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M Pradeep Kumar
Assistant Professor, Department of Mechanical Engineering, Kamala Institute of Technology and Science – Karimnagar, Telangana, India

P Sahithi
B. Tech Student, Department of Electronics and Communication Engineering, Kamala Institute of Technology and Science – Karimnagar, Telangana, India

S Sai Revanth
B. Tech Student, Department of Civil Engineering, Kamala Institute of Technology and Science– Karimnagar, Telangana, India

Correspondence
M Pradeep Kumar
Assistant Professor, Department of Mechanical Engineering, Kamala Institute of Technology and Science – Karimnagar, Telangana, India

Industry of quality (IoQ) – An industry 4.0 perspective

M Pradeep Kumar, P Sahithi and S Sai Revanth

Abstract
The market scenario and product life cycle has been changing from year to year. Few decades ago, the variety of products available in the market for the customers is very low. Now, the situation has become reverse where multiple options are available for the customer for a single product. At this instant it becomes very difficult for the customer to choose and buy a product. However, any customer will think of a product with high quality and low cost. With this baseline; industries materialize efforts to manufacture a product of good quality with reasonable cost. With the evolution of concept of CoQ, industries able to measure the costs expended to produce a quality product. In this paper, initially a critical review on CoQ has made to notify the areas and contributions worldwide. Manufacturing sector has found to be the most applicable sector of CoQ concept. The latest developments in the manufacturing sector making the industries to compete with the present global situations. Fourth industrial revolution i.e, industry 4.0 is the current trend of industries where machine to machine interaction is possible with low man power. At this situation, quality is also an important factor to be considered. The objective of this paper is to cover the concept of CoQ, its evolution, background and models through a bibliometric analysis. This paper also aims to coin a new concept Industry of Quality (IoQ) in relation with Industry 4.0 and cost of quality.

Keywords: Industry 4.0, quality, cost of quality, industry of quality

Introduction
As per ISO 9000, Quality is the totality of features and characteristics of a product or service or information that can bear upon its ability to satisfy the stated or implied needs of the customer [1]. Cost of quality is a quality management tool that focuses attention on areas requiring corrective action. Operations managers and quality managers use the data of cost of quality to enhance manpower efficiency, reduce rework/scrap, enhance the company repute, reduce equipment down time, and other processing constraints, and so on, and, ultimately to improve customer satisfaction [2]. Every organization should be aware of cost of quality so that there will be continuous improvement in the product quality and proper steps are planned in designing and manufacturing process of a product.
Industry 4.0 is the next phase in a digitization of the manufacturing sector where the Internet of Things (IoT) and cyber physical system in combination with software, sensor, processor and communication technology looks to play a huge role [3]. Industry 4.0 ultimately aims to construct an open, smart manufacturing platform for industrial-networked information applications. In this paper, a critical review and bibliometric analysis on cost of quality has been carried out. Further, industry 4.0 which is coined by the German's has been introduced and explained in the backdrop of quality management.

Cost of quality: History and concept
It was Joseph Juran who first discussed the cost of quality analysis in 1951 in the first edition of "Quality Control Handbook". And it was Armand Feigenbaum who identified four quality cost categories in 1956 in "Total Quality Control" in the Harvard Business Review, Vol. 34. The Quality Cost Committee was established by then ASQC in 1961.
The "cost of quality" is not "the cost of producing a quality product." But in fact, it is the cost of "not producing a quality product." This means, the quality will cost, if you do not produce the quality. If the work is redone, the cost of quality increases. The cost of quality service and the cost if there were no failures during manufacture or use and no possibility of failures. The cost of quality can be classified as cost of conformance and cost of non-

conformance. Cost of Non-conformance is the cost incurred as a result of not doing things right the first time. Internal failure cost and external failure cost are the result of non-conformance requirements. On the other hand, Cost of conformance is the cost incurred in ensuring that things are done right the first time. Prevention costs and Appraisal costs are the cost of conforming to the stated requirements

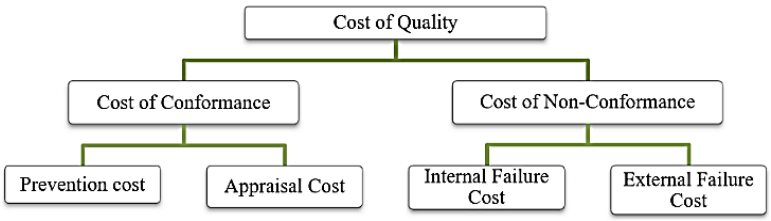

Fig 1: Classification of Cost of quality

Table 1: quality costs for various sectors

	Health care organizations	**Supply chain**	**Manufacturing**
Prevention cost	▪ Salaries and benefits for staff ▪ Training ▪ Quality planning ▪ Preventive maintenance contracts for equipments ▪ Office supplies for documentation and annual	▪ Recruiting ▪ Training ▪ Auditing ▪ Supplier certification ▪ Supplier assurance defects ▪ Redesign ▪ Rework ▪ Reinspection of reworking ▪ Retesting and Scrap	▪ Quality planning ▪ Training ▪ Design review ▪ Design, development and installation of quality measurement and test equipment ▪ Quality improvement programs and quality engineering
Appraisal cost	▪ Quality control ▪ Verification ▪ Supplier rating ▪ Quality audits ▪ External Quality Assurance (EQA) surveys	▪ Inspection of material ▪ Prototype inspection ▪ Quality auditing ▪ Outgoing inspection ▪ Equipmenttests &calibration. ▪ Productioncontrol.	▪ Quality inspection ▪ Product testing ▪ Performing audits to meet quality standards ▪ Equipment used for quality appraisal ▪ Worker time spent on measuring quality
Internal failure Cost	▪ Wastes at inventory level ▪ Reeducating staff. ▪ Repeat ion of tests ▪ Data entry errors	▪ Downtime caused	▪ Identify faulty good ▪ Reworking of defective units ▪ Downtime caused by quality problem ▪ Waste due to poorly designed processes ▪ Costs associated with failure analysis
External failure cost	▪ Warranty expenses ▪ Complaints ▪ Delay in reporting test results to clients	▪ Downtime caused	▪ Liabilities from legal actions/penalties ▪ Repairs and Replacements ▪ Loss of goodwill ▪ Lost business ▪ Loss of market share ▪ Product recall ▪ Warranty work

Benefits of CoQ

There are certain elements that vary with the application and successful implementation of cost of quality. If an organization is able to apply and implement the CoQ, then the market share, reputation, profits, etc. will be increased. On the other hand, defective products, customer complaints etc. will get reduced on successful implementation of CoQ. The various factors that increase and decrease are listed a pictorial form in the figure 2.

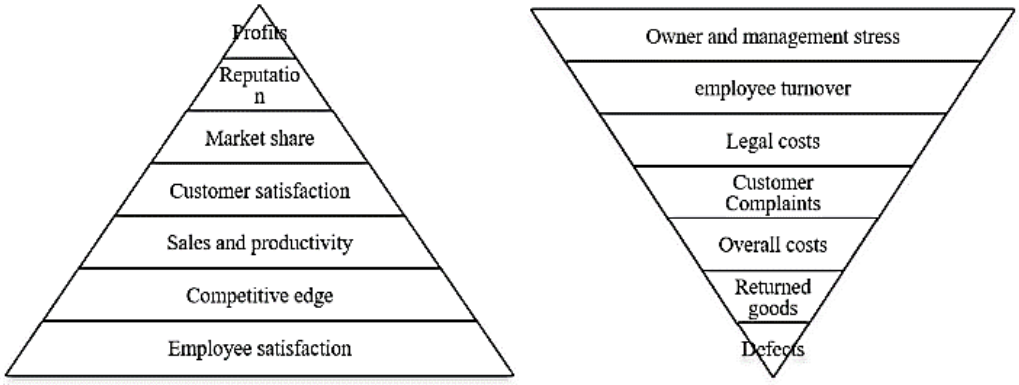

Fig 2: The increasing and decreasing factors on implementing CoQ

Methodology and data source

The analysis is based on the publications related to cost of quality during the years 2016, 2017, 2018 and 2019. For the purpose of the literature, Google scholar data base were used with a key word "cost of quality". Nearly about 145 journals were collected and articles originated from various countries and journals were analyzed.

Table 2: No. of Articles Collected

S. No.	Year	No. of Articles
1	2019	34
2	2018	43
3	2017	36
4	2016	32
	Total	145

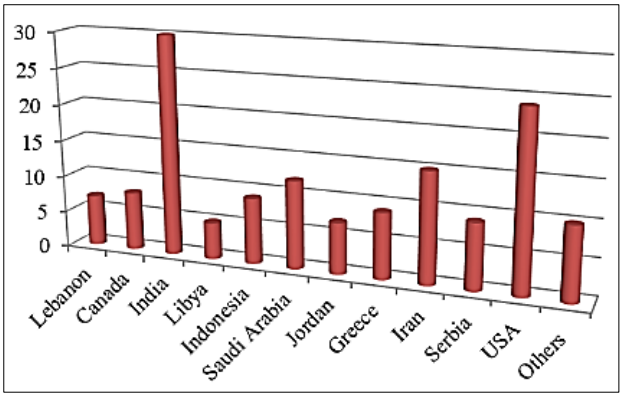

Fig 3: Country wise publication statistics

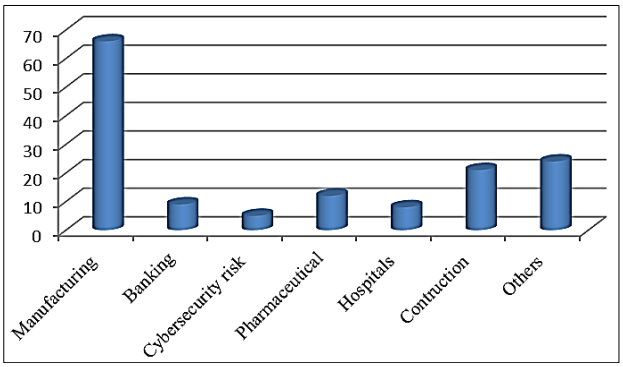

Figure 4 Area wise publication statistics

Review of literature

Modhiya *et al.* [4] conducted a review on cost of quality methods in manufacturing industry and analyzed different cost of quality approaches and reports of the success to provide good understanding of COQ methods. Authors explained the cost items involved in hidden costs as defined by various researchers. Further, they have studied the techniques used in measuring CoQ and their respective outcome. Arsalan Farooq *et al.* [5] have analyzed COQ tradeoffs for inspecting a product. The five stepmethodology has been developed for improving quality of manufacturing systems. Authors successfully developed and discussed cost of quality model for the consumer goods industry that is facing a strong challenge to improve its product quality. Ali Uyar [6] carried out a study to evaluate the performance of an organization after the implementation of CoQ. Paper shows that there is a positive association between COQ-system implementation and sales turnover, and a weak positive association between COQ-system implementation and ISO certification ownership and number of employees. Marie Cermakova *et al.* [7] explained how to decrease the cost on non-conformities by applying quality tools and cost of quality models. They estimated prevention, appraisal and failure costs spent on defects. Following necessary actions may considerably minimize the non-conformance cost. Saleh A. Alsaid *et al.* [8] in a paperfocused the importance of evaluating and reporting the COQ within manufacturing plant to diagnose the quality problems. They found that the TS-4 plant managed to achieve in reduction of internal failure costs by investigating more costs in prevention and appraisal activities. The study revealed that increase in prevention and appraisal costs had contributed to increase sales and decrease ratio of total cost of quality to total sales revenue. Nicole Radziwill *et al.* [9] carried out a study to develop standards for measuring and controlling the costs requiredfor implementing cybersecurity programs. They have developed a mapping using costs of quality and the Framework Core within the cybersecurity framework produced by the National Institute of Standards and Technology. This mapping can be used by organizations that are already using the NIST CSF for cybersecurity risk management to plan, manage, and continually improve cybersecurity operations. Sanaa Maswadeh *et al.* [10] have analyzed the importance of costs of quality, cost associated and deficiencies related to it. The author reported the deficiencies in prevention cost elements is due to mismatch in production specifications, the cost spent to get a good product is deficiencyof appraisal costs, the cost used to transfer a defective product to a defect free one is the deficiency of internal failure costs and the cost spent to estimate decrease in market share is deficiencyof external failure costs. Finally the author recommended that there should be continuous proper planning system. Behnam Neyestani *et al.* [11] have analyzed the impact of ISO 9001 Standard on the Quality Cost. It is seen that among different methods, quality cost analysis is an excellent technique to indicate how much ISO 9001 is able to improve effectively quality performance, and reduce costs. The results reported that ISO 9001 standard significantly affects the reduction of quality cost within construction projects. Peter E. D. Love *et al.* [12] have Conducted a case study on quality failure cost in construction field to reinvigorate the failure costs. A data of quality failure costs in the form of non conformances cost related to 218 construction sites was gathered. 16,000 non conformances which were recorded by the contractors from 218 sites have been recorded and analysed as per the project type. The study revealed that the contractor and subcontractor were required to bear the rectification cost of non conformances. Hussein Reda *et al.* [13] conducted a survey which is intended to assess the level of awareness and quantitative estimates of quality costs as related to the plastic and glass industries. It is concluded that technicians require more training on how to reduce waste and increase productivity. Further, these firms have to keeping periodic maintenance tables and machine breakdown records. Lamiaa Ayach [14] presented a case study which is conducted in a cement industry in order to provide awareness and guidance to top management. Author stated that quality related costs are systematically reduced through the continuous improvement activities which have been implemented. A Pareto analysis was carried out to determine critical quality costs. It has been found that

breakdowns, downgrading and inspection are most prominent factors which are to be reduced understanding root causes and setting up remedial solutions. Malak Aoun *et al.* [15] carried out a study to integrate different quality improvement models such as lean and cost of quality to identify the wastes resulted from the cost of poor quality and spot the opportunities for improving the cost of good quality. The study revealed that providing lean and COQ trainings to accounting staff and facilitating the accessibility of quality assurance team to ledger would help to fill the information gap and build a direct linkage to enhance the hospitals' financials.

Industry 4.0

Industry 4.0 is a new revolution which brought up a wide change in industrial sector. This revolution is involved with internet of things, cyber physical systems and cloud computing. In this technology the machines are automated and connected with one another to make decisions without man power. This makes machines self-automated, self-optimise and self –observance into the industry. This technology increases the productivity and reduces the consumption of resources and further makes digitisation. Industry 4.0 creates opportunity for manufacturers to optimize their operations quickly and efficiently by knowing what needs attention.

The advantages of industry 4.0 is it can transfer data from an industrial system to other industrial systems, devices or other platforms, and it can store the data of an industrial system in the database, use the stored data in the industrial system again and further combine the data of industrial systems in a complex event processing engine so that they can provide data analysis possibilities and complex decision making scenarios that cannot be reached on the industrial system. The overview of four industrial revolutions is shown in table 3.

Table 3: Brief overview of four industrial revolutions

	Industry 1.0	**Industry 2.0**	**Industry 3.0**	**Industry 4.0**
Started in	18th century	19th century	Mid 20th century	21st century
Enabling technology	Steam power	Electricity	Information and communication technology (ICTs), Electronics	Cyber physical systems, Internet of things (IoT), networks
Production	Mechanical production	Mass production	Automation and networked production	Intelligent, flexible, distributed production
Quality	Quality 1.0 Self-inspection	Quality 2.0 Inspection / control / assurance / military standards	Quality 3.0 Software for QMS, improvement and planning	Quality 4.0 Continuous quality with real-time data and IoT

Internet of things

Internet of Things (IoT) is one technology involved in industry 4.0, which is responsible for digital transformation of organisations, cities and society. IoT is a system of interrelated computing devices, mechanical and digital machines, objects, animals or people that are provided with unique identifiers and the ability to transfer data over a network without requiring human-to-human or human-to-computer interaction. It saves money and time by transferring data and improves communication between electronic devices.

IoT provides businesses with a real-time look into how their systems really work, delivering insights into everything from the performance of machines to supply chain and logistics operations. IoT enables companies to automate processes and reduce labour costs. It also reduces waste and improves service delivery, making it less expensive to manufacture and deliver goods, as well as offering transparency into customer transactions.

Cyber physical systems

A cyber-physical system (CPS) is a system designed to control or monitor a mechanism by computer-based algorithms. With the use of the CPS, physical data with sensors can be collected and can influence physical processes with actuators. CPS can be connected via digital communication with other devices and global networks (wireless and / or wired, local and / or global). Examples of CPS may include industrial control systems, smart grid, medical monitoring, autonomous automobile etc.,

Industry of quality (IoQ): A new dimension for overall quality

In the first half of this paper, the concept of CoQ and bibliometric analysis was shown. From the literature analysis, it is observed that the concept of CoQ is prominently used in manufacturing sector rather than service. It is also seen that the cost of quality has a great impact on the product cost and overall customer satisfaction. As described in the previous sections, cost of quality can be classified as cost of conformance and cost of non conformance. As a company spends amount on conformance activities it may reduce costs incurred on non conformance activities. This can be achieved up to a certain limit beyond which the product cost will increase predominantly. Also, the quality of a product and cost of a product are two significant factors which mainly depend on workers (employees), machines and processes. In the cost of conformance, it is cost spent on employees, processes and machines to make everything right. If some mistake has done in these stages it may result in either internal failure cost or external failure cost. Table 4 shows the summary of quality equations and quality costs which indicates the first box and the fourth box are merely essential in order to make the things right and to avoid the mistakes.

Table 4: Quality equations Vs Quality costs

	Right	**Wrong**
Do	Quality by authority Quality does not cost	Quality costs due to rework, rejection, repair, scrap, junk and for prevention
Not Do	Quality costs due to controlling, inspection, testing, and vigilance and for appraisal	Quality by responsibility Quality cost is due to supervision, maintenance and controlling

As a key point it can be noted that, a quality product can be manufacturing and delivered with the involvement of all the people in the organization (from top management to shop floor worker) proper planning of processes and design phases, operation and maintenance of machineries.

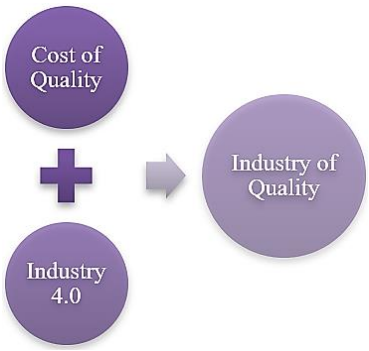

Fig 5: Industry of Quality

In the second half of this paper, the fourth industrial revolution (i.e. industry 4.0) has been introduced and explained. In short, Industry 4.0 is the functioning of an industry with machine to machine interaction that may include CPS, IoT digital twins etc., In industry 4.0 decisions will be made by the machines based on the data stored. Very less man power may require for the functioning of industry. Many aspects of manufacturing have been elaborated with the use of advanced technologies, but at the same time the quality should also be considered equally.

Industry of Quality (IoQ) implies developing the plans, designs and processes with the aim to implement fourth revolutionary changes of industry as well as to produce quality product. In industry 4.0 the major focus is on producing a product by involving advanced technologies. In IoQ, a balance between the technology and quality should be made so that the industries can take the advantage of adopting new technologies (industry 4.0). As very few man power is required for industries driving towards fourth revolutionary changes, there are more chance of producing a defect free product and ultimately to fulfill the customer satisfaction. Figure 5 show that cost of quality and industry 4.0 implies IoQ. Industry of Quality which includes industry 4.0, should spend very low cost for conformance at the cost to make non-conformance zero thence the overall product cost can be minimized. As the entire industry is equipped with machine to machine communication and networking, so there is also need for another element to come into the scenario i.e., trust. Figure 6 shows that IoQ involves two major elements, technology and trust. If an industry balances both technology and trust then it is possible to achieve industry of quality.

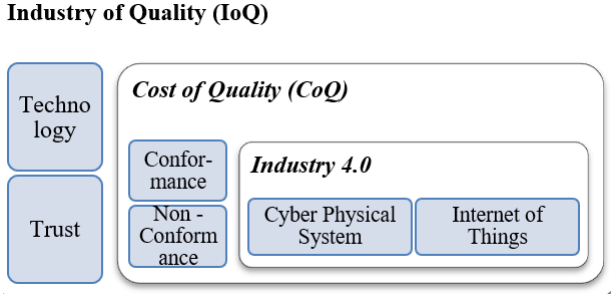

Fig 6: Elements involved in Industry of Quality

Conclusion

Quality is an essential factor for any product under any circumstances. Industries may not withstand if it doesn't deliver quality products. On the other hand, cost is also an important factor that a customer considers before he decides his choice. The concept which relies on these two factors is cost of quality. In general, organizations spend more on conformance cost in order to minimize cost of non-conformances and also for quality output. This may considerably reduce the cost spent on producing quality product but may not reach to zero. With the advent of latest technologies, industries are adopting new mechanisms of making a product. The current revolution "Industry 4.0" taking the manufacturing sector to another level with the involvement of CPS, IoT, data analytics, digital twins etc., In these situations quality management should be considered an important factor otherwise which industries may fail. The term Industry of Quality (IoQ) implies the totality of people in industry, machine and other elements involved in industry should be drive in achieving a quality product along with the adopting of advanced technologies.

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