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Bibliometric Analysis of EWMA and CUSUM Control Chart Schemes

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ABSTRACT

Deployment of statistical quality control (SQC) techniques is imperative to modern businesses. These techniques enable users to monitor and detect any small variability occurred in the business processes. SQC offers; in this regard; two powerful control charting schemes (CCS) which are exponentially weighted moving average (EWMA) and cumulative sum (CUSUM). These CCS are widely applied in different application areas such as manufacturing, services, operations research and management, computer science as well as clinical and surgical processes. In this study a bibliometric analysis is conducted which focuses on the quantitative analysis of published material such as journals, authors, organizations and countries. This paper outlines the research indicators which are reported on CUSUM and EWMA CCS by using the information available at the Web of Science (WOS). The objective of this study is to be informative as well as to highlight the most essential research trends occurring today. The analysis results show that the number of publications on CCS and their citations are consistently and exponentially increasing over the past few years. The data also reveals that Woodall WH is the most influential and active author whereas Quality and Reliability Engineering International Journal is the most influential journal. USA and China are prominent countries in this field. Additionally, the bibliographic mapping represents the links and relations among the co-authors, co-citation authors and their partnering institutions working together in the research field.

Keywords: *Cumulative Sum (CUSUM), Exponentially Weighted Moving Average (EWMA), Control chart schemes, Bibliometric analysis*

1. INTRODUCTION

Statistical quality control is well-established discipline which is commonly applied in industry to monitor critical to quality characteristics for their any un-controllable situations. The most dominant method in the quality control is the statistical control charts. Since their induction in 1924 by Walter Shewhart [1], these charts had been widely applied to control process variation and to detect any change during World War II industrial processes and has been employed with various modifications, ever since. Control charts in SPC are very popular and effective tools used for monitoring process variation over time in manufacturing industries and services
Since their introduction; control schemes have been widely applied in many applications in improving the quality of business processes. There are several control charting schemes being applied in business processes. Determination and selection of an appropriate control charting scheme depends on the process data types. For instance; $\bar{X}R$ and $\bar{X}S$ schemes are used for continuous data depending upon the sub-group size. Whereas *p*, *np*, *c* and *u* types control charts schemes are commonly used when quality characteristics being monitored follows attribute data. However; it is worth to mention that these control shames only monitor process variability if any special cause or assignable cause occur in the process which causes a large shift (more than 1.5σ shift) in the process mean. However, if there is a small to moderate shifts (less than the 1.5σ) occur in the process, then conventional Shewhart control schemes fail to detect these small shifts and one has to apply time weighted control chart schemes to detect small shifts in the process means. Due to their capability to detect any small changes in the real business processes; time weighted control charts namely Cumulative Sum (CUSUM) and Exponentially Weighted Moving Average (EWMA) are getting more attractiveness in different business areas such as clinical, computer networks wireless data and Industrial Internet of Things (IIOT) big data for detection of any small changes. Application of these process monitoring schemes is even getting more attention from researchers in different areas such as operations research and machine learning which they apply these SPC schemes to detect any faults in different computation algorithms schemes and compare their performances using EWMA and Multivariate EWMA control schemes [2]. Furthermore; applications of these control schemes have spread to finance, medicine, biology and reliability as well [3-7]

Exponentially weighted moving average (EWMA) control scheme was firstly introduced by Roberts in 1959 [8]. By using simulation techniques to evaluate its properties, Robert was able to demonstrate that the EWMA is valuable method to detect small shifts in the mean of a process. The recognition of which is that EWMA control scheme can be characterized as a Markov chain which allows its properties to be evaluated more easily and completely than before. Although in the past; the EWMA is known to have optimal properties in some quality control applications [9-10], it was largely neglected as a powerful technique to detect small shifts in the manufacturing processes by the quality control analysts.

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However; recently these time weighted control schemes (EWMA and CUSUM) [11] has been examined and explored for their properties analytically [12-14]

Many research studies have been conducted to compare the performance of univariate as well as multivariate EWMA and CUSUM charts and it is found that both perform approximately equally good [15–16] . However; some studies have shown that former is often superior to the latter for detecting larger shift [17-20]. However, the use of a single EWMA control chart is efficient in detecting small changes in process shifts but relatively less efficient when the changes are large due to inertia problem [21-22].

In this research study, a bibliometric analysis is conducted which analyzes and reviews publications, citations and their sources of information. The main advantage of a bibliometric analysis is that it provides a general picture and overview of a research area. In the literature, many studies have provided a general bibliometric overview of specific research fields [23-25], however, with the best of our knowledge no such study is found for the EWMA and CUSUM control charts.

The aim of this research study is to present a bibliometric synopsis of research growth in these two important statistical quality control charting schemes; namely CUSUM and EWMA over a period of approximately 40 years. The objective is to show the significance of the research area and its exponential growth to the scientific community with the information found in the WOS.

The paper is organized as follows. Section 2 describes the methodology to be used. Section 3 presents the publications data analytics and results discussions for the most influential journals, authors, trend analysis of application areas and the most cited articles of all time in CUSUM and EWMA research, and Section 4 presents the graphical mapping for co-authorships among organizations and countries. Section 5 discusses the main conclusions of the paper.

2. METHODOLOGY

Data analytics is a critical disciple which provides an important and useful information from the given set of data to decision makers. Due to this; it is vital for an analyst to select appropriate tools and methods to conduct an analysis of the given set of data. This research study has collected data available from the Web of Science Core Collection (WOS), which is an online subscription-based scientific citation indexing service that provides a comprehensive citation search. WOS which incorporates several databases and it covers research from most of the well-known scientific resources including more than 15 thousand journals and 55 million articles. WOS was formerly owned by Thomson Reuters; currently being owned by Clarivate Analytics. Other databases such as Scopus and Google Scholar also provide a wide range of research articles. However, they are not included in this research study.

In this analysis, WOS is used to search all research papers on current research study. Keywords included in this search under the title of "topic "are; exponentially weighted moving average, EWMA, Multivariate exponentially weighted moving average, MEWMA, Cumulative sum, CUSUM, Multivariate control charts, multivariate statistical process monitoring. Although WOS contains fifteen different types of publications; however, this study focus is only to conduct bibliometric analysis for the publication types which includes articles, proceedings paper and review articles in English language which reduce the total numbers of publications found from 4158 to 4107 from 1964 to 2017.

VOS Viewer software is also used to do graphical representation of organizations and countries which has contributed as co-authors in their research studies. VOS Viewer is a software tool for constructing and visualizing bibliometric networks.

3. DATA ANALYSIS AND RESULTS DISCUSSIONS

Data from Web of Science core collection is retrieved in February 2018 and a bibliometric analysis has been conducted and presented in the subsequent sections.

3.1. PUBLICATION ANALYSIS

CUSUM & EWMA research is attaining more and more attention in the last few years by researchers, which is strongly illustrated by yearly increase in the number of publications as shown in Figure 1. Undoubtedly; there is an increase in the number of researchers involved in the research area as well as WOS has also included many more journals in the last few years.

According to WOS records (Figure 1); after 2007 more than 100 articles are published each year in the field, and the number of published articles reached more than 350 articles since 2015. After analyzing the total number of publications (forty-seven years data) since the very first article published and recorded in WOS in1964; overall publications growth model follows $y = 0.7079e^{0.1391x}$.

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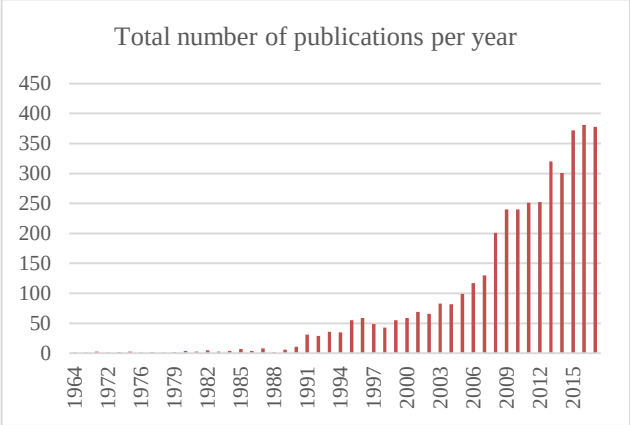

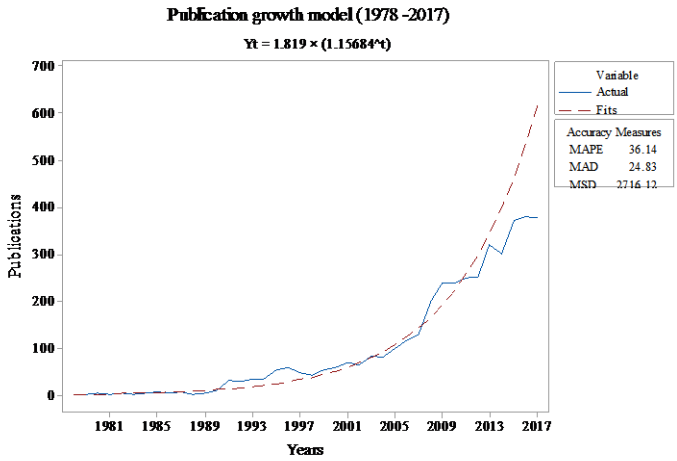

Figure 1: Total number of publications per year since 1964

3.2. CUSUM AND EWMA RESEARCH TRENDS ANALYSIS

From Figure 1, it is very clear that in the early period of 14 years (1964-1977); there is not much attention paid by researchers to these two control chart schemes and only few publications appeared in the literature. However, after 1978 onward, a regular increase on a continuous basis has been recorded. In the last 40 years (1978 – 2017); there is a strong indication of high level of interest by researchers and industry practitioners in the application of CUSUM & EWMA control charts with an exponential growth of publications $y = 1.819e^{1.15684x}$ and presented in a trend chart in Figure 2.

In order to understand a gradual increase whether it follows linear or exponential, the total timespan of 40 years is divided further into a period of 10 years as presented in Table 1.

Furthermore; Figure 3 provides trend analysis based on 10 years' periods. It is interesting to note that trend analysis for the first two periods illustrates a linear growth and there is not much literature published during the first 2 decades. However; in the last 2 periods (1998 -2017) there is a strong exponential growth recorded which follows a growth model as $y = 40.9695e^{1.11916x}$ and $y = 192.995e^{1.07475x}$ respectively

Table 1. Total published articles per year for a period of 40 years

Year (1978-87)	TP	Year (1988-97)	TP	Year (1998-2007)	TP	Year (2008-2017)	TP
1978	1	1988	2	1998	43	2008	201
1979	2	1989	6	1999	55	2009	240
1980	4	1990	11	2000	59	2010	240
1981	3	1991	31	2001	69	2011	251
1982	5	1992	29	2002	66	2012	252
1983	3	1993	36	2003	83	2013	320
1984	4	1994	35	2004	82	2014	301
1985	7	1995	55	2005	99	2015	372
1986	4	1996	59	2006	117	2016	381
1987	8	1997	49	2007	130	2017	378

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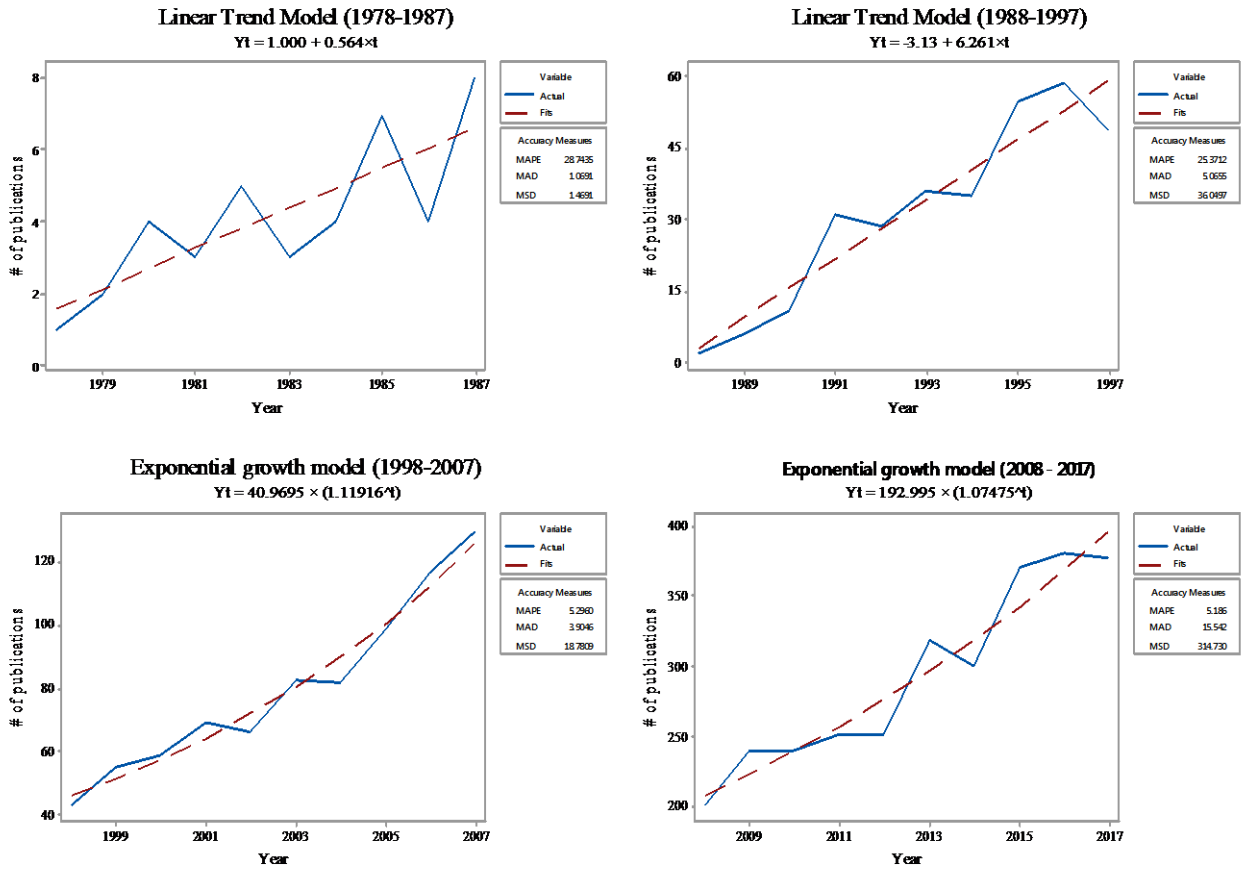

Figure 3: Trend analysis for different time intervals

3.3. CUSUM & EWMA APPLICATION AREAS TREND ANALYSIS

Research areas of these articles has been analyzed and the results illustrates that most of these articles belong to Engineering, Mathematics, Operations Research and computer sciences research areas. Figure 4 shows a trend analysis of CUSUM & EWMA articles classified by research area. Most of the articles are published in the last ten years. Also Figure 4 indicates that a new area such as Business economics, medical sciences such as surgery and telecommunications are also attaining attraction of these control charts schemes for monitoring their business processes.

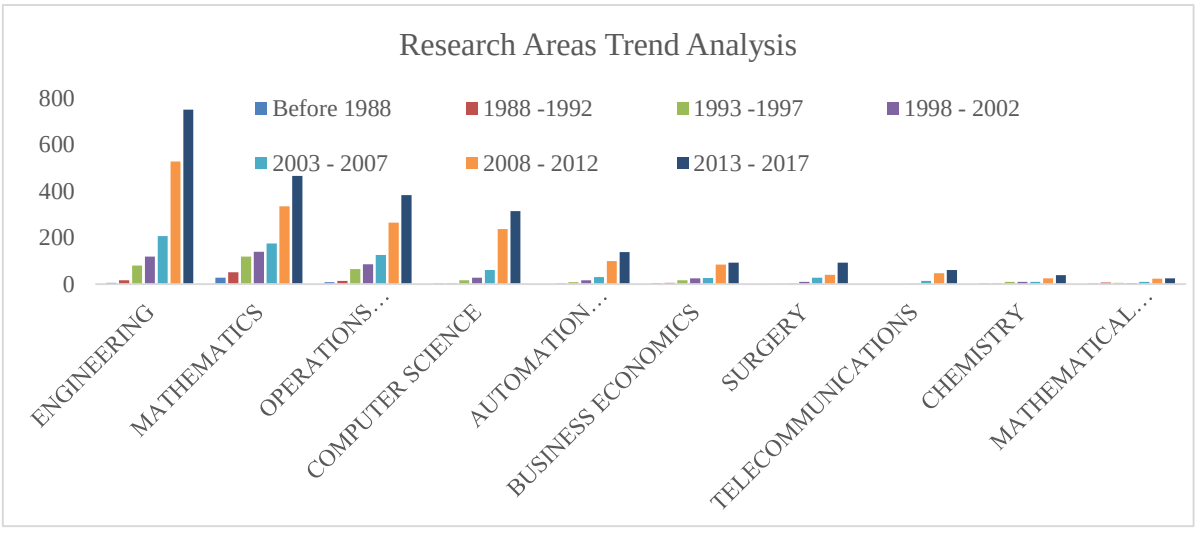

Figure 4 Research areas trend analysis

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3.4. EWMA & CUSUM YEARLY PUBLICATION'S COMPARISON

In this section we will present comparison between these two important control charts schemes and see whether the difference is statistically significant or not. Which control scheme is more active than the other? Analyzing yearly publications data; Actually CUSUM charts is older than the EWMA, and the author claim that CUSUM is still more active by the number of articles published over the last thirty years. In this regards; all the articles from WOS are collected from 1990-2017 related to both charts and presented in Table 2. A time series plot for a visual comparison is depicted in Figure 5. It's worth noting that CUSUM is always exceeding EWMA over the period of all the years.

Although the difference is not much clear to conclude that the CUSUM articles are published significantly more than EWMA articles. To determine this fact; a 2 sample t-test is conducted and the p-value is calculated. Since the P-value of the test is 0.246 > 0.05, we fail to reject the null hypothesis and conclude that there is no significant difference between the yearly publication of EWMA & CUSUM chart articles. Figure 5 also illustrates that exponential growth for both charts is almost same over the selected period.

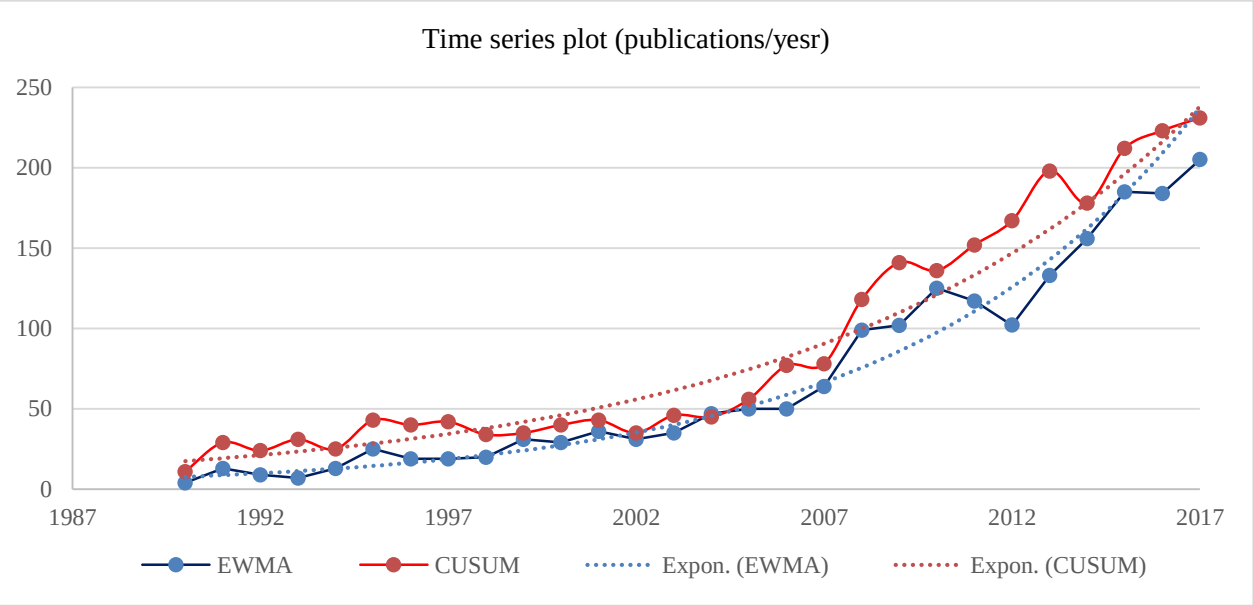

Figure 5: Total publications comparison

3.5. INFLUENTIAL JOURNALS

Number of international journals publishing in the area of statistical quality control have increased over time. The top most 10 influential journals are shown in Table 2. These journals are ranked by the total number of publications published in the area of statistical control charts.

According to total number of publication criterion; Quality and Reliability Engineering International is the leading journal whereas based on H-index criterion; Journal of Quality Technology stands first. Also; the same journal "JQT" is leading for receiving high number of citations for its published articles followed by Technometrics journal. Although Computers Industrial Engineering is ranked at 9th; however; it has obtained the highest impact factor among selected ten most influential journals. Trend analysis for journals publishing in the area of control charts is presented in Figure 6. It is worth mentioning that the number of publication in the last ten years are intensified significantly.

Table 2. Most influential journals in CUSUM & EWMA research

R	Name	Control Charts publications							IF	All Publications		
		H	TC	TP	%TP	>100	>50	>20		TP	TC	H
1	QREI	28	3040	299	14.42	2	1	41	1.366	2,073	14786	40
2	JQT	54	9759	190	13.15	32	27	47	1.833	1,445	34916	89
3	CSSC	20	1035	119	3.20	0	1	17	0.457	3,715	17376	44
4	IJPR	22	1434	101	1.09	0	6	18	2.325	9,231	142783	109
5	CSTM	16	744	93	1.01	0	3	7	0.311	9,202	42060	63
6	IT	29	2301	92	3.46	1	8	31	1.451	2657	50220	84
7	T	38	4322	76	1.96	10	19	15	1.543	3879	119427	144
8	IJAM	13	584	73	0.56	0	0	8	2.209	13,143	116810	73
9	CIE	16	738	63	0.96	0	2	8	2.623	6,556	71340	88
10	JSCS	13	460	62	2.06	0	1	4	0.757	3,016	15951	41

Abbreviations: R: Journal Rank; H: H-index only in control charts, TC and TP: total citations and total publications, %TP: percentage of CUSUM & EWMA articles in the journal, >100, >50, >20, number of papers with more than 100, 50 and 20 citations respectively; TP and TC, total papers and citations; IF, impact factor 2016; QREI: Quality and Reliability Engineering International, JQT: Journal of Quality Technology, CSSC: Communications in Statistics Simulation and Computation, IJPR: International Journal of Production Research, CSTM: Communications in Statistics Theory and Methods, IT: IIE Transactions, T: Technometrics, IJAM: International Journal of Advanced Manufacturing Technology, CIE: Computers Industrial Engineering, JSCS: Journal of Statistical Computation and Simulation.

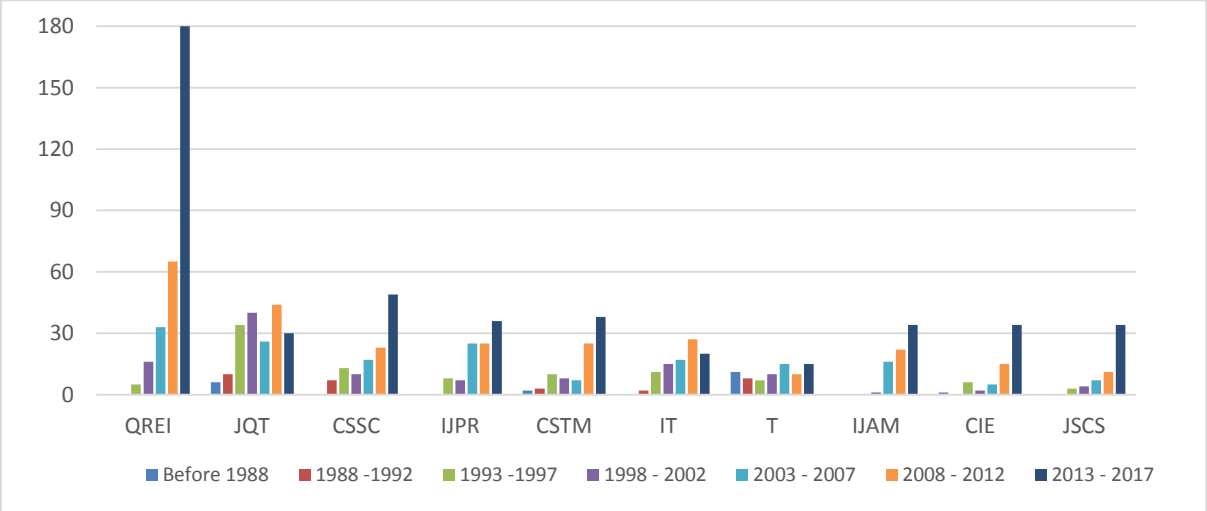

Figure 6: Trend analysis for Journals

3.6. MOST INFLUENTIAL ARTICLES

The most influential articles are classified according to the number of citations received by articles. The paper with more citations is more popular among the researcher's community and hence given high ranked in the classification list as presented in Table 3.

The most cited article has been reported by Macgregor and Kourti in 1995 followed by Lowry et al. published in 1992.

Table 3: Most influential articles

R	J	TC	Author/s	C/Y
1	CEP	556	MACGREGOR, JF; KOURTI, T	25.27
2	AS	531	Tekkis, PP; Senagore, AJ; Delaney, CP; et al.	44.25
3	T	524	LOWRY, CA; WOODALL, WH; CHAMP, CW; et al.	20.96
4	B	453	BROOK, D; EVANS, DA	10.07
5	AJ	413	Bakshi, BR	21.74
6	JQT	372	Kourti, T; MacGregor, JF	17.71
7	JQT	349	MONTGOMERY, DC; MASTRANGELO, CM	13.42
8	IT	341	LOWRY, CA; MONTGOMERY, DC	15.50
9	JQT	290	RACY, ND; YOUNG, JC; MASON, RL	11.60
10	T	271	LUCAS, JM; CROSIER, RB	7.74

3.7. THE MOST INFLUENTIAL AUTHORS

Many authors have made significant contributions in the statistical quality control charts research. Table 4 depicts the top 10 authors with highest number of publications in the subject area. The number of papers are an indicative factor only. Number of other factors should be considering such as article size, number of co-authorships and the rank of the journal and impact factor in the subject area.

Table 4: The most influential authors

R	Name	Country	Control charts			All areas		
			TP	TC	H	TP	TC	H
1	WOODALL WH	USA	80	3599	30	163	6384	40
2	WU Z	SINGAPORE	78	1268	20	104	1744	23
3	KHOO MBC	MALAYSIA	75	599	14	120	864	18
4	RIAZ M	SAUDI ARABIA	60	442	14	95	842	19
5	CASTAGLIOLA P	FRANCE	52	614	16	112	970	19
6	REYNOLDS MR	USA	52	2143	27	96	3326	34
7	JIANG W	PEOPLES R CHINA	39	621	16	39	621	16
8	NIAKI STA	IRAN	38	341	11	185	1897	25
9	TSUNG F	PEOPLES R CHINA	36	679	16	186	6125	37
10	ZOU CL	PEOPLES R CHINA	36	689	15	371	4304	32

From Table 4, Woodall WH from USA stands first in rank with highest number of publications (80 articles), followed by 2nd and 3rd in a row are Wu Z from Singapore and Khoo MBC from Malaysia. Riaz M from Saudi Arabia ranked at 4th level has published 60 articles in the statistical control charts research area. Moreover, some other authors who are not in the top 3 positions of the most productive and influential authors, but they have received a large volume of citations such as Reynolds MR at 6th position got more than 2100 citations.

4. RESEARCH NETWORKS GRAPHICAL ANALYSIS

The graphical representation of the EWMA and CUSUM research articles is also conducted in this current research study. These graphical representations provide a visualization of the common work and occurrence of authors, organizations, and documents [26]. Figure 7 - 8 has been generated by using the VOS viewer software that links with the web of science to enable the visual image of the collected bibliographic data regarding the co-authorship, co-occurrence, citation, bibliographic coupling and co-citation analysis.

In the Figure 7 and Figure 8, the circles are representing the set (for example the organizations, countries or authors), bigger the circle is bigger the association is among the partners. The line between a two sets is representing the repetitions of co-authorship or co-occurrence between them, which called the link strength (for example, in co-authorship analysis, if the link

strength between two organizations is 10, then the two universities exist in together in 10 articles in the field of study), so the thickest the line is strongest the relation is indicated in this graphical representation [27].

4.1. CO-AUTHORSHIP GRAPHICAL ANALYSIS BETWEEN ORGANIZATIONS

Co-authorship mapping shows the volume of publications by organizations and how they are connected with each other. In this section, the co-authorship between organizations is shown in Figure 7. Table 5 shows that among all organizations publishing in the current study. University Sains Malaysia has the strongest co-authorship (133) co-authorships) with other organizations, and the most co-authorship are with Nanyang Technology University, which comes in the third position with 99 total links strength of co-authorships.

Table 5: The most 10 co-authorships organizations

Rank	organization	publications	citations	total link strength
1	Univ Sains Malaysia	81	608	133
2	Univ Nantes	53	618	123
3	Nanyang Technol Univ	85	1460	99
4	Hong Kong Univ Sci & Technol	68	1197	76
5	City Univ Hong Kong	47	194	71
6	Irccyn Umr Cnrs 6597	26	317	69
7	Nankai Univ	64	1168	67
8	King Fahd Univ Petr & Minerals	53	309	61
9	Shanghai Jiao Tong Univ	46	412	59
10	Univ Macau	35	361	56

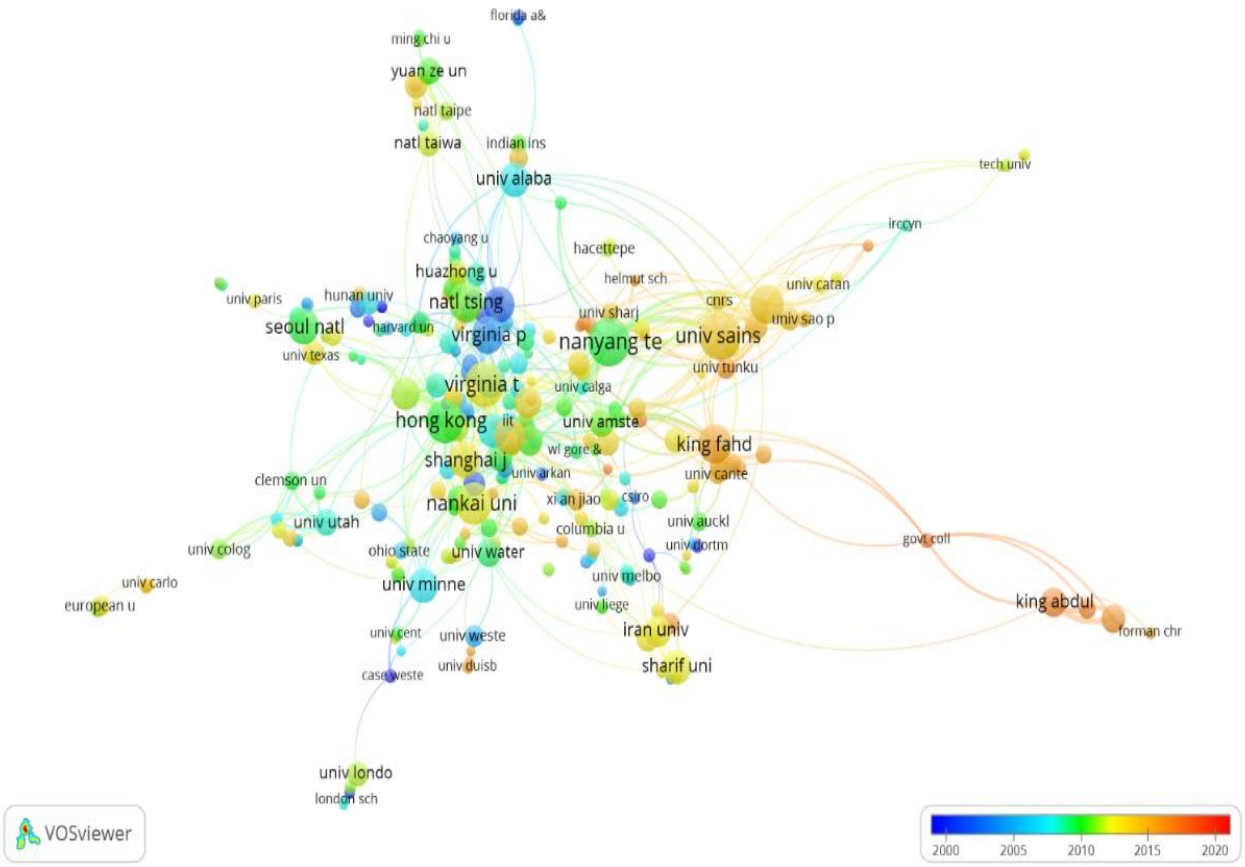

Figure 7: Co-authorship among organizations

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4.2. CO-AUTHORSHIP GRAPHICAL ANALYSIS BETWEEN COUNTRIES

Regarding the co-authorship between countries in the current study Figure 8 shows that the USA has the greatest co-authorship among all other countries. Table 6 depicts that USA obtains 487 times (total link strength) with other countries in 1111 published articles in this field of study. In Figure 8; it is evident that China is the most active partner of USA having 94 articles co-authorship relations together.

Table 6 : The most 10 co-authorships Countries

Rank	country	publications	citations	total link strength
1	USA	1111	24877	487
2	Peoples R China	645	5698	265
3	France	189	2061	164
4	Saudi Arabia	122	613	164
5	Singapore	143	2223	131
6	South Korea	213	2105	126
7	Pakistan	86	571	120
8	England	223	4176	118
9	Canada	181	2907	113
10	Malaysia	133	919	112

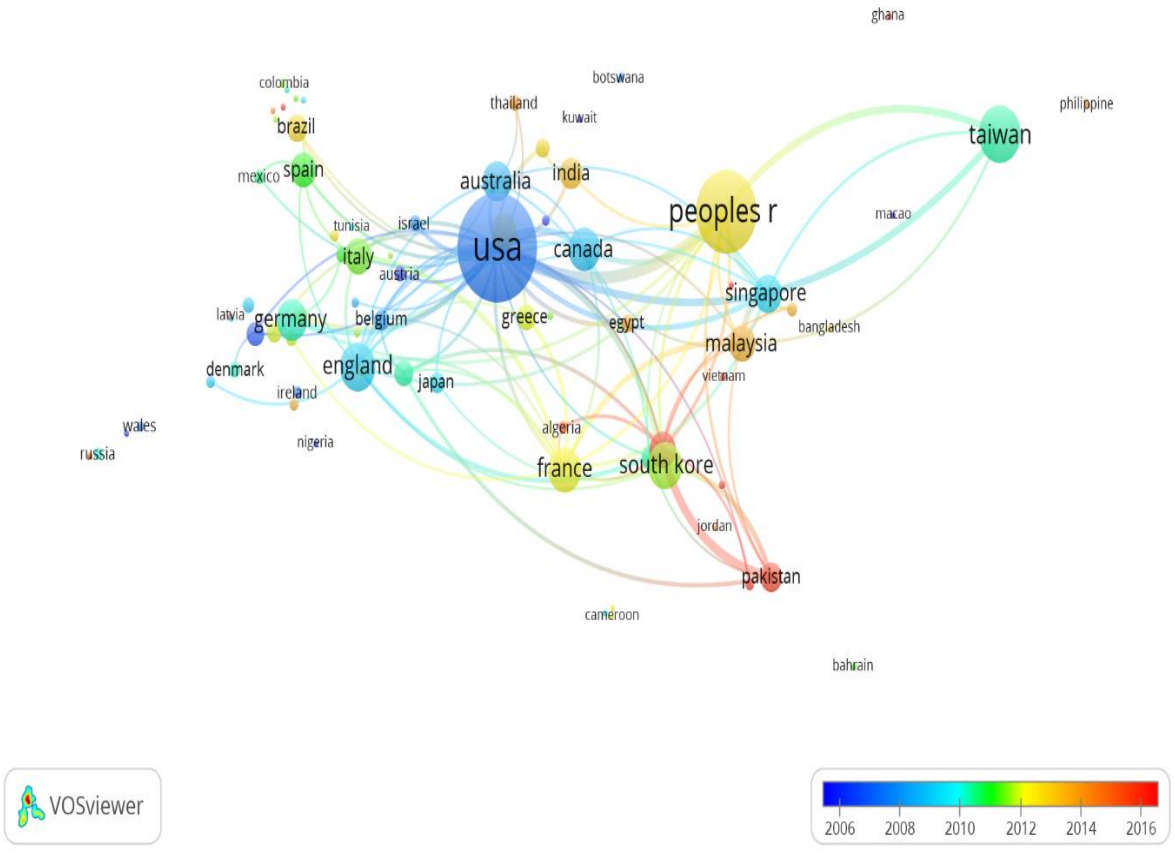

Figure 8: Co-authorship among countries

5. CONCLUSIONS

The study shows that the CUSUM and EWMA has become one of the widely researched topic due to its many useful applications in manufacturing and service businesses. The current paper discussed a bibliometric overview of topic. The main objective of this study is to highlight research trends as well as its exponential growth in the past few years. The study has reported that researcher's community has shown a significant interest in the topic due to its power of detecting small variability if occurred in the business processes. A trend analysis of the application areas in the field of study has revealed its growth to new business areas such as computer sciences and healthcare systems. The data also indicates that Woodall WH is the most influential and active author followed by some other main leaders in this field are Wu Z, Khoo MBC and Riaz M. The two most influential journals are the Quality and Reliability Engineering International Journal and Journal of Quality Technology and the most influential country is the USA followed by China in this research field.

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