Proceedings of the 1999 Annual Reliability and Maintainability Symposium, Washington DC, USA, Jan 18-21, 1999.

Experience in Using MEADEP

Dong Tang • SoHaR Incorporated • Beverly Hills
Myron Hecht • SoHaR Incorporated • Beverly Hills
Abraham Rosin • System Resources Corporation • Washington D.C.
Jady Handal • Federal Aviation Administration • Washington D.C.

Keywords: availability evaluation, failure measurement, parameter estimation, software tool, statistical distribution

SUMMARY & CONCLUSIONS

This paper reports some of our experience in using MEADEP — a newly developed measurement-based dependability evaluation tool that includes both data analysis and modeling functions. Several issues are discussed: identification of time between outages and time to repair distributions, need for more graphical model forms, and consistency between parameter estimation and model evaluation algorithms. The identified distribution functions are valuable for detailed analysis and realistic modeling. The significance of discovering the inconsistency between the failure rate estimation and the availability evaluation algorithms is not limited to only MEADEP because both algorithms are commonly used. The need for more graphical model forms and the demand for better user interface are driving improvements for MEADEP. These issues provide insights into the roles and future directions for this kind of tools.

1. INTRODUCTION

MEADEP is a user-friendly, window-based data analysis and dependability modeling software tool [9].[1] The tool facilitates the use of measurement-based dependability analysis methods [2, 8] and reduces the cost of such analyses. MEADEP is not intended to replace the existing sophisticated modeling tools (e.g., SHARPE [5] and UltraSAN [7]) because they have different application domains. Specifically, MEADEP targets applications with the following features: massive data, multiple categories of statistics to estimate from data, hierarchical construction of small size models (less than 100 blocks or states in each diagram), and non-expert users.

MEADEP consists of the following four modules which will be referenced in this paper. A more detailed description of these modules can be found in [9].

- Data Pre-Processor (DPP) for converting source data in various formats to the MEADEP format
- Data Editor & Analyzer (DEA) for data editing, graphical data presentation and parameter estimation
- Model Generator (MG) for graphically building hierarchical reliability block diagrams and Markov models
- Model Evaluator (ME) for calculating various dependability measures and graphical parametric analyses

MEADEP is currently used by technical staff at SoHaR and System Resources Corporation in availability analysis of U.S. airport runways and runway-related facilities under a contract with the Federal Aviation Administration (FAA). Several universities and companies have also started using MEADEP. This paper reports our experience in the initial use of MEADEP, including issues such as the identification of time between outages and time to repair distributions, the need for more graphical model forms, and consistency between parameter estimation and model evaluation algorithms.

2. IDENTIFICATION OF OUTAGE TIME DISTRIBUTIONS

The exponential distribution is often assumed in practical engineering projects for deriving dependability predictions. This is mostly due to the following limitations or difficulties:

- The data available for analysis do not furnish the distribution identification. This is generally the case when failures are rare.
- Complexity in identifying failure arrival and time to repair distributions from data.
- Complexity in model construction and solution.

MEADEP addresses the second problem by providing an easy means to identify statistical distributions from data. The FAA National Airspace Performance Reporting System (NAPRS) database, which contains two million outage reports for nation-wide airport facilities, provides a valuable data source for MEADEP to identify empirical outage distributions.

For the purposes of this study, we extracted from the NAPRS database the outage data for eight runway-related facilities at Los Angeles International Airport (LAX) for five and half years (1/1/1992 - 6/1/1997). The extracted data were

[1] The MEADEP academic version and user's manual are available to the public at www.sohar.com.

then converted to the MEADEP format by the MEADEP DPP module for analysis. The eight runway related facilities are listed below:

ALS	Approach Light System
ASDE	Airport Surface Detection Equipment
DME	Distance Measurement Equipment
GS	Glide Slope
LOC	Localizer
MALSR	Medium Intensity Approach Light System
RVR	Runway Visual Range
VOR	VHF Omni-directional Range

Because the data contain information on outage occurrence dates and outage durations (which rarely existed in data we analyzed before), we identified statistical distributions for Time Between Outages (TBO) and Time To Repair (TTR) with the MEADEP DEA module. DEA can display histograms for Time Between Events (TBE) or TTR and allows the user to super-plot, over the histogram, five different analytical probability distribution functions determined by the sample mean and sample variance: exponential, gamma, Weibull, normal and lognormal. Meanwhile, the estimated parameters for these functions as well as the results of the Chi-Square and Kolmogorov-Smirnov goodness-of-fit tests are also provided on the screen. Figure 1 shows the histogram for facility ASDE. In this figure, the exponential curve fails to fit the empirical distribution (histogram) because it did not pass the Chi-Square or Kolmogorov-Smirnov test. In contrast, the Weibull curve passed the Chi-Square test at the significance level of 0.32 and the Kolmogorov-Smirnov test at a significance level greater than 0.20.

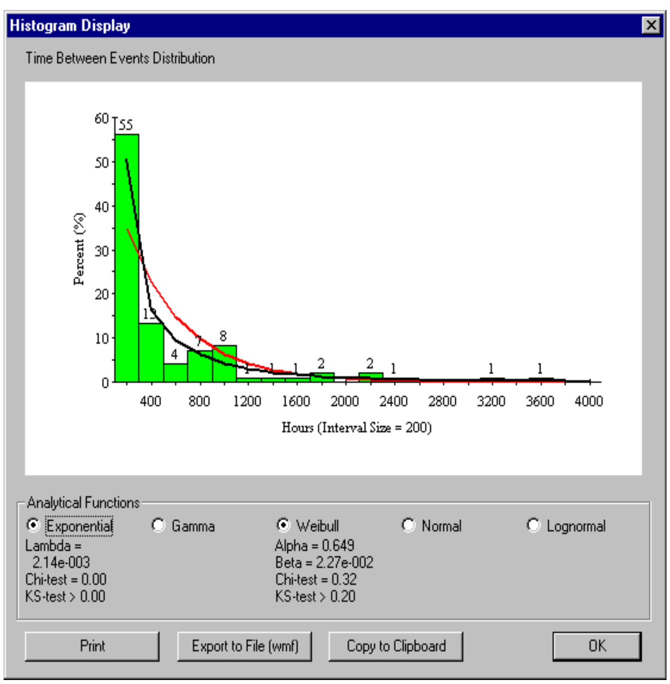

Figure 1 Identification of Distribution for ASDE Time Between Outages

Table 1 shows results for the TBO and TTR for all the eight facilities. Each facility may have multiple units each serving one or more runways. The facility unit that has the largest number of outages was selected for this analysis. The "Runway ID" row is the name of the runway for which the selected facility was used. Facilities ASDE and VOR each have only one unit which was shared by all runways. For facility RVR, because the sample size for any of its six units is not large enough for identifying a TBO or TTR distribution, the outage data on all the six units were used. A cell, crossing a statistical function (Exponential, Gamma, Weibull, Normal, Lognormal) row and a facility type column, is marked by Chi, if the corresponding function passed the Chi-Square goodness-of-fit test at the significance level of at least 0.05. If the corresponding function passed the Kolmogorov-Smirnov goodness-of-fit test at the significance level of at least 0.05, the cell is marked by KS.

Based on Table 1, we can construct another table (Table 2) to summarize the degree of fit for these statistical functions. If a function passed both the Chi and KS tests, it is regarded as a "strong fit". If a function passed only Chi or KS test, it is regarded as a "weak fit". Otherwise, it is regarded as "no fit". Table 2 shows that the Gamma and Weibull functions fit all empirical TBO and TTR distributions and in most cases, the degree of fit is high. The exponential and lognormal functions fit the same number of all empirical distributions (12 out of 16, or 75%). But the exponential curve better fits TTR distributions (100%) and the lognormal curve better fits TBO distributions (87.5%). Four out of the eight empirical TBO distributions (50%) fail to fit an exponential curve. The normal distribution fails to fit almost all empirical distributions except one TTR.

It is not surprising to see that the Gamma and Weibull functions are more representative of empirical TBO and TTR distributions, since previous studies on computer transient errors [4] and on software failures [1] showed similar results. The purpose of this analysis is to demonstrate the capability of MEADEP and to provide parameters for a study of the following issue: Given this result (Weibull is more representative than exponential), what is its impact on dependability evaluation? Consider a simple availability block diagram[2] (Figure 2) developed using the MEADEP Model Generator (MG) module for a runway under the Category I[3] visibility condition. In order to perform an approved landing under Categories I to III conditions, the aircraft must be equipped with appropriate facilities. The blocks in Figure 2 (generated by MG) represent the facilities required for landing under the Category I condition, where λ and μ represent the mean failure rate and repair rate estimated from the data for the facilities[4] listed in Table 1.

---

[2]Because facilities can be assumed to be independent of each other, availability block diagrams are appropriate for modeling runway availability.

[3]Visibility conditions are classified into four categories: Visual Flight Rules (Category 0), I, II, and III, ranking from good to bad conditions.

[4]Although these facilities were used for different runways, for the purpose of this study, their outage and repair rates are used in a single runway model.

Table 1. Identification of Distribution for Facility TBO and TTR

Facility Type	ALS	DME	GS	LOC	MALSR	RVR	ASDE	VOR
Runway ID	24R	06	25L	25L	25R	All	Shared	Shared
No. of Outages	84	41	42	81	24	48	96	36
Time Between Outages:								
Exponential	KS, Chi			KS	Chi, KS			KS
Gamma	Chi, KS	Chi, KS	Chi, KS	KS	Chi, KS	Chi, KS	Chi, KS	Chi, KS
Weibull	Chi, KS	Chi, KS	KS	KS	Chi, KS	Chi, KS	Chi, KS	Chi, KS
Normal								
Lognormal	Chi, KS	KS	KS	KS	Chi, KS	Chi		Chi, KS
Time To Repair:								
Exponential	Chi, KS	Chi, KS	KS	KS	Chi, KS	Chi, KS	KS	Chi, KS
Gamma	Chi, KS	Chi, KS	Chi, KS	KS	Chi, KS	Chi, KS	Chi, KS	Chi, KS
Weibull	Chi, KS	Chi, KS	Chi, KS	KS	Chi, KS	Chi, KS	Chi, KS	Chi, KS
Normal								Chi, KS
Lognormal		Chi, KS			Chi, KS	Chi, KS	Chi	KS

Table 2. Degree of Fit for Tested Statistical Functions

Statistical Function	Time Between Outages			Time To Repair		
	Strong Fit	Weak Fit	No Fit	Strong Fit	Weak Fit	No Fit
Exponential	2 (25%)	2 (25%)	4 (50%)	5 (62.5%)	3 (37.5%)	
Gamma	7 (87.5%)	1 (12.5%)		7 (87.5%)	1 (12.5%)	
Weibull	6 (75%)	2 (25%)		7 (87.5%)	1 (12.5%)	
Normal			8 (100%)	1 (12.5%)		7 (87.5%)
Lognomal	3 (37.5%)	4 (50%)	1 (12.5%)	3 (37.5%)	2 (25%)	3 (37.5%)

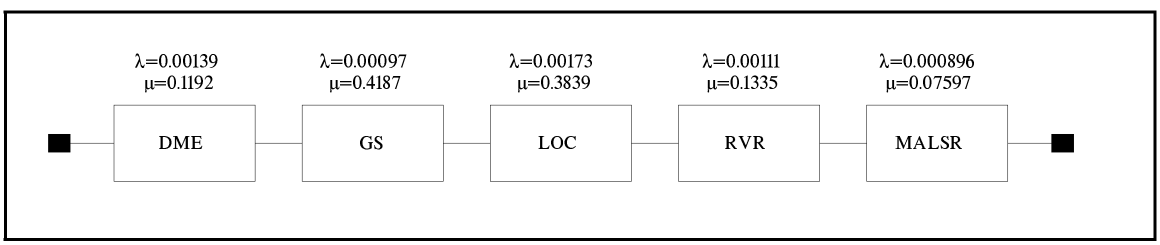

Figure 2 Runway Approach Facility Availability Model under Category I Visibility Conditions

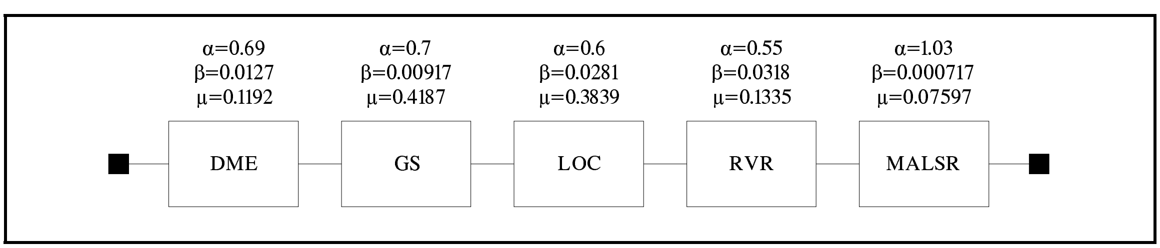

Figure 3 The Equivalent Figure 2 Model with the Weibull Distribution

The model can be used to evaluate both availability and reliability. In our actual contract work, it was used to evaluate steady-state (or limiting) availability (which was also the case for our previous work for FAA). In calculating steady-state availability, only λ and μ are used by MEADEP, regardless of the underlying distribution. It has been shown in [6] that "the limiting availability only depends on the MTTF and MTTR and not on the nature of the failure/repair time distribution" where MTTF is $1/\lambda$ and MTTR is $1/\mu$. Thus, the underlying Weibull distribution should have no impact on availability evaluation for this model.

However, the impact of the Weibull distribution on reliability evaluation (transient solution) is much different. This can be investigated by using the new MEADEP capability in constructing and evaluating the Weibull block, in addition to the exponential block. The equivalent Figure 2 model with the Weibull distribution is shown in Figure 3 (generated by MG) where α's and β's were obtained by the procedure shown in Figure 1.

Both the Figure 2 model and Figure 3 model were evaluated by ME. The results are plotted in Figure 4 where the upper curve is based on the exponential distribution and the lower curve is based on the Weibull distribution. It is seen that the exponential assumption under-estimates reliability by a significant margin. It should be pointed out that this reliability evaluation is presented here only for analysis purposes. The evaluated reliability does not reflect reality because routine maintenance is constantly performed for these facilities.

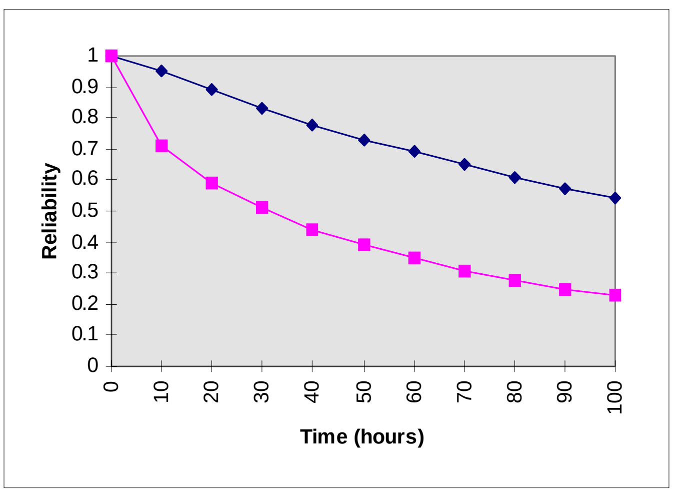

Figure 4 Impact of TBO Distribution on Reliability

3. NEED FOR MORE GRAPHICAL MODEL FORMS

As mentioned in discussing the Figure 2 model, there are four visibility conditions and under each condition, a different set of facilities is required for use in the aircraft landing. Let y_0, y_1, y_2 and y_3 denote the occurrence probabilities for Categories 0, 1, 2, and 3 visibility conditions, respectively. The overall runaway approach availability, A, is then calculated by

$$A = y_0 A_0 + y_1 A_1 + y_2 A_2 + y_3 A_3 \qquad \textbf{(1)}$$

where A_x represents the approach availability under visibility condition x.

Although each of the A_x's can be modeled by an availability block diagram, A cannot be represented by an availability block diagram or a Markov chain. To implement this model, we have to manually insert this expression into the text modeling file generated by the MG module, because it cannot be graphically built with MG from the lower level diagrams (A_1 to A_3). In an availability model developed for an airport, there are many such expressions organized hierarchically. Thus, our MEADEP users wish to be able to graphically develop such expressions. Graphical input of this model form not only allows the generation of a complete text modeling file automatically, but it also avoids human errors (which we have made many times ourselves) in editing the text modeling file.

Another example is the evaluation of Average Yearly Total Facility Downtime (AYTFD) to analyze the impact of maintenance on the facility availability. AYTFD can be calculated by

$$AYTFD = U \times 8760 \ hours \qquad \textbf{(2)}$$

where U is the total percentage of downtime in a calender year for the facilities in consideration and is calculated by

$$U = \sum_{i}^{n} C_i U_i \qquad \textbf{(3)}$$

where U_i is the unavailability for facility i, C_i the count for facility i (number of units), and n the number of the facilities.

It is seen that Equation (3) has the same form as Equation (1) and thus can be implemented by the same graphical model form. Without the corresponding graphical representation, this expression (which may have many terms) has to be manually inserted into the text modeling file. The usefulness of AYTFD is shown by the curve in Figure 5 (generated by ME) which plots the AYTFD parametric analysis results for 13 Dallas Fort Worth (DFW) airport runway related facilities. It was found that two facilities accounted for the majority of the total facility downtime. The curve shows that if one (LOC314EB) of these facility's repair rate is increased from the current 0.02 (50 hours per repair) to 0.2 (5 hour per repair), the AYTFD can be reduced by 43%.

The above examples show that in the application of MEADEP, more graphical model forms may be requested by users. In order to make MEADEP meet the needs of these applications, it is necessary to create and include new graphical model forms in MEADEP. The new MEADEP version has incorporated the "weighted block diagram" which can be used to model Equations (1) and (3), as shown in Figure 6 (generated by MG). To distinguish the weighted block diagram from the reliability/availability block diagram, there is a circle at the midpoint of a link connecting two weighted blocks.

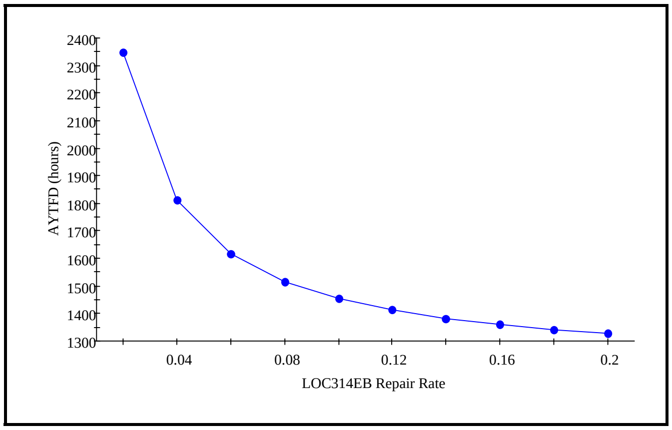

Figure 5 Impact of LOC314EB Repair Rate on AYTFD

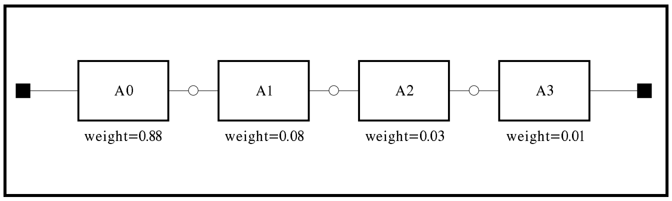

Figure 6 Weighted Block Diagram

In addition to the demand for more graphical model forms, users also requested better user interface and performance. Since the release of the first version of MEADEP, the MEADEP user interface and performance have been constantly improved in later versions.

4. CONSISTENCY BETWEEN PARAMETER ESTIMATION AND MODEL EVALUATION ALGORITHMS

In this section, we report an interesting finding in an attempt to validate the evaluated availability by the MEADEP ME (solution) module. The validation procedure is simple:

(1) The MEADEP DEA module was applied to the LAX airport outage data to obtain failure rate (λ), repair rate (μ), availability (A), and other measures (by running the Multiple Statistics command) for the eight runway related facilities listed in Table 1.

(2) The availability block diagrams similar to the one shown in Figure 2 were drawn with the MG module and the λ's and μ's estimated by DEA were input to the diagrams.

(3) The text modeling file generated by MG was evaluated by ME to generate availability for each facility.

(4) For each facility, the availability generated by ME was compared with the availability generated by DEA.

It was found that there is a small difference between the availability generated by DEA and that generated by ME for most of these facilities, as shown in Table 3. The availability listed in the second column was estimated directly from the data by Equation (4) below. The availability listed in the third column was evaluated from the model by Equation (5) where λ and μ were also derived from the same data. What causes the error? After an investigation, it was found that the error was caused by the inconsistency between the failure rate estimation algorithm used in DEA and the availability calculation algorithm used in ME.

Table 3. Availability Estimated from Data and Model

Facility	A (data)	A (model)
ALS	0.98918	0.98930
ASDE	0.98096	0.98131
DME	0.98998	0.99008
GS	0.98198	0.98230
LOC	0.98567	0.98587
MALSR	0.99656	0.99658
RVR	0.99874	0.99874
VOR	0.98846	0.98859

DEA uses the following equation to estimate availability:

$$A = \frac{T_{up}}{T} \quad (4)$$

where T is the total observation time period and T_{up} the total up-time (operating time) for the facility in T.

ME uses the following commonly used algorithm [6] to calculate availability for a block:

$$A = \frac{\mu}{\lambda + \mu} \quad (5)$$

where λ was estimated by DEA using the following commonly used equation:

$$\lambda = \frac{N}{T} \quad (6)$$

where N is the number of failures occurring in T.

Although both Equations (5) and (6) are commonly used, they are not consistent. It can be shown that the λ required by Equation (5) should be estimated by

$$\lambda = \frac{N}{T_{up}} = \frac{N}{T - T_{down}} \quad (7)$$

where T_{down} represents the total down time for the facility in the time period T. When T_{down} is very small, the difference between the λ estimated by Equation (6) and that estimated by Equation (7) is negligible. But if T_{down} is not very small (which is the case for many facilities we analyzed), the difference may not be negligible and its effect on the availability calculation is visible.

To make failure rate estimation and availability evaluation algorithms consistent in MEADEP, the algorithm in DEA has been changed from Equation (6) to Equation (7) whenever T_{down} can be obtained from data. Meanwhile, to minimize inconsistent parameter input by users, MG provides an unambiguous interface which allows three options for defining the failure parameter for an exponential block: failure rate (λ), Mean Time Between Failures (MTBF), and Mean Time To Failure (MTTF), as shown in Figure 7. The interface explicitly reminds the user that λ is the reciprocal of MTTF, which is equivalent to Equation (7), (instead of the reciprocal of MTBF, which is equivalent to Equation (6)) to avoid inconsistent input.

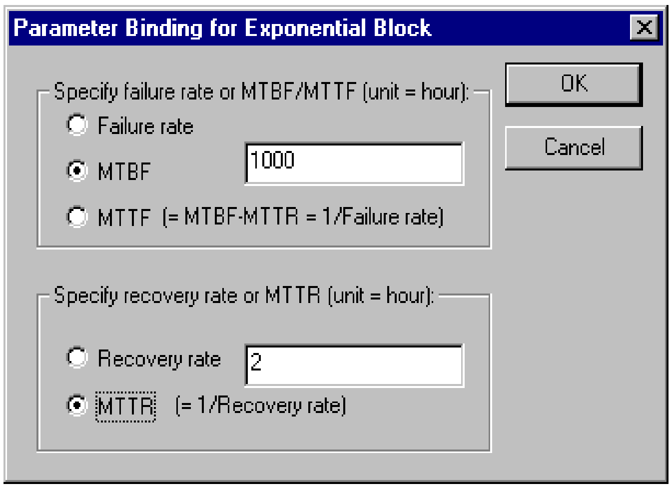

Figure 7 An Unambiguous Parameter Input Interface

The finding of this inconsistency indicates that the combination of data analysis and model evaluation in a single software package provides an easy means for validating parameter estimation and model evaluation algorithms. This is one of the advantages of the MEADEP approach: combining data analysis and modeling.

ACKNOWLEDGMENT

This work was supported by the FAA under Contract DTFA01-93-Y-0169, Subcontract 96-107. The authors thank Mei-Chen Hsueh for helpful discussions on the issue of failure rate, MTBF, and MTTF.

REFERENCES

[1] R. K. Iyer and D. J. Rossetti, “Effect of System Workload on Operating System Reliability: A Study on IBM 3081,” *IEEE Transactions on Software Engineering*, Dec. 1985, pp. 1438-1448.

[2] R. K. Iyer and D. Tang, “Experimental Analysis of Computer System Dependability,” *Fault-Tolerant Computer System Design*, D. K. Pradhan (Ed.), Prentice Hall PTR, Upper Saddle River, NJ, 1996, pp. 282-392.

[3] D. Kececioglu, *Reliability and Life Testing Handbook*, Vol. 1 & 2, PTR Prentice Hall, Englewood Cliffs, NJ, 1993.

[4] S. R. McConnel, D. P. Siewiorek, and M. M. Tsao, “The Measurement and Analysis of Transient Errors in Digital Computer Systems,” *Proceedings of the 9th International Symposium on Fault-Tolerant Computing*, June 1979, pp. 67-70.

[5] R. A. Sahner and K. S. Trivedi, "Reliability Modeling Using SHARPE", *IEEE Transactions on Reliability*, vol 36, February 1987, pp. 186-193.

[6] R. A. Sahner, K. S. Trivedi and A. Puliafito, *Performance and Reliability Analysis of Computer Systems: An Experimental-Based Approach Using the SHARPE Software Package*, Kluwer Academic Publishers, 1996.

[7] W. H. Sanders, W. D. Obal II, M. A. Qureshi, and F. K. Widjanarko, “The UltraSAN Modeling Environment,” *Performance Evaluation*, Vol. 24, No. 1, 1995, pp. 89-115.

[8] D. P. Siewiorek and R. W. Swarz, *Reliable Computer Systems: Design and Evaluation, Digital Press*, Bedford, Mass., 1992.

[9] D. Tang, M. Hecht, J. Handal and L. Czekalski, “MEADEP and Its Applications in Evaluating Dependability for Air Traffic Control Systems,” *Proceedings of the 1998 Annual Reliability and Maintainability Symposium*, Jan. 1998, pp. 195-201.

BIOGRAPHIES

Dong Tang, Ph.D.
SoHaR Incorporated
8421 Wilshire Blvd., Suite 201
Beverly Hills, CA 90211-3204
Phone: (323) 653-4718 ext. 104
Email: tang@sohar.com

Dong Tang received the PhD degree in computer science from University of Illinois at Urbana-Champaign (1992). He has been a Senior Research Engineer at SoHaR since 1993. He was a Visiting Research Assistant Professor at University of Illinois from 1992 to 1993 and a Research Scientist at the Institute of Computing Technology, Academia Sinica from 1983 to 1986. His research interests include performance and dependability measurement, modeling, and evaluation, software reliability engineering, and evaluation tool development. He was the architect and major developer of MEADEP. He has published over 25 technical papers and served on several international conference program committees. He is a member of IEEE.

Myron Hecht
SoHaR Incorporated
8421 Wilshire Blvd., Suite 201
Beverly Hills, CA 90211-3204
Phone: (323) 653-4717 ext. 111
Email: myron@sohar.com

Myron Hecht, co-founder and President of SoHaR, has worked in the areas of software and systems reliability. He directs SoHaR's support of Federal Aviation Administration in current and future air traffic control systems. He has also been active in nuclear reactor safety systems including development of programming guidelines for digital safety systems and the development of reliability analysis techniques. His activities in basic research and development at SoHaR have resulted in new architectures for real time distributed systems, methodologies for the development and verification of fault tolerant software, and he has also developed designs for highly reliable distributed systems for both process control and C^3I.

Abraham Rosin
System Resources Corp.
400 Virginia Ave. SW Suite C140
Washington D.C. 20024
Phone: (202) 488-9740
Email: abe_rosin@mail.hq.faa.gov

Abraham Rosin is the Lead Reliability Engineer for System Resources Corp. (SRC) where he is working on FAA Communication, Navigation, and Surveillance. Prior to joining SRC, Mr. Rosin worked for Rafael, the Armament Authority for the Israeli Ministry of Defense, for Elscint, a manufacturer of medical device equipment, the U.S. Navy Naval Engineering Support Center (NAVSEC) and the Naval Aviation Integrated Logistic Support Center (NAILSC). Mr. Rosin holds M.S. degrees in Reliability Engineering from the University of Arizona and in Quality Assurance from the Technion-Israel Institute of Technology and a B.S., in Aerospace Engineering from Northrop University.

Jady Handal, Ph.D.
Federal Aviation Administration
800 Independence Ave. SW
Washington D.C. 20591
Phone: (202) 267-3214
Email: jady_handal@mail.hq.faa.gov

Dr. Jady Handal is developing a full context enterprise performance analysis system that allows the FAA to make value centered risk based operating decisions.