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Selection of Evaluation Methods for New Weld Demands: Pitfalls and Possible Solutions

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Abstract
New demands often create a need for new evaluation methods. However, there are several pitfalls when choosing those methods that can endanger the expected benefits.

This study shows examples from the implementation of a new welding standard at several sites in the same company. It focuses on possible pitfalls as well as probable causes and potential solutions with a push- and pull-approach. The examples cover the problems with unclear or too simplified demands, lack of evaluation method and incapable evaluation methods.

The ability to handle and prevent the described issues is a prerequisite in order to be able to develop the organisation in means of quality assurance for light weight structures.

Keywords: evaluation methods, weld, welding standard, demands, pitfalls, implementation, push, pull

1. Introduction

Weight reduction of vehicles is high up on the agenda for several companies nowadays. The benefits with lower weight are several; less material used gives lower production costs and the customer gains a vehicle with lower fuel consumption as well as higher loading capacity; all which increase the end user's competitiveness. Reduced weight therefore makes manufacturer, end users and the environment all winners.

1.1 New Welding Standard

Up to as much as 60-80% of the vehicle weight comes from complex welded structures made from steel or steel castings in construction equipment machineries [1]. This area is hence important when striving for reduced vehicle weight.

If the weight reduction is handled by using thinner plates the demands on the welds get even higher because of increased stress. It is desirable that all parts of the welded structure have the same expected length of life everywhere, independent on the stress level. Otherwise some parts will break whereas others will be over processed. In order to get the same life of the entire structure it is therefore necessary to differentiate quality demands of the welds. Welding standards, such as ISO 5817 [2] and Volvo Standard 5605 [3] describe different acceptance limits for the quality levels. Unfortunately the acceptance limits and defects defined do not well reflect the fatigue life of the weld as Barsoum describes in [4]. Karlsson and Lenander [5] suggested changes to the defects and acceptance limits and a new Volvo welding standard was created where the demands were based on their influence on fatigue life [6].

The toe side (transition between weld and plate) and the root side (penetration) are the most important points for the fatigue life of fillet welds without full penetration, Figure 1, but the two sides are handled differently by manufacturing [7]. The toe side is governed by the weld standard where the weld classes have different requirement levels. Only the weld class is therefore stated on the drawing. The root side requirements are instead explicitly specified on the drawing. Figure 1 shows examples of demands and their designations that the organization need to handle in order to be able to reduce weight of the welded structures.

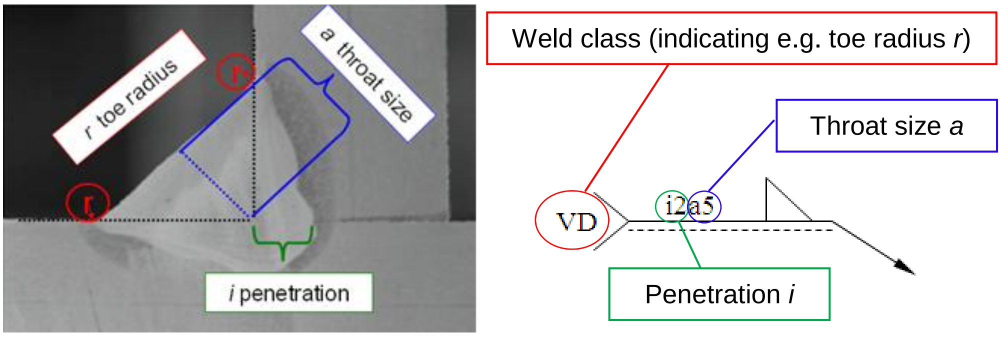

Figure 1. Examples of demands on a weld in cross section and the corresponding drawing designations.

1.2 Problem Characterisation

Assuring new demands being obtained is necessary during implementation. An illustrative system of this consists of several components as Figure 2 shows. In the middle there is a product and a process that needs to evaluated. Surrounding them are different evaluation methods. Defect descriptions and demands define what type of information is needed to get from the evaluation. The outer circle represents the internal customers and how they need the information to be presented for them.

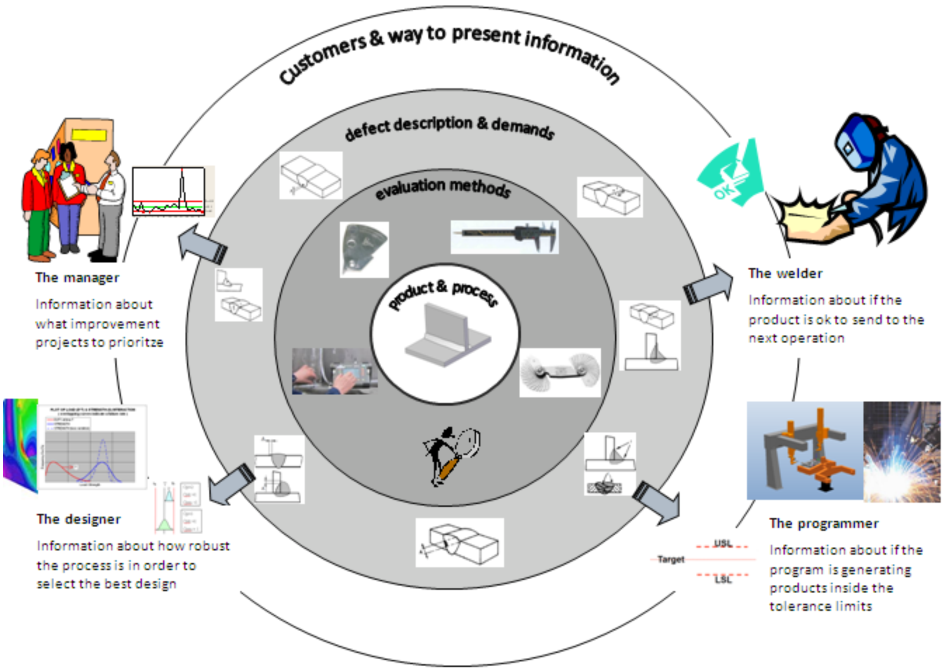

Figure 2. Illustration of components affecting the choice of evaluation system.

The way the organization relates to this can be summarized into two approaches; push and pull. Liker [8] describes pull as an important principle in lean thinking. It means providing your downline customers in the process with what they want, when they want it and in the amount they want. The production is not started before a need is indicated from the subsequent operation.

1.2.1 The Push-approach

This approach generates a push-mentality. In Figure 3 the flow of information is pushed inside and out. By using a certain tool or evaluation method it is set what type of defect or demand you are looking for and what type of information will be generated from the evaluation to the different internal customers. The information is not customized by the needs of the internal customer but is dependent on the evaluation method used. This mental model leads to resource optimisations of the measurement station itself.

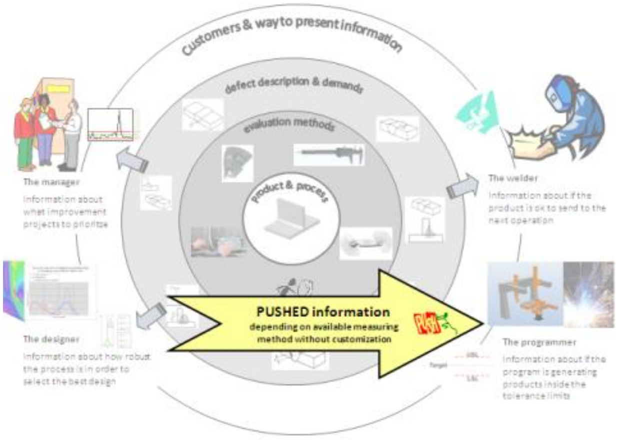

Figure 3. Pushed information originated from choice of evaluation method.

1.2.2 The Pull-approach

If instead a pull-approach is used the flow goes in the other direction as demonstrated in Figure 4. A need for information is identified at an internal customer. The need generates how the information is preferably presented and what types of defects and demands that is in question. Finally that sets the requirements for an evaluation method. This mental model instead leads to information flow optimisation.

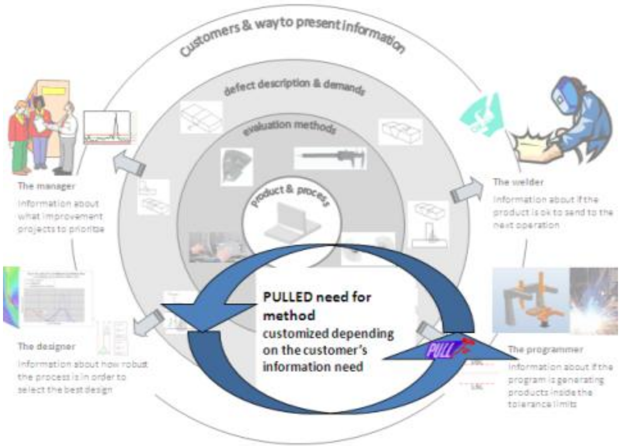

Figure 4. Pulled information originated from an internal customer need.

1.2.3 Why, What and How

Hasenkamp, Arvidsson and Gremyr characterize a methodology in three levels; principles, practices and tools which can be associated with the questions why, what and how [9]. Hammersberg describes an Affinity-interrelationship (AI) analysis performed with representatives from engineering, production and quality/inspection within a company, see Figure 5. The starting point was *"What are the biggest problems to control our welding processes towards new welding classification?"* The group concluded: *"The problem origin in insufficient inter disciplinary co-operation"*.

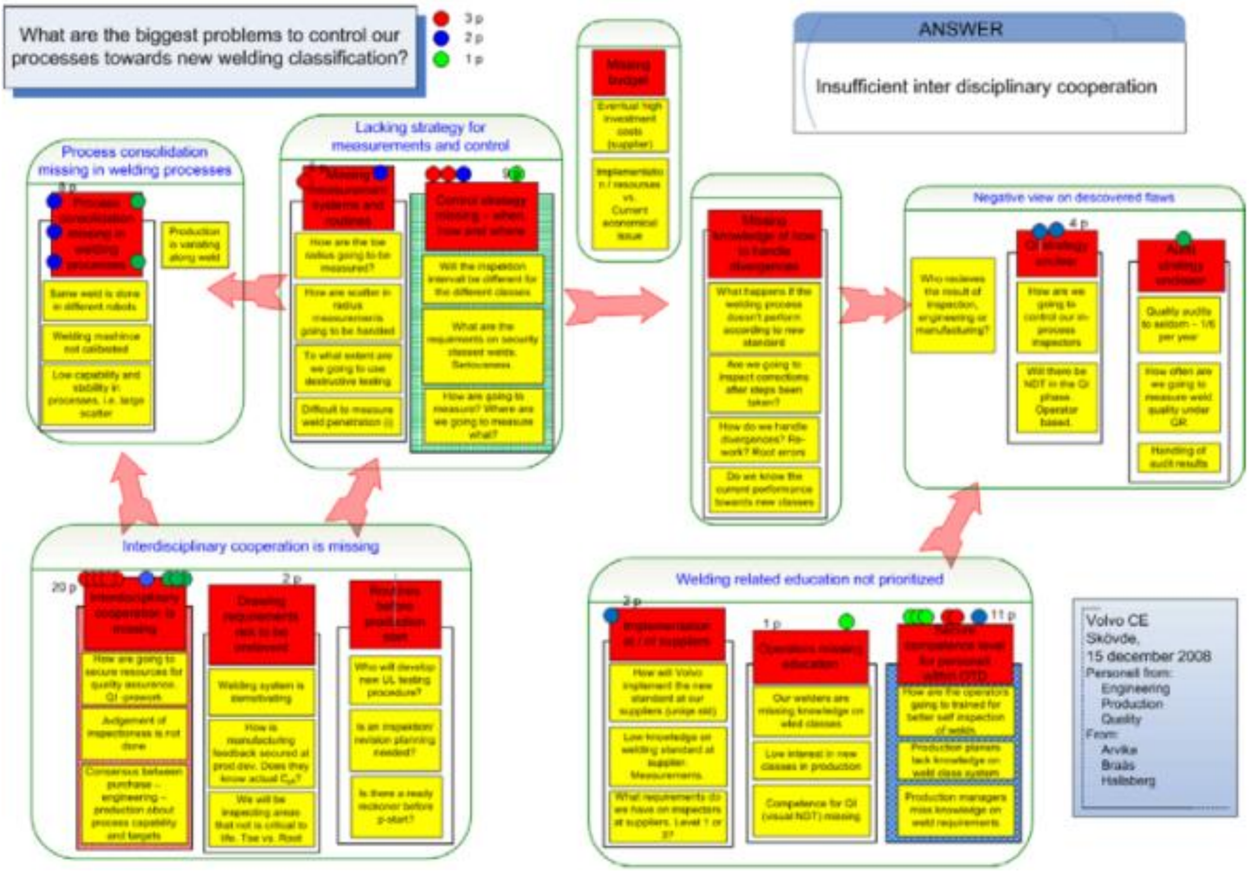

Figure 5. AI-analysis with different functions from one organization representing vehicle manufacturing[10].

Hammersberg determines that the different functions within the company may have the same "how"- picture but different views on "why" and "what". These differences need to be clarified and explored in order to develop cost-effective non-destructive testing (NDT) with the right technology level at the right place. These differences in views probably also drives cost since the cost is highly affected by where design changes occur e.g. as mentioned by Bergman and Klefsjö [11].

2. Empirical Study: Pitfalls and Possible Solutions

The company studied has numerous plants performing welding operations all over the world. This study focus on when the new welding standard was about to be implemented. A survey was performed in order to get a view of the current status of evaluation methods used for each demand. Also other companies performing welding were included in the survey. There was for example no existing NDT method at any plant in the case of penetration in fillet welds.

During the implementation of the welding standard a number of obstacles were observed. Some of them were closely connected to the new welding standard while others could have occurred also in the old system. Three cases of pitfalls are described below which will be discussed from a push- and pull-approach.

2.1 Lack of Evaluation Method

Because of a constantly changing industrial environment and knowledge base within and outside the company demands are changing. In the studied case some demands were new to the organization which means there was no existing evaluation method.

2.1.1 Ultrasonic Testing of Penetration

The currently used method within the company for measuring penetration in fillet welds is destructive testing. The most common test procedure at the company in question consists of four steps; weld test pieces, mark and prepare them, press the plates apart and finally measure the penetration in the flange and waist plate using calliper as Figure 6 shows. The parameters used when welding the test pieces can then be used, assuming it will give the same result on the product as on the test pieces.

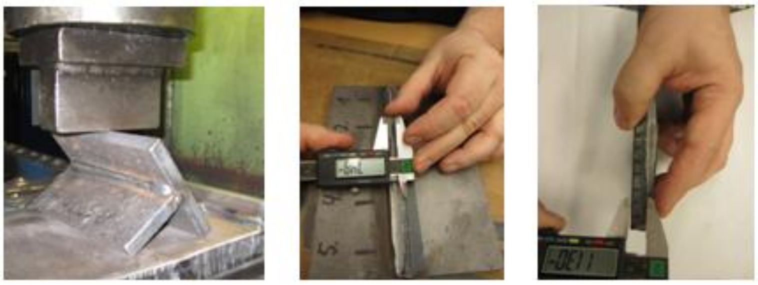

Figure 6. Welded test piece is pressed apart and measured (flange and waist plate).

The downsides with only using destructive testing e.g. lack of possibility to test completed parts, impelled the organization to investigate possible NDT solutions. Because of the current knowledge and use of ultrasonic testing within the company this test method for evaluating penetration was investigated, hence a push-approach was used.

Different types of ultrasonic equipment and test pieces were tested. First tests were performed with both phased array (PA) and conventional ultrasonic technique on machined parts. A PA technique was chosen for additional tests on welded parts and resulted in a method for finding the penetration, *i*, in Figure 7. Further tests were performed with three types of equipment with 16 sensor elements and frequency 4, 5 and 10 MHz respectively.

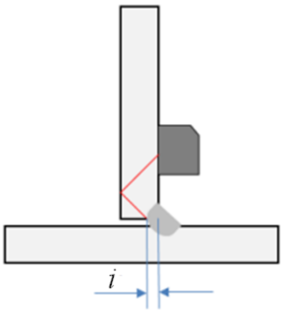

Figure 7. Illustration of measuring penetration *i* on fillet welds using phased array.

2.1.2 Weld Toe Radius

The weld toe radius was also a new demand for the organization. In this case a pull-approach was used. First, the different internal customers were identified. One of them is the welding robot programmer. He needs to know that the welding robot produces parts with the correct radius and that he gets a warning if something is changing, risking defect products being made. A control chart was chosen for giving the programmer information about the natural variation of the welding process. The control chart illustrates the limits which the process is likely to produce within. If it shows data outside these limits it is a signal representing a non-normal variation, meaning that the process is changed, which Figure 8 shows.

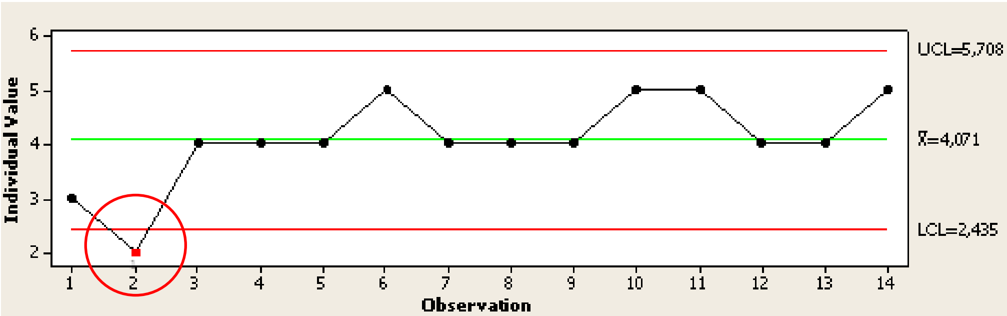

Figure 8: Example of a control chart showing a signal, meaning the process is unstable.

The information generated illustrates how precise the measurement system (MS) needs to be in order to fulfil its purpose to warn for an unstable process. The precision required to monitor the welding process was showed to be not high at all, compared to the technical demands of MS precision generally discussed in the former push-information mind-set. In that case the technical requirements where raised from the technical performance of the MS and not from the process. Wheeler states that a control chart can detect signals even when the measurement error contributes up to 80% of the total variation [12]. Hence a quite simple, and cheap, tool could be used for collecting the toe radius data; a master block and radii blades (Figure 9). The master block has radii corresponding to the different demand levels. First a visual comparison is performed with the blades on the master block. Then the blade is placed on the weld toe. Light leakage between the blade and the weld indicates a radius mismatch.

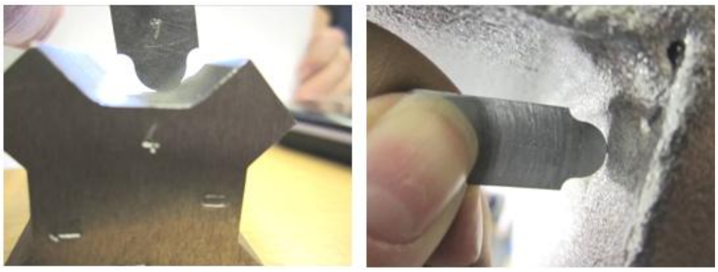
Figure 9. Master block and radius blades used for weld toe radius evaluation.

2.2 Incapable Method

Another pitfall is to assure that the selected method is capable of delivering what is expected. In practice the measurement shows a total of the product value and the measurement error [12]. By performing a measurement systems analysis (MSA) it is possible to estimate how much of the variation that derived from the measurement system. A MSA shows how good the whole measurement system is in regards to repeatability and reproducibility. In order to make sure the suggested evaluation methods could be used a MSA therefore needs to be performed.

2.2.1 Measurement System Analysis of Ultrasonic Measurement of Penetration

The MSA was performed by two experienced operators, both very familiar with ultrasonic inspection and the particular equipment. Three different types of equipment were used. The operators evaluated 15 marked points, each point three times, randomized within equipment.

The MSA showed big differences between equipment and also between test parts depending on the thickness of the plate.

The analysis showed a possibility to continue investigating the method but restricted to certain plate thicknesses because of the method's incapability for thicker plates. Figure 10 is showing the result for plate thickness 8 mm and 10 MHz probe.

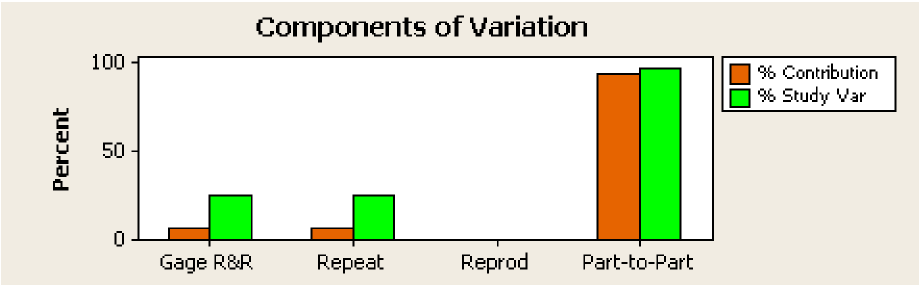

Figure 10. Variation originated mainly from differences between parts and not from the measurement system.

Since the result from the ultrasonic testing was compared to penetration manually measured on the broken test pieces a MSA was performed for that measuring operation as well. The MSA included three operators; all familiar with this type of measuring operation. The tool used was a digital calliper that is calibrated regularly. The operators measured 25 marked measuring points, each point three times, fully randomized.

The first MSA showed an unstable measurement system. The measurement method had to be standardized in order to reduce the variation from the measurement system. The operators discussed their different methods and agreed on the ones showing the least variation. A standardized work sheet was created based on that. A second MSA was performed with clearly improved result. An interesting observation was that even such a well-known measuring operation as a digital calliper showed both low reproducibility and low repeatability compared to the process monitored.

2.2.2 Measurement System Analysis for Weld Toe Radius

The MSA for the weld toe radius evaluation was analysed using Attribute Agreement Analysis since the radius class was considered to be attribute data. An example of evaluation method to use is Kendall's coefficient of concordance which measures the associations among ratings and do not treat misclassification equally. The coefficient ranges from 0 (no agreement) to 1 (complete agreement) where coefficients above 0.9 are considered very good.

The result from the MSA shows very high values on the Kendall's coefficient of concordance (see Table 1, 2), meaning that the operators managed to classify the weld toe radius in categories with high agreement. A measurement system with a coefficient of 0.9 or above is considered very good. The p-value is less than alpha (0.05) for all ratings. That means that the null hypothesis - that the agreement between appraisers is due to chance - can be rejected.

Table 1: Kendall's Coefficient of Concordance Within Appraisers

Appraiser	Coefficient	P-value
1	0,97	0,0003
2	0,96	0,0004
3	0,92	0,0007

Table 2: Kendall's Coefficient of Concordance Between Appraisers

Coefficient	P-value
0,89	0,000

2.3 Unclear or Too Simplified Demands

The way to specify design demands from the designer to the production is by stating them on the drawing or in the standard. To transfer information this way means also losing information in the interface. To be very detailed means more work for the designer but also more information for the production to handle and interpret. Too simplified descriptions on the other hand mean risk of losing information important for the production.

2.3.1 Loading Conditions Creates Different Demands

Due to the different loading conditions originating from the machine's range of application, the critical part of the weld varies. With loads traveling horizontally across the weld the lower weld to radius is critical for fatigue life, as shown in Figure 11.

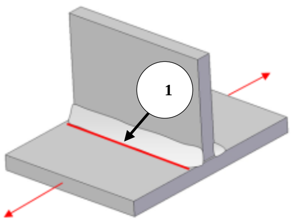

Figure 11. Horizontal forces make lower weld toe radius (1) critical.

Figure 12 instead shows the case with high load carrying demands of the weld, meaning the forces traveling vertical across the weld. Here the penetration and the upper weld toe radius are critical.

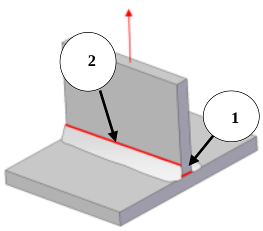

Figure 12. Vertical forces make penetration (1) and upper weld toe radius (2) critical.

This means that for certain loading conditions the penetration is critical but in others it is not. The possibility the designer has to convey this information to the production and the welding engineer is by stating different requirements on the drawing. The risk that the designer is not differentiating the demands but uses a common practise exists which an on-going investigation on a demonstrator from the organization in question shows. In that case the demands, governed by welding class which states the defect limits, was equal everywhere on the product. It showed when doing additional calculations that by differentiating the demands, the total weight of the product could be significantly reduced.

3. Discussion

When there is no existing method it is easy to run for the first and most familiar solution. There is however an obvious risk that the optimal solution is missed when using a push-approach for choosing evaluation method. There are probably different needs for information depending on who you are asking within the organization– the welder, the programmer, the designer or the manager. When using a push-approach those perspectives get lost and the focus will be “what can we do with this tool” rather than “what tool do we need to get the information we need”. The result will be optimisation of the measurement station itself at the expense of the actual value stream.

In a functionally organized company it can be assumed that the viewpoint more easily comes from your own area of expertise, e.g. the department handling inspection focusing on inspection tools. It is difficult to change a system from the inside. The evaluation of penetration using ultrasonic testing exemplifies this. The pull-approach instead drives cross functional initiatives, focusing more on the need and value stream than the measurement equipment itself.

It is also easy to get mislead that the most technologically advanced method is the preferred one. A push-approach could probably find technological solutions that would find the defect but not to a cost that is justified. The pull-approach focuses on what information the internal customer needs which, as in the case with weld to radius, leads to a method that will do that and only exactly that. This also means that it might be necessary to use different methods for evaluating the same defect depending on the specific information need. Finding the right balance between standardized methods and flexibility towards the internal customers’ need is necessary. It can however still be very useful to investigate different methods in order to have a palette of knowledge to choose from when the need arises. Of course on condition that it is clear that is the purpose with the investigation.

When using a pull-approach the need for a certain capability is clearer than using push. In the push-example about penetration it was not clear what this method needed to deliver in order to be capable enough. The capability rather came as a result in that case, restricting the method. The MSA of manual measurement of penetration also showed that methods that are commonly used might not be capable enough in existing or new applications. This is probably more easily missed when starting from the tool-view instead of the internal customer perspective. The need for a certain capability can instead probably guide you towards the right method.

When the push- and pull-approach is viewed in the case of unclear or too simplified demands it is not as clear that any is in favour of the other. If the demands are not correct there is very limited chance that the evaluation method will be able to fix that, no matter if it has its origin in the internal customer information need or not. Undifferentiated demands could also lead to higher production cost; not only because another, more costly, production method might be used but also because of an increased inspection need. It is however a challenge to find the right balances between a standardized and specialized requirement solution.

As often, the solution lies within the cross functional work and understanding of each other’s point-of-view. A pull-approach can therefore be suitable when defining evaluation methods since it stimulates the interdisciplinary information flow. The approach is probably also applicable to other types of manufacturing industries where fast adaptability to new demands is important. Even companies with lean principles well implemented in their production process can have information processes lacking the same.

4. Conclusions

New weld demands creates a need for new evaluation methods which is a prerequisite to gain the advantages from light weight designs. In the implementation work there are several pitfalls; lack of evaluation method, incapable methods or faulty demands.

A pull-approach means shifting focus from the tool itself towards what information the internal customers need. The risk for ending up with an evaluation method not corresponding to the organization's need decreases when using pull-approach. However, when the demands themselves are faulty this approach does not fix the problem.

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