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How Technical Standards Are Developed For Global Engineering And Manufacturing Organizations

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How Technical Standards Are Developed For Global Engineering And Manufacturing Organizations

by

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Thesis

Presented to the Faculty of the Graduate School

Of the University of Texas at Austin

In Partial Fulfillment

Of the Requirements

For the Degree of

Master of Science in Engineering

The University of Texas at Austin

August 2010

Dedication

This paper is dedicated to my husband Robby and our son Camren. I love you.

Acknowledgements

I would like to thank my advisor Dr. Seepersad for her time and advice while I was writing this paper. I would also like to thank Enrique Garza, Gregg Verdict, and Saru Balakrishnan for their time given for the interviews that gave this paper its direction.

Finally, I would like to thank my husband and parents for their input during the paper's editing phase. Your contributions made it a much better piece of work and something I am proud of.

How Technical Standards Are Developed For Global Engineering And Manufacturing Organizations

by

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The University of Texas at Austin, 2010

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This paper explores how corporations can choose technical standards used throughout its organization. A methodology for choosing the standard is introduced. It is based on the methods that professional standards organizations use to create new standards for industries. The steps to choose an external standard as well as create new internal standards are consensus, development, approvals, and maintenance.

Questions about standards from Applied Materials are answered: what technical standard should be used for engineering drawings, should the company use metric units, what tolerance scheme should be used, and how are standards chosen when a merger or acquisition is performed? Applied Materials should use the ASME Y14.5M-1994 standard. The move to metric should be done if the customers request it. Simple parts and complex assemblies should not be toleranced the same way. When mergers and acquisitions are done, the consensus, development, approval, and maintenance method should be used to choose which standards should be used.

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Chapter 1. Introduction

The primary objective of this thesis is to propose a methodology for corporations to develop technical standards. That methodology will be used to provide recommendations on how to choose a technical drawing standard, a tolerancing scheme and also choose between metric and English units for technical drawings.

Section 1.01 Problem Context

Applied Materials is a manufacturer of semiconductor fabrication equipment. In multiple recent cases the technical standard for a part was not clearly defined, resulting in costly delay and wasted resources.

The first case involves a new product. Several threaded holes were being stripped during integration of the standing feet onto a sheet metal enclosure. Those holes were stripping because the threaded hole was a metric size, and the feet were English unit screws. The English fasteners were not the correct size for the metric threads installed on the parts. Each time a foot was installed on the sheet metal enclosure, the threads would strip out and would need to be retapped. As a result, several of these holes were retapped with English threads before the manufacturing engineers learned that the holes were intended to be metric. Time was wasted while the holes were tapped a second time with the proper hardware, and material and labor resources were wasted for the rework performed. The time wasted put the system in danger of late shipment to the final customer.[1]

The second case observed at Applied Materials involved bringing a new outsourced assembly to manufacturing to be tested for the first time with the rest of the system. Three representatives from the vendor in Japan and one software engineer from India were brought to Austin for this pilot test. When the assembly arrived and was integrated with the system, engineers discovered that the air connections were 6mm fittings instead of the 0.25" fittings used in the manufacturing facilities. More time and money were wasted trying to find a converter piece from a local vendor. The size of the facilities connections to be used on the assembly was stated in the assembly drawing, and no one on the product team had followed up with the supplier to ensure the facilities connections on the new assembly were English. The Japanese vendor had assumed that using a metric equivalent would satisfy the requirements for the facilities connection.[2]

Other examples of standards issues have occurred with existing products. Parts outsourced to Asian suppliers had difficulty being produced with the standards used on their drawings. The vendors claimed that they were not able to make the parts with English units because metric is their customary standard. Therefore, when quote packages were created, they included extreme markups for building the assembly using English units. The rationale was that the conversion work for hand tools and machine tools was very expensive and Applied Materials needed to pay for the extra tooling. Applied Materials representatives always pushed back on the suppliers to make them produce the parts without converting the drawings to the metric standard and without the additional cost for tooling.[3]

A final component of the problem involves companies that have been purchased by Applied Materials. The company has moved into the solar business by acquiring companies that have already developed related technology. These companies are typically European and their drawings use metric and ISO standards as opposed to the English and ASME standards that Applied Materials engineers use. When new companies are purchased, the typical agreement is to keep the drawings "as is," yet issues have occurred as a result of Applied Materials engineers' unfamiliarity with the European standards. One problem arose at a customer site because a European ergonomics standard was not called out on the drawing, and the customer refused the shipment. A comparable US standard was found, but could this customer issue have been avoided with better communication about the different standards expected between the United States customary standards and European Union standards?[4]

To summarize, Applied Materials has had problems assembling parts because the supply base did not follow the same technical standards. Furthermore, technical standard mismatches between Applied Materials and companies it has acquired outside the United States have also negatively impacted products and customer satisfaction.

Section 1.02 Research Questions

There are several questions that need to be answered as a result of these incidences. How do corporations choose technical standards? How have corporations dealt with issues such as the conversion from English to metric units? What tolerance method should be used if the technical standard changes? Whose standard becomes the new corporation standard when companies are acquired?

Section 1.03 Thesis Outline

The questions for this thesis will be answered in four phases.

The first phase will be a literature review of material showing the extent of issues with standards in other industries. Then an Applied Materials case study will be introduced. This case study describes research conducted at Applied Materials regarding how its engineering drawing standards were contributing to a rise in materials costs. This discussion will be revisited at the end of the paper as a summary to show how the research throughout this paper can be used to answer the questions posed by the problems at Applied Materials.

The second phase will be a review of standards development from professional engineering organizations. Recommendations will be made for a process of choosing external standards and developing internal technical standards in a corporate setting.

The third phase will detail how other corporations have dealt with developing standards by analyzing how they made the transition from English units to metric.

The final phase will draw conclusions from the previous phases and will discuss potential solutions to the questions posed regarding choosing a technical standard. The Applied Materials questions will be revisited and answered using what was learned from the research in this paper. The questions that will be answered in the case study are:

- What technical standard should be used?
- Should the company move to metric units?
- What tolerance scheme should be used?
- How are standards chosen when a company is acquired?

Chapter 2. Problems Created by Standards

Section 2.01 Introduction

There are some well known cases of confusion among groups about the units used for a technical task. The most infamous mistake with units at NASA will be related. Then the Applied Materials case study will be introduced. Finally, a summary of the problems and the questions that need to be answered to solve the problems will be provided.

Section 2.02 History – NASA

The most notable problem with units occurred at NASA in 1999. A climate orbiter that was heading to Mars lost communication with the Jet Propulsion Laboratory. The investigation into the failure discovered that designer Lockheed Martin was sending the daily thruster data used for steering the orbiter in pounds, while the NASA navigation team was expecting the data in metric units. The result was an orbiter 60 miles off course and subsequently crashed somewhere in the Martian atmosphere. The cost of the failed mission was $125 million and a damaged reputation for NASA as the House Science Committee Chairman F. James Sensenbrenner, Jr., sounding stunned, released a two-word statement after hearing the news about the miscommunication: "I'm speechless." [5]

More recently, in June 2009, NASA decided to not move forward with using metric units. Converting the relevant drawings, software and documentation to the International System (SI) of units would cost a total of $370 million – almost half the cost of a 2009 shuttle launch, which costs a total of $759 million. NASA has received a lot of criticism for this move, most saying that it is hindering a global standard from being attained. In 1988 NASA had agreed to US legislation that stated all government departments needed to move toward using SI units, so this change is a retraction in previous policy.[6] Yet the cost of converting drawings and updating old equipment cannot be ignored. Furthermore, if a standard has not been implemented fully after 21 years, it may be better to redirect the engineering attention to other areas, such as continuing work on the International Space Station or landing on Mars.

Section 2.03 Applied Materials Case Study

Applied Materials is a multinational semiconductor fabrication equipment company with office locations in 21 countries.[7] There are many different regional standards being used, such as JIS in Japan, in addition to the differences between English and metric units.[8] Because of the globalization and outsourcing activities, there has been internal research to determine what technical drawings standards Applied Materials should be following.

Beyond globalization and outsourcing, in 2007 engineering management was being pressured to make a change in technical standards because of an increase in discrepant material costs. Examples of such discrepant material were poorly welded parts and assemblies that could not be integrated due to tolerance stack misalignments. The problems with the parts were being blamed on poorly created engineering drawings. As a result, the manufacturing engineering council asked that presentations be given to determine if a shift was needed from ASME Y14.5M-1994 to ISO and from English units to metric units. The general assumption was that changing to ISO from the current ASME standard would fix the problems with the engineering drawings.

Therefore, the council had two questions: what should the new standard be, and how should it be implemented?

The first presentation concluded that ISO standards with metric dimensions would be the best way for new drawings to be created.[9] This conclusion was based on the number of countries converted to metric and the fact that the United States was in the minority.[10] It also indicated that ISO was a good fit for the types of dimensioning done at Applied Materials, and that it was very similar to the ASME standard being used.[11] The only problem presented with converting to ISO is that the CAD package employed did not support both ISO for new products and ASME or other standard for legacy products.[12] This presentation concluded by saying that training needed to be rolled out for all engineers and implementation plans needed to be created.

Unfortunately, this first presentation did not cover problems Applied Materials would have with moving part design to ISO standards and metric dimensions. Furthermore, the presentation did not try to answer the question of any monetary benefit in reduced discrepant material costs. It was seeking to only determine which standard Applied Materials' designers should employ moving forward, and based on the information presented, ISO and metric were the right answers.

When other senior engineers heard about the decision to change the technical standard, they requested to investigate the issue further and provide another presentation to the council. Several months after the first presentation, this second presentation called for the reversal of the decision to move to ISO and metric. There were several points made about changing the technical standard, the cause of the discrepant material, and the cost of changing standards.

This presentation showed that ISO would not allow geometric dimensioning and tolerancing (GD&T) to be used to call out the critical dimensions for the parts Applied Materials creates. ISO is intended to be used for high volume low complexity parts, not the large complex assemblies that are found in Applied Materials designs.[13] This presentation answered the question about discrepant material by claiming the problem was not with the technical standards being used, it was the application of the tolerancing scheme that caused the problems with the parts. The parts were good parts meeting a bad print.

Furthermore, the presentation showed that there were standards in place to move from English to metric that would help for sourcing in low cost regions.[14] The Drawing Requirements Manual could be used as a standard for converting dimensions from English to metric.

Finally, the cost of training the design engineers in a new standard would be extremely high, equivalent to teaching them all a new language.[15] The cost of implementation was estimated to be $450,000 for 1000 people worldwide to initially learn the ISO standard. This presentation also estimated the efficiency loss for the technical staff would be 5% a year as a result of changing to a new standard, plus a large budget of would be needed each year for remedial training.[16]

This second presentation forced engineering management to reconsider the root cause of the discrepant material. Moving to a new standard alone would not alleviate the problems facing Applied Materials. The discrepant material issue would need more than a standard change to correct it. More training for the technical staff on tolerancing methods would provide the best return on investment to correct problems with parts. In the end, the manufacturing engineering council did not make any changes to the technical standards currently being used. Yet there are questions that remain: how to tolerance these assemblies to improve the quality of the technical drawings?

Section 2.04 Summary of Problems with Technical Standards

The NASA case shows that there was no point during the planning phases where the engineers clearly defined the technical standards that would be used for the project. As a result, a high profile mission failed due to a mismatch in units. NASA should not have assumed their contractors knew what standard would be used, no matter how clearly they believed the standard had been publicized in the past.

At Applied Materials, the initial reaction to a spike in discrepant material problems was to request a complete revamping of the technical standard. Because the two presentations gave two different opinions on the correct course of action to fix the discrepant material, no action was taken to make any changes to the current technical standard.

Chapter 3. Professional Standards Organizations

Section 3.01 Introduction

This chapter will cover a brief description of the standards organization and what was learned regarding the question posed in this thesis: What can be learned from how standards organizations operate that can be incorporated into how a corporation chooses external standards as well as develops its internal technical standards?

Each organization described in the following sections will have the summary of the purpose of the organization, the reason for inclusion in this paper, and the role that group plays in developing standards. Furthermore, other commentary is provided to show other views of the processes used by each organization. The goal of that commentary is to show how well the process works, or if it works to meet the needs of the people using the standards.

The professional standards organizations all work together to provide guidance on standards. The following Figure 1 shows how the societies are related to one another.

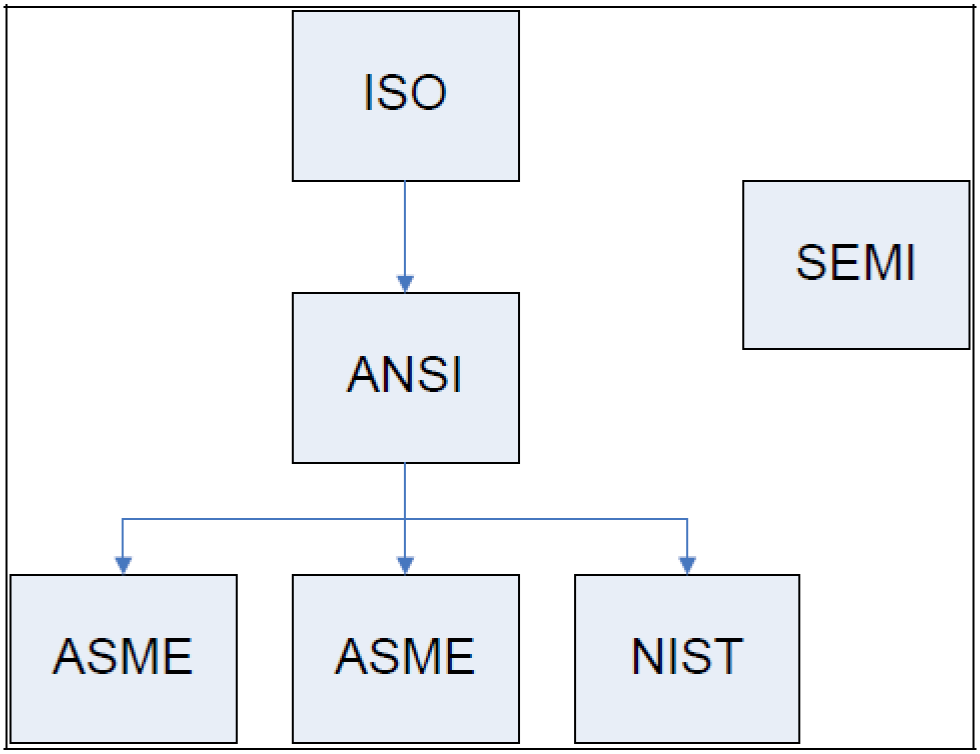

Figure 1: Professional Standards Organizations

SEMI is not a member of ISO or ANSI and therefore is outside the reporting structure of the professional standards organizations.

Section 3.02 International Organization for Standardization – ISO

ISO is the organization that maintains international standards for business, government, and society. ISO officially began operations on February 23, 1947, in Geneva, Switzerland.[17] ISO does not have the authority to regulate or to legislate the changes the members have developed. Membership in ISO is voluntary; organizations must pay dues in order to participate. As a result, there are three levels of membership. The member organizations are the national standards institutes most representative of standardization within their country. Correspondent members do not have a vote in the standards adoption, but can participate in the committees that develop the standard. The subscriber members are countries with smaller economies that want to stay connected to ISO and the standard development activities but have no voting rights.[18] A graphical representation of the ISO structure can be seen in Figure 2.[19]

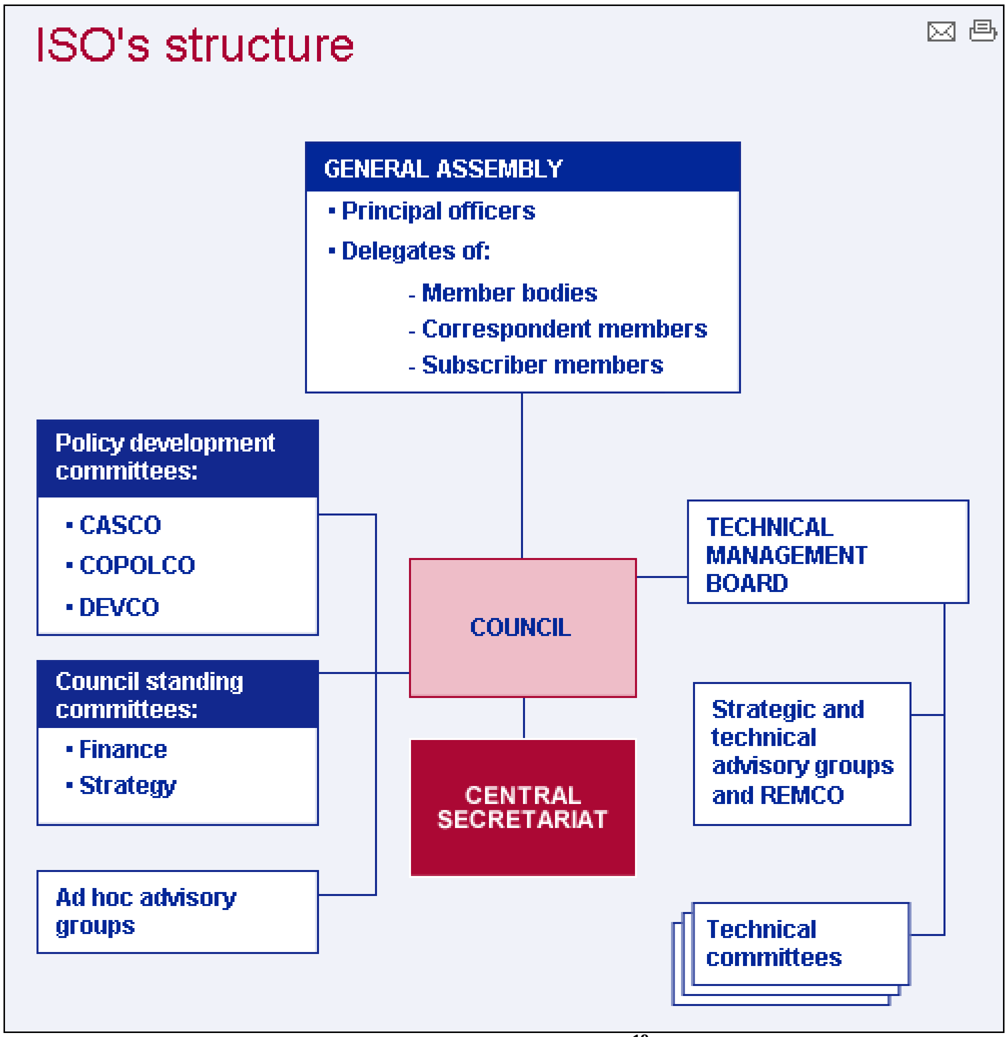

Figure 2: ISO Structure[19]

When engineers refer to ISO, they typically are referring to the metric standards that are used in nearly every other country except the United States (and two others). As shown in this paper, there is a hard resistance to moving to ISO in the United States because of the perceived issues that would come about in a change from the English technical standard to the ISO metric standard. The reason ISO is described in detail in this paper is to understand what the organization is, how it functions, and which of its methodologies can be adopted for standard development within a corporation.

The following paragraphs are quoted directly from the ISO website on how the standards are developed.[20]

> The ISO standards are developed when there is a market requirement and consensus among the experts in the field. Each member country has one vote regarding the standard, no matter how large the economic interest of that country is. ISO believes that this method keeps the countries on an equal footing so that a standard does not economically benefit one country more than another.
>
> There are three main phases in the ISO standards development process as follows. The need for a standard is usually expressed by an industry sector, which communicates this need to a national member body. The latter proposes the new work item to ISO as a whole. Once the need for an International Standard has been recognized and formally agreed, the first phase involves definition of the technical scope of the future standard. This phase is usually carried out in working groups which comprise technical experts from countries interested in the subject matter.
>
> Once agreement has been reached on which technical aspects are to be covered in the standard, a second phase is entered during which countries negotiate the detailed specifications within the standard. This is the consensus-building phase.
>
> The final phase comprises the formal approval of the resulting draft International Standard (the acceptance criteria stipulate approval by two-thirds of the ISO members that have participated actively in the standards development process, and approval by 75% of all members that vote), following which the agreed text is published as an ISO International Standard.
>
> It is also possible to publish interim documents at different stages in the standardization process.
>
> All published standards require periodic revision. Several factors combine to render a standard out of date: technological evolution, new methods and materials, new quality and safety requirements. To take account of these factors, ISO has established the general rule that all ISO standards should be reviewed at intervals of not more than five years. On occasion, it is necessary to revise a standard earlier.

To summarize, requests for standards flow from the bottom up, from the industries to their umbrella organizations to the ISO Council. Committees are then organized and time is taken to develop the standard to ensure all voices are heard. All participants sign off on the standard, completing its adoption.

ISO is highly effective at creating standards. The Harvard Journal of Law & Technology calls ISO a "well respected professional organization" in one of its articles.[21] Another article calls it an "authoritative source.[22] If a corporation wanted to adopt the ISO methodology of standard development, that decision would be supported by outside research as an effective means of standard development.

Section 3.03 American National Standards Institute – ANSI

Founded October 19, 1918, ANSI is the United States representative to ISO and serves as the technical standards coordinating body in the United States. Interestingly, it is a non-profit organization that relies on its membership dues and standards sales to fund itself.[23] ANSI itself does not create standards; rather it provides guidelines and coordinates the standards activities of its member organizations.

The standards that come out of ANSI are known as American National Standards, or ANSes.[24] There is a document that describes in extreme detail the process for developing a standard that will be accredited by ANSI: *ANSI Essential Requirements: Due Process Requirements for American National Standards*.[25] This document lists the process for creating the standard and includes openness, notification and appeal procedures.

The guidelines that ANSI uses can be useful for corporations when developing technical standards. A documented method of creating standards ensures that all standards are reviewed and accepted by all affected people across the organization. It also ensures that the same process is used whenever a new standard is deemed necessary in any unit within the organization.

A Harvard Business Review article points out a weakness in the ANSI process through a case study of swimming pool depths. Because ANSI is supported by industry through membership dues and adhering to the standards is voluntary, standards created are not always in the best interest of the consumer. Instead, the standard may only be protecting the best interests of the industry since that was who created it.[26] This problem would be rectified by including the consumer voice in the process. It shows that all stakeholders, including the end customer, must be included in the standards development process.

Section 3.04 National Institute of Standards and Technology – NIST

NIST is a non-regulatory federal agency within the U.S. Department of Commerce. Its mission is to promote U.S. innovation and industrial competitiveness by advancing measurement science, standards, and technology in ways that enhance economic security and improve Americans' quality of life. NIST is also involved in developing manufacturing standards and provides support to companies in the United States to utilize their best known methods.[27]

The Standards Coordination and Conformity Group (SCCG) is an agency under NIST. It does just as the name suggests – coordinates and ensures compliance for the National Technology Transfer and Advancement Act (NTTAA) of 1995. It is a regulatory group, and it ensures that there aren't duplicate standards being developed in the public and private sectors.[28]

NIST and ANSI work together through a memo of understanding; this memo ensures that there is a coordinated effort between the private and non-private sector on international standards activities.[29]

NIST is included in this paper because it works to prevent duplicate or similar standards from being developed within government agencies. It would be valuable to have an organization like this one within a corporation. Companies going through mergers and acquisitions would benefit from a group that could evaluate and approve standards from both companies.

Section 3.05 American Society of Mechanical Engineers – ASME

ASME has been a standards organization for 125 years, and is best known for its Boiler and Pressure Vessel code that brought the group together in 1884. Not only does it develop codes and standards, it also works to train engineers in how to apply those guidelines. Its website works to educate engineers about the need to learn and understand codes and standards. There is a document about codes that is intended for engineering students[30], and there is another that describes some examples of the importance of codes and standards around the globe[31]. Finally, ASME is one of ANSI's standard development organizations, which is one of the reasons why it is included in this paper. Another reason that it is included is that Applied Materials uses ASME Y14.5M-1994 as the standard for its engineering drawings.

ASME develops its standards in similar fashion to ISO and ANSI, an open forum is used to ensure all organizations impacted by the standard are included in the process. After the 1994 Technical Barriers to Trade Agreement was signed and what was an international standard was being debated, ASME made sure it was part of the discussion.[32] Many of the ASME standards were already in use globally, and the organization has continued to be active in developing new global standards. In order to stay relevant, ASME has translated its codes and standards into many languages and now conducts the standards development process electronically via "C&S Connect."[33] Having an electronic process enables ASME to develop standards quickly, incorporate emerging technology and be used in emerging markets.[34] ASME is the only organization to have a policy specifically detailing how it will keep its standards current in format as well as in content.

The ASME Codes and Standards Board of Directors has responsibility for the activities of the six different supervisory boards reporting to it. Among the groups reporting to the Board of Directors is the Board on Hearing and Appeals, which allows companies to object to a standard or code before it is implemented.[35] A formal appeals process is vital in a standards organization and would be important for a corporation to include in its standards creation process.

No outside commentary was found on the ASME standards creation process.

Section 3.06 ASTM International

ASTM International develops standards for materials, products, systems, and services. It was formed to address rail breaks in the rail industry in 1898 and continued to create standards for steel. These standards improved safety for the entire railroad industry.[36]

It is another standards organization that develops its standards in a manner similar to ASME. A technical committee receives a request for a standard from an individual or industry, then performs research to ensure there is enough industry interest. There are inquiries to see if similar research is being done in other standards organizations, and finally a decision is made to see if the activity to create the standard fits into the ASTM structure.[37]

The reason ASTM International is included in this paper is because of the process used to approve of a new standard. Each person in the ASTM membership has an opportunity to approve to disapprove of the new standard prior to full adoption. The objection must be fully addressed by the committee before the document can go to the next step in the process. The due process is described in The “Regulations Governing ASTM Technical Committees” and the manual, “Form and Style for ASTM Standards,” are among the documents that govern the ASTM standards development process.

Like ASME, electronic communication is used to notify members that a standard is ready for approval. This communication also increases the speed to market for standards and reduces the expense of standards creation.

There is no other research regarding the effectiveness of ASTM standards development.

Section 3.07 Semiconductor Equipment and Materials International - SEMI

SEMI is the global industry association serving the manufacturing supply chains for the microelectronic, display, and photovoltaic industries.[38] It is similar to ASME in that it is a standards development organization for the private sector, yet it is not a member of ANSI.

The reason SEMI is included in this paper is that some of the information available on its website differed from content on other standards development organizations' websites. The website contains information about the correct formatting for standards along with documentation of the approved acronyms to ensure common terminology among all of the standards submitted for approval. This document is the "SEMI International Standards: Compilation of Terms." There are also document templates and manuals on using those templates readily available on the SEMI website.[39] The other reason this organization is reviewed is that Applied Materials is a member of SEMI.[40]

A formal balloting process is used for approving SEMI standards.[41] Anybody can submit a standard to be approved, which is why the required terms and formatting for documentation is available on the website.

No outside commentary was found while researching the standards development methodology at SEMI.

Section 3.08 Summary from Standards Organizations

Each organization has worked to develop a standards creation process that is clear and involves all the members of that organization. Each group recognizes that it is important to allow members the chance to provide input on the standard as it is being created, as well as appeal the standard as the circumstances that merited its creation change.

The lessons learned from this chapter will be used to create a framework that corporations can use to determine which external standards should be adopted. That same methodology can be used to create new internal standards for each corporation's unique set of operating circumstances.

Chapter 4. Dimensioning and Tolerancing

Section 4.01 Research Questions

What engineering drawing standards would be best for Applied Materials to use, considering the complex assemblies that are involved with manufacturing its product? A comparison between ISO and ASME will be made, and the manuals for both of these standards will be introduced. Since poor tolerancing on engineering drawings was identified as a root cause of the discrepant material spike introduced earlier in this paper, the dimensioning and tolerancing schemes that are available will be explored. Finally, this chapter will extend into the steps for moving to SI units over customary English units, since Applied Materials uses English units even though the supply base is pushing the company to use metric.

Section 4.02 ISO and ASME Standards Comparison

Since ISO and ASME are sets of standards and do not necessarily mean metric or English units are being used, there is a need to draw comparisons about the benefits and detractions of both standards.

Table 1[42] shows a basic overview comparing the standards.

Which Dimensioning Standard is Right for Your Organization?		
Issue	**ISO**	**ASME Y14.5M – 1994**
Number of standards for dimensioning	15-20 separate standards	1 standard
Documentation of concepts	Few explanations; mostly pictures (1st angle projection)	Most comprehensive explanation of any standard in the world
Cost	$700	$100
Stability	Each part changes independently (at least one part per year)	Changes about every 10 years
Training Availability in US	<5 Sources	>2000 Sources
Technical understanding of the standard	Little knowledge of technical points	Most companies have a knowledgeable champion
Suppliers' understanding of the standard	Very low	Working knowledge
Addendum to make standard fit your industry needs	40-50 pages est	8 pages
Influence on the standard from your industry	Extremely difficult	Anyone can submit work orders. Meetings are open to the public

Table 1: ISO vs. ASME[42]

ASME is considered to be more comprehensive in its 2D dimensioning and tolerancing than the relatively immature ISO standards. ASME is also more appropriate for complex parts because of the large amount of detail about tolerancing for difference types of parts in its standard.

The ISO standards handbook has two volumes and lists approximately 60 ISO standards in each volume that apply to 2D technical drawings.[43] [44] Following the ISO standard for dimensioning involves 15-20 standards as seen in Table 1. The result of having so many standards is that it is difficult to understand which ones are needed when a customer or supplier requests that a drawing be converted from the ASME to the ISO standard. ASME has only one standard for 2D technical drawings, the ASME Y14.5M standard. It is comprehensively describes how to create 2D drawings. Following all of the ISO standards is a lot for an organization to manage, especially one that is already following the ASME standard.

As Table 1 shows, there are many companies that will train a corporation's workforce in using different international standards. The majority of those in the United States focus on ASME standards; therefore it would be easy for a corporation based in the United States to find training on ASME standards for its technical staff.

Fortunately, there is some overlap between the ASME and ISO standards, approximately 70%.[45] Most applications for engineering drawings will fit within that 70%, and most GD&T requirements can be made so that neither standard is violated. Therefore, if a request is made to move from one standard to the other, the likelihood that the standard requested is already being followed is high. One of the training organizations can be consulted to ensure that the requested ISO standard is being met by the ASME standard. Many books have been written about the ASME and ISO differences as companions to these training sessions, and they would be available as a good reference for engineers working to create the gap document for their organization.

In summary, the recommendation is for corporations to understand that the two standards overlap, and as a result they may already be complying with a request to change from using ASME to ISO, and vice versa. A corporate manual needs to be created to document how standards will be applied throughout the organization.

Section 4.03 Standards Manuals

Manuals have been developed that detail how to use the standards that apply to engineering drawings. The first is the Drawing Requirements Manual, or DRM, which was first written in 1968 and has been expanded many times since then to include 3D models and other new computer aided drafting practices.[46]

The DRM includes ASME and military standards in its explanation of creating and using engineering drawings. Not only does it cover dimensioning and tolerancing of complex assemblies, it also has an extensive section on converting from English units to metric units. The conversion factors are detailed for common measurements in section M2.

ISO also has a standards manual. The Manual of Engineering Drawing is used by companies to comply with ISO and British standards.[47] It also has a section on the differences between ISO and ASME GD&T standards.

These manuals merit their own section in this paper because there is a lot of the work that a corporation needs to do when choosing and using a technical standard. These documents would standardize any conversation between two groups about the appropriate way to handle changing a document from English to metric or guide the conversion from ISO to ASME. Finally, they are good reference and supplementary training materials for engineers and other technical staff.

Section 4.04 Tolerancing

This section will describe methods of tolerancing that can be used on simple and complex parts and assemblies. Since poor tolerancing on drawings was identified as a problem that caused discrepant material in the Applied Materials case study, it is important to see the methods that exist to improve how engineers use tolerance data for their designs.

The goal of tolerancing drawings and solid models is to find an approach that can be easily taught, intuitively understood, and does not require a full understanding of how the entire assembly is mated together, and then to find ways to error-proof the process. [48]

The tolerance standard at any corporation must consider the many groups of people that will be using the drawings for information, from the engineers to the manufacturers, and from the drafters to the machinists. Research has shown that these different groups have been using different tolerancing schemes, which can lead to differences between the drawing and the intended final part.[49]

The ASME Y14.5M standard states that metric or English customary units could have been used without impacting the way tolerances are calculated for the drawings. The way decimals are depicted when using millimeter tolerances differs than when using inch tolerances.[50]

Juster discusses two tolerancing schemas:

1. traditional plus/minus tolerances controlling the size of the part, and
2. geometric tolerances.

Geometric tolerances have four categories. These categories are

1. tolerances of form
2. tolerances of attitude
3. tolerances of location
4. tolerances of runout

According to Shen, etal[51] there are four major tolerancing methods:

1. one-dimensional (1D) tolerance charts
2. parametric tolerance analysis (linearized and nonlinearized)
3. vector loop based or kinematic based tolerance analysis
4. variation zone based tolerance analysis – ASU Tolerance Map® (ASU for Arizona State University)

Table 2[51] summarizes each of these methods and shows how each fits the criteria for use by engineers and manufacturers. It shows what kinds of tolerances are needed for a drawing and how each tolerance method fits the criteria. It also discusses how well each of the methods fits in with ASME Y14.5M-1994 since that was the standard used in 2005 when the article was written. They discuss the shortcomings of the method as was the case when the article was written, but it is shown to be the most superior of the methods available in the summary section.

method	Tolerance Charts	Parametric - Linearized	Parametric - Nonlinearized	Kinematic CATS	ASU T-Maps (evolving)
criteria					
Dimensionality	1-D	mainly 2-D	2-D Constraints and 3-D History	3D	3D
Analysis Type	worst-case only	worst-case + statistical	worst-case + statistical	worst-case + statistical	worst-case + statistical
Scope (Tolerance Types)	dim and geometric	dim and some geometric	dim and most geometric	dim and some geometric	dim and all geometric
Bonus/Shift Tolerances	yes	no	yes	no	yes
Datum Precedence	yes	no	indirect	no	yes
Tolerance Zone Interaction	N/A	no	yes	no	yes
Directly Based on 3D Tolerance Zones	projected zone	no	point-based*	point-based*	yes
Analysis Level	part and assembly	part and some assemblies	part and assembly	good for assembly	part and assembly
Ease of Use and Learning	easy	moderate	difficult	difficult	moderate
Compatibility with CAD	yes	yes	no	no	yes
Accuracy of Results (User Experience, Repeatability)	good	moderate	poor	moderate	good
*The model and variational scheme depend a lot on the user-defined points (control points, end point of vectors, etc.)					

Table 2: Tolerance Analysis Summary from Shen[51]

T-Maps have been heavily researched at ASU, as seen in the following Table 3 from Shah does basically the same comparison as Shen did, showing that T-Maps are going to be the best bet for most drawings. [52]

	Dimen-sion	Analysis Type	Scope - Tolerance Type	Y14.5 Support	Level	Lineari -zation	Auto-mation
Tolerance Chart	1D	worst case only	geometric + dimension	full	part & assy	n/a	manual
Parametric CATS	2D, 3D	worst case + statistical	dimension + <u>some</u> geometric	partial	part & assy	lineariz ed	interactive
CATS with abstract features	3D	worst case + statistical	dimension + <u>some</u> geometric	partial	part & assy	non-linear	interactive
Multi-variate regions, e.g. T-Maps	3D	worst case + statistical	dimension + <u>all</u> geometric	full	part & assy	non-linear	automate

Table 3: Comparison of Tolerance Methods from Shah[52]

The more recent articles show that there have been tremendous developments in software available for designers. Now, there are Computer Aided Tolerance, or CAT, packages that will import a 3D model and allow the user to step through the process of building the tolerance chains. However, this software is in its infancy. For instance, the CAT packages do not import the dimensions from the original CAD model and require the user to input the data all over again.[53]

In summary, the different tolerance methods can be used to create quality drawings that can be used by all technical staff and will ensure that the parts are made as expected. Software that automates the process is ideal for removing the error-prone human factor in drawing creation. But since that software is in its development stages, this paper recommends that the 1D tolerance chart be used for analyzing engineering drawings. It is easy to teach and the results are repeatable, as seen in both Table 2 and Table 3.

Section 4.05 Metric Units vs. Customary English Units

No discussion on standards development for American corporations would be complete without discussing the move to metric, or the International System of Units (SI), from customary English units. The government has had some say in this argument, and the professional standards organizations have also provided input.

The United States is the last of three countries in the world that have not fully adopted SI; the other two are Liberia and Burma. There have been many researchers over the years that report that the United States will be metric "within the next ten years"[54] starting in 1975, but there is still a lot of resistance within the American corporate world.

Stan Jakuba wrote an article in 2001 for ASTM about the need to metricate for corporations. That article references the move IEEE and ASTM took to combine their separate metric standards, ANSI/IEEE 268 and ASTM E 380 respectively, into one that could be used for an "American National Standard."[55] This standard is known as ASTM SI10 has been accepted by ANSI, and is an example of how professional societies are working to move American industry to metric.

ASME has also moved to SI in the last several revisions for dimensioning and tolerancing standards. The newest version of standard ASME Y14.5M-2009 states in section 1.1.2 that the units used throughout the standard are International System of Units because it anticipates SI units to supersede the United States customary units for engineering drawings.[56] ASME Y14.5M-1994 had the same verbiage.[57] ASME refers to English units as customary units in its standard; therefore, that is how this section will refer to English units.

Without discussing the pros and cons of metric over customary, there are some very real drawing issues that must be considered when a company uses both standards. One of those issues is dual dimensioning, where the print has both customary English units and metric units on the face. Traditionally the English units will be shown then the metric units shown next to them in parenthesis as seen in Figure 3[58].

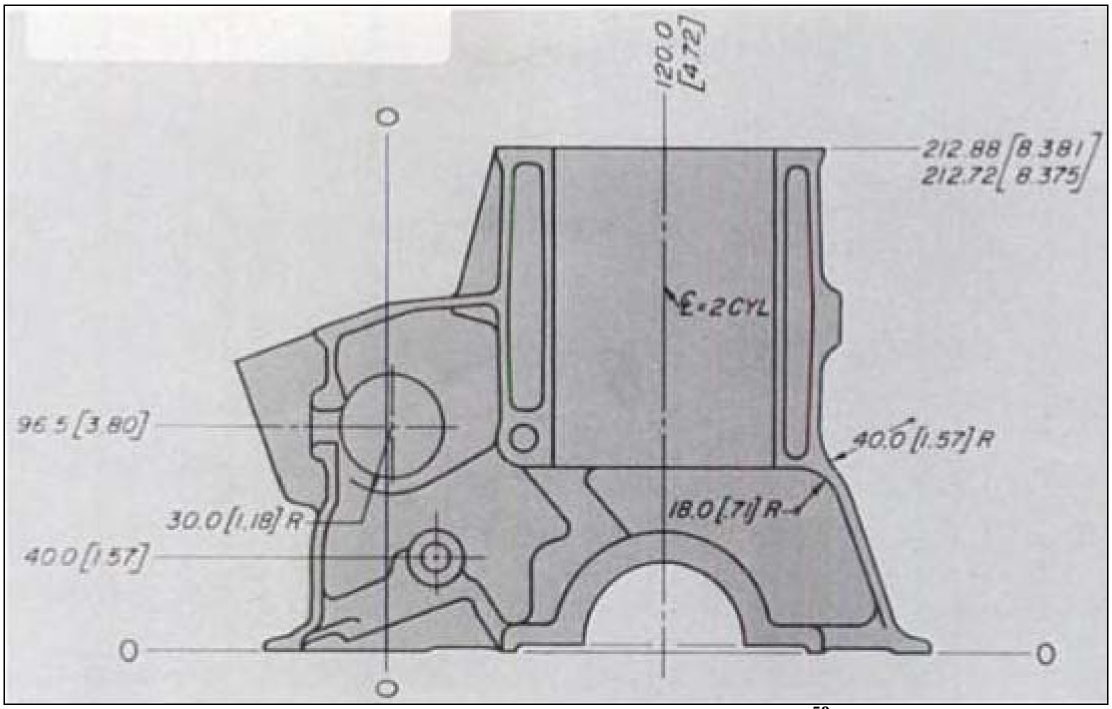

Figure 3: Dual Dimensioning on Drawing Face[58]

If the print is relatively simple, like Figure 3 from Ford, there will not likely be any confusion on what dimension to use for machining. However, if the dual dimensioning is being done by a contract manufacturer or licensee, as in the case for Morgan Construction Company, the problem that can result from this dimensioning scheme is clutter on the print. Their Japanese licensee would convert the dimensions to metric then translate the English notes to Japanese, thus rendering their prints nearly unreadable with all the text that was included.[59]

Another problem with using dual dimensions is that the American design engineering community can avoid learning about metric and stick to the old English system because the familiar numbers are still there.[60] The change over at the company is not truly internalized because no additional learning occurs beyond converting the numbers from English to metric.

There is also a cost associated with dual dimensioning. If the customary and metric units are both shown on the print, the supplier of the part can still be locked into English units while your company is trying to move to SI. At the Lawrence Livermore Laboratory (LLL) a conversion chart was used in the machine shop to handle the millimeter-inch conversions for non-metric machines. At LLL they found the metric conversion was not a problem for the machinists and the chart was very useful in reducing time and cost during the design phase for the parts.[61] Back at Morgan Construction, the decision was made to develop another set of prints in metric as well as English. While it was helpful for machining individual parts, there were occasions when the final assemblies were not truly interchangeable between the two standards. Couplings, cylinders, valves, threaded fasteners, gears and other purchased parts made these parts too different to be interchangeable.[62] Two parts, one metric and one English, were created where there used to be only one part that served the purpose. Whether or not cost was saved in moving to a metric standard in this case is debatable – up front cost is higher with generating a second set of prints, and the cost is also higher on the back end while trying to find appropriate parts for both a metric and an English dimensioned assembly.

The DRM has a section on dual dimensioning, if that option is used as an interim solution during metrication. Section M4 presents a standard method of converting a drawing to metric; again, this guide would facilitate the conversation between a supplier and customer on the methodology to use when using dual dimensioning. Yet even the DRM says that dual dimensioning on drawing is discouraged.[63]

Beyond dual dimensioning, there are some other drawing issues that need to be confronted. These include what conversion table to use, what rounding convention to use, and what projection angle should be used. The conversion tables available now are more complete than they were in 1975. ASTM SI10-2002 has conversion and rounding conventions included in the document, which would provide any company with the tools needed to confront the drawings issues.[64] The projection angle issue is covered in standard ASME Y14.3-2003 and shows show to create and note in the drawing third and first angle views.[65] This standard is good for companies to use since first angle views are predominantly used in many countries while American companies use third angle projections. As long as the standard is referenced on the drawing, there would be no confusion about the projection angle used on the print.

Another factor for companies to consider when moving to SI from customary English units is the opportunity to correct past errors in company standards. If the engineering time is already being spent on reviewing drawings, the opportunity to make corrections may present itself. This commitment may mean that the number of standard screw sizes can be reduced to a more manageable set. More standard sizes can be used during design instead of multiple screws being called out by design engineers. There have been several technical committees that have worked on developing what was called the Optimum Metric Fastener System (OMFS) starting in the early 1970s.[66] It was eventually adopted into the worldwide standard for manufacturing by Kverneland.[67] This reference will help companies tremendously when determining how to change their company standard from English to metric.

Finally, the American government has started many initiatives to start this country down the metric path. In NIST Special Publication 814 - 1998 Edition, the metric laws and the President Executive Order 12770 are noted showing that the law of the land is to move to SI. The Department of Commerce is responsible for directing the efforts of business and local and state governments along the path of SI adoption:[68]

> The Omnibus Trade and Competitiveness Act of 1988(Pub. L. 100-418. section 5164) amended the Metric Conversion Act of 1975 to, among other things, require that each Federal agency, by a date certain and to the extent economically feasible by the end of the fiscal year 1992, use the metric system of measurement in its procurements, grants, and other business-related activities, except to the extent that such use is impractical or is likely to cause significant inefficiencies or loss of markets to United States firms such as when foreign competitors are producing competing products in nonmetric units.

Yet, as seen in the case studies, NASA was unable to make the move to the SI system and has backed off on its commitment to fully implement SI in its designs.[69]

Jeanette Smith writes an article that traces the history of metrication by the government from John Adams through 1998.[70] It shows a pattern of the government supporting the change strongly and then backing off due to corporate pressure. The conclusion is basically that as long as the change-over is voluntary, there will be no change from customary units to SI in the United States.

The risk to corporations is that the government may force companies to metricate and penalize ones that do not have a plan to achieve a metric standard. In this case, to avoid government intervention, corporations in the United States should begin to develop plans for moving from the customary English standard to metric.

Chapter 5. Corporations and the Move to Metric

Section 5.01 Research Questions

How have other corporations dealt with the move to metric? This chapter will focus on how other companies have developed the standards they use in house, and how international standards were incorporated into those standards. The companies profiled were interested in moving from the English customary dimensioning standard to metric. Therefore, not only did these companies have existing standards, they wanted to update them and metricate.

As engineering and manufacturing organizations have matured in the last forty years, more companies have gone from using their corporate standards to using international standards, see Figure 4.[71]

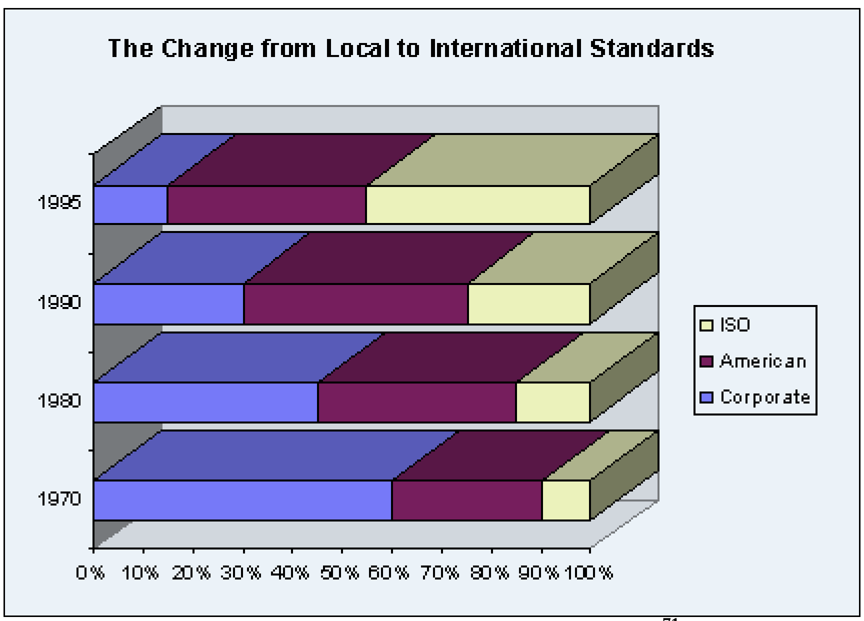

Figure 4: Standards Shift in Corporations[71]

Metrication is part of the move to international standards for American companies, as this chapter will show.

Section 5.02 Metrication

A study of those that have gone before is always helpful when determining the path a company should take with their own standards. There are many companies documented below that transferred from English customary units to metric over a period of time.

At Caterpillar Tractor Co. they developed a list of questions that served to help them determine whether or not it was appropriate for them to go to a metric standard on their drawings.[72]

1. Does it improve the product?
2. Will it result in immediate or future economic gain?
3. Is the market domestic, foreign, or both?
4. What is the service life of product?
5. Are service parts required or is the product discarded when it becomes inoperable?
6. Fasteners – do you service or does customer obtain them from local hardware stores?
7. Do government regulations, trade restrictions, or the customer demand the new standard?
8. Availability – is the standard you're using hard to get?

Caterpillar created a list of questions to guide them while developing a new set of standards as they move to metric from English customary units. These questions are valid for any corporation trying to develop standards for its engineering and manufacturing organizations.

Honeywell, Inc. has a group of Standards Engineers that are responsible for the standards and standardization around the company.[73] They coordinate activity with the

Corporate Standards Council and Corporate Standardization Services to ensure new information and data are considered when new standards are introduced. This information can include new international standards from the different standards organizations as well as standards from other countries in which the company operates.

General Motors maintains and publishes their engineering standards for design, drafting, parts, materials, and processes for use by their divisions. These standards are also made available to other non-GM companies by subscription.[74] That would make these standards available to the supply base to ensure all companies were on the same page as far as required standards are concerned.

All of the companies mentioned were sure to follow what international standards were being developed and what standards are required in the countries of operation. Large committees were used to ensure the information about the standard was disseminated correctly to everybody who uses that standard.

Chapter 6. Framework for Developing Standards

Section 6.01 Standard Development Methodology

Each of the professional standards organizations has developed processes that enable standards to be created. What is the process for developing standards as suggested by the organizations reviewed? How can these lessons be taken back to the corporate setting and used to develop corporate technical standards?

This paper suggests a method called the ABC methodology that can be used for standards creation. Based upon the professional standards organizations, there are four steps:

- Consensus
- Development
- Approval
- Maintenance

Consensus, from ISO, means that a group comes forward with a need for a standard. At this point, a review is done to ensure that no standard already exists that could serve the need. This step prevents duplicate standards from being developed, and ensures that it is clear which standard to use in a given situation. NIST currently checks for duplicate standards between the government and private sectors, which shows how important it is to prevent duplicate standards from occurring.

The second step, development, brings together the interested parties to hammer out the details of the standard. Openness and inclusion of all impacted parties is key; therefore, a process must be created to allow participation. The ASME and ASTM electronic communication tools are a good example of how to enable groups in many locations to collaborate and work together to create a new standard.

There are many forms of collaboration that can be used for development. A collaborative architecture needs to be laid out because the structure and organizing principles of the development team are important. The organization chosen can be hierarchical or flat; ISO uses a hierarchy, and ANSI is flat so that each player has equal voice. Four modes of collaboration are recommended, and their pros and cons are listed in Figure 5.[75]

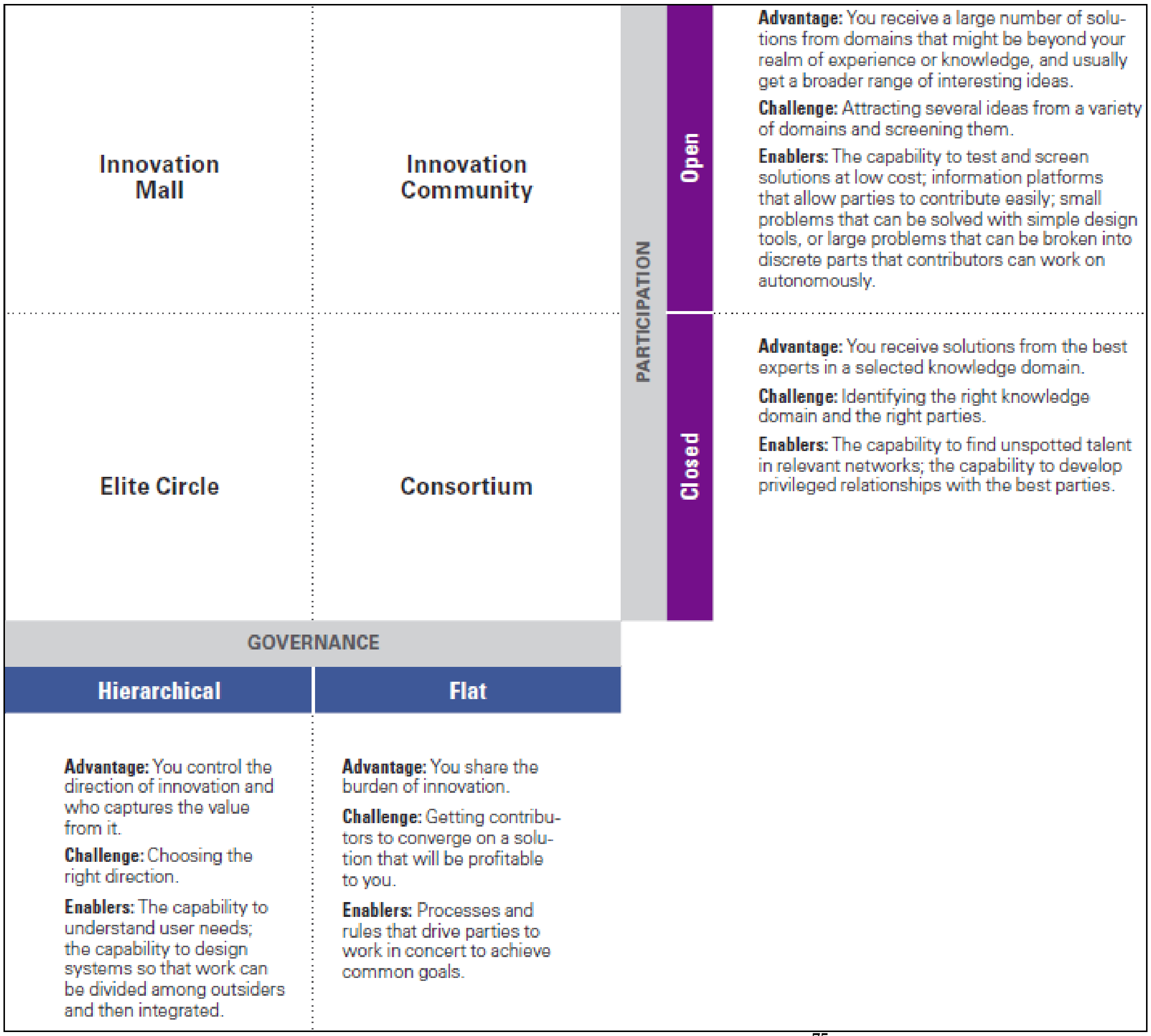

Figure 5: The Four Modes of Collaboration[75]

Whichever method is chosen from Figure 5, the next step is to choose the way that decisions are made. The decision making process must be clearly defined as to make sure everybody on the team understands how the final product will be created. Without this framework, any collaboration will be fraught with difficulties and result in failure.[76] The issue of conflict must be addressed first. Conflict is important to the creative process in order to get new and different ideas, yet it can derail a group and cause it to fail in its mission.[77]

Furthermore, each development team needs to have the best people working to create the standard. How to get employees to share information is based on how they are rewarded. Incentives must be used in all forms of collaboration. Anything from team recognition by top management to salary treatments when the team is successful will help encourage employees to participate. Not only will they want to participate on the development teams, they will be engaged in the discussion surrounding the standard.[78]

Finally, the development phase must provide a common platform for the final document. The format of the document must be clear, and the terminology must be defined. SEMI leads the way by clearly dictating the format and verbiage of any standard that is proposed. A corporation with clearly defined formats and verbiage for documents will be successful in creating standards because they will be clear and easy to follow by all groups within the organization.

The third phase, approval, should be a formality if the development phase included all parties that need the standard. All concerns expressed during the approval process must be addressed, as they are during ASME and ASTM standards development. The standard cannot be approved until the membership, or in the corporation's case, the employees, agrees the standard is fully developed.

Maintenance is the final phase for standards development. ISO standards are reviewed every five years to ensure the standard is up to date and still relevant. Corporations need to have a similar review cycle to keep their documents in the same fashion. Furthermore, an appeals process needs to be outlined. If a standard is found to be too restrictive or has another problem with it, the process to have it changed is known.

The final component of the maintenance phase is educating the employees in the corporation about the standards that exist. ASME stresses the need to educate engineers on their codes and standards; corporations need to create a method of educating the masses on how to use the corporate standards.

Section 6.02 Recommendations for Implementation

How can this process be successfully implemented within a corporation? An umbrella organization is proposed to keep and protect the corporation's standards and the standards development process. This umbrella group would operate like ISO or ANSI do: it wouldn't create standards, but rather guides the creation process.

A company guides the standards creation process though its values. When values are used as the touchstone for creating standards, then those standards can easily be transferred to all locations of a company. Clear standards and processes steer operations in a company and help guide people at all levels of the organization.[79] With the understanding that the standards should flow directly from the values, the standards creation process can begin.

There are two components to making the umbrella group successful: the people and the documented processes and procedures currently in use.

The members of the umbrella organization would be senior managers, such as chief engineers and operations heads. Keeping the responsibility with upper level management shows the corporation's commitment to high quality standards. The group of people should rotate once a year to expose all of the managers to the standards process and keep the individuals interested in the process.

Most corporations have processes and procedures that they use everyday. The processes and procedures that are used as the current standards in the corporation need to be documented. Having this documentation serves many purposes: it provides guidance on where the standard is currently located and helps with aspects of maintenance such as education.

When the people are armed with clear documentation, the ABC methodology can begin: consensus, development, voting, and maintenance.

Consensus is the first step to complete when a new standard is needed. This paper proposes that a paper be submitted to the umbrella organization stating the problem that needs to be solved with a new standard. A standard format for this paper can be prescribed by the umbrella committee to ensure all proposals start on equal footing. That standard ensures all questions the committee may have will be answered, such as why is this change needed and who is impacted by the change? One person can submit that paper or a group can form around the need for the standard. Consensus is achieved when the umbrella committee reviews the proposal and agrees that a development committee needs to be formed to develop the standard.

Who will be on the development committee? The person or group that proposed the need for the standard should serve on the committee. Each organization impacted by the new standard needs to be represented, with the same number of people representing each of the organizations. Based on the complexity of the problem that is being studied, the committee needed may be large or small. That decision needs to be made by the umbrella committee. After that decision is made, there are many ways to fill out the roster. People can be recommended for service by their managers or peers. A call for volunteers can also go out to find people interested in the problem. Using a system like the ASME C&S Connect would be good for putting out a call for volunteers, collaborating, and notifying all employees about the standards work that is occurring. In most corporations, the internal email system would be sufficient to send notifications about supporting the development committee. Updates on the committee's progress would be provided, and interim documents would be sent out as they became available.

Approvals can be arranged by the umbrella committee in several ways as well. This paper recommends that levels of approval be used similar to the ISO strategy. There would be three levels: full, half, and notification. The people that worked on the development committee have full votes, the people that had interest in the work but did not work on the committee have half votes, and people that were not interested at all have no vote but are notified that the standard is approved. Each concern would be addressed prior to full adoption of the new standard; if the standard is disapproved by a half level, it would be at the development committee's discretion whether or not to address the concern.

The maintenance step is the one that benefits most from having an umbrella organization managing the standards creation process. That group sets a schedule for updating the documents like ISO does every five years. In most corporate settings a shorter schedule would be better, no more than three years before a document is reviewed for relevancy. A separate development committee would be appointed to do the review work for the documents. That committee would use the same process for the rolling review and the new documents.

The umbrella committee would also work to develop a method of educating new employees about the corporate standards and the process used to develop them. As shown by ASME, standards are best applied by those taught to use them.

Finally, the umbrella committee sets the appeals process. Change is constant in any corporation, and a process is needed so that a standard can be updated if a change has occurred. The appeals process proposed by this paper is simple – it would be the same as the proposal process for a new standard. A paper is submitted to the umbrella committee that states the standard and why it needs to be changed. Instead of a full development process, a call is sent out to the impacted groups to approve the change. If no one objects, the change is made permanent. If there is an issue, a development group will be formed following the same full development process, a vote is made, and then the change becomes permanent.

Finally, the changes in professional standards would be monitored by the umbrella group, since external changes can occur to those documents as well. One person can be nominated to be the watchdog and report to the umbrella when the standards are in a state of flux.

In the end, an engineering organization should use established standards whenever possible. The internal standards will translate how those standards are used within the company, as well as dictate what standards to use in specific applications.

Chapter 7. Applied Materials Case Study

Section 7.01 Research Questions

This paper has created a framework for developing internal standards as well as choosing external standards that are appropriate for the type of engineering the company does. How would a company use that framework to choose whether to move from the standard currently used to a new standard? That question will be explored using the Applied Materials case introduced at the beginning of the paper. The move from ASME Y14.5M-1994 to ISO standards will be examined using the proposed ABC methodology for standards development.

The second step is to determine the tolerance scheme that is best for Applied Materials, based on the technical standard that is chosen. After that, a method for moving to metric will be explored. Finally, the process for integrating other companies' standards during a merger or acquisition will be discussed.

Section 7.02 Applied Materials Case Study Revisited

In the beginning of this paper, Applied Materials' engineering management was getting pressure to revise the drawing standards used. Due to a sharp increase in discrepant material assumed to be a result of poor engineering drawings, the engineering councils asked that presentations be made to explore the technical drawing options.

The first presentation stated that Applied Materials should move to the ISO standard and move to metric dimensioning and tolerancing. The second presentation stated that the company should stay with the ASME standard and not move to metric dimensioning and tolerancing. The problems that need to be solved as a result of the conflicting presentations are whether or not to move to a new technical standard, whether or not to use English or metric units, and what tolerance method needs to be used as a result of the answers to the first two questions.

Section 7.03 Applied Materials Technical Standard

Armed with an understanding about ISO and ASME standards and a framework for choosing a standard, what recommendations would be presented to the engineering management council now?

First, the questions that need to be answered about the engineering drawings would be more clearly defined by the engineering council. What is causing the part quality problem? The first question is does the technical drawing standard need to be changed to improve the quality of the parts? If so, what standard is the replacement?

The first question can be answered from the research. Knowing that ISO and ASME drawing standards overlap by 70% and that ASME is more suited for complex assemblies, Applied Materials should stay with the ASME Y14.5M standard. The number of complex assemblies at this semiconductor manufacturer dictates the need to stay with the ASME standard.

If a request is made to move drawings to the ISO standard, the company now has some actions while considering the request. Applied Materials can request which ISO standards are desired be specifically detailed in a contract. Because of the large number of ISO standards, simply stating that a drawing needs to be ISO and not the ASME Y14.5M-1994 is not clear enough direction to meet the request. Once this information is gathered, the analysis to see if there are overlapping standards that satisfy the requirement. An outside consultant can be contacted to perform an analysis and provide recommendations. Then Applied Materials engineers can show how closely the drawings already meet the ISO standard with the current ASME standard. If the gap is large, a plan can be developed with the outside consultants to use the ASME document to meet the ISO request.

The technical standard should not be changed, and the knowledge that there is a lot of overlap between the ASME standard and many ISO standards will guide the response to external requests to change drawings to an ISO standard.

Section 7.04 Applied Materials and the Move to Metric

Should Applied Materials move to metric? The companies profiled in this paper made the commitment to start moving to metric over a ten year period. Some allowed the suppliers to begin changing the drawings; others used dual dimensioning as a stepping stone to full metrication.

The values should guide the standards chosen, as discussed earlier in this paper. One of Applied Materials' values is "Close to the Customer." If the customer is requesting new orders to be delivered using metric parts, then the company needs to be able to fulfill that request.

Making the assumption that Applied Materials is getting pressure to move to a metric standard, how should the company proceed? What if Applied Materials is not receiving any pressure from customers to move to metric, but the supply base is calling for the change? How would the company respond to a government mandate that its technical documents need to be metric by a certain date?

Applied Materials should move to metric on a rolling basis. Two things should be investigated before moving a part to metric: cost and fit validation.

If a supplier can provide a part at a lower cost if the drawing of that part is changed from English units to metric, then the cost requirement is met. If that part is simple, like a sheet metal cover, then the second requirement is met. Simple parts that are selected should be easy to validate fit after the part is made metric.

Finally, what if all products were offered with both a metric and English option? The example in this paper described a part that could not be facilitated because of a mismatch in connection sizes between the house facilities and the assembly. If nothing else on that assembly was English units but an optional connection piece was used for the interface with an English system, no time would have been wasted looking for a new part to make the bridge connection.

If the interface with the customer fab is considered and assumed to be metric, here is a proposal. Assume nothing else on an Applied Materials system is changed from English to metric except where the customer needs to connect facilities. Then the connection point has the part needed to convert from English to metric size along with the tool to accomplish the change if it is needed. Returning to the cases described in the beginning of this paper, the 6mm one touch air fitting would have been accompanied by a 0.25mm fitting. Maybe the part is packaged in a small bag and tie-wrapped to the location where it may need to be used. That way if either fitting is needed to facilitate the assembly, both are there. The cost of the part described in this case is small compared to the cost of the entire assembly, since one touch air fittings are low cost parts. Therefore the added cost is small but the time savings is huge, and the benefit to the customer is huge.

The other facilities connections that need to be considered are:

- Gasline connections for process gases
- Vacuum
- Air
- Power
- Water

There are other parts that need consideration. For instance, fasteners such as screws that hold sheet metal covers can be converted from English to metric. How would this choice be made? Either the request comes from the customer or from a general conversion strategy dictated by the company. Whichever reason is the cause, the tool needed for removing the screw should be included close to the location it would be used.

The DRM should be used as the guiding document for metrication. Not only does it provide the conversion factors for the units, it provides guidance on using dual dimensioning. If dual dimensioning is used as a stopgap measure when moving a part from English to metric, this document will ensure the customer and supplier are using common numbers for the conversion.

Section 7.05 Applied Materials and Tolerance Schemes

If the problem with the discrepant parts is bad tolerancing, how can the problem be solved? The biggest issue with tolerancing schemes is the human error component. These processes are very manual and as a result are error prone. As seen in Section 4.04, an automated tolerancing software package should be considered to remove the mistakes that people can make. If the cost of the software is too high for the corporation, then the manual 1D tolerance charts can be used. After the method is chosen, the engineers and other technical staff need to be trained to use the methods. That is the maintenance part of using a standard, according to the ABC methodology. Educating the people using the standard will help ensure the tolerance method is used correctly and help reduce errors.

ASME Y14.5M section 2.1.1 has guidelines for communicating tolerances on a technical drawing.[80] The tolerance calculations should be included with the drawing so that the data is preserved and can be checked by other people that use the part in the future. If that data is kept with the drawing, then any questions about how the tolerances were derived can be answered. Anything that can provide more information about the part will be helpful if there are any issues with the part. When there are cases, such as a spike in discrepant material, that problems are identified with the part, the work done to calculate the tolerance zones does not have to be started again from scratch. Questions about a calculation can be answered more easily if those numbers are included with the print. This addition to the drawing will also help suppliers better understand how to manufacture the part and inspect it.

Finally, the drawing can be checked by another technical person and the method of tolerancing can be verified. A discussion between the creator and checker can be facilitated if they are able to use the same document that shows the calculations used.

In summary, the tolerance method used should be automated by software if possible, and extensive training provided if the manual tolerance chart method is used. The tolerance calculations should be included in the drawing documentation for all parts.

Section 7.06 Applied Materials and Mergers and Acquisitions

When Applied Materials purchases another company, there will be corporate standards in use that may not be congruent with the standards Applied Materials uses. In that case, the ABC Methodology should be used to choose what standards will be used after the acquisition is complete. The ABC methodology will allow the newly acquired employees a change to provide input on the standards that will be used during the development phase. The approval phase will ensure all groups impacted by the standard agree to use the standard. Maintenance of the new standard will entail educating the workforce on the standards that will be used so that there is no confusion, as was the case in the example presented at the beginning of this paper.

Chapter 8. Summary

This paper has explored several research questions, from choosing a technical standard, converting to metric, tolerancing schemes, and how to choose a standard after a merger and acquisition has taken place.

Studying the professional standards organizations led to the ABC Methodology for choosing a standard within a corporate structure. Using consensus, development, approval, and maintenance as steps to guide the process will generate standards that meet the needs of the whole corporation.

Tolerance schemes are dictated by the standard used, but are still complicated and can lead to high discrepant material costs. To remedy that problem, a software package that automates the tolerance calculations is recommended. If software is not used to calculate tolerances, extensive training for the technical staff is needed to ensure tolerances are correctly calculated and applied.

The issue of converting from English units to metric units is discussed in this paper. Since the United States is one of only three countries that use the English system, there is a lot of focus from the government for companies to move to metric. This paper recommends moving to metric units, especially when the customer desires the change, and suppliers are able to offer lower prices on their products. The Drawing Requirements Manual complements the ASME standards and has the conversions for lengths and other dimensions to guide the metrication process. Other companies, such as Ford and Caterpillar, have created metrication strategies that would be useful to reference for other companies that wish to convert to metric.

Finally, Applied Materials was used as a case study for answering the research questions. There are changes that Applied Materials can make as a company in order to improve their issues with discrepant materials costs. First, the ASME technical standard currently used should not be changed to the ISO standard because the ISO standard will not support the low volume high complexity products at Applied Materials. When there are opportunities to move to metric, either because there is a customer request or supplier request, the change should be made. The entire system does not need to be converted to metric, the interfaces between facilities and fasteners can be changed to quickly meet any requests. To improve tolerance issues, a tolerance software package is recommended, as well as improved training for all technical staff. Finally, when a merger and acquisition occurs, the ABC Methodology should be used to choose the standards that will be used by the new company going forward. The ABC Method will ensure the needs of the new organization are met and that the best standards will be used to benefit the entire organization.

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