# Analysis of the Acceptable Deviation for the Measurement Process Established by the MSA and the VDA Manuals

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*Abstract*— **Companies need to select and to analyze the measurement processes used to control the main characteristics of their products, but they have difficulties in establishing the appropriate criteria for analysis. This paper makes a comparison between the acceptable deviations established by the VDA 5 and the MSA manuals. It also shows that there is a need for an interaction between different areas of the company such as design and production so that the selection of the measurement process will be adapted to a given task.**

*Index Terms*— **measurement uncertainty, measurement process analysis, MSA, GUM.**

## I. Introduction

Trying to improve the quality of their products, companies need to select and to analyze the measurement processes used to control the main characteristics of their products. The control of the measurement processes has improved greatly due to the certification of the quality systems based on the ISO 9001:2000 standards, which passed the mark of 951.000 certificates around the world by the end of 2007 [1]. The requirement 7.6 of the ISO 9001:2008 [2] prescribes that the measurement processes should be established to assure that control is introduced in a coherent way and it assists with the measurement requirements. It is noteworthy that the measurement process involves the measurement instrument operating in real conditions, being influenced by the following factors: the device, the operator, the measurement techniques, the environmental conditions and the methods adopted for measuring.

The technical specification ISO/TS 16949:2002 [3] sets additional requirements for the suppliers of the automotive industry, one of them is the following: the analysis of the measurement processes should be in agreement with customer's manuals. Some companies have been adopting the Six Sigma method with the aim of reducing the variation in their productive process: they analyze the measurement process to check whether the measurement variation is significant.

Undoubtedly, the measurement processes need to be controlled and analyzed so as to be suitable for use. This analysis should not be confined to the resolution or the errors related to the measuring instrument, but it should also consider the combination of factors that contribute to measurement uncertainty. Given that the method used for analysis is adapted, the following question can be asked: which are the acceptable deviations that can be attributed to the measurement process?

There are different guidelines for the acceptance of the measurement processes. Given this lack of consistency, the quality of the measurement management suffers because of the following problems:

1) Rejection of good products;
2) Supply of products which fail to conform with acceptable standards to the subsequent production stages or to the customers;
3) Costs of purchase of inappropriate instruments;
4) Wide discrepancies between the results obtained by the company and by the customer.

The aim of this paper is to analyze different acceptable deviations for the measurement processes established by recognized documents, evaluating their impact on the selection of the measurement device and on the performance of the measurement task.

Specifically, the criteria established by the VDA 5 [4] and the MSA [5] manuals will be analyzed. These manuals were developed by the automotive industry and their criteria are presented after this introduction.

Afterwards, a comparison between these manuals is made; their characteristics are investigated through a simulation under similar production conditions, aiming to check the impact of each criterion on the inspection of the products. Finally, some aspects of the measurement processes analysis are discussed.

## II. Acceptable Deviations for the Measurement Process

A measurement process is used to check whether the product was manufactured according to the specifications. The measurement process may show a small variation when compared with the product tolerance. It is important to highlight that the acceptable deviations that we intend to evaluate in this paper are related to errors of the measurement process. In the present processes, the main sources of uncertainty must be considered. A question remains: which criteria should be used to specify the acceptable deviations for the measurement process?

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### *A. The VDA Manual*

A document mentioned by different authors is the EN ISO 14253-1:1998 Standard [6] that establishes a reduction in tolerance according to the uncertainty of the measurement process, so only those products that meet the specification are released by the supplier. In other words, this Standard establishes that, when customer and supplier do not have an agreement, the supplier should provide products that conform to the standards and the customer can only reject products that do not conform, as it is shown in the example of the bilateral specification in Fig 1.

Initially, this method employs inspection limits which are different from the specification limits presented in the design (of product). The supplier should reduce the range of acceptance of the products while the customer should raise the tolerance, rejecting only those products in the non-conformance zone. This means that those products accepted by the customer would be rejected by the supplier generating additional costs to the productive process.

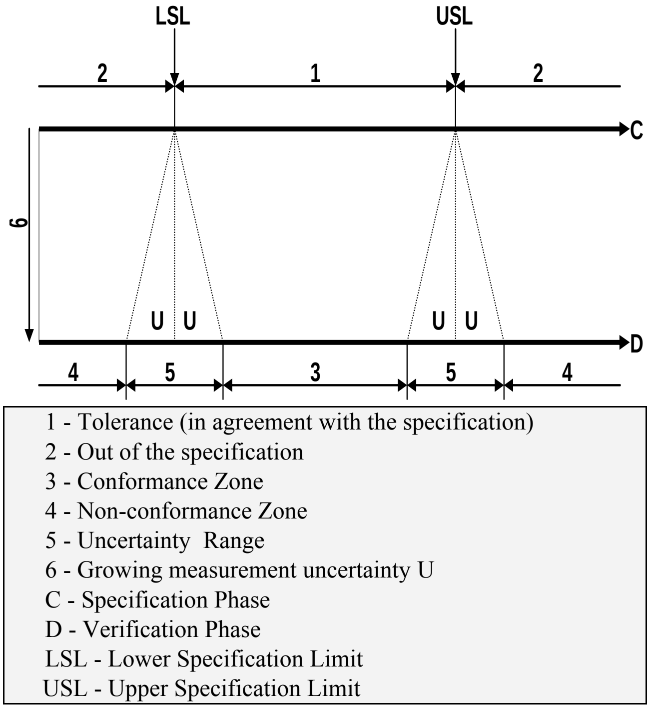


Fig.1: Influence of the measurement uncertainty in the product inspection [6]

According to Pfeifer [7], if the measurement uncertainty is much smaller than the product tolerance, uncertainty does not need to be considered. The limit is set by the "Metrological Practical Rule" (or Metrology Golden Rule) and it says that the measurement uncertainty should not exceed a tenth, at most a fifth of the tolerance.

It follows that the German automotive industry suggests a set of guidelines on the measurement process analysis of geometric characteristics [4] and a parameter $g_{pp}$ is set by the formula (1):

$$g_{pp} = \frac{2U}{T} \quad (1)$$

where: U = expanded measurement uncertainty for level of confidence of approximately 95%;
T = tolerance of the product characteristic.

The acceptable value for $g_{pp}$ depends on the class of tolerance, as it can be observed in Table 1. The acceptable deviations are larger for smaller tolerances. It is not enough to analyze only the parameter, it is also important to evaluate its impact on the product inspection. If the measurement process is used to control a characteristic generated by a productive process, a reduction in tolerance needs to occur.

Table 1: Acceptable deviation $G_{pp}$ [4]

| **Tolerance Class** IT Grade, in agreement with ISO 286-1:1988 [8] | **Recommended acceptable value $G_{pp}$** |
|---|---|
| IT≤ 6 | 0.40 |
| 7 ≤ IT ≤ 10 | 0.30 |
| IT ≥ 11 | 0.20 |

By contrast, as it can be observed in Figure 2, if the value obtained for $g_{pp}$ goes below 50% of the value set for $G_{pp}$, it is not necessary to reduce tolerance

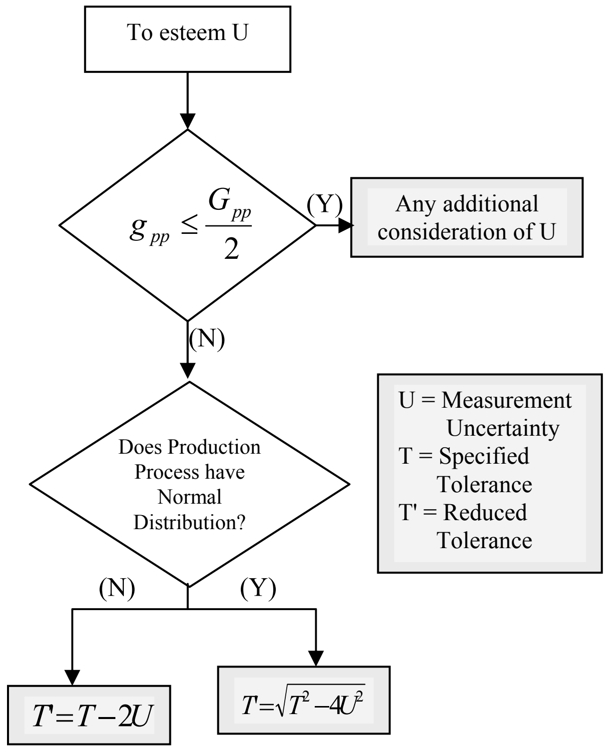


Fig. 2: Consideration of the Uncertainty of Measurement [4]

The VDA manual emphasizes that the measurement uncertainty is related to the characteristic that has been measured and this uncertainty should only be taken into account if the $g_{pp}$ value goes beyond 50% of $G_{pp}$. In these cases, the measurement uncertainty should be reduced directly from the specified tolerance if the distribution of the productive process is not normal. Otherwise, the subtraction can be quadratic.

In order to estimate the measurement uncertainty, the manual VDA 5 recommends the Guide to the Expression of Uncertainty in Measurement – GUM [9]. According to Christoph and Neumann [10], the estimate of the measurement uncertainty includes both the random errors

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and the systematic errors and usually there is no difference between them. This practice becomes evident in the manual VDA 5 as well as in the Enclosure 1 of the DIN EN ISO 14253-1 Standard [11]. In both texts, the errors are treated without distinction as sources of measurement uncertainty.

### *B. The MSA Manual*

The acronym MSA stands for Analysis of the Systems of Measurement. This was characterized internationally as a set of guidelines for American assemblers and applied to evaluate the measurement processes used mainly in industry, standing out the measurement processes that may have each part replicated. According to this manual MSA [5], "it is the statistical properties of the data produced that determine the quality of measurement system". In order to evaluate a measurement process, the MSA method considers the following statistical measures: bias, linearity, stability, repeatability and reproducibility, making use of different evaluation methods. The combined estimate of the repeatability and reproducibility is called Gage R&R or *GRR* (variation of the measurement process).

As acceptable deviations for the measurement process, the MSA Manual establishes that:

1) Bias and linearity errors are acceptable as long as they approximate zero and they do not exceed the agreed maximum error for the measuring instrument;
2) Variation of the measurement system GRR should present acceptable percentile errors in relation to the tolerance of the product. The general practice for acceptance of *%GRR* is given for:
   a) *%GRR* < 10%, it is usually considered to be an acceptable measurement process;
   b) 10% ≤ *%GRR* ≤ 30%, this may be acceptable considering the importance of application, the cost of measurement instruments, the cost or repair, etc.
   c) *%GRR* > 30%, this is not considered acceptable.

The method of evaluation considers that the measurement process shows a normal distribution, and the parameter *GRR* is estimated for a level of confidence of 99,7%. The percentile parameters are established according to the range of tolerance. To sum up, the MSA method recommends that a measurement should be considered acceptable if the systematic errors approximate zero and their variability is not higher than ±15% of the product tolerance.

## III. THE IMPACT OF THE ACCEPTABLE MEASUREMENT PROCESS DEVIATIONS

In the previous section, two different criteria were presented for accepting the measurement processes. More strictly, the $g_{pp}$ value should not be higher than 0.2 and the value of *%GRR* should not exceed 10%. As for the acceptable deviation, we can set values up to 0.4 for the parameter $g_{pp}$ and 30% for *%GRR*. Figure 4 illustrates these acceptable deviations through a numerical example, showing the measurement standard-deviation ($\sigma_{mp}$) for each represented situation. For each case, it is make the assumption that the bias is significantly equal to Zero.

Figure 3 shows that there are differences between the acceptable deviations established by the two methods. Again, the question remains: which values are more appropriate for the industrial reality?

| **VDA 5 Manual (Confidence level of 95.45%)** |
|---|
| ***Tolerance = 1 measure unit (MU)***<br>Restricted situation ($G_{pp}$ =0.2):<br>U = 0.1 MU ⇒ $\sigma_{mp}$ = 0.05 MU<br><br>Acceptable situation ($G_{pp}$ = 04):<br>U = 0.2 MU ⇒ $\sigma_{mp}$ = 0.1 MU |
| **MSA Manual (Confidence level of 99.7%)** |
| ***Tolerance = 1 measure unit (MU)***<br>Restricted situation (%GRR = 10%):<br>GRR = 0.1 MU ⇒ $\sigma_{mp}$ = 0.017 MU<br><br>Acceptable situation (%GRR = 30%):<br>GRR = 0.3 MU ⇒ $\sigma_{mp}$ = 0.05 MU |

Fig. 3: Acceptable deviations established in the VDA5 and MSA manuals

In order to make an additional analysis, it is necessary to estimate the probability of incorrect decisions that may be made in the inspection process (rejection of products that conform or acceptance of products that do not conform). Flaws in the inspection process are related to the specification limits, to the measurement and productive process.

The acceptable limits of probability depend on the risks that the company intends to run and the costs related to the productive process. Considering that several production processes and several measurement methods are represented by normal distributions, it is possible to determine the probability of occurrence for each type of event that generates flaws, starting from the double integration of the probability density function (PDF), using the appropriate integration limits. Donoso [12] specifies that the probability (*P*) of different types of events can be represented by (2):

$$P = \int_{A-\mu_{rpp}}^{B-\mu_{rpp}} \int_{C}^{D} \frac{e^{\frac{-(y)^2}{[2.(\sigma_{rpp})^2}} . e^{\frac{-[x-\mu_{mpp}+y)]^2}{[2.(\sigma_{mp})^2]}}}{(2.\pi.\sigma_{rpp}\sigma_{mp})} dxdy \quad (2)$$

being: $\mu_{rpp}$: mean of the real productive process
$\sigma_{rpp}$: standard-deviation of the real productive process (not included $\sigma_{pm}$)
$\mu_{mpp}$: mean of the measured productive process
$\sigma_{mp}$: standard deviation of the measurement process

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For each type of event, a combination of integration limits is defined, as it is shown in figure 4.

| ***Limits of Integration*** | | | | | |
|---|---|---|---|---|---|
| Event tips | | Production Process (Y) | | Measurement Process (X) | |
| | | A | B | C | D |
| Do not generate flaw cost | PORS | $-\infty$ | LSL | $-\infty$ | LSL |
| | PORB | USL | $+\infty$ | USL | $+\infty$ |
| | PIA | LSL | USL | LSL | USL |
| generate flaw cost | PIRS | LSL | USL | $-\infty$ | LSL |
| | PIRB | LSL | USL | USL | $+\infty$ |
| | POAS | $-\infty$ | LSL | LSL | USL |
| | POAB | USL | $+\infty$ | LSL | USL |

PORS: pieces out of specification (small), being rejected
PORB: pieces out of the specification (big), being rejected
PIA: pieces inside of the specification, being approved in the inspection
PIRS: pieces inside of the specification, being rejected for they be considered small
PIRB: pieces inside of the specification, being rejected for they be considered big
POAS: pieces out of the specification (small), although approved in the inspection
POAB: pieces out of the specification (big), although approved in the inspection
LSL: lower specification limit of the characteristic
USL: upper specification limit of the characteristic

Figure 4: Limits of Integration for determination of the probability

In order to evaluate the impact of the acceptable deviations established by each method of measurement process analysis, Fig. 5 indicates the probabilities of misclassifying the products, considering the conditions of the productive process with *Cpkm* larger than 0.4. *Cpkm* is the index to evaluate the capability of the measured productive process. For each one of these cases, the mean of the productive process is considered to coincide with the central value of the tolerance and the mean moved in one standard-deviation from the measured productive process ($\sigma_{mpp}$).

It is possible to observe that the most common occurrences of incorrect inspections are in processes that are not capable (Fig. 5). Still, the probabilities of accepting products that do not conform are lower in all cases, if compared with the probability of rejecting good pieces. The strictness of the MSA method often demands the use of overestimated measurement processes, so there may be a rejection of those measurement processes that could be supporting the measurement needs.

Table 2 displays an additional compilation which was based on the "practical rule of the metrology", it presents a 20% extension of the tolerance associated with a bilateral specification (10% in each side) so that there would not be a significant loss of the product quality.

In this case, the specification limits were maintained during the inspection, but it was considered that the products within the extended tolerance would be adapted.

Table 2: Probability of incorrect inspections, considering the expanded tolerance

| *Cpkm* | $\sigma_{mp}$ = 0.017 | | $\sigma_{mp}$ = 0.05 | | $\sigma_{mp}$ = 0.1 | |
|---|---|---|---|---|---|---|
| | Centered mean | Mean moved in 1 σ | Centered mean | Mean moved in 1 σ | Centered mean | Mean moved in 1 σ |
| 0,67 | 0 | 0 | 0.00006 | 0.00002 | 0.00058 | 0.00006 |
| 1 | 0 | 0 | 0 | 0 | 0 | 0 |
| 1,33 | 0 | 0 | 0 | 0 | 0 | 0 |
| 1,67 | 0 | 0 | 0 | 0 | 0 | 0 |

As it can be observed, the probability of accepting products that do not conform is significantly reduced although the measurement process presents larger variation.

## IV. Conclusion

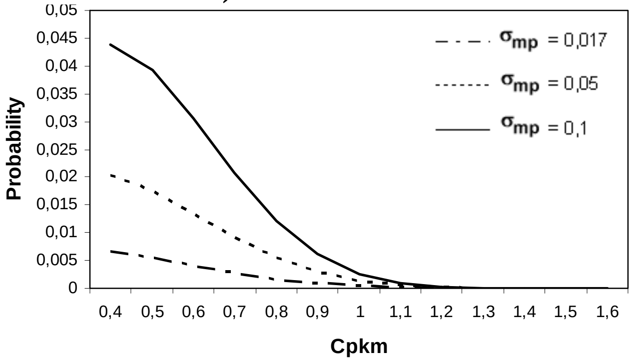
The analysis of the measurement process requires the interaction with different areas of the company, from the design of the product to its production and inspection. This paper tried to show that the decision on the quality of the measurement process cannot just focus on one evaluation parameter obtained from a series of measurements. This practice can reject appropriate measurement processes because it does not reach a previously established value.

The analyses were performed for characteristics with bilateral specification obtained from measurement processes that show a normal distribution. Starting from Figure 4, it is possible to observe that the established acceptance criteria for the MSA are stricter than for the VDA manual, the MSA requires a smaller standard-deviation $\sigma_{mp}$ for the measurement process. However, it can be observed that the probability of incorrect inspections is very low for *Cpkm* > 0.67, for all $\sigma_{mp}$. Considering the possibility of extending tolerance to 20%, the probability of incorrect inspections is extremely low for all the cases. In other words, an acceptable deviation up to 20% of the tolerance is valid for several cases in industry.

It is noteworthy that for measurement or production processes with distributions of different probabilities, the integration should consider the appropriate density functions. New probabilities should also be calculated for measurement processes that present bias significantly different from zero.

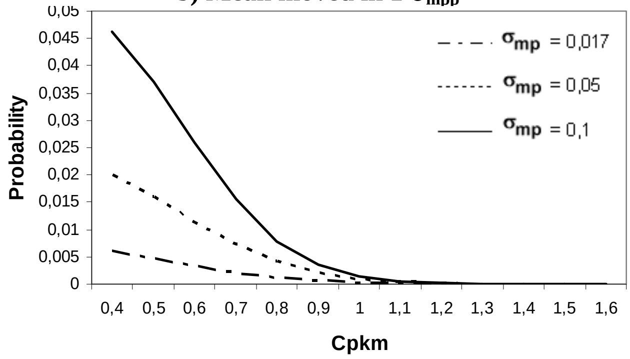
Undoubtedly, parameters for analysis should be established, but a single parameter should not be the basis for acceptance or rejection of a measurement process. As it was shown in this paper, several factors may have an influence on the analysis such as the behavior of the production process and the extension or the reduction of tolerance. Only the interaction between metrology with other areas will allow the selection of the measurement processes adapted to the task of inspection.

**a) Centered mean**

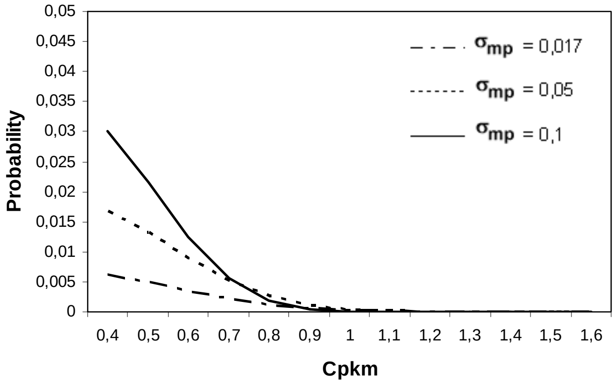



a.1) Pieces inside of the specification being rejected

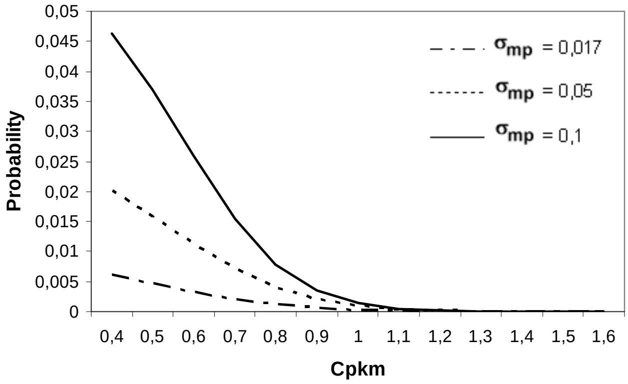
**b) Mean moved in 1 $\sigma_{mpp}$**



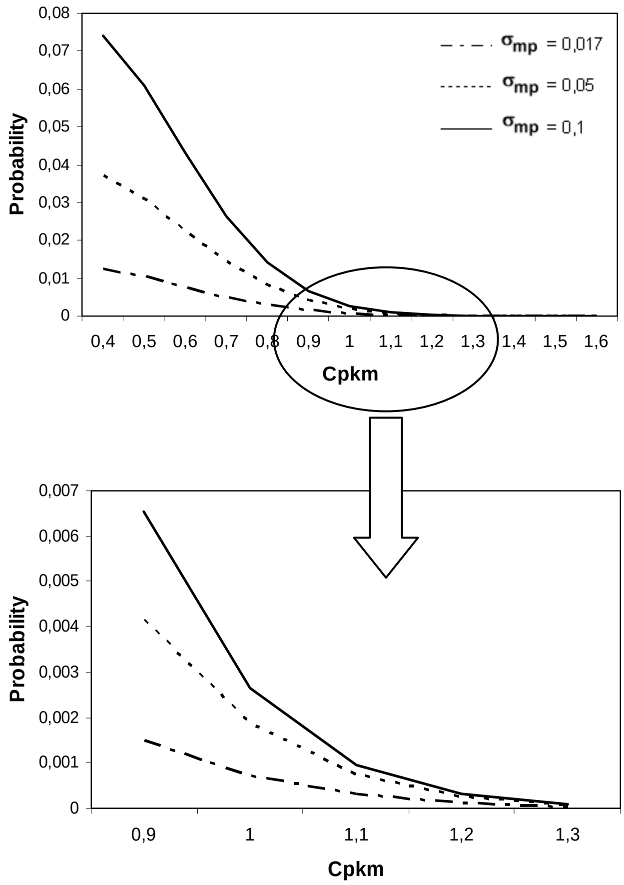

b.1) Pieces inside of the specification being rejected



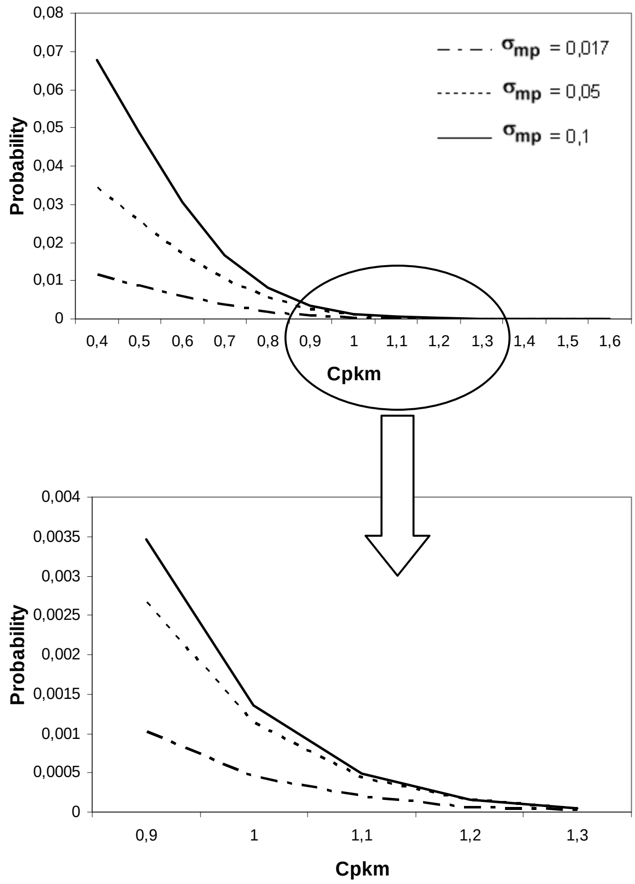

a.2) Pieces out of the specification being approved




b.2) Pieces out of the specification being approved




a.3) Total of incorrect inspections




b.3) Total of incorrect inspections

Figure 5: Probability of incorrect inspections

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