BEYOND THE SUB-OPTIMIZATION OF INTERCHANGEABLE PARTS

The Potential for Thinking Together and Leading Together in the 21st Century

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Abstract

When do *interchangeable parts* cause losses to the enterprise and society? Is the belief system about interchangeability still appropriate for the 21st century, and what other boundaries found in this belief system limit the potential of the organization? Furthermore, in what ways does a focus on "interchangeable parts" hinder progress towards working together? These questions and many others will be raised and answered during a unique exploration of the potential of "thinking together" in the 21st century. Much credit has been given to advances in technology in changing our daily lives. What advances could be achieved when we "think about our thinking" and begin to "*think together, learn together, and work together"* as one global enterprise? Join in and find out more about the exciting developments on "better thinking about thinking" that are underway within The Boeing Company.

Introduction

I was asked recently to offer a quick explanation of the "better thinking about thinking" efforts underway within The Boeing Company and how they differ from what other organizations have done in the past and are currently doing. Fortunately, I had given thought to a simple example designed to prompt a reexamination of the mode of systemic thinking underlying design and manufacturing as conducted in the majority of design/manufacturing companies in the world today. The example begins this paper and explained in further detail on subsequent pages. Perhaps such a simple opening example will begin to call into question one of the fundamental tenets of the industrial age, the belief in the sameness of interchangeable parts. The example challenges the appropriateness and reveals limitations of such a belief system in the 21^{st} century. Additional examples are also shared in this paper, each time-tested in class rooms within Boeing as well as in university class rooms in the U.S. and in public and private class rooms in the United Kingdom, each offering a contribution to break through the thinking associated with the theory of interchangeable parts.

The first example begins with a listing of the potential letter grades for a classroom assignment. Any present or former student would surely know the letter grades to be A, B, C, D, and F, with plusses and minuses added for good measure. The next step is to ask "What is the minimum letter grade requirement associated with hardware or supplies procured by any organization, be it a Boeing company site or a general contractor in the construction industry." Quite often the answer is "A", if not "A+". Had I not known better, one of these would surely been my answer.

It is with great surprise that most who are asked to answer this question learn that my current answer is "D-". As to "How could this be?", or "Why not A+?", the explanation lies with yet another belief system that resides in the majority of the companies in the world today. The additional belief is that when hardware and supplies are judged to be *acceptable*, that is, they "meet procurement requirements", they are all "good"(and "equally good"). This connects with letter grades in that a world of "pass vs. fail" grading, D- is a passing grade, and so are C+, B-, and A+.

Now consider an inventory cache of a particular part, part #2287, and the letter grades on the "good" parts which are in stock. Some of the inventory may well contain parts graded A+, B-, C+, and D-. The awareness that an "A+"-graded part differs from a "D-"-graded part leads to concluding they are not *as* interchangeable as might be expected without such awareness. "Good parts" which pass the minimum procurement requirements are not equally good parts, in the same way that all passing grades are not A+. In this "digital" view of part quality, there are two levels of quality – good and bad. The view implies a sense of mathematical equality, a sense that underlies the belief system of interchangeability. The awareness of distinctions among "good parts" challenges the definition and meaning of the concept of "same" in a world revealing that cloned animals are not identical and that snow flakes are not either. As Dr. Deming's admonitions would remind us, *variation there will always be – what is it telling us?*

Herein lies the misperception associated with interchangeable parts – the view that one "good part" (A+) is as good as any other "good" part (D-), that they are the "same". Seeing these two "passing parts" as different is an essential first step towards understanding the limitations and assumptions embedded in the model of "interchangeable parts". The explanation of "sorting parts" that follows adds further clarification to the belief associated with *complete* interchangeability. This "sorting parts" explanation, plus the introduction of additional concepts for managing variation, forms a foundation for understanding interchangeability, like any other model, as a model with specific limitations. Appreciation of these limitations will unveil the reasons decision making rules lead companies to buy on price tag alone.

The aim of this research paper is to make more visible certain underlying assumptions behind the model of "interchangeable parts" as practiced and to shed further light on how these shared assumptions affect the potential for organizations to "work together" in the 21st century. A collection of common practices and concepts - from "Sorting Parts" to "Cutting Wood", from "Zero Defects" to the "Paradigms of Variation" to the "Quality Loss Function"~~,~~ - are presented in this paper to deepen understanding of significant limitations of absolute "interchangeability". A better view of the world is proposed, one in which interchangeability is viewed as *relative* instead of *absolute*. The paper ends with an example from The Boeing Company selected to illuminate the significant potential benefits residing within organizations when the model of "interchangeable parts" is upgraded to a model of "interchangeable parts of". Creating individual and organization awareness of the choice between *thinking and acting* in terms of "interchangeable parts" and *thinking and acting* in terms of "interchangeable parts of" is the aim of an ongoing transformation to "better thinking about thinking" which is underway within The Boeing Company.

Sorting Parts

As a complement to the "letter grade" example offering further insights on the "interchangeable parts" premise consider a second exercise. Imagine that cylindrical parts are being manufactured to a given length and diameter. Variation being what it is, stemming from sources of "methods, equipment, people, environment and materials", one would not expect three parts chosen at random to be identical in measured diameter or length. As such, imagine Figure 1 as the plot of measured diameters of the three.

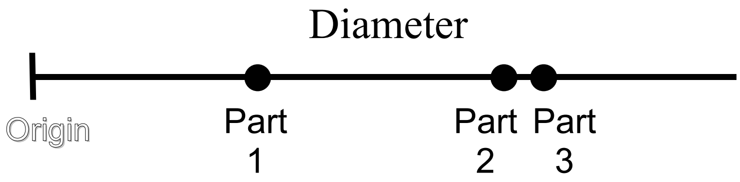

Figure 1 – Diameter variation for 3 manufactured parts.

Given these three part diameters to choose from, the question at hand is "Which two of these~~-~~three parts is closest to being the same in diameter?" When I present this query to adult audiences, I do so in a roundabout way. First, I ask them to imagine someone else's answer. I have them consider that a 4th grade student is sitting next to each of them, about 8 years old. I then present the "diameter" question and collect the supposed "4th grader" responses. The reason for Inserting the vantage point of "4th graders" has a dual purpose, first to lessen the anxiety of the adults in answering this apparent "trick question", second to place the likely answers of the "4th graders" alongside the soon-to-be-collected adult answers. A 4th grade student level was chosen because at that level students would be very likely to understand the concept of diameter.

For as long as I have been using this example, more than five years of responses on every occasion, adults have proposed that the 4th graders will answer "2 and 3". The adults have offered as their answer "2 and 3" every time as well. Only once was another answer given, and by a real elementary school student (reference 1). The "diameter" question is presented to adults as part of a "thinking about thinking" seminar (reference 2) to offer the perspective that the question has more than one answer and that the standard answer "2 and 3" reveals one style of thinking. The "2 and 3" answer requires thinking that defines "same diameter" "closest together" or as "more similar in relative distance from the origin of the scale used to present the data". This thinking style interprets the horizontal scale as being continuous with the data points 1, 2, and 3 placed at three different distances from the origin.

Now consider the use of manufacturing tolerances to define the needed length and diameter of the cylindrical part. Using the system of tolerances, a widespread practice first used in Europe in the 18th century (reference 3), two numbers are provided by the part designer to dictate the respective ranges within which all length and diameter dimensions should fall. According to the protocol of tolerances, the diameter of the part should fall between this "lower specification limit", or LSL, and the "upper specification limit", or USL. Similar demands are placed upon the length dimension of the part. Parts that meet these two demands, and meet other characteristics defined in the LSL-USL manner, are considered to be acceptable parts. Note also that when presenting the "diameter" question to adults, who within The Boeing Company are more often than not aware of such a system of requirements definition, references to LSL and USL values are purposely omitted. Furthermore, no one has requested to have such values as a necessary condition for answering; all offer "2 and 3" without asking for specification limits on the diameter of the part.

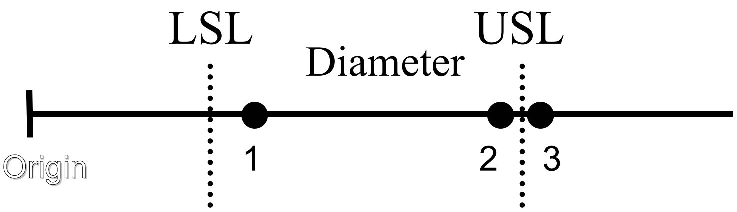

Figure 2 – Variation in part diameter and a system of manufacturing tolerances, LSL and USL.

Including manufacturing tolerances reveals a second answer to "Which two of these three parts is closest to being the same in diameter?" (the diameter question). Consider the tolerances as shown in Figure 2. Using the LSL and USL as specified, the "other" answer to the diameter question is "1 and 2". This answer implies that "same diameter" is being defined as "acceptable for use" or "meet specifications". Both "1" and "2" meet the requirements of being larger than the LSL and simultaneously smaller than the USL. As located, both diameters are acceptable, or "good and equally good". If the length dimensions, and other features of the part fall within defined tolerances, then these two parts would be labeled as "good parts". By contrast, part "3", although closer in physical diameter to part "2", would be labeled a "bad part". By adding tolerances to the example a response different from the more normal "2 and 3" is generated. On what was perceived in the initial responses to the diameter question as a continuum of diameters, a "discontinuous" system has been superimposed; the superimposition affects responses to the diameter question. Accompanying the system of tolerances is the "part" thinking that labels parts as "good" or "bad"~~,~~ with nothing in between – evidence that the thinking has forgotten the continuum. This further explains why I suggest that the minimum letter grade requirement from parts suppliers would be a D-. Parts meeting the minimum requirements are put into stock, and commingled parts barely meeting minimum with all other acceptable parts without distinction. They all passed though some got D- as a grade and are not sorted further. Picture the nature of the customer-supplier relationship when D- parts are procured and integrated in a system as though they were interchangeable with A+ parts. What are the attributes and characteristics of that relationship? What is the perceived downstream impact, or loss, to the enterprise and society of substituting D- parts for A+ parts? The "Quality Loss Function" section of this paper offers an explanation of these losses, and the example of "Cutting Wood" introduces a situation in which the management of variation does not rely on tolerances.

Cutting Wood

In continuing the exploration of the implications of part interchangeability-a third example is introduced, the routine of cutting a piece of wood for a home improvement project. Imagine that a piece of baseboard molding is needed to replace a damaged length of wood in between two existing pieces. We begin with a piece of molding which is too long and needs to be cut to length. In rapid order, the required length is measured, and the piece is marked for cutting. As a next step, a saw is readied. Consider how many lines one typically would draw across the top face of the wood before making the cut. That is, instead of using short marks to indicate where to place the saw, how many lines would be drawn across the top face to guide the placement of the saw blade during the cut? Most often the solution is to use a single line. But, is this the *correct* answer? If not, what other answer could there be? While not immediately obvious, other answers might be "two lines" or "three lines" or even more. What possibly explains the “single line” answer? Could it be that we would draw one line out of habit? Why is the habit not two lines, as in the standard industry use of manufacturing tolerances with an acceptable range, in keeping with the practice of interchangeable parts? The “single line” answer seems to reveal a belief that there is a “target” length for this piece of molding and seems to indicate a strong intuitive sense of knowing that the piece of wood is “part of” something rather than merely a “part”. A “part of” perspective is likely when engaged in a home improvement project where connections are visible and immediate. In the molding example, the poor quality of the fit if the piece is too long or too short will be obvious. Any effort required to adapt the molding piece, because of variation in its length – a little too long or too short - represents quality loss, a concept introduced and developed by Genichi Taguchi (reference 4). As will be shown in the “Quality Loss Function” section, loss increases continuously as the length misses the target by larger and larger amounts. Be it an unsightly gap in need of filler material or the presence of a bulge in the placement of the wood trim, the loss is finite and real. For the molding example, the loss imparted would be to oneself.

Let’s explore this wood cutting example relating it to an organization where all “good parts” are considered to be *absolutely* interchangeable. Consider what has to happen at the assembly operation when parts are cut to the extremes of the LSL and USL, designated by the range of the “2 lines” in Figure 3. Compare the assembly effort when the molding is at the extremes to the effort to that needed to when the molding is cut to the target length, or near target length. Appreciation that there is a difference in assembly efforts, as the wood varies from the target length, is the essence of Genichi Taguchi’s concept of “quality loss”. Relative to an organization, a question to ask is “When do *interchangeable parts* cause losses to the enterprise and society?”~~,~~ The answer is whenever the *interchangeable* parts display variation in dimension from the specified target value. The target value for the molding is the 1 line. This answer will be explored in further detail in the “Quality Loss Function” section of this paper.

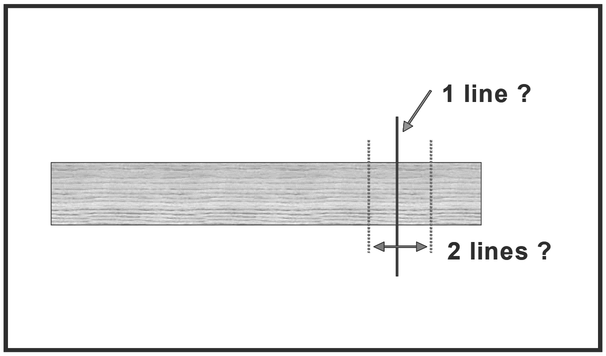

Figure 3 – Marking a piece of wood before cutting it to size.

Zero Defects

The concept of “Zero Defects” is well aligned with the practice of tolerances and the belief system that “good parts are equally good”. The developer as well as promoter of “Zero Defects” as a quality achievement was Philip Crosby, former vice president of Quality for International Telephone and Telegraph (ITT). Much earlier in his career, Crosby worked as a quality professional in the defense industry in the early 1960’s. While employed there, he witnessed the known shipment of non-conforming, (defective) hardware to the customer (the U.S. government), albeit at an “acceptable” level of defects. Crosby set a higher goal for himself, the delivery of zero defects, or 100% “good parts.” In doing so, he initiated what was to become known as the “Zero Defects” philosophy. Years later, upon retirement from ITT in 1979, Crosby released the first of his many texts on quality management, “Quality is Free” (reference 5). In it, Crosby theorized that there are but four “Absolutes of Quality Management”:

1. Quality is defined as conformance to requirements, not as 'goodness' nor 'elegance'.
2. The system for causing quality is prevention, not appraisal.
3. The performance standard must be Zero Defects, not 'that's close enough'.

4. The measurement of quality is the Price of Non-conformance, not indices.

Upon closer review of these four *absolutes*, one will find references to the practice of tolerances in phrases such as "conformance to requirements", "the performance standard must be zero defects", and "the price of non-conformance". The belief system associated with these absolutes appears to be consistent with the model of absolute interchangeability of parts. The concept of the "Paradigms of Variation", to be introduced next, sheds more light on how the inevitable variation in parts produced under the guidelines of "interchangeability" and the associated use of manufacturing tolerances contrasts with the belief system of "Zero Defects".

The Paradigms of Variation

In 1996, I co-authored a paper entitled "The Paradigms of Variation: Effects on Identifying Opportunities for Quality Improvement." (reference 6). From the paper's abstract:

> Among the many rediscoveries accompanying the quality revolution of the 1980's were the acknowledgment of the concept of paradigms and a renewed interest on the topic of variation. Together, these two concepts can provide quality improvement opportunities that are visible to only a few in the 1990s. This lack of visibility can be explained by the essence of what paradigms are known to do, which is to cause information to become expected. Since variation is commonly defined as but one of several dimensions of quality, the role of one's variation paradigm is critical to one's ability to recognize opportunities for quality improvement. The objective of this paper is to present a variation paradigm model and explain the role it may play in the delivery of higher quality products and processes.

The presence of the "paradigms of variation" will be revealed through another time-tested example. As an extension to the illustration used in "Sorting Parts", I employ a "purchasing decision" among four suppliers. Four histograms for a given dimension of a part are shown in Figure 4, wherein dimensions for parts from supplier 1 are distributed per the first histogram, dimensions for parts from supplier 2 are distributed per the second histogram, and so on. Which supplier is to be preferred? Differences in answers to this question provides additional insights to the assumptions underlying "interchangeable parts".

The example is presented as follows:

> As a procurement agent in "your company", you have been tasked with making a purchasing decision. The decision is from which among the four suppliers of this part will you buy. For educational purposes, great liberty has been taken in simplifying this decision. That is, the decision rests solely on the histogram data provided by the suppliers for *one* of the features of this part, a dimension. Nothing else matters; and the following conditions apply simplifying the situation even further. The conditions are:
>
> 1. All four suppliers will charge equal prices (per part) and deliver with equal delivery schedules.
> 2. The four distribution averages and associated levels of variation will not change position or shape (the processes are stable - now and forever).
> 3. All four suppliers guarantee Zero Defects will be delivered.
> 4. The selection of the specification limits, along with the target value of 15, was a team decision by co-workers in "your company".
>
> For further clarification, the target value is explained as the "preferred value" requested by the co-workers. Having set up the conditions for the example, the question to be answered is "Who is the preferred supplier?" Five possible answer options are offered – "supplier 1", "supplier 2", "supplier 3", "supplier 4", or "it doesn't matter."

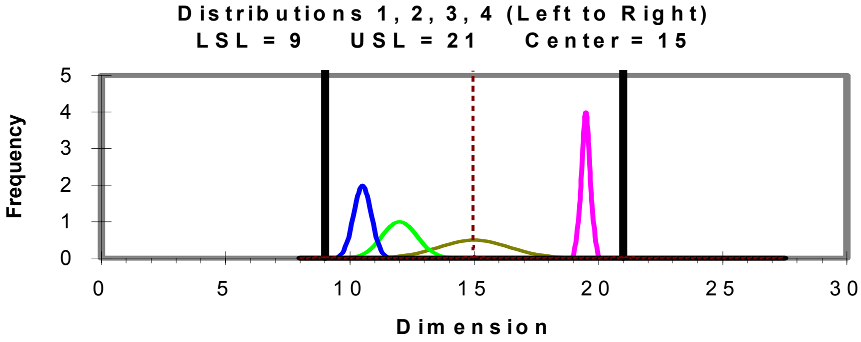

Figure 4 – Part dimension variation (resulting from process variation) for four suppliers.

This example has been in use within The Boeing Company since 1996, with surprisingly stable (and predictable) results over this eight year period. While there are "special causes", the "common cause" results reveal the overwhelming popularity of supplier 4's parts - the 4th histogram. Typically 60-70% of those asked, either in a class room or during a presentation when more than 10 attendees are present respond with that answer. Among the remaining respondents, 20-25% prefer the 3rd histogram and a small number, at most 5%, answer "it doesn't matter."

When participants in this decision exercise are asked to explain the popularity of the 4th histogram, the standard answer is "it has less variation." When prompted by the question "Less variation from what?", the reply is "less variation from each other." For those who are asked to explain the reason for choosing the second most popular choice, the 3rd histogram, the answer is "less variation from target." Selecting supplier 3 – the 3rd histogram - represents what is known within Boeing as "paradigm C thinking." The emphasis of paradigm C is *piece-to-target* consistency. Piece-to-target consistency reflects the "Quality Loss Function" concept and a reflects an appreciation for the extended system in which this piece fits and exists. Selection of the 4th histogram as the best alternative reveals an emphasis on *piece-to-piece* consistency. The piece-to-piece selection known within Boeing as "paradigm B thinking." The conclusion that "it doesn't matter", echoing the belief system of "Zero Defects", is recognized as "paradigm A thinking." Upon closer examination, neither "paradigm A thinking" nor "paradigm B thinking" reflects the target thinking demonstrated in the "Cutting Wood" example. Unlike "paradigm C thinking", which emphasizes the role of a target focus, both paradigm A and B thinking focus on *acceptability* and, as such, the belief of interchangeable parts. An explanation of the economic advantage possible selecting supplier 3, the use of "paradigm C thinking", is further explored in the next section of this paper.

Quality Loss Function

I was first introduced to the ideas of Genichi Taguchi in 1987. Among the initial big impressions **is one** that remain**s** to this day**,** is Taguchi's novel concept of quality**. H**e defines as "the minimum of loss a product causes to society after being shipped" (**reference 4**). After years of reflection, I have come to realize that the focus on "loss….after being shipped" acknowledges the existence of a never-ending connection (and impact) between the provider of the part and what it is "part of". The technical aspects of this holistic model are shown in Figure 5, where the horizontal axis represents the specific value of a part dimension on a continuum and the vertical axis represents the associated "quality loss" for a corresponding part dimension. If one considers the "quality loss" to be the "extra effort required" for installing a part of a given dimension, the distribution ("loss function") theorized by Taguchi - a parabola centered on the target dimension (with minimum loss at target), resembles the observation made in the "Cutting Wood" example. That is, more and more effort ("quality loss"), be it puttying efforts or an extra hammer swing, is needed for a piece of wood cut further and further away from the preferred target value. Taguchi's model brings in to question the belief that all parts within the range of the tolerances are "equally good", or *absolutely* interchangeable. The degree to which variation from a target dimension produces harmful effects downstream in the "organization and society" is a function of the steepness of the parabola, which in turn depends on the specifics of the system which the part is actually a "part of". Taguchi's model suggests that interchangeability should be modeled as being *relative* and not *absolute*.

By comparison to Taguchi's model of continuous quality loss, the mathematical model associated with the concept of "Zero Defects" is a "step-function." Figure 5 offers a side-by-side comparison of these models. In keeping with a step-function model, all parts within tolerance are "good and equally good". No change in quality is perceived across this range and the only changes in quality that do occur happen instantaneously at the transition across either of the two tolerance limits. The unchanging quality within the tolerances and the step-function degradation are assumptions are also the assumptions of "paradigm A thinking" as well as "paradigm B thinking". Neither model indicates a sensitivity to the impact of variation in dimensions from a target value as long as the value remains within the tolerances. As presented, Taguchi's parabolic model is consistent with "paradigm C thinking", which recognizes economic value (i.e., lower loss downstream) for parts with dimensions closer and closer to the target value. Since the 1950s, Taguchi has modeled part quality as continuous, rather than discrete, with a preferred value (target) that provides for minimal loss. Such a view forces a conclusion that there is always loss "imparted downstream" by the part *after its shipment to the customer*. So impressed was Deming after learning of this holistic model that he described it as *"a better view of the world"* (reference 7). Both Taguchi and Deming are saying that the world is filled with connections poorly approximated by "interchangeable part" thinking. The question being raised more and more within Boeing is when and where should classic "interchangeable part" thinking be replaced by "paradigm C thinking". The answer lies in a "case by case" judgment, as in the popular answer "it depends." It depends on the investment of resources required to implement "paradigm C thinking" and the resulting return on this expenditure. An example of when the returns to Boeing, namely lower loss to the organization and society, was worth the investment, follows.

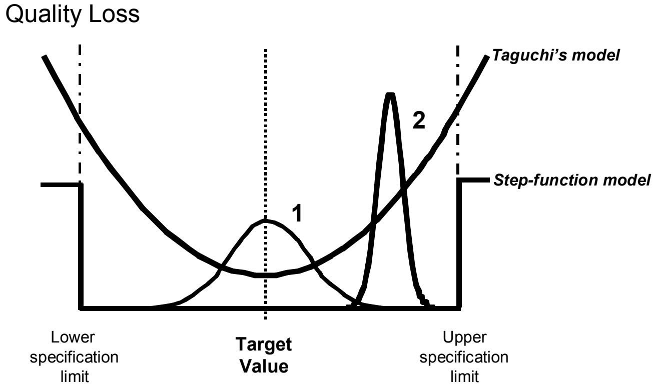

Figure 5 – Genichi Taguchi's Quality Loss Function reflects a continuous model of part quality. Histograms 1 and 2 are examples of possible results for 2 suppliers of parts.

Rocket Science

Over the past 20 years, since the realization of target thinking's application in Japan (reference 8), the practice of managing process variation with respect to target values has represented a valuable alternate practice to the industry norm of adherence to tolerances and the belief in absolutely "interchangeable parts." Instead of judging the goodness of a given process, or of given parts, in terms conformance to manufacturing tolerances, "paradigm C thinking" offers an economically valuable departure from the standard practice of "interchangeable parts". Progress in applying the thinking is being made within The Boeing Company.

Consider the ultimate quality goal of an organization practicing "paradigm A thinking" - 100% good parts or *zero* defects. As explained throughout this paper, a closer evaluation of this goal reveals that the practice of part thinking runs counter to target thinking. Over the recent years, a Boeing team has been actively applying Taguchi loss function thinking and has achieved a remarkable gain in hardware braze quality when fabricating rocket engine hardware. The hardware consists of a flat plate with 628 holes (of *equal* size), in which 628 round posts (of *equal* size) are brazed in place. (That is, as *equal* as manufacturing processes will deliver.) The successful brazing of this hardware now creates 1,256 braze fillets - 2 per joint, one at the interface of the post with the top face of the plate and one at the interface with the bottom face.

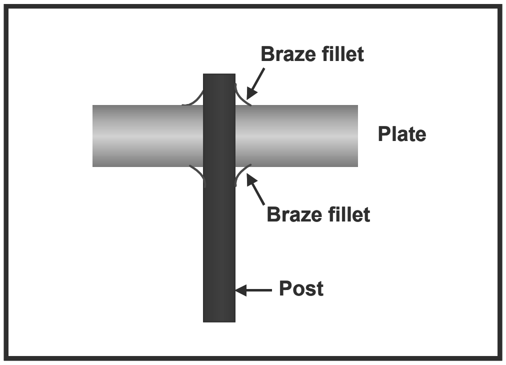

Figure 6 - Cross-section of hardware assembly showing 2 braze fillets per joint.

The Integrated Product and Process Team approached this hardware design (Figure 6) by abandoning the traditional expectation that two or three braze cycles would be required to complete all 1,256 fillets. Using the traditional practice, a wasteful time-consuming and expensive second (sometimes third) brazing operation was necessary to complete the brazing of all 1,256 fillets. Applying traditional "paradigm A thinking" gave these results which were the best the enterprise knew how to do. With growing enterprise awareness of the potential advantage of "paradigm C thinking" over "paradigm A thinking", the team decided to explore the possibility that additional braze cycles could be eliminated by shifting the thinking of the team from "parts" to "relationships between the parts." Using the mental model of Taguchi's parabolic loss function, the team could more readily see the previously invisible "quality losses" (extra braze cycles, extra assembly efforts, etc.) - losses that were a by-product of "paradigm A thinking." Through a concerted effort to manage the variation in the outer diameter of the posts and the diameter of the holes they would be inserted into, the team predicted that all 1,256 fillets could be achieved in one braze cycle. And, they were right. The never before heard of, and never before conceived of, result of 100% first pass braze quality was achieved with the first hardware set. For a production volume of one hardware sets per week, the savings in cycle time was well worth the effort to manage the process variation with respect to the target values for both the diameter of the 628 holes and the outer diameter of the 628 posts. Although more time and effort was required to manage the variation of these dimensions in this manner, the added attention to detail on relationships eliminated the need for far more expensive second and third braze cycles. To date, 100% first pass braze quality results have been repeated on a routine basis, results which have made it unnecessary to obtain a second braze furnace.

Conclusion

Returning to the opening question, "Is the belief system about interchangeability still appropriate for the 21st century?", I would answer "it depends". There are certainly situations in which the extra effort associated with "paradigm C thinking" education and implementation does not offer significant advantages over traditional "interchangeable part" thinking, also presented as "paradigm A thinking." The good news to report is that more and more awareness of these distinctions is emerging within Boeing and organizations with whom we are "thinking together", that is, within our *Enterprise Thinking Network*. While much credit has been given to advances in technology in changing our daily lives, members of this thinking network are more and more aware of the advances which could be achieved when we "think about our thinking" and begin to "*think together, learn together, and work together"* as one global enterprise.

Dr. Deming ended this last book, The New Economics (reference 9), with a quotation from Donald Wheeler;

"Conformance to specifications, zero defects, Six Sigma Quality, and other [specification-based] *nostrums, all miss the point."*

To borrow from a previous paper (reference 10) "Deming's admonition lies in the limited focus of these efforts to improve quality, for all of them *miss the point*. As to what is *the point*, could it be that the quality, and value, of the products and processes we utilize as consumers suffers from *specification-based* thinking and we haven't yet noticed the impact?" It is hoped that the examples shared in this research paper serve to illuminate the possibilities of "thinking together" and "leading together" in the 21st century and reveal some of the limitations imposed by thinking of parts as being *absolutely* interchangeable.

Acknowledgements

The author would like to acknowledge the enormous time invested in after-hours conversations with Rudy Hernandez and Tim Higgins in developing the ideas presented in this research paper.

References

(1) Bellows, W.; (personal research by the author.) The one exception when the question was raised with *real* elementary school students. Among the 40 to 50 students who have been asked the "diameter question" as part of a research study, only one gave an answer different from "2 and 3". "1 and 2" was an answer given to a father, who was conducting a survey of his four sons including this son. When asked to explain, this son's response was "Dad, the answer '2 and 3' was too obvious, so I figured it was a trick question and answered '1 and 2' ".

(2) Bellows, W.; The "Enterprise Thinking" seminar has been offered within The Boeing Company in various formats since 1993. The aim of this seminar is to provoke "better thinking about thinking" and introduce the prospects of better "working together, learning together, and thinking together."

(3) Delavigne, Kenneth and J. Daniel Robertson; Deming's Profound Changes: When Will the Sleeping Giant Awaken? Prentice-Hall, Englewood Cliffs, NJ, 1994.

(4) Taguchi, Genichi; Introduction to Quality Engineering, Asian Press Organization, 1983.

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(10) Bellows, W., "Conformance to Specifications, Zero Defects, and Six Sigma Quality: A Closer Look", prepared in 2003 for publication in the International Journal of Internet and Enterprise Management,