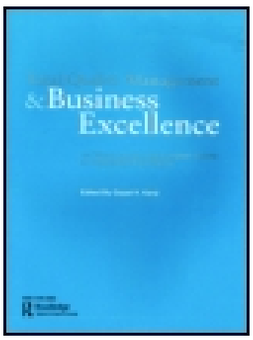

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Total Quality Management & Business Excellence

ISSN: 1478-3363 (Print) 1478-3371 (Online) Journal homepage: http://www.tandfonline.com/loi/ctqm20

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To cite this article: Sarina Abdul Halim Lim, Jiju Antony, Norin Arshed & Saja Albliwi (2015): A systematic review of statistical process control implementation in the food manufacturing industry, Total Quality Management & Business Excellence, DOI: 10.1080/14783363.2015.1050181

To link to this article: http://dx.doi.org/10.1080/14783363.2015.1050181

Total Quality Management, 2015
http://dx.doi.org/10.1080/14783363.2015.1050181

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A systematic review of statistical process control implementation in the food manufacturing industry

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This paper is a systematic review of the literature on statistical process control (SPC) implementation in the food industry. Using systematic searches across three decades of publications, 41 journal articles were selected for the review. Key findings of the review include motivations: to reduce product defects and to follow the food law and regulations (benefits); barriers: high resistance to change and lack of sufficient statistical knowledge; and (limitations) an absence of statistical thinking and a dearth of SPC implementation guidelines. Further findings highlight the predominance of publications from the USA and the UK within this topic. Future research directions concerning SPC implementation issues as well as a ready reference of the SPC literature in the food manufacturing industry are also discussed.

Keywords: statistical process control; food manufacturing industry; systematic review; continuous improvement; statistical thinking

1. Introduction

The fierce global competition in current businesses contributes to the growing popularity of continuous improvement practices. Despite being designated as the largest industry in the UK, the food industry's performance (based on an assessment conducted against the European Business Excellence Model criteria) is lagging behind other industries such as the automotive, aerospace, and insurance (Dora, Van Goubergen, Kumar, Molnar, & Gellynck, 2013b; Mann, Adebanjo, & Kehoe, 1999). Food quality is not only related to the product alone, but also to the factors in production processes (Orr, 1999). Furthermore, quality control (QC), which is a crucial activity in the food manufacturing industry, which is commonly carried out by inspecting quality of final products, arguably fails and is ineffective to support continuous improvement efforts (Paiva, 2013).

Although statistical process control (SPC) is widely applied in the manufacturing industries, many are sceptical with its applicability in the food industry due to the special characteristics of food products. Until now, there has been a lack of a sound, structured review analysing past publications and guiding future research on the implementation of SPC in the food industry context (Dora et al., 2013b; Grigg, 1998). To fill this void, a systematic review of published articles on SPC implementation in the food industry has been undertaken. Using a systematic literature review approach, the remainder of this paper identifies key areas of SPC implementation from the perspective of operational and managerial aspects, which include: motivations, benefits, barriers and limitations, and agenda for future research.

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2. Methodology

A systematic review was undertaken because of its transparency and repeatability to investigate the principle aspects in the SPC implementation within the food industry from 1980 to 2013. The systematic review followed four phases, adopted from Tranfield, Denyer, and Smart (2003) (Figure 1).

In the planning phase, the context–intervention–mechanism–output (C–I–M–O) framework (Figure 2) was applied to formulate the review questions and to undertake the scope of the review (Denyer & Tranfield, 2009). The sampling phase was rendered by the application of four databases (EmeraldInsight, IEEEXplore, ScienceDirect, and ABI/Inform).

Selection of the articles (Figure 3) was carried out based on the inclusion/exclusion criteria. Since the review was contextualised within the food manufacturing industry, the exclusion criterion was food services and laboratory trials. The interventions of Quality Function Deployment, Zero Defects, and Just-in-Time were excluded due to the absence of SPC techniques underlying these respective tools.

3. Publication trends: countries and growth

In total, the search strategy identified 2008 journal articles, of which 41 met the final inclusion criteria. In order to characterise the body of literature, we depict in Figure 4 the growth of articles from different countries across the years.

The literature shows that the publications of SPC implementation in the food industry peaked in 1996 due to the rapid rise of Six Sigma becoming a cornerstone philosophy for world-class corporations. However, it began to slowly deteriorate in later years due to a

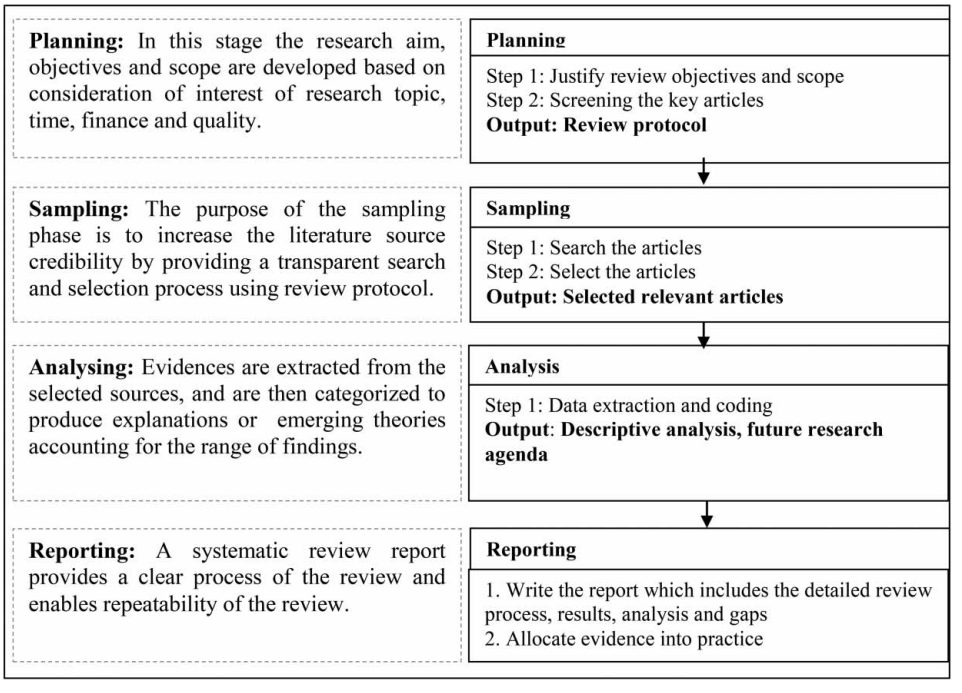

Figure 1. Systematic review roadmap.

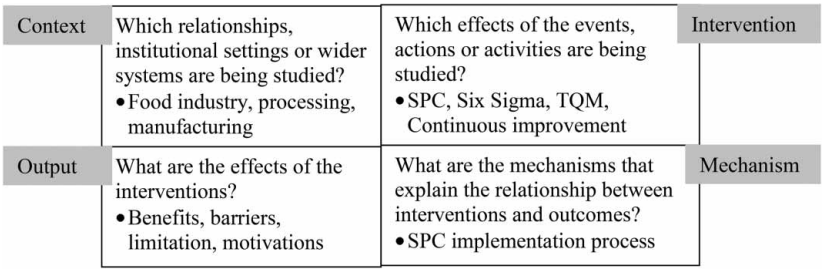

Figure 2. C–I–M–O framework.

heightened interest in the services and public sector studies (Brady & Allen, 2006; Sharma, Gupta, Rathore, & Saini, 2011).

The distribution shows a high concentration of studies conducted in developed regions (USA and UK), where most ISO certified organisations are located and continuous improvement studies were conducted. Similarities between both countries are rooted in governmental reforms, which included the UK government making changes in 1980 to narrow the gap of UK's manufacturing practice and the USA government undertaking macro-economic reforms affecting manufacturing practices (Swamidass & Winch, 2002).

4. Integration of SPC with other quality programmes

Figure 5 depicts that SPC is highly integrated with Hazard Analysis of Critical Control Points (HACCP) and TQM. The application of continuous improvement methods and techniques in the food industry are not as advanced as other industries and hence there are very few publications on Six Sigma and Lean Six Sigma in the food industry (Dora, Kumar, Van Goubergen, Molnar, & Gellynck, 2013a; Dora et al., 2013b; Mann et al., 1999).

The major drawback of current quality control practices in the food industry is a time delay, as the products are already sent to customers before the analysis has been completed (Hayes, Scallan, & Wong, 1997). As HACCP is applied using off-line data, SPC is, on the other hand, a practical method to facilitate HACCP real-time process control (Barker, 1990; Wiklund, 1999). Hence, SPC can play a dual role in quality control and safety assurance by integrating the Critical Control Point (CCP) concept with SPC for efficient food safety management (Hayes et al., 1997; Mataragas, Drosinos, Tsola, & Zoiopoulos, 2012;

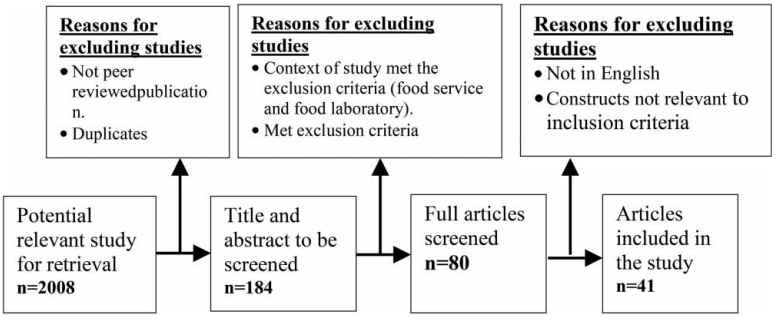

Figure 3. Article selection process.

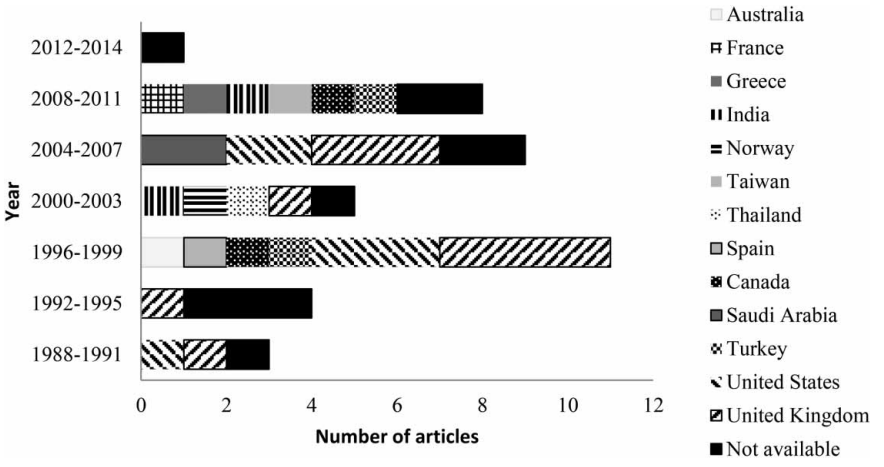

Figure 4. Country and year of publications.

Tokatli, Cinar & Schlesser, 2005). SPC serves as an important component of Six Sigma (Schroeder, Linderman, Liedtke, & Choo, 2008), where SPC is applied in the Measure and Control phase to maintain its improvement under the Define–Measure–Analyse–Improve–Control methodology (Dahlgaard & Dahlgaard-Park, 2006; Knowles, Johnson, & Warwood, 2004; Montgomery, 2009). However, in TQM, although SPC is suggested as one of the important techniques within its implementation (Barker, 1990; Dahlgaard, Khanji, & Kristensen, 2008; Nandyal & Welch, 1991), there is no information on 'how' and 'where' SPC should be applied as TQM is introduced as a philosophy which has no clear roadmap of its implementation.

5. Results and discussion

5.1. *Motivations*

The authors categorised the motivations of SPC implementation in the food industry into 'proactive' (i.e. the desire to realise operational benefits) and 'reactive' (responds to regulations and threats, failure to do so may result in adverse effects) (Brannstrom-Stenberg & Deleryd, 1999; Grigg & Walls, 2007a) (Figure 6). The prominent impact on the type of motivation is often based upon the organisation's experience, to a greater extent, of benefits because the implementation is based on the company's own desire in comparison with defensive-based implementation (Brannstrom-Stenberg & Deleryd, 1999; Cheng & Dawson, 1998; Dale, van der Wiele, & van Iwaarden, 2007).

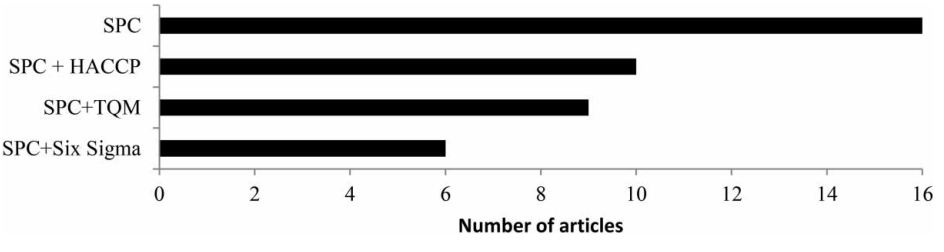

Figure 5. SPC integration with other quality programme.

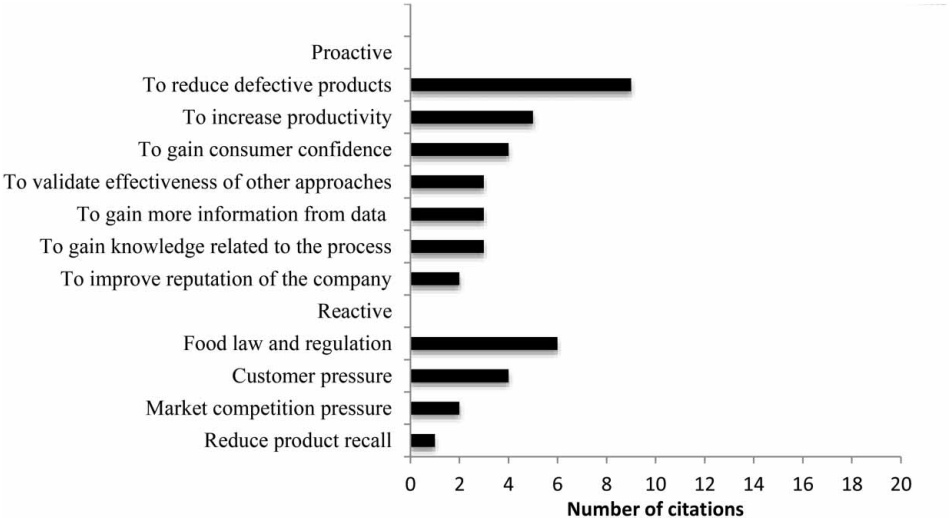

Figure 6. Motivations of SPC implementation.

The concern with food quality was that food products were found to be highly inconsistent due to process variability and the nature of their perishability (Gauri, 2003; Pable, Lu, & Auerbach, 2010; Yang, 1999). Compared with other industries, SPC is arguably effective for reactive motivation as well, which frequently refers to obligations to follow the food regulations UK's Food Safety Act (1990) and Weight and Measure (1985) (Grigg, 1998; Grigg & Williams, 2000; Surak, 1999).

SPC is commonly applied by food manufacturing companies due to the specific quality of practices required by the concerned third-party audits (Jha, Michela, & Noori, 1999; Lennox, Goulding, & Sandoz, 1999; Rohitratana & Boon-itt, 2001; Scott, Wilcock, & Kanetkar, 2009). Similarly, the companies that involuntarily sought certifications, such as IS0 2008 and ISO 22000, are required to use powerful control techniques for reducing non-conforming products (Hubbard, 1999). Nevertheless, based on the review, current food manufacturers are too focused towards the tertiary party, the voice of the customer, and the food law auditors; the voice of the process (process variation) is taken for granted and neglected.

5.2. *Benefits*

This review reveals eight groups of benefits which emerged from the SPC implementation literature. The top three most cited benefits in this industry are defective products' reduction, food safety management improvement, and cost savings improvement (Table 1).

Most of the articles reported that variation reduction of the product is achievable due to effective application of control charts. However, the applications of other SPC tools have rarely been discussed. Such practice is argued to be against the definition of SPC – 'SPC is a combination of statistical and problem solving technique where control chart is one of the tools listed in SPC' (Montgomery, 2009).

Variation reduction enable the SPC users to achieve other SPC benefits as depicted by the Deming's chain reaction model – a range of benefits which includes reduction of defects, wastage, scrap, cost of quality, improving process efficiency, compliance to food law and regulatory and improvement in business image (Barker, 1990; Deming, 1986).

Table 1. Benefits of SPC implementation.

Benefits	References
Reduced non-confirming products • Process variation reduction • Increased consistency in product	Scott et al. (2009), Alsaleh (2007), Grigg and Walls (2007a), Grigg and Walls (2007b), Kourti (2005), Tokatli et al. (2005), Knowles et al. (2004), Daniels (2005), Gauri (2003), Grigg (1998), Özdemir and Özilgen (1997)
Guaranteed food safety • Establish trend of CCP data • Control the product shelf life • Control microbiological contamination level • Minimise the risk of product recalls	Hayes et al. (1997), Tokatli et al. (2005), Narinder, Aastveit, and Naes (2005), Srikaeo, Furst, and Ashton (2005), Augustin and Minvielle (2008), Mataragas et al. (2012), Alsaleh (2007)
Improved cost savings • Reduced process waste • Reduced rework • Reduced scraps • Reduced number of inspectors	Mazu and Conklin (2012), Hung and Sung (2011), Knowles et al. (2004), Daniels (2005), Gauri (2003), Grigg (1998)
Improved process visibility and understanding • More information can be extracted compared to pass/fail: (i) Process behaviour (ii) Process stability (iii) Warning signals for non-compliance	Hung and Sung (2011), Hersleth and Bjerke (2001), Srikaeo and Hourigan (2002), Ittzes (2001), Grigg and Walls (2007b), Hayes et al. (1997)
Improved decision-making process • Enable to distinguish type of process variation • Able to pinpoint day/time that is out-of-control for corrective action • Facilitates people to identify areas for improvement • Improve communication between process actors	Mazu and Conklin (2012), Pable et al. (2010), Simoglou, Georgieva, Martin, Morris, and Feyo De Azevedo (2005), Tokatli et al. (2005), Hersleth and Bjerke (2001), Orr (1999)
Competitive advantage • SPC indirectly generates higher business sales through consistently producing quality products • SPC is able to strengthen company's survival in the global market • Continuous learning through SPC improve organisations competitive advantage	Grigg and Walls (2007a), Grigg and Walls (2007b), Knowles et al. (2004), Psomas and Fotopoulos (2010), Alsaleh (2007)

(*Continued*)

Table 1. Continued.

Benefits	References
Improved customer satisfaction • Food manufacturers are able to satisfy customers (consumers and retailers) by sustaining consistency of quality products through SPC application • Reduced customer complaints	Rábago-Remy, Padilla-Gasca, and Rangel-Peraza (2014), Alsaleh (2007), Gauri (2003), Grigg (1998)
Reduced product giveaway or underfill • Prevents unnecessary rejection and overfill in food packaging	Grigg, Daly, and Stewart (1998), Gauri (2003)

Another type of indirect benefit is the opportunity to learn more about the process from the data instead of rational thinking, enabling the facilitation of the employees' ownership of the process and increasing the motivation of employees to undertake or apply the application of SPC under the continuous improvement culture (Rungtusanatham, Anderson, & Dooley, 1997; Gauri, 2003).

Many food manufacturers considered certifications such as ISO 9000 and British Retail Consortium (BRC) as QI initiatives in their businesses (Dora et al., 2013b; Grigg & McAlinden, 2001; Hubbard, 1999; Paiva, 2013). However, given that audits were completed, these certifications are arguably far from the culture of continuous improvement. The process control and continuous improvement are only a few of the many critical criteria required for such certifications. The authors also argue that implementation of SPC, which endeavours a continuous improvement culture in process management, enables the facilitation of the food manufacturers, which in turn reduces the burden on the efforts of getting the certifications of interest.

5.3. *Barriers*

The top three barriers discussed in the literature are the resistance to change, lack of sufficient statistical knowledge, and deficiency of management support. More details on the barriers of SPC implementation in the food industry are provided in Table 2.

Similar to that in other industries, lack of top management commitment is the top barrier; however in the food industry, resistance is much more of a dominant issue (Surak, 1999). The resistance to change was contributed by the shop floor, where the shop floor perceives SPC as a short-term QC technique, while top management were reluctant to provide sufficient time for the employees to become involved in the SPC projects (Dora et al., 2013b; Hersleth & Bjerke, 2001). Lack of statistical knowledge has an alarming contribution to the fear of employees towards the technique. For example, 22% of Saudi Arabia (UAE) food companies are incognizant of quality tools (Alsaleh, 2007) and Dora et al. (2013a) reported that visual inspection is the most popular tool for QC in the food industry instead of SPC, as it requires less statistical expertise and resources. One of the causes identified was the lack of a statistical-based quality techniques introduced in current tertiary education (Grigg & Walls, 2007a).

Table 2. Barriers of SPC implementation.

Barriers (frequency of citation)	Examples/ explanations	References
Resistance to change	• Current food organisations have not fully accepted the need for continuous improvement techniques • Fear of failure	Dora et al. (2013a), Jha et al. (1999), Hersleth and Bjerke (2001), Srikaeo et al. (2005), Hung and Sung (2011)
Lack of statistical knowledge	• Unfamiliar with the use of advanced statistical techniques	Alsaleh (2007), Hersleth and Bjerke (2001), Bidder (1990), Hung and Sung (2011), Grigg (1998)
Lack of management support	• Resistance to provide sufficient resources • Lack of management awareness on SPC • Improvement project activities are not at the highest priority • Managing directors do not appreciate the value of SPC • Lack of encouragement for employee involvement	Grigg and Walls (1999), Srikaeo et al. (2005), Jha et al. (1999), Hersleth and Bjerke (2001)
Poor measurement system	• Lack of awareness the importance of capable measurement system	Srikaeo et al. (2005), Gauri (2003), Grigg (1998)
Lack of practical guidelines	• There is no practical manual for food manufacturers to initiate SPC implementation	Grigg (1998), Grigg and Walls (2007a)
Lack of employee empowerment	• Survey shows Norwegian food companies do not welcome suggestions and opinions from employees for quality improvement purposes	Hersleth and Bjerke (2001), Grigg (1998)
Lack of trained employees	• A study in a high-volume production facility that applied	Hung and Sung (2011), Grigg (1998), Grigg and Walls (2007b)

(*Continued*)

Table 2. Continued.

Barriers (frequency of citation)	Examples/ explanations	References
	extremely rigorous SPC abandons the technique due to lack of in-house expertise • Many statistical techniques are perceived as too advanced for untrained staff in the food industry	
Lack of experience		Hung and Sung (2011)
	• Lack of experience in using quality tools obstructs quality improvement initiatives in food companies, for example, Taiwan	

Hence, awareness of SPC is a good starting point to increase employees' acceptance towards the technique (Dora et al., 2013a; Gauri, 2003; Knowles et al., 2004). The training programme began with management and eventually cascading down to the supervisors and operators, which contributed to the success of the implementation of SPC in the company (Gauri, 2003). Such training included the concept of natural/special variability, its relevance to the control limits, effects of taking action without considering data from the control chart, and hands-on training to develop and interpret the control charts. According to a readiness study by Holt, Armenakis, Feild, and Harris (2007), the continuous awareness training of a technique is arguably able to reduce the resistance to change.

5.4. *Limitations*

This study found that the limitations of SPC application (Table 3) are often not discussed. It is important to highlight the general limitations whereby SPC is unable to solve all problems and must be applied wisely. Most cited limitations for the food industry, which implements SPC, include the lack of a fundamental mindset for statistical thinking (ST). SPC is perceived as too complex and the absence of applicable SPC guidelines in the food industry context is apparent. ST domain covers the processes and a reduction of variation that exists in each of the processes, which provides opportunities for improvement (Hersleth & Bjerke, 2001). By nurturing ST mindset within the processes, the perception of SPC as a complex technique for the non-statistical users can be reduced.

Based on the results from the literature, it was observed that the employees in the food industry are significantly lacking of ST understanding, which arguably leads to the fear of statistical techniques and a resistance to change. ST has a critical role in the platform of SPC implementation (Nandyal & Welch, 1991). Grigg and Walls (2007a) and Srikaeo and Hourigan (2002) discuss the importance of ST in the food industry, which subsequently implies the need for a systematic practical guideline for its implementation. Current codes of practice in the food industry, such as the Codex Alimentarius Commission, cover quality assurance aspects such as sanitary hygiene in detail, but there is no systematic guideline to operate SPC (Grigg 1998; Paiva, 2013). Consequently, insufficient source of guidelines for the

Table 3. Limitations of SPC implementation.

Limitations	Details/examples	References
Lack of ST		Dora et al. (2013b), Grigg and Walls (2007b), Hersleth and Bjerke (2001), Gauri (2003)
	• Decision-making based on data is not a customary practice in the food industry	
SPC is considered too advanced		Paiva (2013), Srikaeo et al. (2005), Buco (1990)
	• SPC is perceived as too advanced for the food industry • Multivariate control chart application is too challenging for the shop floor employees to handle	
Existing manuals cannot comprehend food manufacturing applications		Grigg (1998), Gauri (2003), Grigg and Walls (2007b), Psomas and Fotopoulos (2010)
	• Current available manual within the food industry (DTI manual) for control and monitoring is arguably too complicated for real application in food manufacturing • Quality parameters depend on multiple factors, increasing the time needed for corrective action	
Costly technique		Alsaleh (2007), Gough (1989)
	• SPC is considered as a luxury option due to training and software requirements for its application	

implementation may demoralise the companies to adopt this technique, as they would not want to jeopardise their investment for the implementation.

6. Future research directions

This exhaustive literature view offers practical insights into the position of SPC implementation in the food industry. The arguments that have been presented by various authors and studies sofar highlight the advantages and limitations associated with the adoption of SPC in the food industry. One of the most significant findings from the analysis highlights an invaluable empirical focus on technical aspect of control charts.

Research on the 'how to do it' has been taken for granted where existing implementation guidelines have been universally applied. The authors argue that there may be

innate organisational characteristics (type of industry) resulting in difficulties to accommodate standard SPC implementation, leading to critical demand on the development of systematic guidelines of SPC implementation in the food industry. The guidelines could be developed from an integrated real-world case study that includes elements of *how, where*, *when*, and *who* should be involved in the implementation.

SPC literature is generated by successful projects. However, the literature of SPC dominantly only considers the positive results of implementation, but in reality there are chances of implementation failure, which is overlooked. There is very little research on addressing the management of failed SPC projects where the principle questions are: 'How is SPC failure defined?, How do we manage the failed SPC project?, Do we rework the project or terminate the project?'. To encourage such research efforts, academics and industrial practitioners should take the lead by encouraging knowledge exchange workshops between both parties to introduce the value of publications concerning SPC and its practical impacts for the use of industry.

Finally, the review illustrated that the application of SPC in the food industry is lacking in terms of the elements of learning within their manufacturing practices. As SPC is a continuous process improvement technique, there is a great opportunity for continuous learning cycles through double-loop learning and facilitation for companies in achieving organisational learning (OL). Sustainability is one of the most challenging phase in the SPC implementation and the authors argue that OL facilitates the sustainability of SPC implementation in food companies. Hence, more studies on the relevance of SPC in OL is greatly required to maximise the benefits of SPC usage in the company and subsequently facilitate companies by gaining competitive advantage in the current fierce market.

7. Conclusions

The conclusions are based on the analysis of 41 articles concerning SPC implementation in the food industry published from 1980 to 2014. In particular, the trend implies that research and publications within this topic are dominated by studies from the UK and the USA. Generally, the review depicted that in the food industry, SPC was applied not only for QC and QI, but also for quality assurance purposes.

It was observed that the application of SPC in the food industry is evolving with the integration of other quality techniques. This was applied within other quality improvement programmes such as Six Sigma and TQM. In comparison with other industries, SPC encompasses similar activities guided by the HACCP guidelines, where the certification is specified for the food industry. However, HACCP principal is primarily used to monitor food safety aspects; it was inapplicable for other food quality issues, and hence the integration of both techniques is able to provide a powerful quality control in the food industry.

Food producers typically applied SPC to reduce defects through process variation reduction and to facilitate companies following the national food legislation by monitoring food safety aspects. In a similar fashion, the major advantages achieved through SPC are reduction of defective products and improvement in food safety management. Food quality attributes are developed through a network of rules and legislation from government bodies, whereby companies are penalised for not abiding by such standards. However, the true impact of this technique is difficult to gauge, mainly due to lack of measures supporting its role in improving business performance.

Employees' high resistance and lack of statistical knowledge are the critical barriers faced by the food producers in adopting SPC. Clearly, the barriers cover a wider issue

than technical aspect; however, training is able to reduce most of the listed barriers. Prominence of knowledge and focusing on ST within the food industry is crucial to overcome the barriers faced. This is especially significant as reducing the resistance to change is a long-term effort. It requires a longer period of time to change the attitude of employees starting from the individual level and working towards the organisational level in the hope that both at the micro and macro levels, acceptance of the application of SPC will become routine practices rather than treating the technique as an additional part of their daily workload. Although SPC is a statistical-based technique, the challenges and limitation factors depicted that SPC implementation in the food industry will be hindered if other key elements such as management, education/training, culture, and human resource availability are neglected.

To conclude, the authors anticipate that this review will reinforce the importance of SPC in the food industry and affirm its role as a powerful technique for QC and quality improvement that should be practised in food organisations. Although there are barriers in implementing the process, if executed correctly and greatly facilitated, SPC can be a versatile technique for managing quality improvement efforts in the food industry and sustaining food process quality.

Disclosure statement

No potential conflict of interest was reported by the authors.

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