Semi Standards

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Hello, my name is Thomas Bzik. I'm a research associate in the Statistical Sciences section of the Computational Modeling Center. I work at Air Products and Chemicals and I also chair the Statistical Methods Task Force in Semi Standards. Today's talk is going to have 5 sections to it. First, we're going to talk about the motivation as to why develop a Ship-to-Control Standard. We'll talk about the activities of the Semi Standards Statistical Methods Task Force. We'll talk about the underlying data and statistical issues in developing such a standard. We'll briefly describe the Semi Standard Statistical Methodology and the last subject will be the likely impact on the industry.

Why should we develop an Industry Standardized Procedure for ship-to-control? There are a variety of reasons. Device manufacturers want to reduce the variability in incoming materials to obtain less product variation. It is part of the ITRS roadmap. In general, SQC and SPC practices are inconsistent from company to company. We're pushing SQC and SPC methodologies into new territory. They're used as specifications, not just as control limits and supplier use of SQC and SPC will result in Continuous Improvement. Industrial Statistical Quality Control and Statistical Process Control Practices are inconsistent. Companies use differing sets of rules as their statistical practices. In fact some companies are even inconsistent in their practices internally from either factory to factory or division to division.

In Air Products experience, we've not had any customers ask us for the same ship-to-control method. The practices are that different when you get down to the details. The substantial differences imply potential for product fragmentation, higher cost associated with product fragmentation, and potentially product availability issues also associated with product fragmentation. In general any difference in statistical methodology will provide a different ship-to-control specification.

The historical use of SQC and SPC in the industry has been in a transition stage going from soft to hard. In the soft mode we used SQC, but we did not make product acceptance or rejection decisions based upon the control limits. Because it was used in a soft manner, problems with common SQC statistical methodologies have largely been ignored and will need to be addressed in ship-to-control. In a hard mode of using statistics, product would be accepted or rejected based on the statistical quality control limits. We can no longer ignore these problems if we're going to make product acceptance or rejection decisions based on statistics.

In general, whether we use quality control in a hard or soft manner, there's going to be a root cause analysis, possible supplier and producer discussion, quarterly or semi-annual reviews, and annual audits. Those things don't go away, in any case, they are still there, but now we're going to make a much harder use of control limits. The electronics industry is pioneering ship-to-control; the use of quality control limits to specify product.

The effort to develop a standardized procedure for ship-to-control was headed up by the Statistical Methods Task Force in SEMI Standards. SEMI Standards is the primary standards making organization for the electronics industry. The task force started its activities in December 2005 and met on a very aggressive schedule, typically on a weekly basis to accomplish this. The task force had extensive participation from both suppliers as well as device manufacturers.

The SEMI Statistical Guidelines for Ship-to-Control which is now a SEMI Standard was balloted as a SEMI Standard in Fall 2007 and was published as a SEMI Standard in February 2008. The task force still has some remaining cleanup activities with respect to the standard. We need to make the Method Detection Limit Guide more consistent with the Ship-to-Control Guide in terms of its practices and we also need to determine how to best make ship-to-control software available to the electronics industry.

In developing the standard, the task force had to deal with many data and statistical issues and this guide that has been developed addresses most of these issues. Which data do we use? What frequency should this data be collected with and evaluated? How do we calculate the control limits? Which adjunct statistical quality control rules, if any, do we use? How should data problems such as outliers be addressed? The use of ship-to-control limits as specifications will require fully defined answers to these questions. Some of the statistical issues that had to get resolved include: How do we handle data censoring? How do we handle data when we censor to a method detection limit? When someone censored something to 100% when they measure a value higher than it or a 0 when they measure a negative number? How do we handle non-normally distributed data? How should seasonality be treated? What should we do about a process change? How do we account for multiple tests when we may be testing on 30 or 40 properties simultaneously? How do we treat an out-of-control data point? In standard Statistical Quality Control, a control chart is a time ordered plot of process data which illustrates the process average as a center line and upper and lower control limits which are traditionally 3 sigma or 3 standard deviation limits. It is a useful visualization tool.

Associated with control charts, there are 2 types of errors we can make with respect to product—Type 1 errors and Type 2. A Type 1 error is the percentage of product from an in-control process that is declared as being out-of-control. It should be considered as the supplier’s risk, the false alarm rate that they will declare product out of control that is actually in-control. And in general, it is easier to control than the Type 2 error in a statistical framework. Type 2 error is the percentage of time out-of-control product is not identified as being out-of-control. It can be thought of as the producer or device manufacturer's risk. Its calculation requires you to know how out-of-control the product actually is and, in general, in statistical methods one tries to minimize the Type 2 error when they achieve a fixed level of Type 1 error.

In electronics, the measurement of multiple product properties is typical. Often there are 10 to 40 simultaneously specified product properties for many electronics materials. If we fail to account for the overall risk of all these tests being simultaneously executed, we will end up with a cherry picking exercise where while we may have a low false rejection rate for each product property, the overall collection of 40 such rates adds up to a number that could be as large as 20 or 30%. For a given overall product level of Type 1 or Type 2 error, the more properties we specify, we will have less error of that type to apply to each individual property.

Another issue impacting electronics data is the common practice of data censoring. One type of data censoring involves detection limits—a measured result below a detection limit in some sense is judged as too unreliable in a statistical sense. We don't trust the measurement because our measurement gauge isn't capable enough and sometimes we can't even quantify a result below the detection limit, for example when we do not obtain any measurable signal. An example of a censoring with a detection limit of 10 parts per billion and result of 5.7 parts per billion was measured; this result would often be reported either as less than 10 or just perhaps as 10.

Consider an example of the impact of data censoring. This example is going to show on average half the data being censored. We're going to assume that there's an in-control distribution that has a method detection limit of 10. The average value obtained is 10. The standard deviation is 3 and it's following a normal distribution which the blue line above the green and red bars is illustrating.

Before the application of the method detection limit, the average is 10, standard deviation is 3, R-bar would be 3.4—the upper control limit would be 19. If we then apply the detection limit, we basically take away all those bars on the left hand side, they have all been set to 10 in terms of how it's typically treated and now that left half of the distribution has disappeared and we have a concentration of probability on the left hand side of the new distribution. If we then calculate the statistics again on the newly censored data, we would get an average of 11.2, a standard deviation of 1.8, an R bar of 1.7, and an upper control limit of 15.7 when nothing had changed. The real upper control limit is still 19, but yet the data censoring made us erroneously calculate it as 15.7. Having too low a detection limit exacerbates the chance of falsely finding a point out-of-control. The SEMI Statistical Methodology basically addresses all of these issues and provides a methodology for calculating upper or lower control limits that target control of the product Type 1 error at 1%. This product Type 1 error is the risk that future in-control product, product that is truly in-control, will fall outside the control limits for that product. In its calculation the SEMI Method corrects for sample size, the number of measurements to calculate the control limits from, the number of parameters being simultaneously specified, method detection limit censoring, and it also corrects for non-normally distributed data. The SEMI method assumes that the historical process data is representative of the process; that it's a real snapshot of the data from that process. If the supplier's process is unchanged, it will reject on average the 1% of the future most statistically extreme values from whatever production distribution existed historically. If a supplier’s process changes, however, if the process goes out-of-control, the SEMI Method can reject any percentage of the product all the way up to and including 100%. Air Products in-control offering makes use of the SEMI Method.

The SEMI Statistical Methodology differs somewhat from traditional Statistical Quality Control. Typically, an upper control limit is expressed as the average plus 3 standard deviations. The SEMI limit form is very similar; it's the average plus a factor W times the standard deviation where W can be equal to 3 or can be larger as necessary. Essentially this larger multiplier, W is potentially a function of sample size based on normal theory, the number of parameters being specified, and the degree of data skewness or non-normality. Obviously in the equations on this slide, one could replace the plus sign with a minus sign to define a lower control limit.

The SEMI equation is expanded out for you to see. I'm not going to talk about any of the pieces of this other than the expansion of W itself which makes use of a t statistic and Skewness Correction factor abbreviated SC. This calculation is used in conjunction with an annual review methodology: When do we change limits? Should limits be changed? Should they be left alone? This subject is not developed as part of this slide set.

The SEMI Method was tested extensively with real data. We evaluated not only the SEMI Method, but 4 common traditional methods of trying to define ship-to-control specifications on data from 18 products from 11 member companies. We tried 3 Sigma Control Limit Methods; two of these were used. One approach used the overall standard deviation to calculate sigma; the other used the range-based estimate of Sigma (an R-bar type individuals control chart). We also used the historical maximum in the training set to set the upper control limit and we also tried using the 99th percentile for each product property as a mechanism for setting the upper control limit and we used the SEMI Method.

These statistical methods were tested by using 2 years of product data. The first year of data was used to establish or estimate the control limits. The second year of data was used to test performance to the control limits. The results were as follows: For the SEMI Method a 2.6% rejection rate was seen. For the use of 3 sigma control charts, if the overall standard deviation was used, 25% of future product would be rejected or if a R bar control chart was used 42% of future product would be rejected using those ship-to-control limits. If a historical maximum was used almost a 21% rejection rate would be observed and if the 99th percentile was used a 25.5% rejection rate was noted. The simple alternative statistical methods gave very high product rejection rates and they basically imply since these were viewed as stable processes from these 18 products, that essentially a statistical cherry picking scheme would result from use of such simpler methods. This helped us establish that the SEMI Method was, in fact, a more useful way of actually testing for out-of-control product.

We also tested the SEMI Method more extensively on a larger set of data from 16 companies on 34 products and that gave a 2.8% average rejection rate. In general these results were theoretically expected and they were actually the driving force for the task force to develop the SEMI Ship-to-Control Methodology. It was the inability of the simpler methods to be applicable to this problem that made us devise the SEMI Method. Obviously the SEMI Method's formulas are not something you'd want to be calculating by hand. The task force itself used an Excel spreadsheet for testing. There is a Windows application that is under active development. This application can be requested and it will be provided when it becomes available which should be in the relatively near future. The Excel spreadsheet can also be requested, but is not supported.

Additional education on ship-to-control would be beneficial. There's a link that provides a detailed Ship-to-Control Tutorial that was provided at SEMICON West in 2007. It's ever so slightly out-of-date, but it provides a much more detailed review. The task force functioned very strongly as a team and approached its task as an iterative problem-solving effort. Many ideas were tested. The ones that worked best were developed further and tuned to give the type of performance that was needed on real industrial data. The task force revisited key issues in detail. It was a highly cooperative effort. There are a lot of ad-hoc sub-groups to explore particular issues and the task force is confident that their intensive data-based effort has resulted in a reasonable Industry Standardized Methodology.

There will be a variety of benefits that accrue from using this methodology. Standardization reduces the need for customer specific ship-to-control specifications. It minimizes material variation as much as is feasible without cherry picking a process. It minimizes incoming material variation and will make producer processes more stable. Out-of-control supplier processes will be expensive for the supplier. Good SQC and SPC Practices result in better supplier processes and Continuous Improvement. Device manufacturers will receive the best grade of material that a given supplier's process can consistently produce.

I want to thank you for listening to this talk and if you have questions, you can call me at 610-481-6650 or you can e-mail me with questions at bziktj@airproducts.com. Thank you very much.