QUANTIFYING SUPPLIERS' PRODUCT QUALITY: AN EXPLORATORY PRODUCT AUDIT METHOD

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ABSTRACT

The quality of the raw material and supplied product from suppliers plays a critical role in the quality of the final product. It has become the norm that vehicle manufacturers require their suppliers to measure product quality and service with a product audit method. Measuring quality of product is emphasised by QS9000 VDA6.5 and ISO/TS16949. From a competitive standpoint, and also to see continuous improvement in business, companies need to monitor their suppliers' performance. Quality and delivery are two very important indicators of supplier performance. This paper presents a statistical method for measuring the quality of supplied product. This method allocates different weights to variables and attributes characteristics. Moreover, following normal distribution, the tolerance zone is divided to three regions with different scores. Therefore, the quality of suppliers' products can be monitored based on the Product Quality Audit Score (PQAS). However, this method may be employed for organisations to monitor their raw material, work-in-process parts, and final product. It can be an indicator to monitor supplier quality behaviour.

OPSOMMING

Die gehalte van grondstowwe en produkte/komponente wat deur leweransiers verskaf word, speel 'n kritiese rol in die gehalte van die finale produk. Dit het die norm geword in die motorvervaardigingsbedryf dat daar van leweransiers verwag word om hulle produkkwaliteit en –diens te meet by wyse van 'n produkouditmetode. Die meting van produkkwaliteit word benadruk deur QS9000 VDA6.5 en ISO/TS16949. Uit 'n mededingingshoek en ook om kontinue verbetering te monitor, is dit noodsaaklik dat leweransiers se verrigting gemeet word. Gehalte en aflewering is twee van die belangrikste indikatore van leweransiersverrigting. In hierdie artikel word 'n statistiese model voorgehou vir die meting van die kwaliteit van die gelewerde produk. Die metode ken verskillende gewigte toe aan die veranderlikes en attribute. Daarbenewens, volgens die normaalverdeling, word die toleransiesone verdeel in drie areas met verskillende tellings. Gevolglik kan die kwaliteit van die leweransiers se produkte gemonitor word aan die hand van die produkgehalte-ouditteling ("product quality audit score – PQAS").

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1. INTRODUCTION

Quality has been described and variously defined as value, conformance with specifications, conformance with requirements, fitness for use, loss avoidance, and meeting and/or exceeding customer expectations. Quality provides a basis for strategic advantage, and thus improvements in product quality should lead to enhanced performance. How product quality contributes to quality performance is one of the specific interests to organisations attempting to evaluate the efficiency of their quality programmes [1]. Traditionally 'quality' has been defined in terms of conformance to specification, and so quality-based measures of performance have focused on issues such as the number of defects produced and the cost of quality [2]. In fact, quality is a concept that depends on many auditable factors. Performance evaluation is often considered as the most beneficial element for ISO 9000 series quality management systems because it reveals ways to further improve quality and incrementally increase customer satisfaction [3]. In this context, this paper introduces an exploratory method for measuring the quality performance of supplied products, to help supply chain parties enhance the entire supply chain performance over time.

2. LITERATURE REVIEW

Supply chain performance

Supply chain management (SCM) can be seen as the process of strategically managing the procurement, movement, and storage of materials, parts, and finished inventory [4]. SCM performance evaluation, supplier selection, SCM quality, customer satisfaction, and so on are the most researched area within the scope of SCM since 1980. Many studies have been done of supplier selection and evaluation. The prioritisation of suppliers for development depends upon, for example, the supplier's quality performance and the importance of the product supplied. It is an accepted fact that delivery and quality are two of the most important indicators of supplier evaluation [5]. According to the review of automakers' requirements (BMW, PSA Peugeot Citroen, and Honda), quality of product (service) is one of the important indicators in the supply chain of automotive industry [6]-[7]-[8], and supplier performance is monitored through delivered product quality and delivery schedule performance [9].

Quality audit

One of the important ways to measure quality performance in a quality management system is known as 'audit'. Quality audit, as a method for evaluating a system, product, and/or process performance against established criteria, has grown in use worldwide in recent years [10]. Quality audits are a part of the evaluation and assessment process that managers employ to uncover areas for improvement in their organisation. When used appropriately, audit findings can serve to focus the organisation on the areas that need most attention. ISO/TS16049 and QS9000 state that organisations in the supply chain of the automotive industry shall audit products at appropriate stages of production and delivery to verify conformity to all specified requirements, such as product dimensions, functionality, packaging and labelling, at a defined frequency[9]-[11]. Other standards define a quality audit as "a systematic and independent examination" to determine whether quality activities and related results comply with planned arrangements, and whether these arrangements are implemented effectively and are suitable to achieve objectives[12].

There are several different approaches to classifying audits. From a quality management system viewpoint, there are three types of audits: system, process, and product audit[13]. Evaluation is facilitated by quality audits[14]. A quality audit is an activity that is carried out to assess or examine a product, the process used to produce the product, or the system in which the production (or service) takes place [15]. A quality audit also aims to determine whether or not the subject of the audit is operating in compliance with the source documentation. There are three basic quality audits: first party or internal audits, second party audits or customer audits, and third party or external audits [16]. Quality audits have gained prominence in the last 20 years as a tool for assessing the effectiveness of quality assurance efforts and, more recently, for the evaluation of compliance with applicable quality standards. Further research was recommended in the domain of sampling techniques in quality auditing, modelling of audit maintainability, and suitability[17]. It has been emphasised that quality audits are not only meant for checking the systems for compliance with quality system standards: they can also be used to exercise continuous quality improvement and to reach the benchmarks of total quality management[18].

Quality and the automotive industry

The word 'quality' has taken on new meaning in the automotive industry over the past two decades. There are three perspectives on quality in the automotive industry: quality in product, quality in production, and quality in ownership. Quality of product is the product's overall ability to perform its required functions. In this context, a widely accepted classification system with three major groupings for defects (A, B, and C) has been developed by the automobile industry. The 'A' category includes safety or critical functions such as brake functions, electrical operation, and steering. 'B' includes operations that affect the primary functions of the vehicle. 'C' includes items that do not affect vehicle functions or the appearance of items. Manufacturers require that many of the parts being replaced be returned for teardown and analysis. Root-cause analysis using the 'plan-do-check-act' (PDCA) model can be accomplished by the responsible engineer or supplier using these returned parts [19]. Market demands, especially within the automotive supply chain, are pushing towards increased product complexity and performance with zero defect part per million (PPM) requirements. To gain market share, suppliers will routinely specify products to tighter than six sigma specifications. To maintain quality levels, the product must be 100% tested in production to screen out parts that do not meet the specifications [20].

Part per million (PPM) is an index for measuring the rate of quality on a scale of 1 million. In the automotive industry supply chain, a survey was conducted on second-tier automotive suppliers achieving QS-9000. It reported that evaluating the quality parts per million (PPM) is one measure to determine the success of a quality management system (QMS). A company might have a quality system in place and be ready on the day that the audit team audits; but it might not produce quality products, as evaluated by quality and delivery PPMs, and have no statistically significant relationship between organisational variables and quality and delivery performance [21].

PPM can be measured either after the inspection of a lot, or after using the whole lot by the producer's customer. Usually, there are three types of inspection: inspection of incoming material, inspection of process, and inspection of final product. The aim of raw material inspection is to prevent defects from entering a process. Acceptance sampling is a type of inspection [22] where samples are taken from incoming parts, and certain quality characteristics of the units are inspected. A decision is made after inspection, usually to accept or reject the lot. Rejections of entire lots provide a strong motivation for suppliers to improve their quality [23].

One of the disadvantages of the acceptance sampling method is that it does not provide enough information about the product or production process [24]. Single sampling plans are developed for attributes and continuous variables. The military standards (MIL-STD-105D) were designed to inspect incoming lots from suppliers. Initially an acceptance quality level (AQL) value is specified for the product, and the type of sampling plan is decided. The special feature is that lots can be subject to normal, tightened, or reduced inspection. All suppliers are required to satisfy specified quality levels for their products [25]. A scoring method for evaluation open learning materials was developed by aggregating the product of the compliance and weighting factors for each of the 12 assessment criteria, expressed mathematically as:

$\text{Score} = \sum_{x=1}^{12} a_x b_x$
where:

Score = total product score
a_X = weighting of criteria *X*
b_X = product ranking for criteria *X*

It was asserted that, by examining all 12 criteria, it is possible for a product to meet the maximum evaluation points. It showed a new method for evaluating open learning materials, which has been proved on a selection of materials used by the engineering industry[26].

In this context, a probabilistic cost model was developed in which suppliers' quality performance is measured by non-conformance with the end product measurements, and delivery performance is estimated based on the suppliers' expected earliness or tardiness in delivery. As a growing number of companies are adopting lean manufacturing and SCM as their primary competitive weapon, many practitioners and academics have shifted their attention from traditional, short-term based multiple sourcing strategies to a supply based reduction strategy and to long-term supplier partnerships. The results of the case analysis indicate that single sourcing could be a cost-effective policy, but it is not a panacea when a firm pursues product quality and delivery excellence [27].

Moreover, a product audit method called SQFE (quality monitoring by the supplier) was employed in the Iranian automotive industry to monitor the quality of the product delivered to the vehicle manufacturer. The method works by demerit rating. Samples of products are chosen, and critical characteristics according to the supplier and vehicle manufacturer agreement are measured accordingly. Weights for characteristics are defined in steps – 0, 3, 5, 15 and 55 – according to criteria. The rating of characteristic zones has also been defined in three sections. The method measures demerit points (DMR) and summation of DMR by DUM (Mean Unit Demerit). A lower DUM shows that the measurement is close to the nominal value, and meets the customer's expectations[28]

$$Dmr = Dr/n$$

where

Dr: sum of demerits for a characteristic =$(3 \times n_3 + 5 \times n_5 + 15 \times n_{15} + 55 \times n_{55})$
n: Sample size (population demerit)

and

the mean unit demerit (Dmr) is an indicator of the measure of the quality of the product. This extremely sensitive indicator gives a relative measure of quality and allows improvement objectives to be fixed.

3. METHODOLOGY

Figure 1 shows the algorithm that is developed to monitor supplier performance via quality of product. The method includes the opportunity for improvement programmes and also for corrective action when needed. According to the algorithm, a method of product audit is established. This method assigns different scores of measurements based on specification tolerance. As different parameters on products have different importance for buyers and producers, different weights are assigned to specifications in the method.

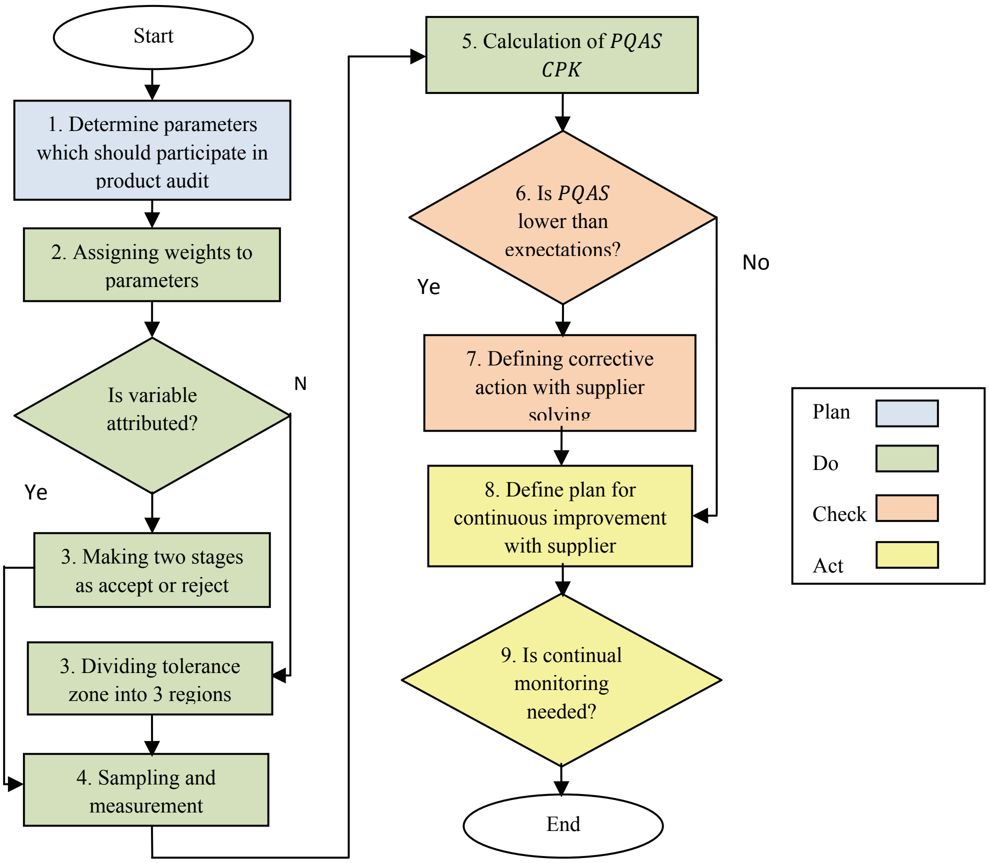

Figure 1: PQAS monitoring suppliers' product quality algorithm

According to normal distribution (Figure 2), the tolerance of the specification is divided into three levels with different quality scores: 0 for 'out of specifications observations', 1 for 'observations into third sigma', 2 for 'observations into second sigma' and 3 for 'observations into first sigma' from nominal value N. For attribute parameters the judgment of quality is either 'accept' or 'reject'. If judgment result is 'accept', then the assigned score is 3 out of 3; otherwise it is 0 out of 3.

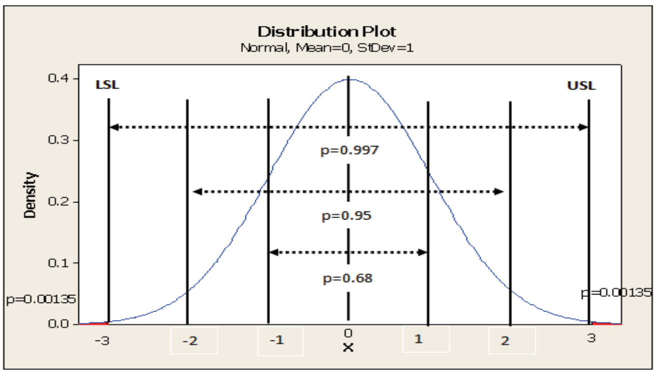

Figure 2: Probabilities associated with a normal distribution

Figure 2 presents a standard normal distribution with $f(x;0,1)$. where the probability density function is $f(x;\mu,\sigma)=\frac{1}{\sigma\sqrt{2\pi}}e^{\frac{-1}{2}\left(\frac{x-\mu}{\sigma}\right)}$ $\quad -\infty < x < \infty$ [29].

The density curve is symmetric about μ and bell-shaped, so the centre of the bell is both the mean and the median. The value of σ is the distance from μ to the inflection points of the curve. When $CPK=1$ then it means that $\overline{\overline{X}}$ is fitted exactly on μ, and USL and LSL are matched with $\mp\sigma$ of normal distribution. The frequencies for the set of scores with a normal distribution are stated by a function which includes as controlling features both the mean, μ, and the standard deviation, σ, of the set of scores. Because the process's natural tolerance limits lie within the specifications, very few nonconforming units will be produced. If C_p=1, the fraction of nonconforming units is 0.27% or 2,700 parts per million. If the process is not centered, then CPK is often used [30]. Based on the above, the formulation of the product audit score has been deployed to cover different parameters, different samples, and different weights as follows:

3.1. Assumptions:

- Variable specifications are two sides bounded.
- The considered product capability $CPK=1$ where $CPK=\min\{\left(\frac{USL-\overline{\overline{X}}}{3\hat{\sigma}}\right),\left(\frac{\overline{\overline{X}}-LSL}{3\hat{\sigma}}\right)\}$ [31]
- Different parameters have different importance. A parameter could be safety, assembly point, appearance character, regulations and so on. Different numbers are assigned as weights, such as $1,3,6$ and 9 to weights.
- Following three standard deviation in normal distribution, scores are assigned as $0,1,2$ and 3.
- The sampling plan for product audit can be followed by company procedure or MIL-STD 105E.
- Score of Zone One: 3; Score of Zone Two: 2; Score of Zone Three: 1
- The score of out of specifications measurement is 0.
- USL: Upper specification limit
- LSL: Lower specification limit
- $SL(N)$: Nominal value on drawings or standards= $LSL+\left(\frac{USL-LSL}{2}\right)$
- $USL-LSL$= Tolerance zone = 6σ of standard deviation of Normal distribution

3.2. Model parameters:

s_i : achieved score by measuring a variable specification: 0,1,2,3

w_i : weight of variable specification: 1,3,6,9

s_j : achieved score by measuring attribute specification: 0,3

w_j: weight of attribute specification: 1,9

k: number of samples

n: number of variable specifications

m: number of attribute specifications

x: measured dimension

According to the above, Figure 3 depicts the adjusting of tolerance distance with 6σ Normal distribution distance when $\mathrm{CPK} = 1$ (process capability index).

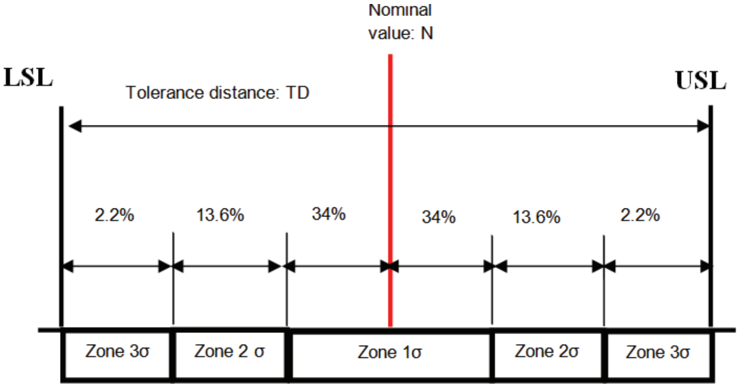

Figure 3: Conceptual tolerance zone based on standard deviation region

Zone 1: $N - \left(\frac{USL - LSL}{6}\right) \leq x \leq N + \left(\frac{USL - LSL}{6}\right)$

Zone 2: $N - \left(2\left(\frac{USL-LSL}{6}\right)\right) \leq x \leq N - \left(\frac{USL-LSL}{6}\right)$ and $N + \left(\frac{USL-LSL}{6}\right) \geq x \geq N + \left(2 \times \left(\frac{USL-LSL}{6}\right)\right)$

Zone 3: $N + \left(2 \times \left(\frac{USL - LSL}{6}\right)\right) \leq x \leq USL$ and $N - \left(2 \times \left(\frac{USL - LSL}{6}\right)\right) \geq x \geq LSL$

And finally PQAS= $[(\frac{\sum_{f=1}^{k}((\sum_{i=1}^{n} w_i \times s_i)+(\sum_{j=1}^{m} w_j \times s_j))}{3k\left((n\sum_{i=1}^{n} w_i)+(m\sum_{j=1}^{m} w_j)\right)}) \times 100]$

This method can help companies to determine the quality level of their suppliers' materials or parts, based on laboratory or measurement results. The advantage of this method is that we assign a quality score to a lot or to a range of production, and it can be monitored for controlling production processes and quality improvement, and can be used to assess the product's process efficiency.

4. NUMERICAL EXAMPLE AND RESULTS

Figure 4 shows a metal part that a rubber industry uses to produce a shockabsorber. The company measures the supplier's quality using the PQAS method. From the received lot, an inspector took five samples. The critical characteristics are shown in Figure 4, and the measurement data are given in Table 1. The company has determined that its target level for quality is equivalent to 80% or above (customer expectation for PQAS≥80%).

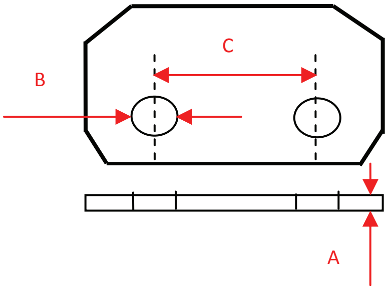

Figure 4: Drawing of metal part as case study

The five samples were chosen by the inspector, and the samples' characteristics were measured (Table 1). The PQAS was computed for characteristics and products samples. According to Figure 3, a calculation for the recognition of zones was done, and appropriate scores based on the data obtained from the measurements were allocated. The minimum PQAS level has been defined by the customer as 80 out of 100; the results reveal that three samples do not meet the customer's expectations (Figure 5).

The result shows that further investigation should be proposed to find out why there had been the reduction of quality discovered by the PQAS. The same calculations have been done on the characteristics of the product.

Location	**Characteristics**	**Variable/ Attribute**		**Weight**	**Sample 1**	**Sample 2**	**Sample 3**	**Sample 4**	**Sample 5**	**PQAS by characteristic**
A	Thickness	V	2.54-2.74	3	2.65 Zone: 3	2.54 Zone: 1	2.48 Zone: 0	2.55 Zone: 1	2.51 Zone: 0	30%
B	Diameter of holes	V	10.12-10.52	9	10.18 Zone: 2	10.27 Zone: 3	10.28 Zone: 3	10.24 Zone: 2	10.25 Zone: 3	86.6%
C	Centre to centre (C to C)	V	90.98-91.58	9	91.36 Zone: 3	91.43 Zone: 2	91.38 Zone: 1	91.39 Zone: 2	91.41 Zone: 2	66.6%
D	Appearance shape	A	Accept	6	OK	OK	OK	OK	OK	100%
PQAS by product					87.6%	81.4%	66.6%	70.3%	77.7%	**77%**

Table 1: Calculations for product quality audit score method

Figure 5 shows that the PQAS for samples 3, 4 and 5 is lower than the customer's minimum requirement, and corrective action should be taken in relation to these lots.

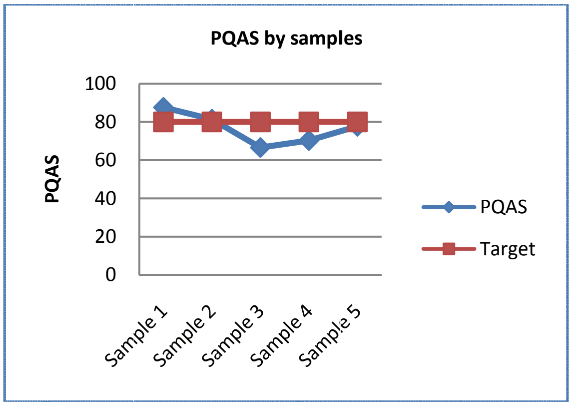

Figure 5: Trend chart for PQAS by product

According to Figure 6, dimension A (thickness) and dimension C (centre to centre) have significantly affected the reduction of scores, and corrective action should be taken to achieve further improvements.

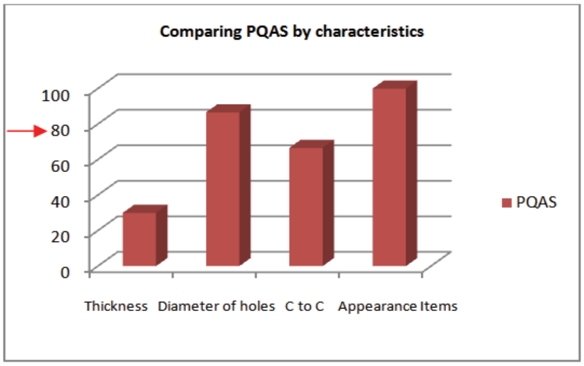

Figure 6: Histogram for PQAS by characteristics

5. CONCLUSION

Because of competitive market conditions, the superiority of organisations is based on the quality of their products and services; so the majority of them use sampling plans when accepting raw material and parts from their suppliers. This paper demonstrates a weighted product quality method for measuring the quality level of products, parts, and materials. The method design is based on normal distribution and its relation to the tolerance distance. Companies with different expectations about the capability index may decide to use this method to improve their suppliers' product quality. Based on the results, it can be concluded that the PQAS method can identify lower quality where it occurs. For this study, the quality of a metal part was affected by the dimensions of centre to centre (C) and thickness of the part (A). After investigation of the part's function, it was found that the thickness dimension is also a critical assembly specification for an automaker when assembling the part on the body of the vehicle. Investigations should be more focused on parameter (C) than on (A).

In traditional sampling plans, a predetermined number of units (samples) from each lot are inspected, and then the whole lot is accepted; if they do not pass the inspection, the whole lot is rejected. Acceptance sampling can be used either for the number of nonconforming units or for nonconformities per unit. For the automotive industry, the quality of parts is critical, defined by fitness compatibility, appearance reliability, the durability function, and safety regulations, all of which need more investigation rather than do other parts. In this respect, each part has different quality characteristics with unequal quality requirements. The methodology proposed in this paper is based on automotive standard requirements, the PDCA cycle, and the capability process based on normal distribution and part per million (PPM). The advantage of the PQAS method is that different weight can be assigned to different specifications, and also deviation in the nominal value has an immediate negative effect on the total quality score of the product. Furthermore, the result of PQAS may allow customers to monitor their suppliers' product quality consistently, and thus to define corrective action or improvement plans based on the supplied parts' recognised lack of quality. The PQAS can be a supplementary monitoring tool for incoming lot inspection. Further research can be conducted to investigate the mechanisation of this method by software, employing control charts, and carrying out a capability process (CP) study on the results of this method.

Generally, PQAS has two advantages over other monitoring methods. First, it assigns different scores to measurements based on the deviation of nominal value in a normal distribution environment. Second, the quality of the lot quantifies out of 100 as a reference scale for further action.

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