Making the Right Measurements at the Right Points in the Product Cycle

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Abstract

Inspection and therefore measurement in general is often considered a necessary evil that does not add value to the finished product. However, by making the right measurements at the right time to support product development and get the tolerances right and support process development to ensure that the right production machines are put in place and run at the optimum process parameters, smart companies can gain a significant advantage.

The value of a measurement is determined by the consequences of the decisions the measurement data support. Therefore, there is a much better return on investment in making precise, advanced geometrical measurements early in the product life cycle, where it can support the most significant decisions, i.e. the specifications used to ensure correct functionality and the design of the processes used to manufacture the parts, rather than downstream where the measurements can only support process control and simple pass or fail decisions of individual parts against a specification that may or may not be functionally relevant.

The paper discusses some of the advantages of applying complex and accurate measurements upstream in the product development cycle. These include reducing scrap, manufacturing downtime, the reliance on final inspection and time spent fighting fires.

1. Introduction

Measurements do not inherently create value. The value in a measurement is in the application of its result. So the measurements that are made to be filed away just in case an auditor asks for them some day are worthless and truly do not add any value. A lot of measurements made in industry fall into this category. Unfortunately these are also the measurements that are scrutinized in most detail from a "quality" point of view. So many resources go into ensuring that these measurements are traceable, that the uncertainty is documented and, if the measurements are performed by a 3rd party, that they are supported by accreditation.

Another significant group of industrial measurements are the pass/fail measurements that are made to accept or reject individual parts. These are also often the subject of much "quality" scrutiny. They add some more value than the previous group, but the value is still limited to the value of the pass/fail decision.

The most valuable measurements that an industrial concern makes are the ones that drive the follow types of decisions:

- Whether it is feasible to make a certain product.
- What the proper specifications are for the parts that make up the product.
- What manufacturing processes are good enough to reliably make the parts without being too expensive.

These types of measurements are typically not subject to anywhere near the same level of scrutiny as the measurements discussed above, so in many cases these measurements are made without concern about whether they have the proper uncertainty to support the decisions that are based upon them and whether they are the right measurements to support the decisions in terms of the characteristics measured, e.g. is it the diameter of a shaft that needs to be controlled or is it the roundness, to ensure functionality?

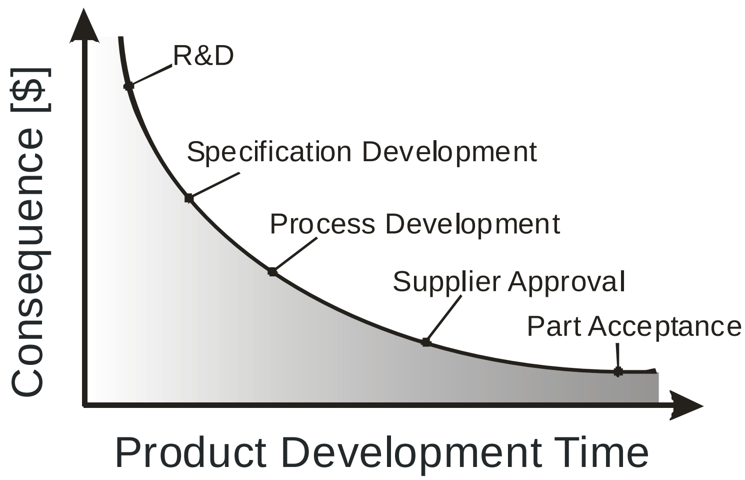

Figure 1: The potential monetary impact of the decisions that can be made based on measurements performed at various stages of the product development life cycle.

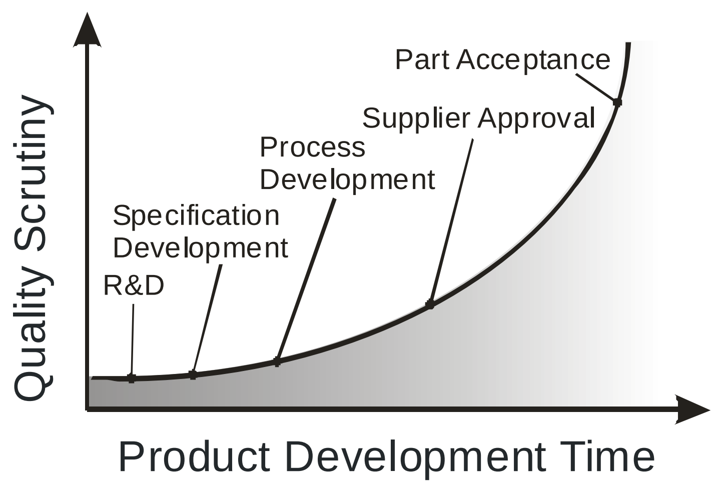

Figure 2: The amount of "quality" scrutiny afforded to measurements performed at various stages of the product development cycle.

By making the right choices for the latter category of measurements, companies can become much better at making the big manufacturing decisions that have profound impact on the company's profitability. One of the advantages gained may be that it eliminates measurements and inspections further downstream in the product life cycle.

2. R&D and Specification Development

In the usual manufacturing paradigm the specification, i.e. the drawing requirements, is what drives all the choices for manufacturing processes, process control and other measurements during the manufacturing process. All quality control and quality assurance efforts are focused on ensuring that the product meets the specification. In a sense the specification is treated as if it originates entirely from divine inspiration. This is of course not the case. In fact, the measurements that are made to create the specification are probably the most critical measurements a company makes, yet very little rigor is applied to ensure the reliability of these measurements.

There are requirements where the specified characteristic and one or both tolerance limits are trivial to derive. Simple, static fits where a shaft has to fit in a hole is the prime example of one tolerance limit, the maximum material condition (minimum size for the hole, maximum size for the shaft), for each part being trivial. But even in this case the other tolerance limit for each part (maximum size for the hole, minimum size for the shaft) are not trivial to determine and the cost of manufacturing depends heavily on this choice.

However, for most industrial products, the difference between the merely acceptable products and the very good products is not in the simple, static fits, but in the dynamic interfaces within the product. These interfaces where parts roll or slide against each other are the ones where wear, noise and longevity of the product are differentiated and the ones that cannot be determined without experimentation and measurement.

Since it is impossible to know a priori what characteristics control the performance of the product, it is necessary to measure a number of characteristics to determine which ones really control the performance. For a shaft rotating in a hole it may be necessary to look at the difference in diameter between the shaft and hole as well as the roundness, straightness, overall cylindricity and surface finish of the shaft and hole to find out which ranges of values for these characteristics yield the desired performance. In addition, it may be necessary to measure these characteristics with different settings, e.g. different cut-off values for form and surface finish and different association criteria for the diameters (e.g. least squares or maximum inscribed/minimum circumscribed) to determine which set of characteristics measured with what set of settings has the best correlation to the function of the product.

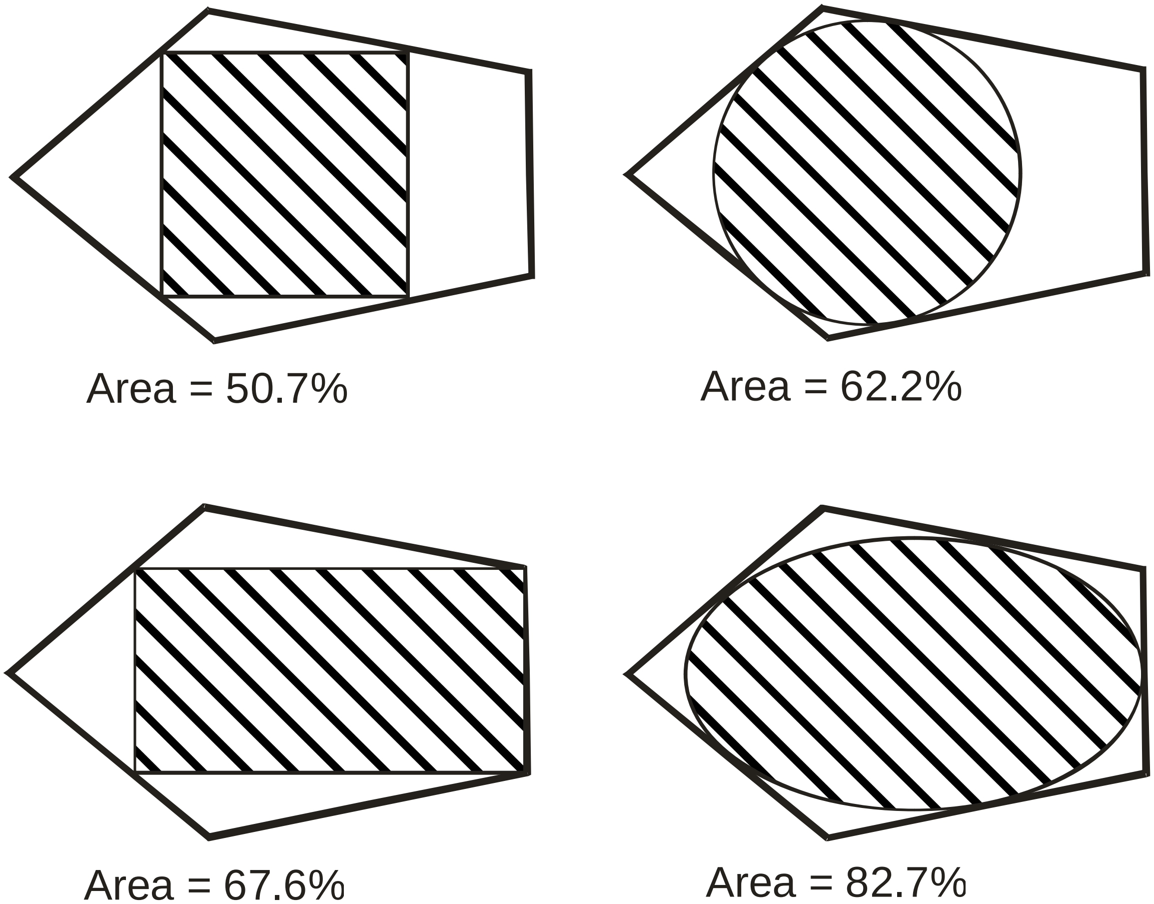

Figure 3: The pentagons represent the complex boundary of the functional requirements for a feature. The shaded figures represent different specifications of various complexity. The areas of the shaded figures in percent of the area of the pentagon are indicated. The figure illustrates that a simplistic specification artificially limits the area of acceptability.

In general, the functional requirements for a feature can be considered as a complex space. A feature with a set of characteristic values that fall within this space will function satisfactorily. For example, for a cylindrical shaft, the axes of the space may represent diameter, roundness, straightness, cylindricity and roughness. In this case the space is 5-dimensional. Each of these parameters has to be within a certain range for the shaft to function and there may be some relationship between these boundaries, such that e.g. the acceptable cylindricity variation depends on the diameter and the roughness. It is virtually impossible to precisely define the exact boundaries of this functional space. The purpose of the specification is to define a geometrical figure that is inscribed in this space, such that all parts that meet the specification will function. The larger the space allowed by the specification, the easier and less expensive it will be to meet the specification. Most specifications are very simplistic compared to the complexity of the functional requirements space. Consequently, the specification will disallow some of the functional space and reduce the space available for manufacturing. This in turn increases manufacturing cost.

Performing the experiments and making the necessary support measurements to determine the shape of the functional space are very valuable activities, if they lead to a specification that increases the acceptance space while still remaining inscribed in the functional space.

3. Process Development

The measurements made for process development once the specification space has been determined do not have the same impact as the R&D and specification development measurements, but still have more impact than any other measurements the company makes.

These measurements determine which processes and which machine tools are capable of producing the parts reliably. The process that uses up the most of the specification space yet will reliably make parts that do not violate the specification space will generally be the least expensive process for making the part. If it can be shown that the process is sufficiently reliable, it may be possible to eliminate in-process measurement or end-of-the-line inspections that would be superfluous if the process is reliable.

4. The Performance Profile of a Measurement

Different measurements have different requirements. Generally, the earlier in the product development cycle the measurements are made, the higher the requirements to accuracy and complexity. Shop floor measurements on the other hand primarily have a requirement for speed, so the feed-back can be as rapid as possible. In some cases there may also be a fairly stringent accuracy requirement, but it is rare that complex measurements are made on the shop floor.

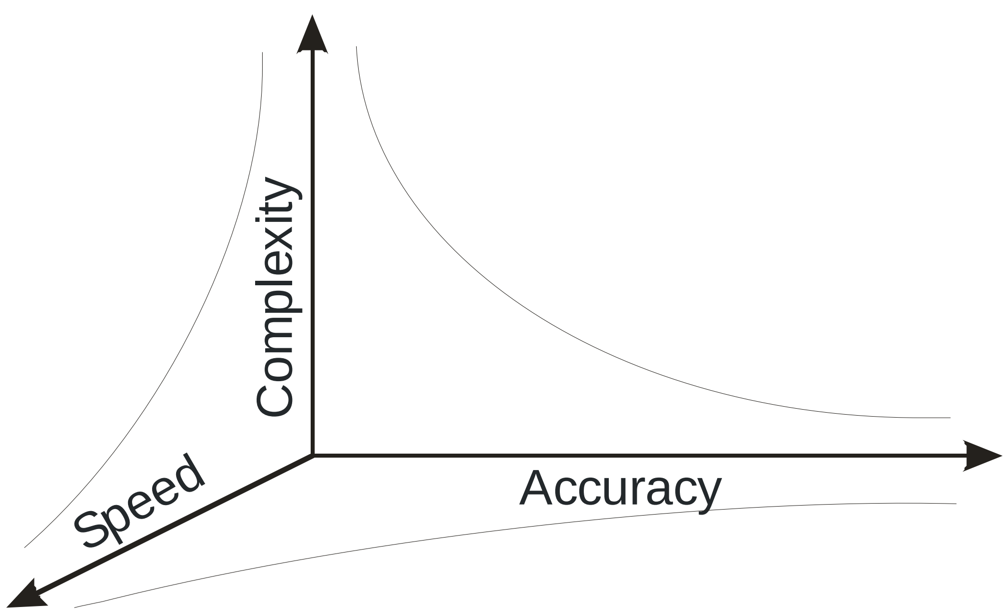

Figure 4: A measurement can be characterized by its accuracy, complexity and speed. In general only, one or two of these can be high; the last parameter has to be sacrificed

The complex and accurate measurements made during specification development and process development can also be used to determine which simplifications are acceptable in shop floor measurements used to control the process or inspect the finished parts. In many cases, once the specifications are known and the manufacturing processes are characterized, it will not be necessary to make complex measurements on the shop floor, simply because the chosen manufacturing process will guarantee that many specification requirements are fulfilled. So while it may be necessary to measure roundness and straightness very accurately and including a broad range of wavelengths during specification and process development, once the process and machine tool are chosen, it may not be necessary to measure either because the bearings and the guideways of the machine tool guarantees that the requirements will be met and a simple two-point diameter measurement may be all that is needed to monitor the process.

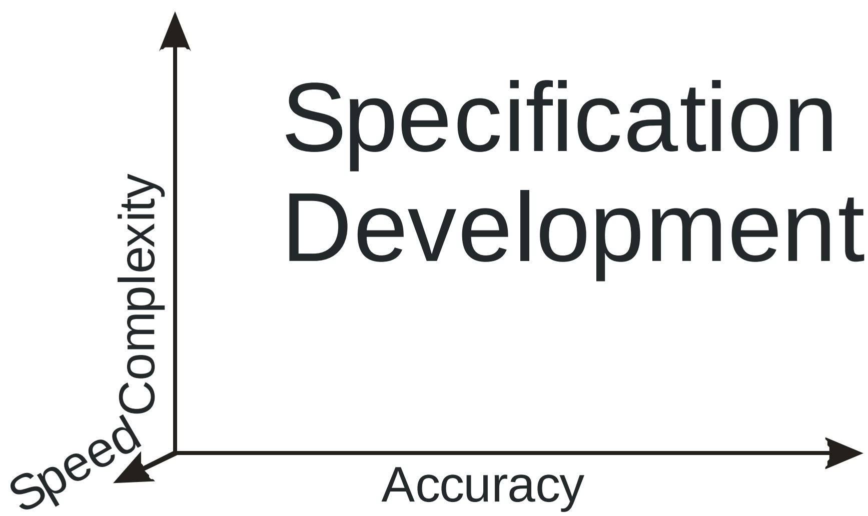

Figure 5: The performance profile for specification development measurements: These measurements have to be accurate since the final tolerances are not known yet and they have to have sufficient complexity, i.e. wavelength content, data density etc. to be able to capture the differences between functional and non-functional parts, which may be subtle. There is no need for great speed in these measurements as they are not part of production feed-back loops.

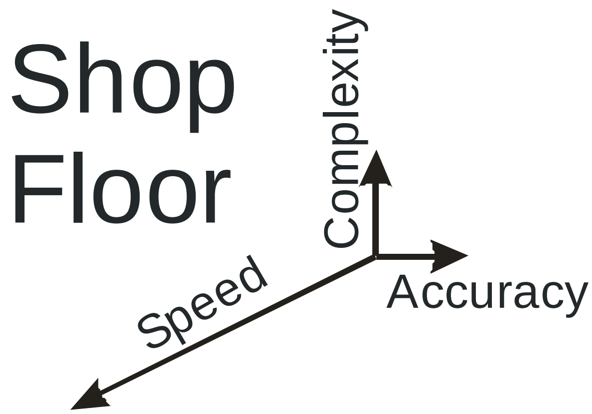

Figure 6: The performance profile for shop floor measurements such as process control measurements and part inspection measurements. These measurements do not need much complexity because it can be determined which attributes are likely to go out of tolerance. They usually do not need high accuracy either, since they are mostly used to track changes, not to measure in absolute terms. The one thing they do need is speed, so the feedback to the production process can be timely.

5. Conclusion

Smart companies can make better high-consequence decisions by making accurate and complex measurements when they determine the functional space and the specification early in the product development cycle. By making these measurements and by writing more complex and precise specifications, they can increase the specification space, such that the requirements to the manufacturing processes become less stringent which leads to less expensive manufacturing.

By also making accurate and complex measurements during process development these companies can determine the least expensive process that can reliably produce parts that meet specification and which attributes are automatically fulfilled and which need to be monitored on the shop floor and in final inspection.

This approach maximizes manufacturing flexibility by precisely defining the functional requirements and minimizes manufacturing cost further by better identifying sufficient manufacturing processes.