International Journal of Supply and Operations Management

IJSOM

August 2014, Volume 1, Issue 2, pp. 167-189
ISSN-Print: 2383-1359
ISSN-Online: 2383-2525
www.ijsom.com

A Literature Review on the Fuzzy Control Chart; Classifications & Analysis

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Abstract

Quality control plays an important role in increasing the product quality. Fuzzy control charts are more sensitive than Shewhart control chart. Hence, the correct use of fuzzy control chart leads to producing better-quality products. This area is complex because it involves a large scope of industries, and information is not well organized. In this research, we provide a literature review of the control chart under a fuzzy environment with proposing several classifications and analysis. Moreover, our research considered both attribute and variable control chart by analyzing the related researches based on the content analysis method, to classify past and current developments in the fuzzy control chart. This work has included a distribution of articles according to the journal, the case studies related to fuzzy control chart, the percentage of types of fuzzy control charts used in the literature, performance evaluation of the fuzzy control chart and summary of key points of each review paper. Finally, this paper discusses some future research direction and our overviews. The results of this study can help researchers become familiar with well-known journals, fuzzy control charts used in sample case studies, and to extract key points of each paper in minimum time.

Keywords: Fuzzy Control Chart, Fuzzy Set Theory, Literature Review, Conceptual classification**.**

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1. Introduction

To survive in today's competitive world and satisfy customers, organizations need to improve their quality continuously**.** During the 1920s, W.A. Stewart first proposed the use of control charts. The control charts are important tools for quality control. We use a control chart when controlling ongoing processes by finding and correcting problems as they occur, predicting the expected range of outcomes from a process, determining whether a process is stable in statistical control, analyzing patterns of process variation from special causes (non-routine events) or common causes (built into the process) and determining whether your quality improvement project should aim to prevent specific problems or to make fundamental changes to the process. Fuzzy set theory was introduced for the first time by Zadeh (1965). Fuzzy set theory used to describe uncertainty and imprecision. Therefore, we can merge the chart control with fuzzy theory to more accurately control the quality of products. For this reason, fuzzy control charts are more sensitive than Shewhart control chart. The use of fuzzy control charts leads to produce more quality products leads to producing better-quality products. Bradshaw (1983), for the first time used fuzzy sets as a basis for the explanation of the measurement of conformity of each product units with the specifications. Tzvi Raz and Jyh-Hone Wang (1990) have attempted to extend the use of control charts to allow for linguistic variables. Ray Cheng et al (1995), proposed economic statistical np-control chart design. Fiorenzo Franceschine and Daniele Romano (1999), proposed a method for the online control of qualitative characteristics of a product/service using control charts for linguistic variables. Kimmo Latva-Kayra (2001), proposed EWMA and CUSUM with fuzzy control limits and their fuzzy combination is used. Murat Gulbay, Cengiz Kahraman (2006), direct fuzzy approach to fuzzy control charts without any defuzziffication, and fuzzy abnormal pattern rules based on the probabilities of fuzzy events is proposed. The suggested fuzzy control chart is illustrated with a numerical example. M. H. Fazel Zarandi, I. B. Turksen and. H. Kashan (2006) suggested design of control charts regarding the uncertain process parameters for both variables and attributes. Chih - HsuanWang-Way Kuo (2007), multi-resolution relied on robust fuzzy clustering approach is suggested by Chih - HsuanWang-Way Kuo (2007) to classify six categories of control chart patterns, three filtering approaches including mean, EWMA, and wavelet filters are evaluated to compare their denoising performance. H. Moheb Alizadeh, A. R. Arshadi Khamseh and S.M.T Fatemi Ghomi (2010), developed multivariate variable control charts in fuzzy mode. Each observation per sample is a canonical fuzzy number with a triangular membership function. A new methodology for fuzzy process control was presented by Alireza Faraz, Arnold F.Shapiro (2010), which monitors processes with fuzzy outcomes represented by *LR* fuzzy sets. Osman Taylan, and Ibrahim A.Darrab (2012), describe the use of artificial intelligence (AI) methods such as fuzzy logic and neural networks in quality control and improvement. A fuzzy inference control system has been proposed by Inci Saric-ic-ek and Omer C- imen (2011) for detecting the mean and/or variance shifts in a process. Through statistical measures, the performance of the proposed method has been compared to traditional control charts through two measures, the wrong decision percentages and Type II error. It is found that for both measures, the proposed method outperforms the traditional control charts. The proposed method is intelligent, does not need a training process and captures past information. It is suggested that the fuzzy inference system is applicable to detecting the mean and/or variance shifts in a process. Detecting variability occurring in mean and/or variance in a process and investigating the causes of this variability can help to improve the product quality and to reduce costs; detecting variability occurring in mean and/or variance in a process and investigating the causes of this variability can help. The effect of the measurement error on the $\tilde{X}$-$\tilde{R}$ fuzzy control chart is surveyed by M.Moameni, A. Saghaei M. Ghorbani Salanghooch (2012). The model used is a linear covariate model. The effectiveness of the control chart in detecting the changes in the mean value is calculated using the average run length (ARL). It is shown that when the mean values of measurements are different, a smaller value of measurements' variance results in greater effectiveness of the $\tilde{X}$ -$\tilde{R}$ fuzzy control chart.

Because of the importance of the fuzzy control, the studies that have already been done in this regard must be well organized, so we can analyze them properly.

Consequently, there is an absence of recent review papers that summarize articles dealing with fuzzy control chart. As an attempt to fill this blind spot, this research surveys the major literature and the key findings of fuzzy control chart research. Thus, important journals and books published between 1983 and 2014 are reviewed. The main objectives of this research are:1- Creating different classifications and analysis for reviewing fuzzy control chart articles and finding the key contents of the papers, 2- Categorizing and summarizing the literature findings and to identify the research trends, 3- Proposing suggestions for fuzzy control chart researchers based on the literature survey. The paper is organized as follows: Section 2 describes research methodology. Section 3, proposes several classifications and analysis of literature review papers. Section 4, conclusion, contains discussion and direction for future research.

2. Research methodology

Three basic search methods exist for literature review. According to Li et al (1995), the first is the Delphi. The second is meta-analysis. The third approach, which is used in this paper, is content analysis. Bernard Berelson defined Content Analysis as a research technique for the objective, systematic, and quantitative description of manifest content of communications (Berelson, 1974). The main purpose of the content analysis method is to identify and classify key scientific contributions to a field or question and the method's results are often presented and discussed descriptively. The procedure for conducting content analysis is relied on two main steps: 1) of sources and procedures for the search of articles to be analyzed and, 2) the classification of the selected articles. In this study, these steps have been used. Two selection criteria are used to choose and accept the fuzzy control chart research articles. If the papers do not meet one of the two criteria, they are removed. The two criteria are as follows: 1) papers are found via computerized search of the topic areas. The search is narrowed using the following terms: fuzzy control chart, fuzzy control of uncertainty environment, capability index in a fuzzy control chart. In addition, the references cited in each relevant paper are analyzed to find out additional sources of information. This research considers the published researches, including the electronic literature sources such as Elsevier, Taylor & Francis, Springer, Emerald Insight, Scopus and etc. 2) This survey involves well known journal & conference (Journal of Intelligent Manufacturing, Computational Statistical &Data Analysis, Expert Systems with Applications, Information Sciences, Math ware and Soft Computing, Intelligent Journal, Journal of Applied Statistics, International Journal of Quality and Reliability Management, Applied Soft Computing Qual Quant, International Advanced Manufacturing Technology, Quality Technology & Quantitative

Management, SCIENTIA IRANICA, International Journal of Production Research, European Journal of Operational Research, Computer &Industrial Engineering, International Journal of Computational Intelligence Systems, Journal of Manufacturing Technology Management, Fuzzy Sets and Systems, International Journal of Applied Mathematics & Statistical Sciences, Economic Quality Control, 10th International Conference on Development and Application Systems, Romania, International Journal of Engineering Science and Technology, Applied Mathematical Sciences, Iranian Journal of Fuzzy Systems, Production planning &Control, The Journal of Mathematics and Computer Science, American Statistical Association and the American Society for Quality Control, Studies in Fuzziness and Soft Computing, International Journal of Research and Reviews in Applied Sciences, IIE Transactions, Applied Mechanics and Materials, International Journal of Research and Reviews in Applied Science .Other publication forms such as, unpublished working papers, master and doctoral dissertations, newspapers, etc. are not included). This study involves a period of 30 years: from 1983 to 2014.

3. Classification and analysis

Each of surveyed articles is classified according to the following categories: 1) New fuzzy conceptual control chart category. 2) Distribution of reviewing articles according to the journal title 1983–2014. 3) Case studies related to fuzzy control chart. 4) Percentage of types of fuzzy control chart applied in literature papers.5) Performance evaluation of the fuzzy control chart based on ARL. 6) Fuzzy Control Chart papers content review.

3.1. New fuzzy conceptual control chart category

Fuzzy control chart is more sensitive than similar control chart. These control chart construction parameters are fuzzified. Construction of fuzzy control chart has some advantages. The major contribution of fuzzy set theory is its capability of representing vague data. With the help of the fuzzy set theory, flexibility of the system is improved. Correct classification of fuzzy control charts is important. It assists engineers to select a better chart.

In this section, we categorized fuzzy control chart based on attribute and variable specifications as indicated in Figure 1. Attribute charts could monitor more than one quality characteristic simultaneously and need less cost and time for inspection than variable control charts. Variables charts are used to evaluate variation in a process where the measurement is a variable which can be measured on a continuous scale (e.g. height, weight, length, concentration). Fuzzy attribute control charts can be divided into 4 categories: a) P-fuzzy chart b) C-fuzzy chart c) NP-fuzzy chart d) U-fuzzy chart. Each of the mentioned control charts used when following situations are satisfied: **P-fuzzy chart** is used for controlling fraction nonconforming, independent observation and size of shift to detect large (>= 1.5 σ). **C-fuzzy chart** is used to for controlling Number of nonconformance, independent observation and size of shift to detect large (>= 1.5 σ). **NP-fuzzy chart** is used for controlling number nonconforming, independent observation and size of shift to detect large (>= 1.5 σ).**U-fuzzy chart** is used for controlling nonconformance per unit, independent observation and size of shift to detect large (>= 1.5 σ). Also fuzzy variable specifications charts can be divided into 7 categories: a) Xbar-R fuzzy chart. b) Xbar-S fuzzy chart. c) S^2 -fuzzy chart. d) X-MR fuzzy chart. e) CUSUM- fuzzy chart. f) EWMA- fuzzy chart.

g) T^2- fuzzy chart. Each of the above control charts used when following situations are satisfied: **Xbar-R fuzzy chart** is used for controlling quality characteristic measurement, sample size within each sub group (4-6), independent observation and size of shift to detect large(>= 1.5 σ). It was used for characteristics that can be measured on a continuous scale, such as weight, temperature, thickness etc. The R-chart shows sample ranges (difference between the largest and the smallest values in the sample). **Xbar-S fuzzy chart** is used for controlling quality characteristic measurement, sample size within each sub group (more than 7), independent observation and size of shift to detect large(>= 1.5 σ). It was used for characteristics that can be measured on a continuous scale, such as weight, temperature, thickness etc. S chart plots the process of standard deviation over time for variables data in subgroups. This control chart is widely used to examine the stability of processes in many industries. For example, you can use S charts to examine process variation for subgroups of part lengths, call times, or hospital patients' blood pressure over time. **T^2-fuzzy charts** are used to monitor a process when more than one quality variable associated with process is being observed. **X-MR fuzzy chart** is used for controlling quality characteristic measurement, sample size within each sub-group (equal1), independent observation and size of shift to detect large(>= 1.5 σ). **CUSUM- fuzzy chart** is used for controlling cumulative sum of quality characteristic measurement, sample size within sub-group equal1, independent observation and size of shift to detect small (<1.5 σ). **EWMA-fuzzy chart** is used for controlling exponentially weighted moving average of quality characteristic measurement, sample size within each of sub group equal1, independent observation and size of shift to detect small (<1.5 σ). **S^2fuzzy chart** is often used in the monitoring of shifts in the process variance and it is quick in detecting big shifts but is less sensitive to small shifts.

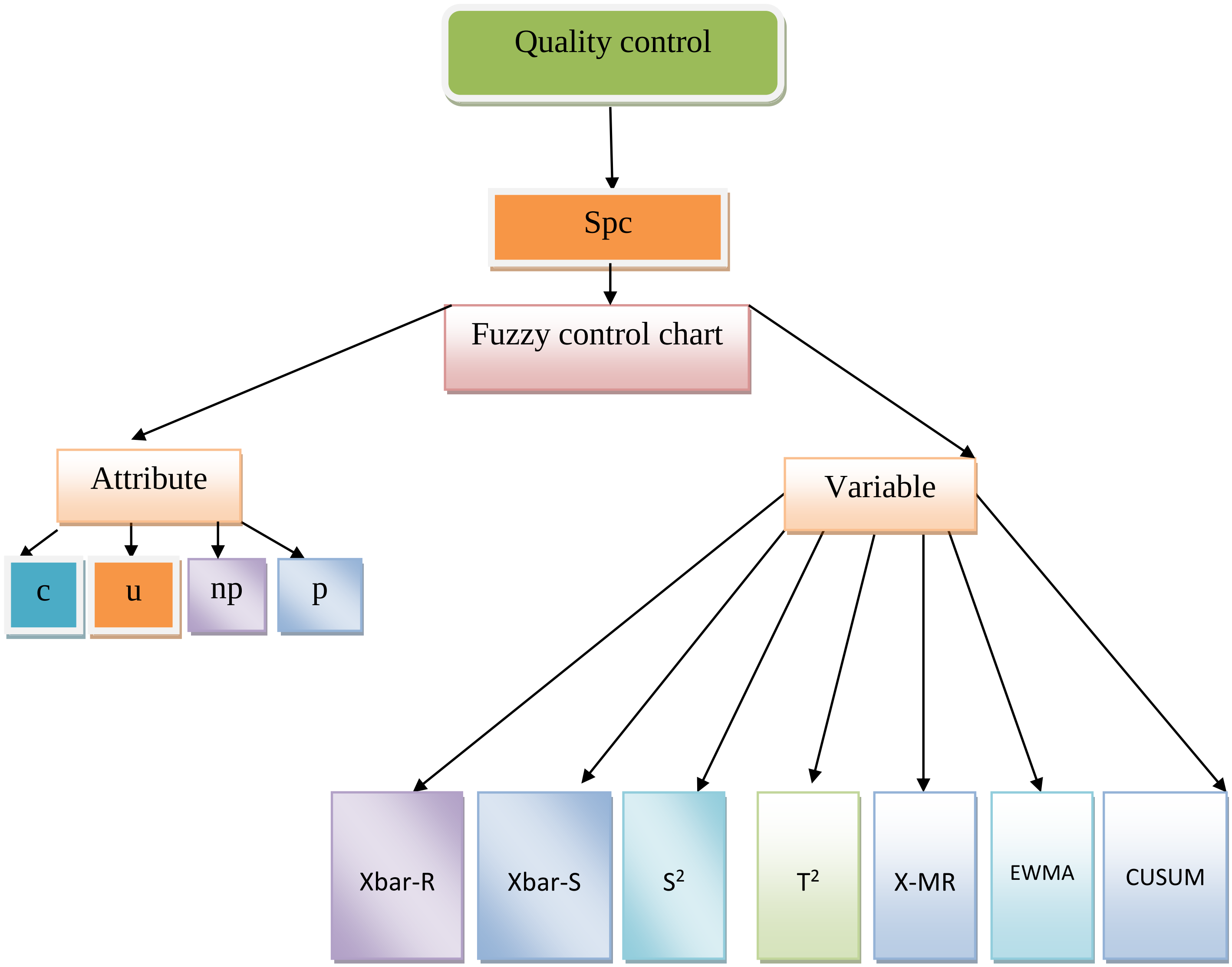

Figure1. New fuzzy conceptual control chart category.

3.2. Distribution of reviewed articles according to the journal title

The surveyed articles based on journals are categorized in Table 1. The study period of 1983–2014 has been divided into 10-year periods in order to identify trends in the chronological progression of research on fuzzy control chart by academic journals. Table 1 identifies journals that published two or more fuzzy control chart articles as well as the other journals that published only one article dealing with the subject.

Table1. Distribution of reviewed articles according to the journal title 1983–2014

	Period			
Journal	**80-90**	**91-00**	**01-10**	**11-14**
Journal of Intelligent Manufacturing			***	
Computational Statistical &Data Analysis			*	
Expert Systems with Applications			**	*
Information Sciences			*****	
Math ware and Soft Computing			*	
Intelligent Journal			*	
Journal of Applied Statistics			*	
International Journal of Quality and Reliability Management		*		
Applied Soft Computing			*	
Qual Quant			*	*
International Advanced Manufacturing Technology			**	
Quality Technology & Quantitative Management			*	
SCIENTIA IRANICA			*	
International Journal of Production Research	*	**	**	
European Journal of Operational Research	*			
Computer &Industrial Engineering				*
International Journal of Computational Intelligence Systems			*	*
Journal of Manufacturing Technology Management				*
Fuzzy Sets and Systems			**	
International Journal of Applied Mathematics & Statistical Sciences				*
The 4th International Conference on Quality and Reliability			*	
Economic Quality Control			*	
10th International Conference on Development and Application Systems, Romania			*	
International Journal of Engineering Science and Technology				*
Engineering, Technology & Applied Science Research				*
International Journal of Innovative Computing, Information and Control				*
Applied Mathematical Sciences				*
Iranian Journal of Fuzzy Systems			*	
Integrated Manufacturing Systems		*		
Production planning &Control	*			
The Journal of Mathematics and Computer Science			*	
American Statistical Association and the American Society for Quality Control		*		
Studies in Fuzziness and Soft Computing			*	
International Journal of Research and Reviews in Applied Sciences				*
IIE Transactions		*		
Applied Mechanics and Materials				*
International Journal of Research and Reviews in Applied Sciences				*

As presented by Table 1, the largest number of papers appeared in the ‘‘International Journal of Production Research and information sciences" which account for each journal about 10%. There are 8 journals that published at least two articles, while 29 other journals have published only one article, in each journal.

3.3. Sample case studies related to fuzzy control chart

After peer review of papers, we extracted sample case study based on the type of control chart. It is presented in Table 2. This table helps researchers to become familiar with the fuzzy control charts which were used in sample case studies. It can be useful for quality control engineers too.

Table 2. Sample case studies related to fuzzy control chart

Types of Fuzzy Control Chart	Sample Case
Xbar-R	Shear carpet
EWMA	Coating Thickness of an Industrial Cutting Tool Manufacturing Process
EWMA(Multivariate)	Food process
CUSUM & EWMA(Multivariate)	Tourism Industry
P	Engine Piston Manufacturing Process
P	Textile Company
Xbar-S	Biscuit Factory
Xbar-R	Oil field centrifuge
CUSUM &EWMA	Typical Mechanical Printing Paper Pulp
P	LED lighting
C	IC(Integrated Circuit)
Xbar-R	Touch panels
Xbar-R	Controlling Piston Inner Diameters Compressors
Xbar-R	Threading of the Natural Gas Valve by CNC Machine
CUSUM & EWMA	KLC-WEDGE Process
Xbar-R	Inside Diameter Measurement of Piston ring
Xbar-R	piston manufacturer in Konya’s Industrial Area
Xbar-R	electronic company

By using Table 2, the percentage of sample case study based on fuzzy control charts can be calculated. The Result is presented by Figure 2.

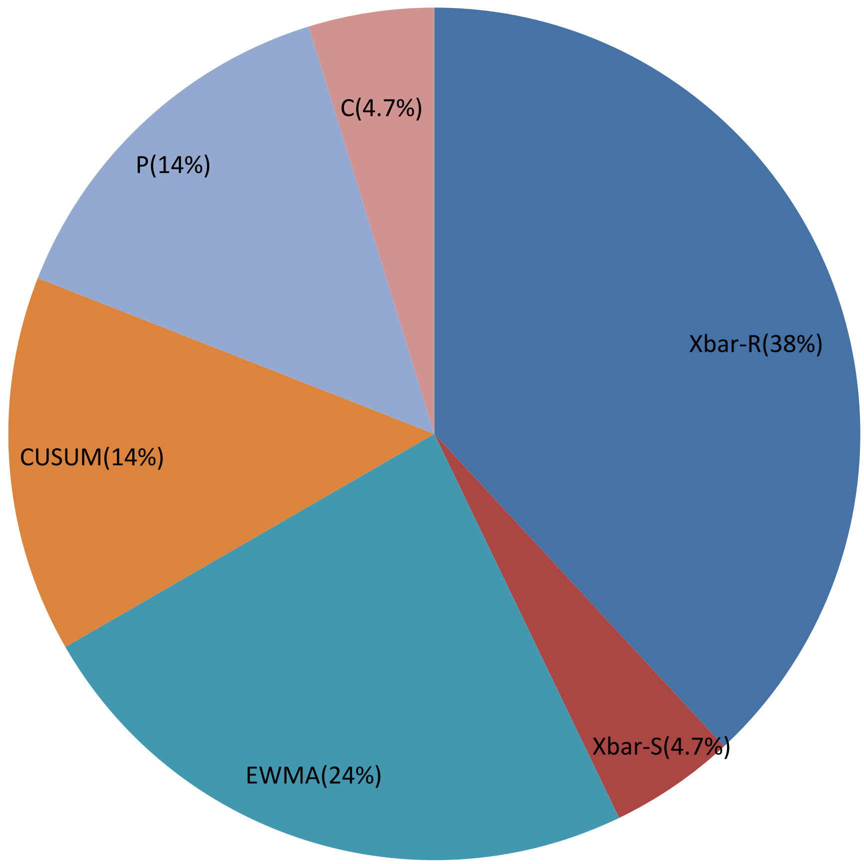

Figure 2. The Percentage of case study based on fuzzy control charts

According to Figure 2, Xbar-R fuzzy control charts were the most used in the case studies (38%). Sequentially, EWMA (24%), CUSUM and P (14%), C and Xbar-S (4.7%) were the most used in the case studies.

3.4. The percentage of types of fuzzy control chart applied in literature papers

In this section, we categorized the percentage of types of fuzzy control chart applied in literature papers for controlling quality. It is indicated in Figure 3.

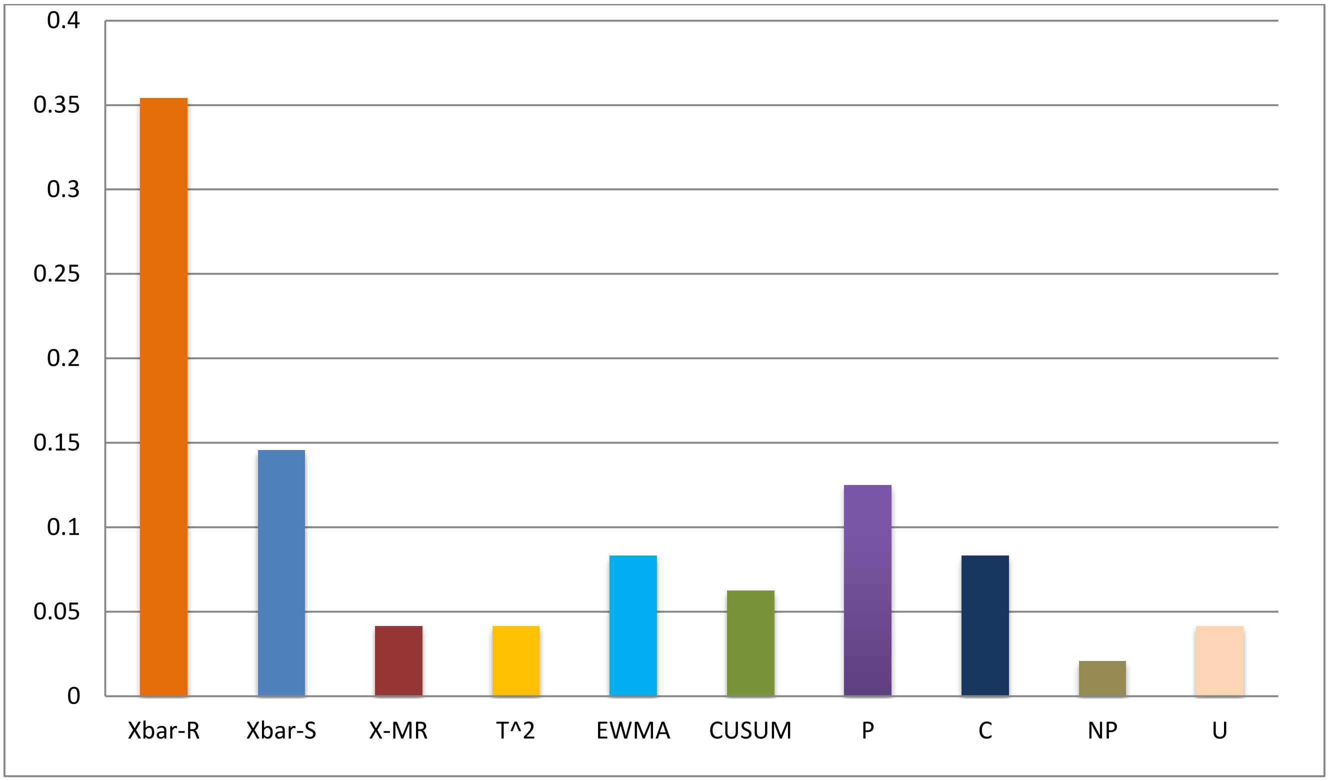

Figure 3. The Percentage of types of fuzzy control chart used in literature paper

According to Figure 3, Xbar-R fuzzy control charts were the most used in literature papers (35.5%). Sequentially, Xbar-S (14.5%), P (12.6%), C and EWMA each of them (8.4%), CUSUM (6.3%), X-MR, $T^2$and U each of them (4.1%), NP (2%).Totally, attribute control charts (27%) and variable control charts (73%) were used in literature papers.

3.5. Performance evaluation for fuzzy control chart based on ARL

ARL is a famous index for performance evaluation and effectiveness of control chart (2012). Effectiveness of control chart is specified with ARL index. ARL_1 is the average number of points that must be plotted before a point indicates an out-of-control condition. We analyzed literature papers about performance evaluation in 3 levels: with ARL, without ARL, without performance evaluation. According to Figure 3, Xbar-R fuzzy charts were the most used in literature papers. For this reason, we analyzed performance evaluation both in Xbar-R fuzzy chart and all types of fuzzy control charts. The results are indicated in Figure 4 and Figure 5, respectively.

According to Figure 4, 12% of performance evaluation of papers included fuzzy Xbar-R chart based on ARL, 29% without ARL, 59% without any performance evaluation. According to Figure 5, 14% of performance evaluation for all types of control charts based on ARL, 36% without ARL, 50% without any performance evaluation.

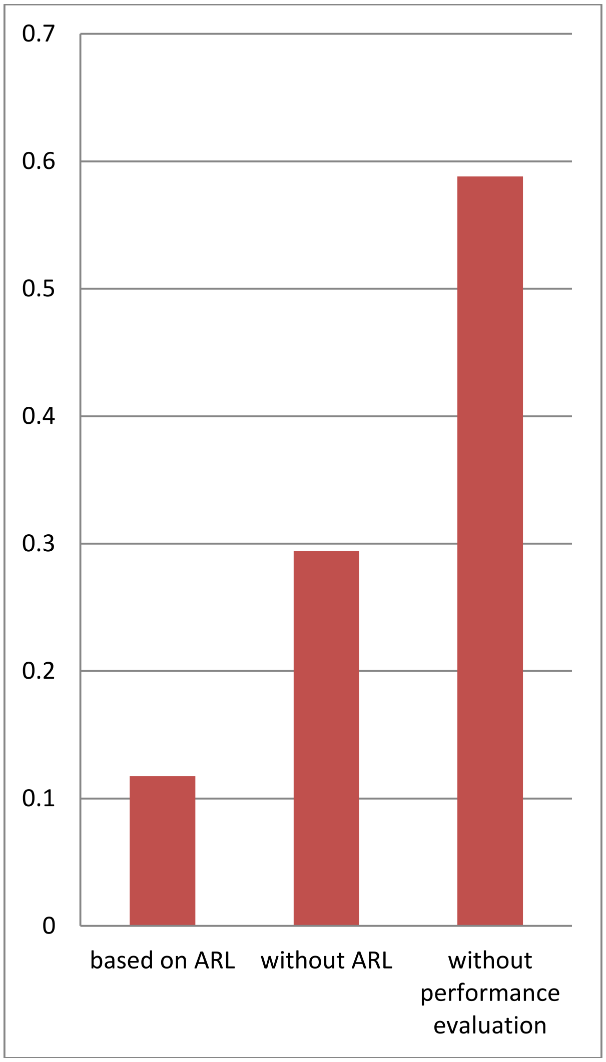

Figure 4. Performance evaluation of fuzzy Xbar-R chart

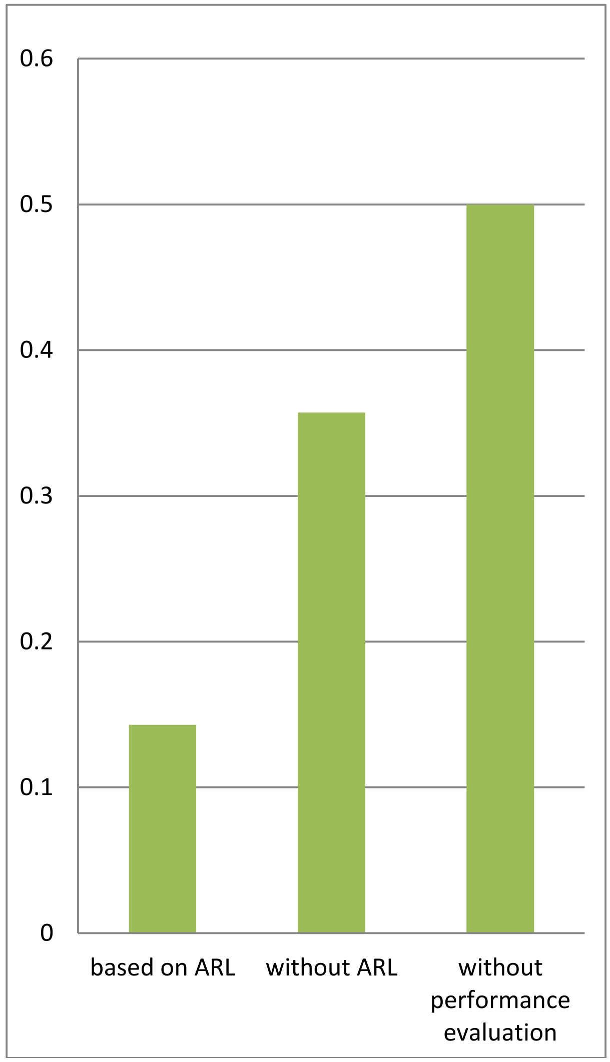

Figure 5. Performance evaluation all types Of control chart

According to Figure 5, 50 percent of the articles did not evaluate the performance of the control chart. This figure is alarming. After creating control charts, performance evaluation in the industry is important. Creating a chart control in theory and applying it without evaluating its performance in the industry can cause a lot of problems.

3.6. Fuzzy Control Chart papers content review

In this section, we analyzed literature papers then extracted key points. Table 3 indicates key point of each paper based on the type of control chart used in paper & author/authors of the paper. Also, we separated papers about fuzzy parameters in construction of control chart, as indicated in Table 4, from other papers. These tables help researchers to become familiar with the key point of papers in less time.

Table3. Fuzzy Control Chart Papers content review

Type of Fuzzy Control chart	Author/Authors	Fuzzy applications
control chart patterns	Chih - HsuanWang-Way Kuo (2007)	In this paper, multi-resolution relied on robust fuzzy clustering approach is suggested to classify six categories of control chart patterns, three filtering approaches including mean, EWMA, and wavelet filters are evaluated to compare their denoising performance. Furthermore, three fuzzy clustering algorithms relied on FCM, KFCM and EFCM are used to compare their classification performance. Compared to other denoising approaches, wavelet filters shows the best performance for the subsequent pattern classifier because it is capable of making more information in both time and frequency domains via the so-called multi-resolution property. As a result, mixed framework combining wavelet filter with robust fuzzy clustering is proposed to identify six traditional types of control chart patterns.
P,C ,U	Murat Gulbay ,Cengiz Kahraman (2006)	In this research, Direct fuzzy approach to fuzzy control charts without any defuzziffication, and fuzzy abnormal pattern rules based on the probabilities of fuzzy events is proposed. The suggested fuzzy control chart is illustrated with a numerical example. Fuzzy abnormal pattern rules are extended and applied to the test problem. This paper defined fuzzy unnatural pattern rules relied on the fuzzification of the crisp rules.
C	Kin-Lin Hsieh,Lee-Ing Tong.Min-Chia Wang (2007)	This paper used fuzzy theory in building a control chart to simultaneously control two approaches: defect count and defect clustering degree.
C	Murat Gulbay,Cengiz Kahraman (2007)	In this study, linguistic data proposed by asymmetric fuzzy numbers, various possible decisions should be faced. This type of linguistic data should be processed by DFA to preserve the loss of information in linguistic data. It is very useful to define a α-cut and a permissible percentage which enable the quality expert to set the tightness of inspection. This method preferred a fuzzy comparison method based on field measurement in DFA approach because it evaluates the degree of being outside the control limits.
P	D.J.Fonseca,M.E. Elam and L.Tibbs. (2007)	The aim of this paper was to revise the α-cut method for fraction nonconforming control charts to account for the case when data collected from the process is of a short-run nature. The results of the study included algorithms for all chart parameters involving the center line, plot values, and upper and lower control limits.
P	Hassan Talebs and Mohammad Limam (2002).	This study showed that for the porcelain example, the performance of the fuzzy control chart is affected by the degree of fuzziness and the transformation method. These fuzzy control charts perform more sensitive than probabilistic charts when a mix of fuzzy probabilistic approach, fuzzy median and membership functions is used.
P	Ming-Hungshu. And. Hsien-Chung Wu. (2010)	In this paper, fuzzy data play a critical role in measurement of quality characteristics; the traditional *p* control chart constructed using real-valued data seems to be abnormal. In this case, fuzzy theory was applied to overcome the problem. Using the fuzzy-*p* control charts and the suggested permissibly function to categorize the manufacturing process let the decision-maker to make linguistic decisions.
NP	Reay-cheng Wang and Cheng-ho Chen (1995)	In this paper, The problem of determining economic statistical *np*-control chart designs has been considered under the fuzzy environment of closely satisfying the type I and II errors in this article. The solution

		can be thought of as an improvement to economic statistical design because it provides for more flexible statistical constraints on economic models and less costly yields under the assumptions of the economic statistical model.
P	Orhan Engin,Ahmet Celik,Ihsan kaya (2008)	In this article, parameters such as (defective item rate for bench (stage)- defective item rate for raw material- defective item rate for every stage- proportion of defective item in stage i,....) are examined as fuzzy and the model is solved to distinguish sample size n by GAs..
EWMA and CUSUM	Kimmo Latva-Kayra (2001)	This paper proposed EWMA and CUSUM with fuzzy control limits and their fuzzy combination is used. The quality observer was developed for UPM-Kymmene Jiimsankoski TMP2- plant.
multivariate EWMA & CUSUM	Shahram ghobadi ,Kazem Noghandarian-Rasoul Noorassana.S.M. Sadegh Mirhosseini (2012)	This paper studies how the profile functional relationship between a fuzzy response variable and a predictor variable can be monitored by using a fuzzy regression model which is referred to as profile. The purpose of this paper is to develop a multivariate approach for monitoring process/product fuzzy quality profiles in phase I for applications where the quality characteristic is linguistic, imprecise, vague or deficient.
multivariate EWMA	Hossein Alipour-Rasoul Noorassana (2010)	In this article, multivariate control chart with fuzzy logic was considered simultaneously to develop the F-MEWMA control chart. Performance of the suggested control chart was compared to the fuzzy T^2 control chart using the ARL criterion.
MaxGWMA (EWMA)	Ming-Hungshu-Thanh Lamnguyen-Bi-Minshu (2013)	In this paper, fuzzy data analysis method is used to construct the F-MaxGWMA control chart. Next, it is used to determine the non random causes of unusual variations and alarming the need for corrective actions existing in the underlying processes.
T^2	Hassan Taleb-Mohmed Limam-Kaora Hirota.(2006)	In this study, two approaches are suggested. First is relied on fuzzy theory and the other is relied on probability theory. The plotted statistic in the fuzzy is obtained after transforming fuzzy observations into their representative values.
T^2	H.Moheb Alizadeh-A.R.Arshadi Khamseh and S.M.T Fatemi Ghomi.(2010).	This article develops multivariate variable control charts in fuzzy mode. Each observation per sample is a canonical fuzzy number with a triangular membership function.
X-MR	J.D.T. Tannock (2003)	In this article, the fuzzy method described is much simpler and more transparent than the NN methods, which have been developed by many authors for such purposes.
X-MR	W.Jerry Parkinson,Ronald E.Smith,Fred N.Mortensen,and Paul J. Wantuck. (2002).	In this research, the Feed-Change-Magnitude is accounted with fuzzy rules. Fuzzy technique is used because of the multi-variable nature of the feed.
Xbar-R	.Charles.W.Bradshaw.Jr (1983)	In this research, the overwhelming advantage of fuzzy economic control limits is that they provide an indication of severity as well as the frequency of product nonconformance.

Xbar-R	Ming-hung Shu, Hsien-Chung Wu. (2011)	This article, compares the fuzzy averages and variances to their fuzzy control limits. Decision-makers enable will be able to make the better decision.
Xbar-R, Xbar-S	Seril Senturk,Nihal Erginel.(2009)	In this research, it is shown that the fuzzy set theory is applicable on the traditional variable control charts. Also, α -cuts fuzzy X-R, X-S control charts are extended together with α-level fuzzy midrange transformation techniques.
Xbar-R	Fiorenzo Franceschine and Daniele Romano (1999)	This article proposes a method for online control of qualitative characteristics of a product/service using control charts for linguistic variables.
X-Regression	Seril Senturk (2010)	The aim of this study is to present the theoretical structure of the “α-level fuzzy midrange for the α-cut fuzzy *X* -regression control chart”. The proposed fuzzy *X* -regression control chart is illustrated with a numerical example of threading inner diameters of a natural gas valve. In addition, the fuzzy *R* control chart is implemented to monitor the variation of inner diameters of the natural gas valve. In fuzzy control charts, an α-cut represents the ability to determine the tightness of the collection sample process. The fuzzy midrange transformation technique can transform the fuzzy samples to a crisp number. Other transformation techniques and membership functions can be applied to obtain an α-cut fuzzy *X* -regression control chart for further research.
Xbar-R Xbar-S	Pandurajan &R.Varadharajan (2011)	This study shows that the fuzzy set theory is appropriate to distinguish the signals in the variable control charts, because its gives some flexibility to the control limits. The α-cut Level fuzzy midrange transformation techniques are used to describe applications in a production process.
Xbar-R	.Osman Taylan,and Ibrahim A.Darrab (2012)	The aim of this study has been to describe the use of artificial intelligence (AI) methods such as fuzzy logic and neural networks in quality control and improvement.
X	Y-K.Chen.C.Y.eh. (2004)	This study promoted the DSI control charts by softening their borderline of sampling zones in the fuzzy-set approach while adjusting the maximum and minimum sampling interval lengths through genetic algorithms.
X	Alireza Faraz,r.Baradaran Kazemzadeh. M.Bameni Moghadam.Ali Asghar Bazdar(2010)	This article introduced the fuzzy chart and showed that the control limits in classical Shewhart charts must be adjusted when there is an ambiguity in the process mean beside randomness. These charts have the advantage of simplicity with respect to other fuzzy control charts because its control limits are adjusted and are direct analogue of Shewhart control charts.
Xbar-R	Kudrat demirli,suji kumar,vijay kumar. (2010)	In this research, the fuzzy inference engine developed in this work analyzes the unnatural patterns exhibited on a X chart. Generally X chart is used in conjunction with R chart to monitor the process variation
X	Hsi -Mei Hsu and Yan- Kwang Chen (2001)	In this paper, a new on-line detective system based on fuzzy reasoning to monitor and diagnose the process has been described. This detective system will support the operators to quickly identify the possible causes when a process is going unstable. In this research, the concept of fuzzy sets and membership functions for softening Nelson's rules to detect abnormal patterns of symptoms was applied. Moreover, in knowledge acquisition aspects, also a new methodology, named MSM, was presented, to acquire the knowledge about the relationship between causes and symptoms from data. MSM method has good performances to justify the possible causes.
Xbar-S	Irfan Ertugrul ,Esra Aytac (2009)	In this research, to supplement the binary classification, several intermediate levels which describe product quality are used. These intermediate levels are expressed in the form of linguistic terms with the help of fuzzy logic. Fuzzy

		probabilistic and membership control charts which were proposed by Wang and Raz are constructed. The main difficulty of constructing fuzzy control chart is selecting suitable membership function of linguistic variables. The assignment of membership function to each linguistic variable is not easy for process and quality engineers. The shape of membership function should be based on system behavior and user's preferences. And also increasing and decreasing number of linguistic variables affect the performance of fuzzy control chart.
Xbar-S	Alireza Faraz, arnold f.shapiro. (2010)	In this research, the area under the membership function has been considered to be an appropriate measure of fuzziness, and a new methodology for fuzzy process control was presented, which monitors processes with fuzzy outcomes represented by *LR* fuzzy sets. The proposed approach constructs the fuzzy in-control region, and the chart measure determines the grade of membership, i.e., the degree to which the process belongs to the out-of-control state.
Xbar-S	Nihal erginal, Sevil Senturk,Cengiz Kahraman,Ihsan Kaya. (2011).	In this paper, the fuzzy standard deviation is firstly introduced to obtain fuzzy X and S control charts and then these fuzzy control charts are employed in food industry to monitor if the processes are under control or not. Additionally, the fuzzy X and S control charts are developed for the case that the population parameters are known. There are two extensions to this paper: 1. A new way of calculating fuzzy standard deviation has been proposed. Also, the application of fuzzy *X* and *S* control charts has been illustrated in a food industry for evaluating the packing process of biscuits. 2. The theoretical structure of fuzzy *X* And *S* control charts has been proposed for the case that the population parameters (mean and standard deviation).
Xbar-S	Jyh-hone wang and tzvi raz. (1990)	This research has attempted to extend the use of control charts to linguistic variables by proposing several ways for determining the CL and the control limits.
Xbar-S	A.K anagava, F.tamaki and H.Ohta (1993)	This paper proposed control charts for linguistic data from a standpoint different to that of Wang and Raz in order not only to control the process average but also to control the process variability. Control charts are aimed at directly controlling the underlying probability distributions of the linguistic data.
X U C	M. H. Fazel Zarandi, I. B. Turksen and. H. Kashan (2006)	In this paper, design of control charts regarding the uncertain process parameters for both variables and attributes quality characteristic was investigated. Derived control intervals are more flexible than the similar crisp case because they are a function of degree of expert presumption. In case of fuzzy data, we develop a deffuzifier index based on the metric distance between fuzzy sets, which is flexible and easy to compute and efficiently uses the information encompassed by the possibility distribution of sampling fuzzy sets.
X	Rungsarit Intaramo (2012)	This paper is to calculate the ARL of FEV theory control charts, using α -cut with the methods of α -level fuzzy midrange for skewed populations which are Weibull, lognormal and Burr's distributions. The result of the study is, the ARL of FEV theory control charts which have lognormal distribution is most efficient at a coefficient of skewness 0.1. Burr's distribution is most efficient at a coefficient of skewness 0.5, 1.0 and 2.0. Weibull distribution is most efficient at a coefficient of skewness 3.0, 4.0, 5.0, 6.0, 7.0, 8.0 and 9.0. The results of the ARL calculation of FEV theory control charts at a coefficient of skewness 0.1 of Weibull , lognormal and Burr's distributions are, ARL = 212.01, 215.13 and 206.76 respectively. In this study, the ARL using FEV theory is greater than when using EV theory studied by A.Pongpullponsak, W. Suracherkiati and R. Intaramo, (2006). It shows that when fuzzy theory is applied to control charts, the performance is better.

Xbar-R	_Inci Saric_ic_ek and Omer C_ imen (2011)	In this research, a fuzzy inference control system has been proposed for detecting the mean and/or variance shifts in a process. Through statistical measures, the performance of the proposed method has been compared to traditional control charts through two measures, the wrong decision percentages and Type II error. It is found that for both measures, the proposed method outperforms the traditional control charts. The proposed method is intelligent, does not need a training process and captures past information. We showed that the fuzzy inference system is applicable to detecting the mean and/or variance shifts in a process. Detecting variability occurring in mean and/or variance in a process and investigating the causes of this variability can help to improve the product quality and to reduce costs.
Xbar-R	M. Moameni A. Saghaei M. Ghorbani Salanghooch (2012)	In this study, the effect of the measurement error on the $\tilde{X}$-$\tilde{R}$ fuzzy control chart is surveyed. The model used is a linear covariate model. The effectiveness of the control chart in detecting the changes in the mean value is calculated using the average run length (ARL). It is shown that, when the mean values of measurements are different, a smaller value of measurements' variance results to greater effectiveness of the $\tilde{X}$ -$\tilde{R}$ fuzzy control chart. Also, the ARL changes show that in similar condition, the effectiveness of the control chart increases when the slope of the linear covariate model increases.
P	S.Selva Arul Pandian Dr.P.Puthiyanayagam (2013)	TFM control chart with VSS using α – level fuzzy midrange has been proposed for linguistic data. To draw the chart, samples of varying sizes are chosen from free defined set. α – level fuzzy midrange techniques are also applied to construct TFM chart with VSS. The proposed method is compared with regular p-chart with VSS and FM chart with VSS. The TFM control chart with VSS using α – level fuzzy midrange is more economical and more sensitive in identifying the shift in the process for multi-attribute quality data in linguistic terms.
CUSUM	Renkuan GUO, Tim Dunne (2005)	This paper has developed two small-sample based grey predictive process control charts: grey Shewhart control chart and CUSUM control chart. Moreover, this proposes a grey-fuzzy control chart which is , in general , more logical and more efficiently utilizing the data information because it does not need to split data sequence into upper (positive) and lower (negative) sides. Furthermore, the membership function can be characterized by regarding both product specifications and tolerance parameters (process capability).
Xbar -R	Ihsan Kaya , Cengiz Kahraman (2011)	In this paper, measurements and SLs have been defined as TFNs or TrFNs to increase the flexibility of PCA. This has provided more information and more flexibility. Fuzzy PCIs also include crisp values with a membership value of 1.00 and show all possible values of PCIs.
X	Yan-Kwang Chen Hsu-Hwa Chang Fei-Rung Chiu (2008)	The objective of this paper is to propose an economic design of the X control chart for a process that is subject to a non-random cause, and the magnitude of process shift by non-random cause is not precisely known. In order to cover the true magnitude, the process shift is treated as a fuzzy number with a given membership function.

Table4. Content review based on Fuzzy parameters in construction of control chart

Type of Fuzzy Parameter	Title	Fuzzy Applications
Sampling	Chi-Bin Cheng (2008)	This paper has suggested a novel methodology for FPC whose aim is to monitor a process with fuzzy outcomes proposed by fuzzy numbers. Two fuzzy control charts have been constructed to directly monitor the fuzzy outcomes to get to establish whether or not the process is in control.

Sampling	M.H. Fazel Zarandi, A. Alaeddini , I.B. Turksen (2008)	In this research, a fuzzy expert system has been proposed for online, simultaneous pattern recognition and parameter adjustment of the control charts. The performance of the proposed method has been compared with different traditional run rules and adaptive sampling schemes through two statistical measures. furthermore, fuzzy adaptive sampling rules part and fuzzy run rules part of this method can be used separately and independently to solve different kinds of problems.
Sampling	Adel Alaeddini , Mehdi Ghazanfari , Majid Amin Nayeri .(2009)	This paper, based on fuzzy clustering concepts and statistics, proposed a new hybrid approach to estimate change-points in the mean of normal processes for both fixed and variable sampling schemes which have not been studied yet. This paper also examined the performance of the proposed approach and showed that it performs as effective as powerful MLE based approaches in some cases and much better than them in other cases.
Linguistic number	Tzvi Raz and Jyh-Hone Wang.(1990)	This article has attempted to extend the use of control charts to allow for linguistic variables. This article proposed two approaches For determining the centre line and the control limits. The results obtained with simulated data suggest that control charts based on linguistic data are significantly more sensitive to process shifts than conventional ***p*** charts are. The computations involved in the construction of control charts for linguistic data can be done by ordinary and fuzzy arithmetic and are not very complex.
Sampling	Alexandru-Mihnea Spiridonica, Marius Pislaru, Romeo-Cristian Ciobanu. (2010)	In this paper, based on some theoretical concepts regarding the statistical process control, we presented a fuzzy approach using the Shewhart charts in order to ensure a better competitiveness for a industrial process. The fuzzy approaches have taken significant amplitude in the last years because these are very close to human language. The main goal of the rules that are presented here is to reduce the variability of a process, the principal cause that determines a big number of scraps. As a future direction and based on this paper contributions, we will try to implement some of the systems independently at a large number of industrial processes.

According to Table 3 and 4, we found the majority of papers based on the statistical fuzzy control chart. In a competitive world, we would like to use economic model for constructing fuzzy control chart when other conditions are satisfied. Also, each of the papers has not any certain reason for choosing triangle or trapezoidal number in special situations.

Some of the papers were about process capability; hence we reviewed these papers individually, and did not mention them in the above tables. Chung-Ho Chen and Chao-Yu Chou (2002) proposed a method based on fuzzy sets and applied it in a study of the process capability index Cpm. Cheng-Che Chen.Chun-Mei Lai · Hsiao-Yu Nien (2010), suggested an analytic method to get fuzzy measures relied on the classical definition of process capability index Cpm. The proposed method can construct the membership function of C_{pm} ˜ for triangular fuzzy numbers. Ihsan Kaya, Cengiz Kahraman (2010) proposed specification limits which have been defined as TFN, and TrFN. Also, the process' variance has been analyzed under fuzzy environment. FPCIs have been obtained by using fuzzy specification limits and standard deviation. The RPCIs are also examined based on fuzzy set theory. Mohammad Abdolshah, Rosnah Mohd. Yusuff , Tang Sai Hong b, Md. Yusof . Ismail. (2011), Aghdas Naimi Sadigh, employed C_{pmk} the α-cuts of the fuzzy observation in order to find the membership function of process capability fuzzy PCI. Ihsan

Kaya ,Cengiz Kahraman, (2011) suggested the fuzzy set theory bringing an advantage to the flexible definition and evaluation has been utilized. The fuzzy values of process mean and variance have been produced by the estimation theory relied on confidence intervals. SLs have also been introduced as TFNs and TrFNs to promote the flexibility of PCA. Kaya Cengiz Kahraman. (2011) proposed, fuzzy PCIs with asymmetric tolerances have been provided by using fuzzy SLs, variance, mean, and target value. The fuzzy formulations of the indices for asymmetric tolerances C_{pk}; C_{pm}; C_{pmk} have been extracted by K.S. Chena, T.W. Chen (2008). This paper evaluated the capability of competing processes relied on distance values in the process capability analysis plot. Abbas Parchami, Mashaallah Mashinchi, Ali Reza Yavari, and Hamid Reza Maleki (2005), proposed the fuzzy process capability indices (PCIs), when the engineering specification limits (SLs) are triangular fuzzy numbers. Also, several relations between them are revealed. Bi-Min Hsu-Ming-Hung shu, (2008) suggested a general method combining the vector of fuzzy numbers to produce the membership function of fuzzy estimator of Taguchi index is introduced for further testing process capability. With the sampling distribution for the precise estimation of C_{pm}, two useful fuzzy inference criteria, the critical value and the fuzzy *P-value*, are proposed to assess the manufacturing process capability based on C_{pm}. The presented methodology takes into consideration a certain degree of imprecision on the sample data and leads to the three-decision rule with the four quadrants decision-making plot.

4. Conclusion

This survey proposes a methodical literature review of the fuzzy control chart studied in 1983–2014. The content-analysis review methodology is used with a new conceptual classification. More articles published in leading scientific journals are analyzed and classified. Some limitations still exist. First, readers should be noted in interpreting the results of this literature survey, because the findings are based on papers published in academic journals. Also, journals that are not well known and some new journals have not been included in this survey since they are not within the scope of our search. In spite of time consuming and energetic work for providing this research, the authors did not claim this paper was exhaustive. We can receive messages from each section of this paper which can help researchers to choose a correct path to continue in this field.

In section 3.1, a new fuzzy control chart category is proposed in Figure 1. It assists followers of this field have a good overview of fuzzy control chart based attribute and variable charts. It assists the followers of this field to have a good overview of fuzzy control chart based on attribute and variable charts. Also, applications of each chart briefly are proposed. In section 3.2, distribution of reviewing articles according to the journal title is indicated in Table 1. Researchers can analyze journals easily based on periods. It is very important to researchers which journals have published the most papers based on periods. For example, between 2001 and 2010, journal of information had published more papers than other journals. In section 3.3**,** case studies related to fuzzy control chart is proposed in Table 2. We can find each of fuzzy control charts where the most used in industry for controlling quality based on Table 2.

Of course, this information was extracted from literature papers. In section 3.4, the percentage of types of fuzzy control chart applied in literature papers are shown in Figure 3. This section assists researchers to find which of the fuzzy control charts were used in literature papers the most. It can help them to research on other fuzzy control charts that were used in the papers less. It can offer new opportunities for researchers. In section 3.5, performance evaluation of fuzzy control chart based on ARL is indicated. For each method, validating is important when we use a fuzzy method for the fuzzified control chart, we should evaluate performance of the new control chart. ARL is a famous index for performance evaluation of control charts. Based on Figures 4 and 5, 59% of papers are without any performance evaluation. It can be a new opportunity for researchers to evaluate the performance of former fuzzy methods to construct a fuzzy control chart and compare methods in order to find which of them the best is. It can be considered for future study. In section 3.6, fuzzy control chart papers content review is proposed in Table 3. It is a very useful section in this paper. Researchers can easily review the content of papers based on author/authors and control chart which has been used in the paper. It prevents rework, and researchers can focus on their favorite field.

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