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A fuzzy expert system to increase accuracy and precision in measurement system analysis

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ABSTRACT

In this paper, we have presented the first proposal to apply measurement system analysis (MSA) in fuzzy environment. Nowadays, because the quality control techniques are applied a lot in manufacturing, research and development environments, many decisions are made in processes and equipment evaluation, control, and improvement. Besides, the philosophy of measurement system analysis (MSA) depends on measurement error which hides true process capability; therefore, it must be implemented prior to any process improvement activities to minimize the measurement errors. Since the capability of each quality system is related to the accuracy of its measurement system, this research develops a novel methodology to increase precision and accuracy of MSA. To do so analyzing measurement systems under fuzziness of indices are investigated to make the environment more realistic. In this article, not only fuzzy measurement system analysis with gauge repeatability and reproducibility (GR&R) index as a triangular fuzzy number is proposed, but a fuzzy measurement system analysis a fuzzy expert system is presented to make more reliable and appropriate decisions. At the end, the applicability of the proposed methodology has been demonstrated within a case study in automotive parts industry to show impact of uncertainty in the reality.

1. Introduction and literature review

Measurement system analysis (MSA) has been implemented as one of applicable quality techniques in each process. Nowadays, many quality control techniques are used for recognizing reasons of error and preventing their occurrence. Undoubtedly, comprehension of quantifying process performance is severely essential to reach successful quality improvement initiatives. One of the most important quality techniques for decreasing process error in factories is MSA. MSA is one of the most important quality techniques for decreasing process error in factories and is also the process of evaluating an unknown quantity and expressing it into the divided numbers that are usually considered as precedence of any statistical process control. Moreover, MSA is provided as one of the main requirements in the old QS 9000 Quality Standard, Six Sigma technique, and even new standards such as ISO TS16949. Expanded applications of MSA are due to its various advantages including promotion of the compatibility of the measurement system for the given process and reduction of the contamination of measurement variation in the total process variation [1].

MSA is based on an important philosophy which believes measurement error lied in any process measurement method. Therefore, it should be considered as the precedent process of any quality measurement system [2]. MSA quantifies measurement errors via the examination of multiple sources of variation in a process. These variations consist of the variation resulting from the measurement system, the operators, and the parts themselves.

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Since statistical measures are estimated by data obtained by sampling, they are usually unreliable [3]. In this case, it is required to be mentioned that a measured value is included summation of two variables: (I) the quantity of measured value and (II) corresponding error (e_i) as

$$Y_i(Measured\_value) = X_i(True\_value) + e_i \quad (1)$$

The measurement system increases the total observed variability (σ^2_{obs}) of the measured parts. In any measuring, some of the observed variability is due to variability in the process (σ^2_p), whereas the rest of the variability is due to the measurement error or gauge variability (σ^2_{msa}). The variance of the total observed measurements can be expressed as Eq. (2). It means that total variability equals to the sum of process variability and measurement variability [4].

$$\sigma^2_{obs} = \sigma^2_p + \sigma^2_{msa} \quad (2)$$

Gauge variability (σ^2_{msa}) includes two major types of the error that are called repeatability and reproducibility. Repeatability ($\sigma^2_{\text{Repeatability}}$), which was determined by measuring a part for several times, quantifies the variability in a measurement system resulted from its gauge [5,6]. Reproducibility ($\sigma^2_{\text{Reproducibility}}$), which was determined from the variability created by several operators measuring a part for several times, quantifies the variations in a measurement system resulted from the operators of the gauge and environmental factors [7,8]. Square root of σ^2_{msa} is called gauge repeatability and reproducibility (GR&R) which formulated the all errors related to the gauge. It can be shown as

$$\sigma^2_{msa} = \sigma^2_{repeatability} + \sigma^2_{reproducibility} \quad (3)$$

Foster [9] proposed some procedures to compute different indices of MSA especially to calculate GR&R as major output of MSA. In order to distinguish product variance from device variance, many researchers carried out MSA studies on two or more measurement devices and provided a procedure to estimate the sensitivity of the measurement devices [3,10]. Senol [11] statistically evaluated MSA method by the means of designed experiments to minimize α–β risks and sample size. A GR&R investigation which estimates the repeatability and reproducibility components of measurement system variation with the primary objective of assessing whether or not the gauge is appropriate for the intended applications was carried out by Pan [5]. Also, Evaluating measurement and process capabilities by GR&R with four quality measures was presented by Al-Refaie and Bata [12].

Nowadays, one reason that causes indices calculated by sample data be unreliable is the uncertainty of data. Therefore, statistical calculations such as standard deviation, point and interval estimation, hypothesis testing and other similar ones are utilized. Besides, unreliability of indices has another reason which is resulted from the impreciseness of data. In the literature, to deal with impreciseness and uncertainty usually fuzzy concept is used which was first introduced by Zadeh [13].

Since there are not any works in the literature with the legend of fuzzy MSA (FMSA), this study concentrates on reviewing the most relevant works on application of fuzzy modeling in different quality indices and quality control charts. Lee [14] and Hong [15] estimated C_{pk} index using fuzzy numbers. Parchami et al. [16] developed new fuzzy types of all these process capability indices using fuzzy specification limits rather than precise ones. Parchami and Mashinchi [17] introduced a new method that uses confidence interval of capability indices to produce fuzzy number. Faraz and Bameni Moghadam [18] and Gulbay and Kahraman [19] proposed efficient methods to create fuzzy quality control charts. Also, a framework for achieving required measurement quality was presented by Rossi et al. [20]. Vladimir and Bokov [21] demonstrated an empirical method for high-pressure gauge modeling in which pneumatic gauging involved the estimation of dimensional deviations from measurement experiments using a valid gauge model.

As mentioned above, MSA assisted to judge compatibility of the measurement system with the given measurement process to provide conditions for more reliable decisions. This work makes a significant contribution to the MSA literature and develops fuzzy concept on MSA method to create indices of MSA more accurate. In fact, this article present first applying MSA method in fuzzy environment named FMSA. Zadeh [13] have introduced fuzzy logic to formulate the human knowledge. Fuzzy logic shows knowledge, experience, and subjective viewpoints of decision maker (DM) in natural language format [22]. This fuzzification considers uncertainty which may be affected in the outputs and consequently in the final decision. Since DM can observe variation related to uncertainties, final decision is made with more accuracy and precision. Ganesh Kumar et al. [23] propose a novel Genetic Swarm Algorithm (GSA) for obtaining near optimal rule set and membership function tuning. Due to any deterministic approach does not exist to make accurate decisions by experts, in this study, a fuzzy expert system is proposed to do it. Therefore, as another contribution of this paper, a fuzzy expert system is applied to provide more accurate decision after determining fuzzy GR&R.

The rest of the paper is organized as follows. The next section illustrates developed methodology. Section 3 describes a case study in automotive parts industry to demonstrate performance and applicability of the proposed methodology. At end, conclusions and future research are given.

2. The developed methodology for MSA

In this section, first, the MSA method is investigated in details. Then, the new developed methodology is illustrated step by step.

2.1. Traditional MSA

As mentioned previously, measurement system is the collection of instruments or gauges, standards, operations, methods, fixtures, software, personnel, environment, and assumption used to quantify a unit of measure or fix assessment [24]. Correspondingly, MSA is a collection of statistical methods for the analysis of measurement system capability [6]. It seeks to describe, categorize, and evaluate the quality of measurements; improve the usefulness, accuracy, precision, and meaningfulness of