Paper 44-25

MOTOROLA'S ENGINEERING DATA ANALYSIS SYSTEM:
10 YEARS OF ANALYTICAL EXCELLENCE

C. Michael Whitney & Leslie Fowler, Motorola, Austin, TX

ABSTRACT

In an effort to improve semiconductor product yields, an engineering data analysis application was developed in 1989 for engineers at Motorola's Advanced Products Research and Development Laboratory (APRDL). This application was called EDAS – the Engineering Data Analysis System. What began as a small text-based tool providing a handful of statistical reports used in one laboratory has grown to a large graphical system providing over 55 different analytical tools, used globally in Motorola's wafer fabrication plants and final manufacturing sites.

The SAS system has been used as the basis of the EDAS system throughout its ten-year history. Whenever SAS Institute releases a new version of the SAS system, EDAS is upgraded to take advantage of those new features. Currently, the Analysis & Reporting Tools team is evaluating SAS version 8 to determine which new features can be utilized in the next major release of EDAS.

SAS products discussed in this paper include SAS/AF, QC, GRAPH, STAT, and others. The intended audience is anyone interested in semiconductor data analysis.

INTRODUCTION

SEMICONDUCTOR OVERVIEW

Semiconductor processing begins with a bare silicon wafer and ends with a number of integrated circuits, such as microprocessors or memory chips. Wafers are processed together in groups called lots (generally 25 wafers), and range in size from 3" to 12" across. A photographic mask is used to lay out the pattern that is used to make the semiconductor chips. This pattern is called a reticle, and it's imprinted onto the wafer in a series of rectangles. Each reticle will contain one or more "die" – the die are the actual semiconductors that are being produced. Depending on the size of the chips being produced, the wafers could contain thousands of die. In addition to the reticles and die, test structures are built into the wafer in strategic places between the reticles.

During the manufacturing process, the lots of wafers are processed through many steps (100+). At each step, physical and electrical data may be collected from the test structures, as well as the individual die themselves, and the resulting test information is stored in a database. After all processing is complete, 100-1000+ electrical tests may be performed on a die.
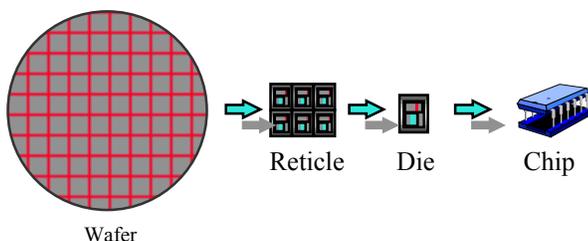

Figure 1 – Semiconductor overview

After the semiconductors have been created, the wafers are cut up into the individual die, and mounted into the familiar plastic casings. During this process, even more tests are run, and the resulting data stored.

HISTORY OF EDAS

By the late 1980's, the volume of data generated during the semiconductor manufacturing process required the development of a more powerful and efficient analytical tool. Manual analysis of the data proved too time consuming and error-prone. The software applications available to the engineers were outdated, or didn't provide enough functionality.

Work began in 1989 to provide a new application for the engineers for use in analyzing the engineering data in APRDL, where new chip designs and the processes used to produce them are developed. A text-based tool was developed, written in SAS v5.18, that provided a small suite of text-based reports and graphs. This application would eventually be called the Engineering Data Analysis System – EDAS.

In 1990, a project was begun to create a standard Oracle database in which the semiconductor test data would be stored and would be used by all Motorola semiconductor fabrication plants (fabs). This database and the software written to move the data in and out of it were named Synergy, and were coupled with EDAS in 1991. After this, the two applications began to be used in factories outside of APRDL.

With each major release of the SAS system, EDAS was updated to take advantage of improvements in the language and the development environment. The text-based interface was replaced with SAS/AF program entries in 1991, and AF/FRAME in 1996. In 1998, the latest major revision of EDAS was released, taking advantage of the features provided by SAS version 6.12. EDAS release 5.0 featured a new graphical user interface (GUI), and many new statistical analysis features for the engineers to use. 1999 saw EDAS being installed in many more locations throughout Motorola, as the final manufacturing facilities began to use it after a tool was provided to read in the Final Test database (FTDB) and binary data files. This allowed the final manufacturing sites, whose data comes from test devices that store their data in Standard Test Data Format (STDF) binary files, to be able to use EDAS in place of an older application that was no longer supported.

The design goals have always been to provide an interface to the engineers that wouldn't require any programming knowledge on their part. In short, an engineering version of SAS/ASSIST.

DATA

While EDAS can accept any delimited text file for input, the manufacturing data used by the system usually comes from two main sources: the Synergy database, and the FTDB database.

Physical and electrical data recorded during the wafer manufacturing process is stored in the Synergy database, which is based upon Oracle. EDAS users can extract the information via a Pro C and Motif interface, which stores the extracted data in several SAS datasets required by EDAS.

Physical and electrical data recorded during the final manufacturing process comes from the testers in binary files

using the industry standard Standard Test Data Format (STDF) files. The FTDB system records information about the contents of these files into an Oracle database. EDAS users can query the database, then acquire the proper STDF files and have them converted to SAS datasets using a SAS/AF application that is part of EDAS.

Any Motorola Synergy or FTDB database anywhere in the world can be accessed remotely, allowing engineers to analyze their products from inception to shipment, as parts move through various factories.

EDAS uses two datasets for its analysis. The first holds the information about the wafers and lots under test, as well as the test results data.   The second contains information describing each test – the values used, as well as any boundary, spec or control limits associated with each test that may be in the database.

USERS
Since it's an engineering tool, EDAS is used primarily by the engineers working in the semiconductor manufacturing and research facilities. Its primary use is yield enhancement. It provides the engineers with an easy-to-use tool that gives them a wide variety of analytical charts and reports with which they can view their data, and is used during the entire manufacturing process, from bare silicon through chip packaging.

EDAS currently supports three engineering communities. Device engineers work in the fab, and are responsible for the product through the fab and for yield enhancement and improvement efforts during this time. Final test engineers work in the Final Manufacturing sites where final test (tests performed after the die is packaged) occurs. Product engineers are responsible for a given product from first silicon to a packaged part. All these engineers want access to the engineering data and need analysis tools in helping them analyze products and improve yields.

THE EDAS SYSTEM
Written in SAS/AF, EDAS currently consists of over 100 AF/FRAME panels, and over 500,000 lines of SCL code. Despite its size, the system is easily maintained, as the developers followed a well-defined set of programming standards.   The system is highly modular – the SCL associated with each frame deals only with getting data from the user. It then calls a separate SCL module to do the functional processing via CALL DISPLAY and the 'entry' command to pass parameters in the form of SCL lists.   Further, generic utilities and statistical methods are often called via SCL 'method' entries.   Macro code is used throughout to handle repetitive chores such as data initialization.

With few exceptions, the entire SAS product line is used by EDAS. SAS/STAT, QC, and FSP are used extensively. All of the graphs are, naturally, handled by SAS/GRAPH.   Some graph customization is done via Annotate and the Data Step Graphics Interface.   SAS/Share is used to allow the users to share their datasets, which are stored in each user's personal account. EDAS also allows the users to call SAS/LAB and INSIGHT to analyze their data.

EDAS was initially written on the VMS platform. In 1992, it was migrated to Unix, and development of the system switched to Unix in 1993. Today, EDAS usage is almost entirely based on the Unix platforms (HP and Sun). SAS has made it easy to support EDAS on multiple platforms.   Recently, the user community has expressed some interest in having it migrated to the Windows platform, as well as a desire to see a web-based or web-enabled version of EDAS.

USER INTERFACE
While previous versions of EDAS used a single interface for interacting with the user, EDAS v5 uses multiple panels. The main interface is the menu bar, which consists of seven buttons, each of which displays a select list when the user clicks the button.   The lists are created from site configurable datasets, allowing the various factories to customize the features presented to the users, or even add new site-written capabilities to the system.

Figure 2 – EDAS main menu

Each analytical module uses a common look and feel.   Pull down menus offer access to various system settings, views of data, scripting options, etc.
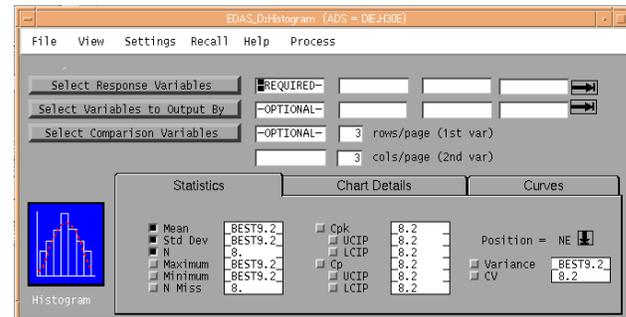

Figure 3 – A standard analysis frame

To make better use of available screen space, the SAS tab widget has been used throughout EDAS v5.

DATA HANDLING
In a perfect world, all data is good and clean, with no outliers to foul up statistical analysis, and all the variables needed are in the dataset.   Unfortunately, we don't live in a perfect world. Therefore, EDAS provides a wide array of tools to help the user get the most of the data.

The Data menu allows for the import and export of data. These functions include the two database extraction tools mentioned earlier, as well as a means of importing and exporting delimited text files. Data maintenance tools are provided, with the ability to copy, delete, append, merge, print and transpose the datasets. Options that affect the variables include allowing the user to add new or delete variables, format variables, and perform if-then processing on the data, which can add new or modify existing variables.

Specialized functions within the Data menu options include the ability to create "split" variables, limit tables, and parameter lists.

Make Split Variable allows the engineer to create a new variable within the dataset, providing a means of subsetting the data for analysis. This is called a "split" variable, as it is usually used to split the data up to match experimental processes that are run on

the lots during the manufacturing process, where parts of the lot receive differing experimental processes designed to improve yield.
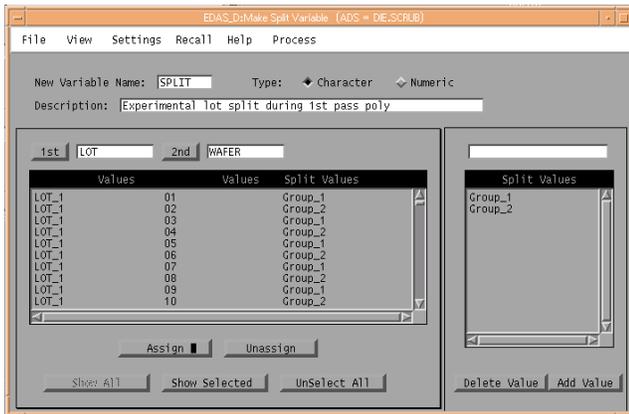

Figure 4 – Make Split Variable tool

As mentioned earlier, the parameter dataset can hold limit variables for each test variable. These include boundary (screening), control and spec limits, as well as target values. These limits may be extracted from the databases, or they may be hand entered. By default, the parameter dataset is used for limits, but custom tables can be created via the Limits Dataset Management tool.
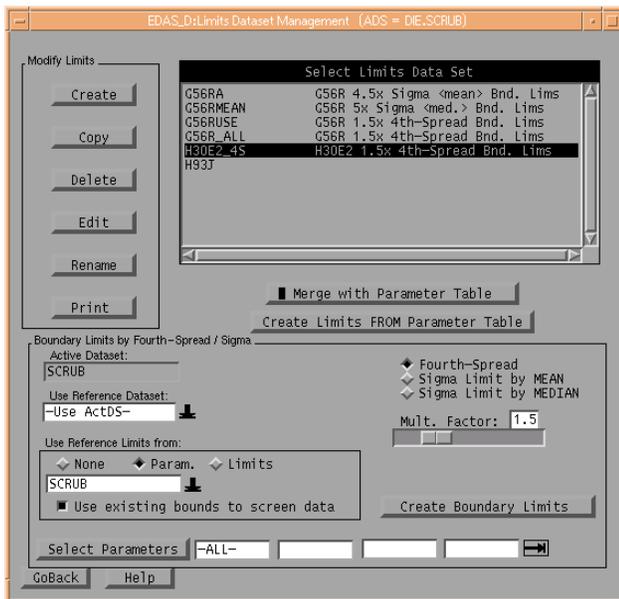
Figure 5 – Limits Dataset Management tool

The user can specify which custom limits tables to use in their analysis. EDAS will look in each table in the order listed, and use the limits for the first instance of the test parameter under analysis. EDAS v5 has the ability to generate boundary limits based upon the data, by using either the forth-spread method, or via sigma limits for mean or median, useful for removing outliers from analysis.

The Parameter List Management tool allows the user to store a list of commonly used variables. This is extremely useful when trying to choose which tests results to analize from a large list. Instead of hunting for each of them, the user can instead specify to use those from a saved parameter list, and they will be automatically selected.

ANALYSIS

The Analysis menu provides advanced statistical charts and graphs. Among these are the Analysis of Variance, Correlation Analysis, Descriptive Statistics, Probability Tests, Regression Analysis, and T-test.

The Analysis of Variance (ANOVA) tests for the significance of the effects of specified independent variables. For example, testing the effect a given piece of fab equipment has on yield. EDAS provides four types of analysis with this tool: standard ANOVA, multitivariate ANOVA, means comparison, and the Kruskal-Wallace nonparametric test.

The Descriptive Statistics tool generates a text report giving a broad range of detailed statistics, quantile statistics, and extreme values for a given test. In addition, it can also provide several text-based plots - stem leaf, box plot, and normal probability plot.
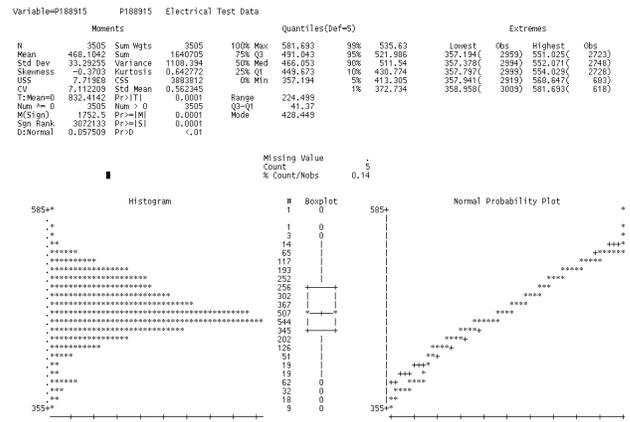

Figure 6 – Descriptive Statistics output

The Correlation Analysis measures the strength of the relationship between two tests, and is often used to find correlations between engineering tests. Its output is displayed as a text-based matrix table. It can provide Pearson, Kendall, or Spearman correlations.
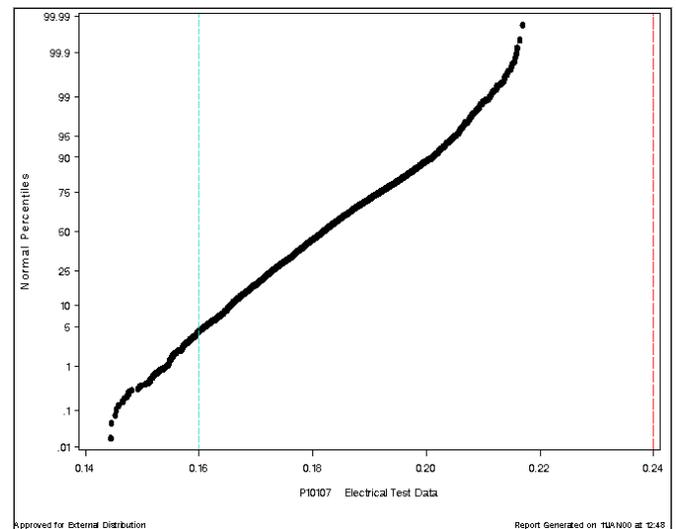

Figure 7 – Probability Test graphic output

The Probability Test graphically displays the data fit against a normal, lognormal, exponential, or gamma distribution and allows the user to visually see the fit of the data for a given distribution. It outputs both a graph, and Descriptive Statistics report.

The Regression Analysis tool fits regression models by using the least-squares method, handling both linear and multiple regressions.

PLOTS

This section provides such standard plots as Histograms, Bar Charts, and Scatter Plots, as well as several custom analysis tools designed to allow engineers to graphically examine test data at the wafer level.

These custom plots include the Bin and Parameter Wafermap Analysis, which visually present data either by individual wafers, or many wafers by a variety of composite wafermaps that graphically summarize the data at the lot level. Both make extensive utilization of the capabilities provided by the Data Step Graphics Interface to build custom graphs.
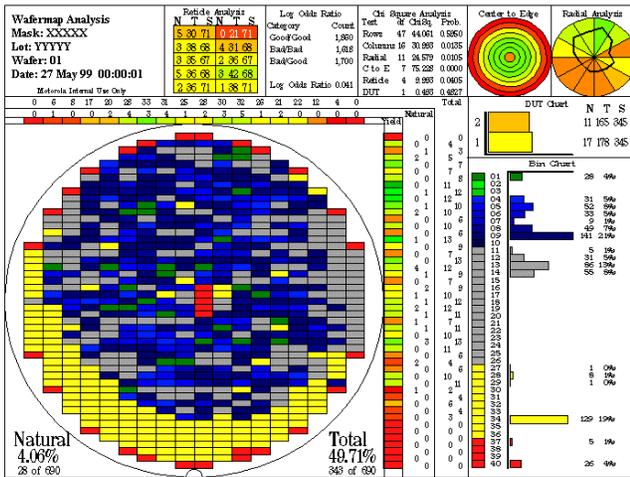

Figure 8 – Bin Wafermap Analysis graph

Previous releases of EDAS provided only the wafermap itself, displaying color-coded representations of the discrete groupings of the data, or in the case of electrical data, the numeric values.

The Bin Wafermap Analysis tool provides a great deal of information to the engineer:

- Yields, total and natural, by column and row - Memory components can be repaired by laser, greatly improving yields. Thus a "natural" yield for non-repairable and un-repairable parts, and a "total" yield that may include repaired die.
- Reticle Analysis - if a particular die location in a reticle fails often, this could be indicative of a problem in printing the photo-mask upon the silicon.
- Chi-Square - uses chi square statistics to determine the probability of a problem existing in a particular Bin Wafermap analysis.
- Center-to-Edge - Also known as a ring analysis, the data is grouped in rings from the center of the wafer to the edge. This can show problems in the manufacturing process where chemicals are applied to the wafer in an uneven fashion.
- Log-Odds - analyzes the relationship of each die in relation to those surrounding it, and tells whether the relationship is dependent or independent. Research has shown that this test isn't as valid when yields are sparse. The Chi-Square test has been shown to be a more consistent indicator of patterns. This test will be removed in the next release.
- Radial analysis - Data is grouped in pie-shaped sections, and like the Center-to-Edge, it could reveal problems in the manufacturing process.

- Device Under Test (DUT) - Could show problems with the testing equipment if the number of tests performed by each head on the tester isn't identical.
- Bins - When individual die are tested, the results are grouped by category. These bins are depicted graphically in a wafermap, with an accompanying frequency count column on each graph. Patterns in the wafermap could be indicative of physical defects caused during the manufacturing process, such as scratches, gas discharges or other particle-caused defects, mask problems, etc.

The Bin Wafermap Analysis tool can also display single wafers, percent yield, modal, difference and directional wafermaps.
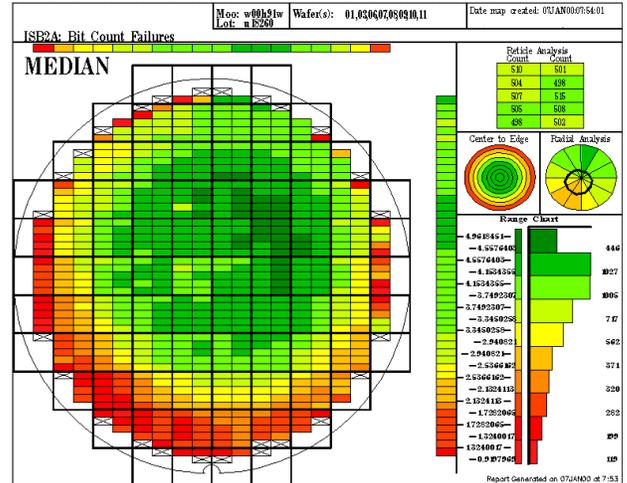

Figure 9 – Parameter Wafermap Analysis graph

The Parameter Wafermap Analysis tool is quite similar to the Bin tool, but works with the data collected from the inter-reticle test structures on the wafer. Instead of discrete bin data, the tests examined here are various electrical results.

TRENDS

Most of the Trend menu options allow the user to generate control charts, or graphs used to determine whether a process is in a state of statistical control. Several of the more popular options are the Cumulative Sum Chart, Multi-Vari Chart, and the X-Bar series.
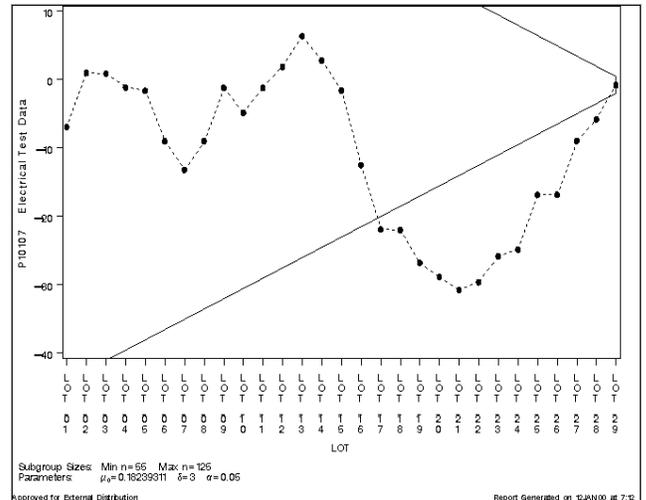

Figure 10 – Cumulative Sum Graph

The Cumulative Sum Chart is a non-Shewhart control chart in which the deviation of the current data point from a reference value is added to the sum of the previous deviations, and this sum is tested against the appropriate control limits. Each point on a CuSum chart is based on information from all samples up to and including the current subgroup. By comparison, the points on a Shewhart control chart stand for each individual subgroup. For this reason, the CuSum chart is more efficient in detecting small shifts than Shewhart control charts.
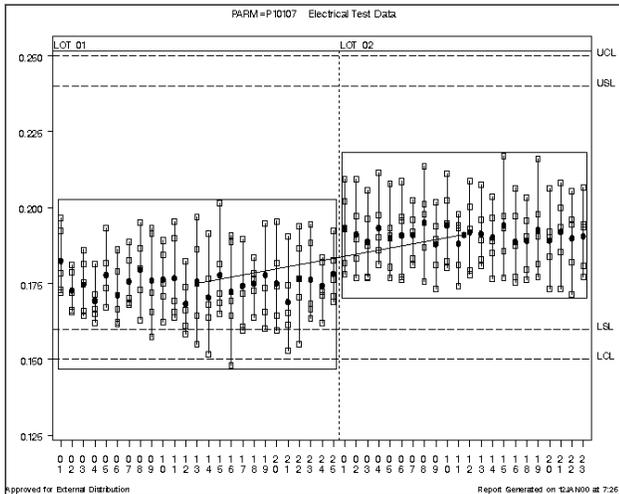

Figure 11 – Multi-vari Graph

Another extremely useful graph provided by EDAS is the Multi-vari (a semiconductor abbreviation for "multiple variable"). Most often, the data is grouped by wafer and lot, giving the engineer a very good visual representation of cross-wafer variation in the data, as well as wafer-to-wafer and lot-to-lot variations. Previous versions of EDAS used an algorithm developed in-house to generate these graphs by using Proc Plot with a lot of symbol statements. EDAS v5 uses the SAS/STAT Proc Shewhart's boxchart capabilities to create this.

Figure 12 – X-Bar S Graph

EDAS provides three X-bar series graphs - the X-Bar, the X-Bar S, and the X-Bar R. These are standard variable control charts that plot subgroup averages. The X-Bar R adds subgroup ranges for the given response variable, while the X-Bar S adds standard deviations. Each of these charts can have any or all of the eight Western Electric control tests plotted on them, as well.

REPORTS

Four standard reports are available via the Reports menu - the Capability, the Three-Way Summary, the Summary, and the Wafer Summary reports.

Figure 13 – Capability Report

The Capability report is a textual report, and can optionally output a boxplot of the data as well. It provides a wide range of summary statistics (mean, std dev, quartiles), counts (number of rejects, number less than the lower spec limit, number higher than the upper spec limit, and the percent within spec), various limits, and Cp/Cpk information, including confidence intervals for Cp/Cpk.

The Three-Way Summary report provides summary statistics grouped at three levels and in a tabular format. The Summary report is similar to the Three-Way, but provides its results in a list format as opposed to a tabular one. It also gives the greatest flexibility in subgrouping and statistics calculated.

Finally, the Wafer Summary report generates summary statistics for wafers and overall for a lot. This is similar to the Summary report, but is specifically tailored to subgroup only by lot and wafer. It will also determine which wafers fail to meet in-spec criteria.
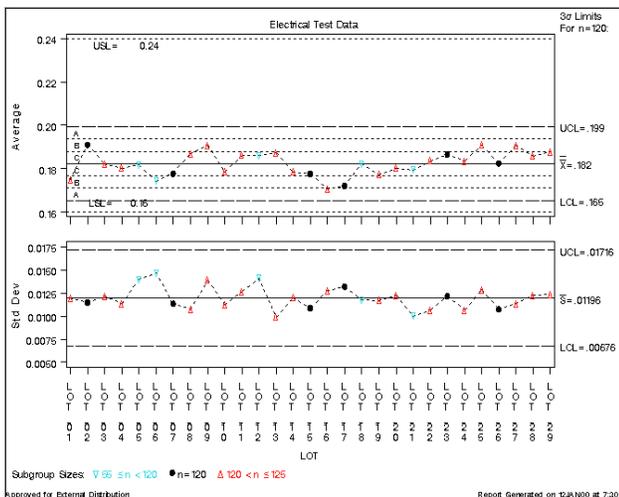

Figure 14 – Three Way Summary report

Figure 15 – The Wafer Summary report.

```
                                                                 Coeff.
Parameter Description            Parameter  LOT  WAFER    Mean      Std Dev   of Var.  Num Obs
Electrical Test Data             P10107     LOT_01  01   0.1824854  0.01131341  6.19962693      5
                                            LOT_01  02   0.1728036  0.00702123  4.06312555      5
                                            LOT_01  03   0.1746648  0.00945387  5.4125765       5
                                            LOT_01  04   0.1693396  0.00752277  4.44241488      5
                                            LOT_01  05   0.1778846  0.01006559  5.65849352      5
                                            LOT_01  06   0.171218   0.01086028  6.34295311      5
                                            LOT_01  07   0.1757276  0.00935162  5.32165667      5
                                            LOT_01  08   0.1795642  0.01234436  6.87462164      5
                                            LOT_01  09   0.1760102  0.01503048  8.99366166      5
                                            LOT_01  10   0.176421   0.01073679  6.08589191      5
                                            LOT_01  11   0.1768318  0.01469909  8.31247134      5
                                            LOT_01  12   0.1683046  0.00981856  5.83103327      4
                                            LOT_01  13   0.175848   0.01929067  10.9825706      5
                                            LOT_01  14   0.1704498  0.01477988  8.67110592      5
                                            LOT_01  15   0.177782   0.01464552  8.23790957      5
```

Figure 16 – A portion of the Summary report.

THE OUTPUT MANAGER

A separate SAS-based application, the Application Output Manager (AOM), handles all of the output from EDAS. EDAS registers its output files upon completion of the requested analysis, and then the Output Manager presents the output to the user. EDAS allows the user to configure the system to not display the output, instead just registering it for future viewing, or sending it directly to a file or printer.
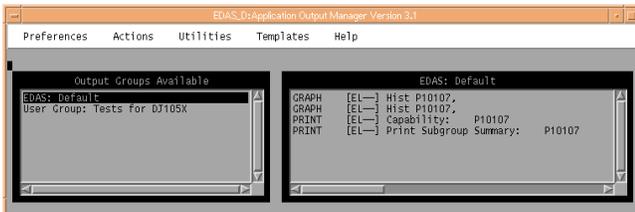

Figure 17 – The Application Output Manager interface

The AOM allows the user to view, print or save their output, as well as convert it into GIFs or HTML files. All output can be stored in a temporary default group, or into a user-created one. Further, the AOM provides for the configuration of multiple printers, giving the user choices in where and how the output is printed.

In addition, the AOM supports the printing of multiple graphs per page (user specified), and the creation of custom page layout templates

SCRIPTING AND RECALL LISTS

A very useful feature of the EDAS system is the ability to capture the SAS code generated by the SCL routines, and store it in the form of scripts for later use. When each script is saved, the user's printing preferences are captured as well, and stored in a like-named SAS catalog as saved lists. These scripts can then be run interactively from within EDAS, allowing the user to specify alternate datasets to use, or via command line. Further, the engineers extracting data from the Synergy database can use that system's Scheduler, which stores the user's extraction queries and links them to a given EDAS script via a point-and-click interface. The user then specifies a time and frequency for when to run the linked query and script. This allows the user to get standard reports for her data every morning when she walks in the door.

Each EDAS frame also allows the state of the widgets and the contents of the text entry fields to be stored, providing a very convenient method for repeating experiments without having to reconfigure each analysis from scratch every time. The user simply loads a list containing the previously stored settings, which re-populates the panel with that information.

THE FUTURE OF EDAS

Enhancement requests from the engineering community continue to arrive at a steady pace. As the usage of EDAS expands, so does the need for new capabilities and for variations to the current analytical tools. The development team will continue to meet the needs of the Motorola engineering community by modifying the system as needed.

EDAS' role is shifting slightly to that of an ad-hoc analysis tool, as the Analysis and Reporting Tools development team rolls out a new product specifically to produce engineering data reports, the use of which requires a less steep learning curve on the part of the engineers.

Currently, EDAS v5 runs under version 6.12 of the SAS system. Due to the diverse methods used to create the system, EDAS has not lent itself to being migrated to SAS v7 easily. The decision was made to wait for the release of SAS v8 and handle all the migration issues at that time, instead of going through both 7 and 8.

EDAS and the Output Manager will both benefit from the new features provided in SAS version 8. The SAS Output Delivery System (ODS) will have a dramatic effect on the Output Manager, especially in its ability to create style sheets and HTML-formatted output for easy insertion into web sites, or rich text format for easy inclusion into text documents and manuals. Enhancements to AF/Frame should allow improvements to be made in the user interfaces, and new features SAS has provided to their statistical methods will give greater flexibility and power to the tools provided to Motorola's engineering community.

Beyond SAS version 8, the development team is looking at two different methods of client/server access to EDAS: WebAF and Enterprise Guide – two new tools from SAS. Using either tool would require some re-writing of EDAS. WebAF is a tool created by SAS which provides a method of using the existing SCL code via a Java interface, and allow its use over the company Intranet via Java clients or applets on the user's PC or browser. Enterprise Guide is a thin client running on the user's PC and has the ability to access any SAS server on the company Intranet, providing JMP-like capabilities. Adapting EDAS to use Guide as the user interface has the advantage of being able to provide the engineers with EDAS v5's analysis capabilities, as well as the improved graphics, flexibility, and ease of use provided by Guide.

CONCLUSION

In conclusion, EDAS has been, and will continue to be, a highly valuable software tool for Motorola. Semiconductor engineers around the world rely on it to improve their products, and continually seek new capabilities and enhancements in the system.

ABOUT THE CODE

EDAS was developed in-house by Motorola, and is considered to be a intellectual property of Motorola. We regret that we are unable to share our application or any of its source code with anyone.

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CONTACT INFORMATION

Your comments and questions are valued and encouraged. Contact the authors at:

C. Michael Whitney
Motorola SPS
7700 W. Parmer Lane
Austin, TX 78729
Work Phone: (512) 996-7151
Fax: (512) 996-7148
Email: Michael.Whitney@motorola.com

Leslie Fowler
Motorola SPS
7700 W. Parmer Lane
Austin, TX 78729
Work Phone: (512) 996-4244
Fax: (512) 996-7148
Email: L.Fowler@motorola.com