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CONSISTENCY OF DMAIC PHASES IMPLEMENTATION ON SIX SIGMA METHOD IN MANUFACTURING AND SERVICE INDUSTRY: A LITERATURE REVIEW

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Abstract
High business competition demands business players to improve quality. The Six Sigma with DMAIC phases is a strategy that has proven effective in improving product and service quality. This study aims to find the consistency of DMAIC phases implementation and analyze the objective value in Six Sigma research. By using a number of trusted article sources during 2005 until 2019, this research finds that 72% research in manufacturing industry consistently implemented DMAIC roadmap especially in case study research type for problem-solving, while service industry pointed out the fewer number (60%). The causes of variations and defective products in the manufacturing industry are largely caused by a 4M 1E factor, while in service industry are caused by human behavior, and it's system poorness. Both manufacturing & service industry emphasized standardization & monitoring to control the process which aimed at enhancing process capability and organization performance to increase customer satisfaction.

Keywords
Six Sigma, DMAIC, manufacturing industry, service industry.

Introduction

The increasing competitions in the industrial sector worldwide affect business players to choose the proper strategy. Providing quality products and services is one strategy for staying ahead of that competition [1]. Quality is important for business success that can be achieved if a process has a good capability and meets the specified requirements. Good capability is characterized by a process that can produce products with minor variations and defects. Efforts are needed through structured steps to obtain sustainable quality products. At the planning phase, a quality planning procedure is required. In the implementation phase, quality assurance is required. In the evaluation phase, it is necessary to control the quality [2]. A quality control system is needed with an effective approach to get a good process capability. Six Sigma is a proven approach to the world's largest companies in controlling the process in making quality products.

Six Sigma which has a systematic and structured method commonly known as DMAIC (Define, Measure, Analyze, Improve, Control) has been proven to be effective in identifying, measuring, analyzing, improving and controlling the process [3]. Six Sigma as an effective management strategy has been applied in some of the world's largest companies to improve the company's performance [3–5].

Six Sigma is widely used in manufacturing and services industries for more than one decade in reducing defects, variations, eliminating error to achieve product excellence, exceed customer expectations and gain company's efficiency performance [1, 4–9]. The Six Sigma method provides substantial evidence of success in reducing variations and defective products in manufacturing processes caused by the 4M 1E (Man, Material, Method, Machinery, and the Environment). While in the Six Sigma application service sector, it can reduce human and system transactional errors and also non-value added activities [10–12].

The most fundamental thinking in implementing Six Sigma is enhancing the process capability. In the manufacturing industry, increasing the process capability can be focused more on controlling variation and defective products [4, 9]. In the service industry, improving the process capability can be focused more on the improvement of human behavior in the system by integrating Six Sigma with management performance. Several service industries had successfully implemented Six Sigma as in the banking industry, education, hospitals, and transport services. Performance in the service sector can be measured on non-financial aspects such as employee satisfaction, and ability to provide services that combine internal with external factors to increase the level of consumer satisfaction [6], which become a successful indicator of Six Sigma application in the service industry.

This research is a Literature review that accommodates hundred Six Sigma articles from trusted sources. In this paper, some literary sources come from the best journal publishers in the world and some randomly selected from reliable journals, namely those that publish Six Sigma papers by discussing useful and interesting Six Sigma topics. The research question is that why the same method (Six Sigma with the DMAIC phase) is different in implementation.

The purpose of this research is to find out the consistency of DMAIC phases and obtaining objective values in applying Six Sigma in manufacturing and services industries.

Literature review

Quality is an important requirement for business success in both manufacturing and service industries. Also, productivity is a business thought that is a major factor in increasing the profit of the company [1, 13]. Quality and productivity can be created when the processes have good capabilities and can make processes and products that meet the requirements to satisfy customers [14].

Six Sigma is a method that emphasizes the process execution based on customer focus, prevention, commitment, and support from management [15, 16]. Six Sigma with DMAIC phases often use the quality tools known as seven tools, but the Six Sigma flexibility can also be combined with other tools such as TQM, ISO 9000, Lean Management and TOC (Theory of Constraint), etc. [17, 18].

The Six Sigma method begins by recognizing critical elements of quality (critical to quality) of a process to provide suggestions on improvements related to defects that arise [19]. Six Sigma has measurable improvement steps that will result in costs reduction and increased customer satisfaction to maintain the sustainability of a company as a whole [1, 8, 20, 21].

The main goal of the Six Sigma is continuous improvement through a project. But the Six Sigma application is not easy and is not detached with the obstacles to be encountered; there are three major obstacles that are often encountered in the implementation of Six Sigma methods: (1) lack of top management commitment; (2) the implanted expensive cost; (3) the culture of fear of change. But it is not an excuse for not implementing the Six-Sigma method with these obstacles, the high level of dedication and responsibility of empowering human resources (HR) is the answer to the barriers to applying the Six Sigma [8]. The top management commitment is a fundamental factor for the success of Six Sigma [15], with an adequate implementation strategy that focuses on customer and team, and integrates investment plans in a safe-source resource that focuses on team training and work. In addition, managers must have a reward program that encourages motivation and acknowledges the achievement of the human resources involved [22]. So that top management support and commitment is one of the determinants of successful implementation of Six Sigma, which can result in the elimination of two other barriers (cost and culture of fear of change).

The tools of Six Sigma are most often applied within a simple performance improvement model known as DMAIC which is used when a project's goal can be accomplished by improving an existing product, process, or service [23]. The basic principle of the approach is a structured step with the following phases [24]:

1) Define phase, is the first phase of the process of identification or defining problems, setting problem issues, and targets to be achieved [24]. This phase is important and is considered not as easy as the identification of the inadequate problem will affect the analysis and the results to be obtained [4, 25, 26].
2) Measure phase is the measurement of critical quality factors to follow-up performance measurement that causes problems found in the define phase [24].

3) Analyze phase is the phase of identification of the current condition and identification of the improvement opportunity [24]. By analyzing the causal factors of the problem, then improvement actions can be focused.
4) Improve phase is the election activities of the best-acting alternative measures [24], which decompose the occurrence from the analysis phase by conducting the test of the action taken.
5) Control phase is a phase for monitoring and standardizing the solution to assure the cause of the problem is controlled and also obtain support from management [15, 16, 24].

Six Sigma is a focused approach to reduce process variation and reduce defective products to 3.4 DPMO (Defect per Milion Opportunity). The key success is an approach with a database that is useful for reducing personal bias. With steps starting from data collected of defective and critical causes of defects known to the proposed corrective action. Furthermore, the proposal improvement was implemented, and the results were then re-collected for further identifying the outcome of the remedial action taken.

Research methodology

The research is a study of Literature review on the application of Six Sigma methods in the manufacturing and services industries. This study was conducted by reviewing the various scientific articles from trusted sources. The methodology of this research is described in the study framework (Fig. 1).

The DMAIC consistency means the Six Sigma project is working on each stage of DMAIC with tools at each stage. In this case, consistent is defined when the Six Sigma project is performed by doing all phases/stages of DMAIC, whereas inconsistent when the Six Sigma project does not do at least one stage of the DMAIC phases.

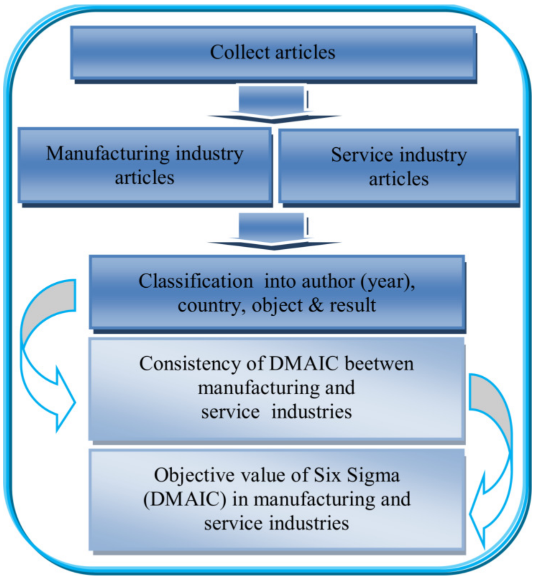

Fig. 1. Study framework.

Result and discussion

Six Sigma with structured stages known as DMAIC focuses on improving process capability. Various research in Six Sigma implementation proved that Six Sigma (DMAIC) can solve various problems experienced in manufacturing and services industries such as: reducing the variation and defective products, decreasing production costs, reducing the error rate, lowering complain, increase productivity, increase equipment lifetime, increase customer satisfaction, improve performance and increase business profits.

Six Sigma in the manufacturing industry

A number of articles have been obtained about the application of the Six Sigma method in the manufacturing industrial sector (Table 1). The DMAIC consistency of Six Sigma articles in manufacturing industry presented in Fig. 2.

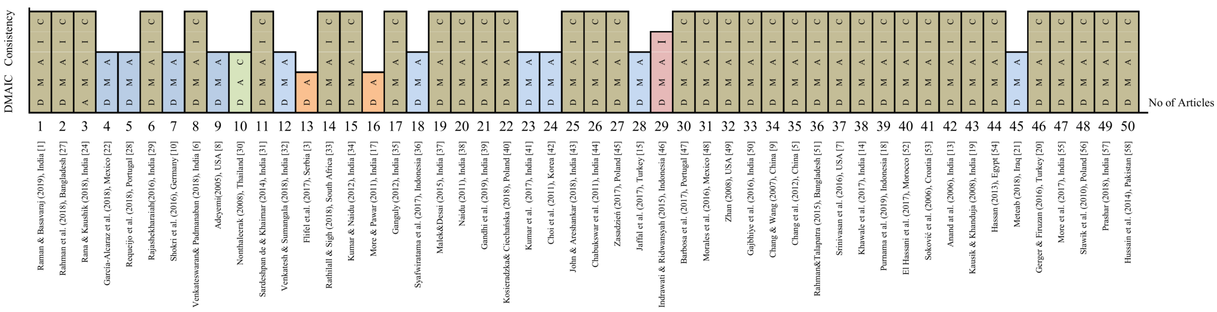

Fig. 2. DMAIC consistency of Six Sigma articles in the manufacturing industry.

Table 1
Six Sigma articles in the manufacturing industry.

No	Author (Year), Country	Object	Result
1	Raman & Basavaraj (2019), India [1]	capacitor industry	Identify the rejection during manufacturing & propose a solution
2	Rahman et al. (2018), Bangladesh [27]	garment industry	Achieve 2% desired defect rate
3	Rana & Kaushik (2018), India [24]	automotive industry	Defect reduction from 1550 to 100 PPM, COPQ reduction
4	García-Alcaraz et al. (2018), Mexico [22]	various industries	Quantify through statistical analysis to measure dependency among variables
5	Requeijo et al. (2018), Portugal [28]	various industries	Six Sigma & BSC applied in maintenance assessment as collaborative ecosystem
6	Rajashekharaiah (2016), India [29]	various industries	Application of Process capability analysis and benchmarked against Six Sigma
7	Shokri et al. (2016), Germany [10]	various industry	Focus on human-related behavior factors associated with Lean Six Sigma
8	Venkateswaran & Padmanaban (2018), India [6]	manufacturing industry	Focus on reducing defect turn around time (DTAT)
9	Adeyemi (2005), USA [8]	various industries	Analyze capacity small companies in implementing Six Sigma
10	Nonthaleerak (2008), Thailand [30]	various industries	Exploring weakness in six sigma implementations & key success factor
11	Sardeshpan de & Khairnar (2014), India [31]	automotive industry	Improving the quality of four wheeler platform truck
12	Venkatesh & Sumangala (2018), India [32]	various industries	Investigating companies that have been benefitted to Six Sigma implementation
13	Flifel et.al. (2017), Serbia [3]	various industries	Identification potential Six Sigma project & recommendation of techniques and tools from the literature
14	Rathilall & Sigh (2018), South Africa [33]	automotive industry	Investigating the integration of Lean & Six Sigma tools in automotive component manufacturing
15	Kumar & Naidu (2012), India [34]	garment industry	Absenteeism can be controlled by implementing LSS
16	More & Pawar (2011), India [17]	textile industry	Implementation of Six Sigma QMS with ISO resulted in competitiveness & performance improvement
17	Ganguly (2012), India [35]	aluminum industry	Addressing the problem in the aluminum industry by applying six sigma principles
18	Syafwiratama et al. (2017), Indonesia [36]	fiber industry	Reducing NC products in polyester short cut production & increase capability from 2.2 to 3.1 sigma
19	Malek & Desai (2015), India [37]	casting industry	Focus on providing a path for initiating six sigma
20	Naidu (2011), India [38]	steel industry	Reducing down time machines by obtaining optimum preventive maintenance frequency
21	Gandhi et al. (2019), India [39]	automotive industry	Identification of blowholes occurrence & defect reduction from 28,111 to 9,708 PPM
22	Kosieradzka & Ciechańska (2018), Poland [40]	industrial automation enterprise	Assessing the readiness of the organization (company maturity level) using Six Sigma implementation
23	Kumar et al. (2017), India [41]	process industry (thermal power plant)	Identification of capacity waste
24	Choi et al. (2011), Korea [42]	electronic industry	Sig Sigma based management in improving competitiveness
25	John & Areshankar (2018), India [43]	automotive industry	Focus on reducing the bearing end plate reworks due to variation in thickness & diameter
26	Chabukswar et al. (2011), India [44]	pharmaceutical industry	Improvement of process capability from sigma level 1.5 to 4, and reduce defect to 50%
27	Zasadzień (2017), Poland [45]	pipe industry	Presents an implementation of Six Sigma in production processes connected with maintenance
28	Jaffal et al. (2017), Turkey [15]	carpet industry	Determining key success factor & investigating obstacles in implementing Six Sigma
29	Indrawati & Ridwansyah (2015), Indonesia [46]	mining industry	Improving the process capability of Iron ores manufacturing
30	Barbosa et al. (2017), Portugal [47]	automotive industry	Improving performance & product quality rate in bead APEX production process
31	Morales et al. (2016), Mexico [48]	concrete blocks industry	Eliminating machine downtime & reduction of scrap from 18 to 2 percent
32	Zhan (2008), USA [49]	electrical industry	Identification & deduction of variation in the average motor speed
33	Gajbhiye et al. (2016), India [50]	casting industry	Reduction in the number of accidents in the manufacturing industry using Lean Six Sigma
34	Chang& Wang (2007), China [9]	various industry	Collaborative planning, of Six Sigma with forecasting & replenishment (CPFR) can decrease variances
35	Chang et al. (2012), China [5]	chip industry	Simulating Six Sigma to improve performance of production planning procedure
36	Rahman&Talapatra (2015), Bangladesh [51]	casting industry	Defect reduction in the casting process
37	Srinivasan et al. (2016), USA [7]	furnace industry	Increasing sigma level from 3.31 to 3.67 in the case of drilling a hole in a 'furnace nozzle' component
38	Khawale et al. (2017), India [14]	automotive industry	Defect reduction of piston rod & increased productivity
39	Purnama et al. (2019), Indonesia [18]	manufacturing industry	Improvement by DMAIC in implementation of ISO 14001
40	El Hassani et al. (2017), Morocco [52]	sugar industry	Decrease Coefficient of Variation (CV) which varies in the range of [38% -45%] to 22.51%
41	Soković et al. (2006), Croatia [53]	automotive industry	Reduction in production time, control time, material & internal scrap
42	Anand at al. (2006), India [13]	automotive industry	Improvement at deep drawing operations by minimizing punch load & variation in sidewall thickness
43	Kausik & Khanduja (2008), India [19]	thermal power industry	Reducing DM water consumption in thermal power plant using Six Sigma
44	Hassan (2013), Egypt [54]	wire industry	Improving the quality of manufactured welding wires using Lean Six Sigma
45	Meteab (2018), Iraq [21]	cement industry	Identification of Six Sigma impact in improving total quality management
46	Gerger & Firuzan (2016), Turkey [20]	aerospace industry	Significant progress has been achieved with the alkaline cleaning process by employing Six Sigma
47	More et al. (2017), India [55]	gear box industry	Minimizing the Dent defect using DMAIC control strategy
48	Sławik et al. (2010), Poland [56]	automotive industry	Six Sigma method can achieve product continuous improvement & aeration model identification
49	Prashar (2018), India [57]	engineering equipment industry	An exploratory study to conceptualize & validate Lean Six Sigma deployment for manufacturing SMEs
50	Hussain et al. (2014), Pakistan [58]	textile industry	Sigma level was improved from 2.2 to 3.

Table 2
Six Sigma articles in the service industry.

No	Author (Year), Country	Object	Result
1	Deniz & Çimen (2018), Turkey [59]	healthcare industry	Identifying the reason behind not using six sigma in healthcare organizations
2	Narula & Grover (2015), India [60]	various industries	After dividing the process into three phases and mean service resolution time was reduced from 10,7 to 7.6 hours
3	Manchosu et al.(2018), Italy [61]	healthcare industry	Applying Lean Six Sigma in radiotherapy
4	Sahbaz et al. (2014), Turkey [62]	healthcare industry	Six Sigma was applied to reduce complications during & after intravitreal injections
5	Zhuo (2019), China [63]	banking industry	Designing a bank's Six Sigma service process based on empirical analysis
6	Omar & Mustafa (2014), Malaysia [64]	various industry	Six Sigma is a systematic approach to gain financial benefits, productivity, and customer satisfaction
7	Patton (2005), USA [12]	various industry	Six Sigma integration with orientation in behaviorally performance management can address the whole system
8	Vijay (2013), India [65]	educational services	Bringing a new innovative student-driven Quality rating system for the Higher Education Institutions
9	Al Kuwaiti (2016), Saudi Arabia [66]	healthcare industry	Reducing medication errors from 56.000 PPM to 5000 PPM and improving sigma level from 3.09 to 4.08
10	Vijay (2014), India [67]	healthcare industry	61% cycle time reduction of the patient's discharge process
11	Al Kuwaiti & Subbarayalu (2017), Saudi Arabia [68]	healthcare industry	Decreasing pre-intervention falls rate from 6.57 to 1.93 (70.93 percent reduction)
12	Laureani et al. (2012), Ireland [69]	healthcare industry	Presenting a case study of Lean Six Sigma implementation techniques through a series of students projects
13	Elbireer et al. (2011), UK [70]	laboratory service	Reduction in data entry errors from 423 to 166 errors/month over 12 months
14	Ekinci et al. (2015), Uganda [71]	healthcare industry	Evaluating the complications occurred during and after hemodialysis session
15	Gijo et al. (2012), UK [72]	healthcare industry	Reducing patient waiting time from 24 to 11 minutes
16	Tetteh (2014), Ghana [73]	educational services	Identifying attributes of the lecturer to improve student's prior knowledge by using Six Sigma
17	Kim (2010), Korea [74]	educational services	Describing Six Sigma implementation in the university library
18	Taner et al. (2011), Turkey [75]	healthcare industry	Improving workflow by eliminating failure causes in the medical imaging department
19	Southard et al. (2011), USA [76]	healthcare industry	Eliminating NVA of locating supplies/equipment, and the 'return' loop of preventable post operative infections
20	Chow & Downing (2014), USA [77]	educational services	Improving retention of first-year college students in an academic institution
21	Cunha & Dominguez (2015), Portuguese [78]	car dealer	Improving the warranty billing process using Six Sigma
22	Ur Rehman et al. (2012), Pakistan [79]	telecom industry	Implementation of Six Sigma made saving US$ 0.45 million
23	Nagi & Charmonman (2010), Thailand [4]	educational services	Focusing on the reduction of variation & defects of learnig
24	Chakraborty &Tan. (2006), Singapore [80]	various industry	Focus on the application of six-sigma to a wider range of services which depends on the identification of KPI)
25	De Koning et al. (2008), Netherland [26]	financial services	Facilitating the process of defining LSS projects in finance
26	Kalra & Kopargaonkar (2016), Canada [81]	healthcare industry	Provides an opportunity for major improvements in delivering error-free & timely clinical diagnostic lab services
27	Gutiérrez-Gutiérrez et al. (2012), Spain [82]	educational services	Investigating the effect of Six Sigma teamwork & process management on absorptive capacity
28	Chakraborty, & Tan (2012), Australia [25]	various industry	Exploring Six Sigma implementation on identifying critical success factor, CTQ, tools, techniques & KPIs
29	Nar & Emekli, (2017), Turkey [83]	healthcare industry	Evaluating the analytical performance of the laboratory by calculating process sigma values
30	Le Mahieu et al. (2017), USA [11]	educational services	Demonstrating application of Six Sigma in a school-community partnership in Milwaukee
31	Almasarweh & Rawashdeh (2016), Jordan [16]	healthcare industry	Analyzing the effect of using the Six Sigma method on the quality of healthcare services in Prince Hashem hospital
32	Gunawan & Karimah (2017), Indonesia [84]	accounting services	Exploring the implementation of Six Sigma in improving accounting information systems performance
33	Kukreja et al. (2009), Louisiana [85]	educational services	Improving curriculum using Six Sigma in the accounting section of the Educational Testing Service (ETS)
34	Zhang et al. (2016), Singapore [86]	logistic industry	Practical implications – Lean and Six Sigma are applicable for improving logistics operations.
35	Nayeri & Rostami (2016), Iran [87]	bank industry	Investigating the effectiveness of Six Sigma through balanced scorecard aspects
36	Vouzas, et al. (2104), Greece [88]	various industries	Exploring the critical factors related to Lean Six Sigma application
37	Hung et al. (2015), Taiwan [89]	healthcare industry	Make model integrating VSM & HFMEA into the DMAIC
38	Khaidir et al., (2013), Malaysia [90]	healthcare industry	Review structural analysis of Six Sigma and organizational performance
39	Bhale et al. (2017), India [91]	hospitality industry	Integrating discrete event simulation & Taguchi method along with Six Sigma
40	Arcidiacono & Pieroni (2018), Italy [92]	healthcare industry	Applying Lean Six Sigma 4.0 to reduce costs, improving at the same time the QoE perceived by the patient
41	Gutiérrez-Gutiérrez et al. (2016), Netherland [93]	logistic industry	Improving performance in logistic service environment using Lean Six Sigma
42	Sethi et al. (2018), India [94]	healthcare industry	Assessing Six Sigma between private & government healthcare
43	Ongy (2018), Philipina [95]	educational services	Identification of the problem in enrollment processing & develop improvement measures
44	Rehman & Sharma (2014), India [96]	healthcare industry	Reducing total holding time by 14000 seconds & improving call operation process by 21.8%
45	Furterer (2018), USA [97]	healthcare industry	Improving throughput by reducing the patient's length of stay by 30% in 3 months
46	Pandey (2016), India [98]	bank industry	Exploring Six Sigma applicability for training design & delivery operationally efficient & strategically effective
47	Psychogios et al. (2012), Greece [99]	Telecommunication industry	Exploring the critical success factors that affect Leas Six Sigma implementation
48	Prasad et al. (2016), India [100]	various industries	Problem identification & measurement of initial Six Sigma level
49	Dave (2017), India [101]	various industries	Presenting the potential area where Six Sigma could be exploited in service functions
50	George et al., (2018), India [102]	healthcare industry	Increasing Sigma values by utilizing strategies against medication errors

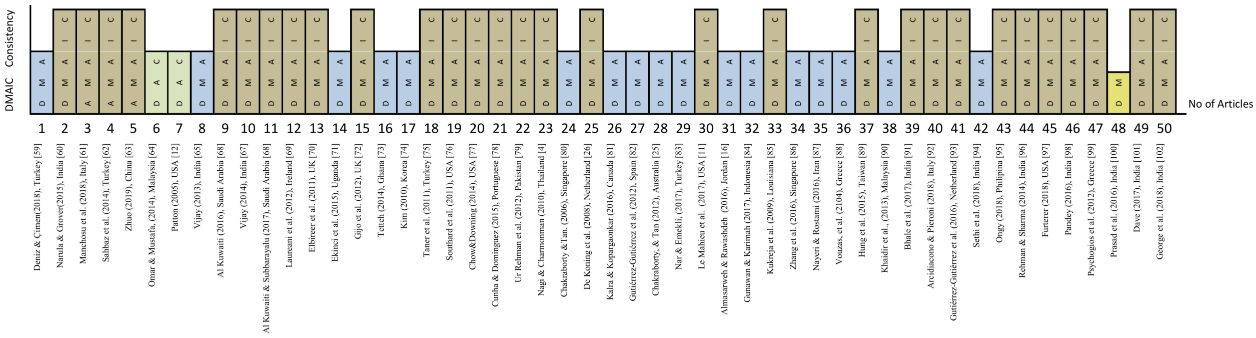

Fig. 3. DMAIC consistency of Six Sigma articles in the service industry.

Based on the 50 journal articles of Six Sigma implementation in manufacturing industries, 72% of articles consistently implemented complete DMAIC phases, especially in case study research type. It is because, in the case study research, DMAIC phases are needed to maintain the stability of variations and defective products & will not happen again in the future. In contrast to explanatory research, which usually has the purpose of scientific development, its implementation only comparing several different industries to get new knowledge and do not need improvement and controlling step. Thus in explanatory research often only carry out the D-M-A phases without implementing the I-C phases.

Statistical tools become imperative in implementation of DMAIC phases, but no rules in each phase should use a definite tool. In general, the tools used are customizable with the respective descriptions of the phases:

1) Define phase: Voice of customers (VOC), Voice of Business (VOB), brainstorming, historical of data, collecting of data, SIPOC diagrams, processing maps, flow diagrams. The tools identify all current problems to obtain critical to quality (CTQ) that indicate the problems that will be corrected.
2) Measure phase: capability analysis (sigma level), Pareto diagram, Gauge R & R measurements, control charts, Anova, VOP (voice of process). The tools reflect the measured baseline performance organization before improvement.
3) Analyze phase: Cause & effect diagram (CED), Pareto diagrams, VA & NVA analysis, regression, and correlation analysis, RCA, 5W analysis, FMEA. The tools can generate the cause of the problem as in the define phase, then improvements are planned.
4) Improve phase: DOE (design of experiment), simulation, Anova, p-chart, SEM (structural equation modeling), risk matrix, FMEA, 5W 1H, boxplot diagram. The tools are corrective actions that can eliminate the problem.
5) Control phase: standardization, documentation, WI, control plans, control charts, SPC, Comparative data. The tools aim to control processes for better variation & product defects level.

Six Sigma in the service industry

A number of articles have been obtained about the Six Sigma aplication in the industrial service sector (Table 2). The DMAIC consistency of Six Sigma articles in service industry presented in Fig. 3.

Compared to the Six Sigma implemented in the manufacturing industry, lesser research of case study applied problem solving (60%) in the service industry. There is more explanatory research compare to case study research in the service industry because many processes in service industries are intangible and difficult to measure. Six Sigma applied in the service industry often emphasized finding the key success factors. Several tools that can be utilized in the service industry are:

1) Define phase: data collection, questionnaire, VOC, SIPOC.
1. Measure phase: Likert scale, Cronbach's alpha, sigma level, data stratification.
2) Analyze phase: regression and correlation, factor analysis, CED (cause and effect diagram).
3) Improve phase: corrective action, redesign, DOE, FMEA, risk, and sensitivity analysis.
4) Improve phase: standardization, training, control plan, SOP.

The objective value of Six Sigma (DMAIC) method used in manufacturing and service industries

From the articles in manufacturing industries, it can be described that based on the country of study: Asia 64%, Europe 20%, America 10%, and Africa 6%. The research objects are classified: automotive 20%, various 18%, garment/textile 8%, casting 6%, and

Table 3
The objective value of Six Sigma (DMAIC) in manufacturing and service industries.

	Industry	
	Manufacturing	Service
Main problem	• Low-performance organization • Low capability process • The defect caused by 4M 1E	• Low-performance organization • Defect caused by wrong human transaction or wrong system
Universal needs	• Product quality improvement • Quality management improvement • Explanatory science improvement	• Service quality improvement • Explanatory science improvement
Measure/Analyze	• Quantitative data • Parametric statistics (t-test, Anova, DOE, etc.)	• Qualitative data • Non & parametric statistics (corelation & regression, etc.)
Objective found	• Reduce defect • Increase performance organization • Increase the capability process	• Reduce complain • Increase performance organization • Increase customer satisfaction
Control	• Documentation • Standardization • Monitoring	• Training • Standardization • Monitoring

the rest are mixed (power plant, electronic, pharmaceutical, electrical, etc.). Besides, the investigation in service industries based on country of study: Asia 50%, Europe 30%, America 14%, Africa 4% and Australia 2%. The research objects are classified: healthcare 42%, educational services 18%, various 16%, banking 6%, and the rest are mixed (telecom, logistic, etc.).

The objective values of Six Sigma in manufacturing & service industries are described in Table 3.

Conclusion

Implementation of Six Sigma (DMAIC roadmap for problem-solving) in the manufacturing and services industries from a number of research articles can be concluded that there is a consistency of all DMAIC phases, especially in case study research. But in the explanatory research, not all DMAIC phases are implemented.

In the manufacturing industry, the problems (variation or defect) are often caused by a 4M 1E factor. It has more quantitative data and can be measured by a statistic measuring device (DPMO/Cp, Histogram, Pareto diagram, etc.), then analyzed with parametric statistics (Anova, t-test, R & R measurements, etc.) and improved with FMEA, 5W1H, DOE. Thus the capability process can be improved, which is characterized by the decline in defects occurrence and increase organizational performance. In the Control phase that aimed to prevent problems from occurring later in the future, a better capability process achieved should be maintained by standardization, documentation, and monitoring using control chart, SPC, etc.

In the service industry, problems often arise due to transactional errors caused by human error or the poor system itself. Therefore, the analysis conducted with qualitative data obtained from data collection through interviews, questionnaires, then utilized nonparametric statistics (regression & correlation). Improvements were performed to make the correction and action plans (redesigning, FMEA, etc.), aimed at reducing customer errors or complaints to improve customer satisfaction. In the Control phase, standardization, training & monitoring are performed to gain organizational performance to enhance customer satisfaction.

This study's limitation is that this paper does not correlate with the specific tools used in each stage of DMAIC. The recommendation for further research is that in applying Six Sigma methods in the industry, the teams involved in the projects should have an adequate understanding of the application of tools for each phase of DMAIC. Therefore the results obtained are purely based on Six Sigma as indicated by changes in sigma level.

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