{t-1}) F_t$$

- Smoothed α Trigg-Leach Model:

$$\alpha'_t = \delta (\alpha_t) + (1 - \delta) \alpha'_{t-1}$$

$$F_{t+1} = \alpha'_t X_t + (1 - \alpha'_t) F_t$$

where: e = forecast error
 E = smoothed forecast error
 β = smoothing parameter for error
 M = smoothed absolute error
 α = computed smoothing parameter

SIMPLE LINEAR REGRESSION

$$b = \frac{n \sum XY - (\sum X)(\sum Y)}{n \sum X^2 - (\sum X)^2}$$

$$a = \frac{(\sum Y)}{n} - \frac{(b \sum X)}{n}$$

$$F_m = a + bm$$

where: Y = the period of the time series
 n = the number of quarters included
 m = length of forecasting horizon

APPENDIX B
LIST OF ACRONYMS

APPENDIX B
LIST OF ACRONYMS

DFAMS	Defense Fuel Automated Management System
DFSC	Defense Fuel Supply Center
DFSP	Defense Fuel Supply Point
DFW	Navy Distillate Fuel Oil
DF2	Regular Grade Diesel Fuel Oil
DLA	Defense Logistics Agency
DMRD	Defense Management Review Decision
DODAAC	Department of Defense Activity Address Code
DORO	DLA Operations Research and Economic Analysis Management Support Office
F76	Navy Distillate Fuel Oil
JP4	Aviation Turbine Fuel, Grade JP4
JP5	Aviation Turbine Fuel, Grade JP5
JP8	Aviation Turbine Fuel, Grade JP8
MAD	Mean Absolute Deviation
MIPE	Modified Index of Predictive Efficiency
MSE	Mean Squared Error
RFWG	Requirements Forecast Working Group
SAMMS	Standard Automated Materiel Management System
TAE	Total Absolute Error

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