Six Sigma in Supply Chain

Alireza Shokri

1 Introduction

Customer satisfaction and competitiveness are in the centre of attention for any quality improvement and performance measurement practice in integration with supply chain (SC). The new perspective of quality improvement in SC demands improvement in profitability besides the customer satisfaction and competitiveness. Enhancing both customer satisfaction and profitability through having a customer- and profit-focussed corporate vision is required to perceive the strength of supply chain management (SCM) (Sila et al. 2006; Lado et al. 2011). The necessity of a dynamic, systematic and reliable process-based performance measurement tool to improve SC and logistics measures as future requirement in SC (Thakkar et al. 2009), and a more rigorous and less complicated quality improvement tool in logistics and SCM (Forslund et al. 2009 and Shams-ur-Rehman 2006); and acknowledgement of versatility between Six Sigma and SCM (Yang et al. 2007 and Dasgupta 2003) have already been indicated by researchers. In other words, Six Sigma projects can be indicated as the performance measurement toolset for any SC process, while it could be used as an entire inter- and intra-business improvement strategy through cultural change. This means that Six Sigma has ability to be integrated with SCM as more straightforward performance measurement tool, a clear and rigorous quality and business improvement methodology and more reliable business strategy in relation to SC to promote profitability and customer satisfaction. But, there is unlikely to find a single research output to capture the real benefits of Six Sigma programme in different perspectives as a performance measurement tool, quality improvement and problem solving methodology and finally a potential business strategy in relation to actual SC and logistics measures in one single and structured output.

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The purpose of this chapter is to instigate the reality of inter-relationship between different perspectives of Six Sigma (performance measurement tool, quality improvement and problem solving methodology and business improvement strategy) and practical SC measures through one single resource, which could be used for both research and pedagogical purposes in higher education and also in practical projects. This would reduce the gap between Six Sigma principles and SC research, while introducing an organised source of integration between SC and Six Sigma in performance measurement, quality and performance improvement and business strategy perspectives. The practical aspect of implementing Six Sigma in SC and methodology and examples related to them are not in the centre of attention for this paper.

It was decided to initially present the role of performance measurement and quality management in SC in the following two sections. This would potentially prepare a platform to review the role of Six Sigma in SCM after briefly introducing the Six Sigma programme. It was decided to present some practical and research-based findings through quantitative and qualitative data analysis in Sect. 5 to indicate the practical implications of this research article. These findings were obtained through conducting a PhD research programme in a specific SC and logistics industry (food distribution) to evaluate the role of Six Sigma in SC and logistics.

2 Performance Measurement in SC

Performance measurement in SC is a complicated practice, whilst it is highly recommended to trace back its performance and commit to the customer satisfaction. The essence of performance measurement in supplier evaluation and supplier development (Lo and Yeung 2006) and also planning to deal with deviation (Tummala et al. 2006) in any SCM practice to improve performance more effectively and proactively was highlighted in research studies. It was highly recommended that good quality performance measurement systems with high effectiveness should be simple, practical, focussed, relevant and reliable to provide the right feedback (Gunasekaran et al. 2007 and Morgan et al. 2007).

The criteria of balanced score card (BSC) and supply chain operation reference (SCOR) model as two common performance measurement models in SC was presented in different research outputs (Shepherd et al. 2006 and Aramayan et al. 2007). These two models were criticised by some researchers in respect to complexity and difficulty to implement especially for organisations with less resources (Barber 2008 and Thakkar et al. 2009). It was highlighted by other researchers that performance measurement system in SC should provide signals, followed by innovative set of actions, which are based on strong planning (Gunasekaran et al. 2007 and Morgan et al. 2007). Therefore, adopting a more contemporary performance measurement tool with more systematic and comprehensive approach towards strategic problem solving and improvement could be considered. It is highly beneficial to select a tool or methodology, which can satisfy the potential users in SC in terms of focusing on performance dimensions, nature of measures (financial or non-financial) and levels of decision making.

Implementing Six Sigma methodology addresses a comprehensive and systematic performance measurement toolset through which different SC and logistics measures can be targeted and evaluated by various tools and techniques in more scientific and reliable way. Six Sigma toolset is a comprehensive and simple-structured methodology with reliable and flexible tools with focused and practical purposes, which can target all types of quantified SC and logistical measures (financial, non-financial, organisational, functional…). The great news here is that this performance measurement practice will not be abandoned or relied on other practices for SC improvement, and has ability to expand its focus to identify the gaps in performance, solve them and sustainably improve the performance. It means that unlike SCOR and BSC models Six Sigma methodology also has ability to improve the quality of performance measures in SC and logistics. In fact, any Six Sigma project starts with defect identification and performance measurement, and continues with quality improvement and finalised as a business strategy as part of the business culture. Therefore, it is essential to review the impacts of quality improvement in SC in next section to highlight the benefits of the Six Sigma in SC through more fundamental fashion.

3 Quality Improvement in SC

The impact of the customer satisfaction on improving the demand chain (Camra-Fierro and Polo-Redondo 2008) and supplier selection (Lo et al. 2006); and consequently, increasing the value in SC was proposed in research studies. It means that the buyer in a modern SC considers the level of effort by the supplier to improve the customer satisfaction (Lo and Yeung 2006). In this respect, the significant role of quality management (QM) to improve the customer satisfaction in SC was acknowledged (Sila et al. 2006 and Kuei et al. 2008).

The importance of integration between SC and QM as operational efficiency (Kuei et al. 2008) and strategic decision making (Carmignani 2009) was a major breakthrough in promoting the adoption of any QM initiative in SC. This means that QM initiatives could impact on the change management in SC and logistics. For instance, the value adding effect of QM in adoption of purchasing strategies (Fung 1999 and Shokri et al. 2010) and logistics (Ballou 2007 and Barber 2008) was highlighted. Key benefits of integrating QM in SC are presented as "more value adding" (Kuei et al. 2008), "increasing customer satisfaction" (Kuei et al. 2008 and Carmignani 2009), "improving competitiveness" (Sila et al. 2006), "improving down-stream and up-stream performance" (Sila et al. 2006) and "reducing process variation and waste" (Flynne 2005). This would potentially demonstrate more profit and quality-oriented values of quality improvement in SC rather than just cost-oriented benefit.

The integration and coordination of QM and SCM in a series of processes, such as measuring, analysing and continually improving the performance and product resulted in large transformation towards quality improvement and was called the supply chain quality management (SCQM) (Vanichinchai 2009). Figure 1 depicts the key quality-related dimensions of the route map to SCQ. Quality-related dimensions are within four different drivers of the successful SCQM. This means that QM can be integrated with SCM to deliver more effective and efficient SC activities and practices.

The Six Sigma methodology can be considered as a perfect quality improvement methodology by which the four quality management dimensions presented in Fig. 1 and also key benefits of QM integration in SC will be addressed. It is a systematic quality improvement methodology with customer satisfaction, continuous improvement and profitability focus. It can substantially and systematically improve the customer experience and supplier performance in all quality dimensions of SC and logistics. This will make Six Sigma more distinctive with other quality improvement initiatives such as TQM, lean and ISO9000. It is essential to generate some aspects of Six Sigma programme in next section before reviewing some actual benefits of Six Sigma in SC and logistics.

4 Six Sigma Programme

Six Sigma is a top–down approach that can be described in business perspective as a customer-driven (Nakhai and Neves 2009) and project-driven (Kwak and Anbari 2006 and Assarlind et al. 2012) approach, a business-driven (Savolanainen and Haikonen 2007) methodology, or a business improvement strategy to improve profitability and efficiency of all operations (Anbari and Kwak 2004), which focusses on decision making based on quantitative data (De Koning and De Mast 2006)

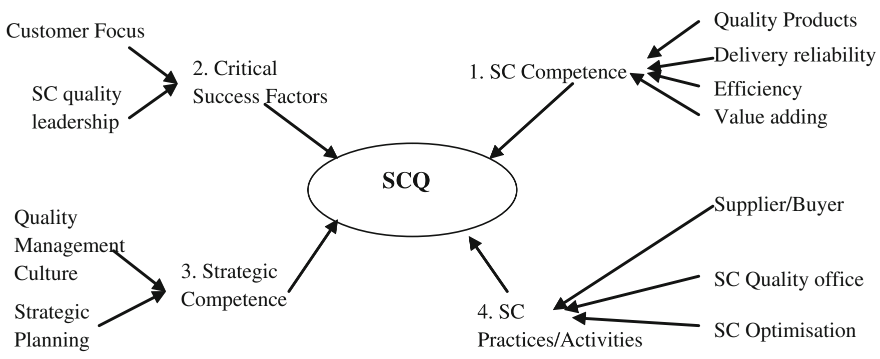

Fig. 1 Route map to supply chain quality (quality management-related dimensions) (Kuei et al. 2008)

and meet or exceed customer satisfaction. This will lead to improving the organisation's product, process and service (Kwak and Anbari 2006) financial performance of the organisation (Nakhai and Neves 2009) or generally business strategies continuously by focussing on eliminating the variables (Saolainen and Haikonen 2007). Numbers represent features and characteristics of processes in Six Sigma and therefore data availability and statistical tools and techniques in Six Sigma is key, as it focuses on opportunities of defects not just defects. In statistical term, Six Sigma is about reducing the sigma level as representation of variation in process by reducing the gap between target and mean value in normal distribution and approaching to 99.99997 % perfection. The complementary application of statistical and business aspects of the Six Sigma was expressed as a necessity in successful project executions (Kwak and Anbari 2006 and Kumar et al. 2009a, b).

Six Sigma is an ever-increasing integration of quality and business strategy (McAdam and Lafferty 2004), which its growing interest in the UK and globally has been acknowledged (Grigg and Walls 2007). The competitive nature of the market in SC is demanding quality and perfection in both production and service and Six Sigma could be an attempt to manage global competitive market to pursue continuous improvement (Kumar et al. 2008). There are numerous studies to describe Six Sigma as a tool, methodology or strategy. It was once described as a top–down managerial strategy, methodological improvement programme, and as a set of quality tools or techniques (Johannsen and Leist 2009). It was also accepted as a business strategy to bring excellence (Antony et al. 2007) or a vision and philosophy (Naslund 2008). Six Sigma is characterised by its customer-driven approach, by its emphasise on data-driven decision making, priority on profitability, systematic training, effective utilisation of knowledge and focussing on relevant measures (De Mast 2006).

Six Sigma was established in mid 1980s by some engineers in Motorola, a leading manufacturer of electronic devices, as a comprehensive quality programme (Naslund 2008 and Chakrabary and Chuan 2009). It was then established by so many big national and multi-national organisations, including General Electric (GE), Honeywell (Allied Signal), Polaroid, Sony, Honda, American Express, Ford (Chakrabary and Chuan 2009), Caterpillar, Nissan, Kraft Foods. There are many more organisations around the world, which have implemented Six Sigma successfully, and it is a significant part of their business strategy. Six Sigma has already been introduced as a process-focussed strategy in operational level, which focusses on projects, processes, deliverables and problems (Haikonen et al. 2004 and McAdam and Lafferty 2004). It focuses on "customer satisfaction" (Kumar et al. 2008), "cultural change" (Raisinghani et al. 2005), "quality improvement" (Wessel and Burcher 2004), "enhancing financial performance" (Kumar et al. 2008) and "systematic projects" (Andersson et al. 2006) to tackle the problems with unknown solutions (Kumar et al. 2009a, b). The level of focus by Six Sigma programme is depicted in Fig. 2 as a summary of understanding from literatures. It was stated in this figure that cultural change or business transformation is the first stage of Six Sigma to be focused followed by operational aspects and finally focus on strategic level.

Business transformation is required to promote Six Sigma (Al-Mishari and Suliman 2008) as the first step followed by a project-by-project process improvement, strategic performance measurement and problem solving practices with clear responsibilities and boundaries. There is also a new modern approach of Six Sigma, which is its application in small to medium-sized enterprises (SMEs) (Kumar et al. 2011 and Kaushik et al. 2012), which their role in any SC improvement is substantial. The Six Sigma approaches in successful application are presented in Fig. 3. It indicates that the outlier approach is necessary to exercise the insider layer. It means that focusing on mind-set components is a prerequisite for any Six Sigma implementation, which includes project set-up and execution through road map or methodology and tool-set.

Principles of Six Sigma

There are some constructing elements of any Six Sigma project that are necessary to formulate the Six Sigma programme. Attention to customer's needs, solving a variety of problems and devising a "project" to improve operations are the main principles of the Six Sigma programme. The problem must be strategically critical for both the organisation and the customer and it is necessary to select the right project to solve the right problem. The results from research analysis identified project selection as the most critical and most commonly mishandled activity in launching Six Sigma (Antony et al. 2007 and Kumar et al. 2009a, b). Six Sigma is a toolset and needs to focus on a single measure within a period of time. In this respect, criteria prioritisation was recommended by some authors (Kumar et al. 2009a, b) to select the right projects in Six Sigma. Selecting the right criteria or project in Six Sigma needs resources; voice of the customer (VOC) is the most common resource followed by voice of the business (VOB) (Antony et al. 2007), which then could be used to set up a Six Sigma project. Duration, customer

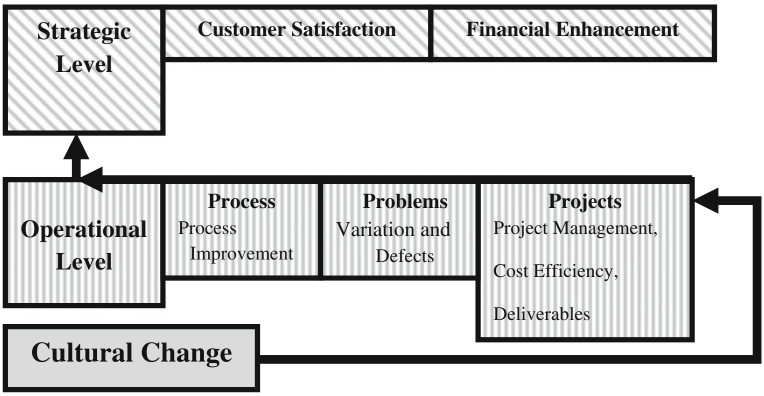

Fig. 2 Six Sigma focus in different levels

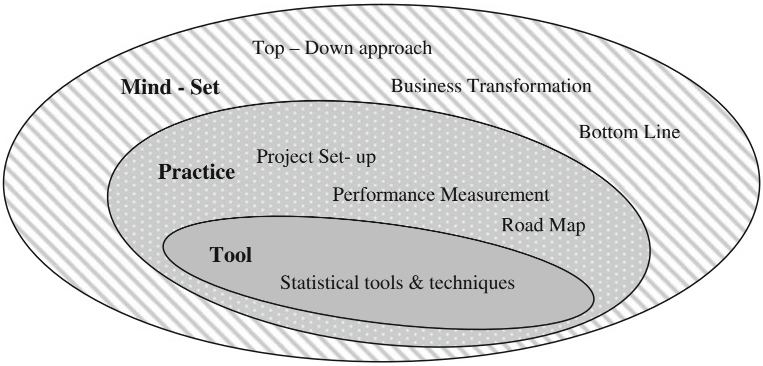

Fig. 3 The Six Sigma approaches

requirement, business strategy and feasibility could be the most common prioritisation aspects for any Six Sigma project. Analytical hierarchy process (AHP) (Kumar et al. 2009a, b), failure mode and effect analysis (FMEA) (Kumar et al. 2008) and quality function deployment (QFD) (Kumar et al. 2008) alongside brainstorming and Pareto Analysis are some common tools and techniques that could be used in Six Sigma programme to select the right project.

Key Success Factors in Six Sigma

Six Sigma is not a magic bullet that solves problems automatically. It needs good people who can communicate, think well and work together. It also needs managerial support, resources, training, leadership skills, methodology and organisational focus. The result of a secondary data analysis amongst many Six Sigma-related articles, which is presented in Fig. 4, indicates that there are some human resource or leadership factors that have the most significant impact on Six Sigma success or failure. It was understood as part of the author's research review that "top management commitment", "training", "leadership" and "project selection" are the most common key success factors (KSFs) in Six Sigma projects (Fig. 4). Furthermore, it was suggested by one of the most recent articles through studying the Six Sigma evolution that top management support could be the most critical success factors in first few years, and then it is established the project selection would play the biggest role in Six Sigma success (Firka 2010). Training and education is another key factor that could be including in-house training or any outside training that is provided by training organisations. The extend and criticality of training for a small organisation to implement Six Sigma is not as big as for bigger organisations, since it could cover the basic required training for smaller organisations.

Benefits of Six Sigma

It is indicated from Fig. 5 that process and people as two key elements of the organisation can benefit from a Six Sigma programme. Systematic data collection and methodology of Six Sigma promotes a more scientific approach and easier

Fig. 4 Most common literature recommended KSFs for Six Sigma projects

decision making (Grigg and Walls 2007). The utilisation of different sets of statistical tools and techniques, besides managerial and problem-solving tools, will enable the people who are involved in the Six Sigma project to experience better results. Management involvement in training and project utilisation results in management development. This in turn addresses more opportunities for employee training and development in the project team and increases their job satisfaction and loyalty. Systematic team building and task delegation in Six Sigma projects could also have positive impact on employee empowerment. Then, defects could be detected in more professional manner, and this results in product and service improvement. The first financial benefits of the Six Sigma programme appear within the processes by reducing the cost of poor quality (COPQ) and cycle time. This will result in net profit increase. Six Sigma utilisation also promotes effectiveness and efficiency together by promoting both quality and value for customer. Therefore, customer satisfaction will increase as a result; this will promote sales, market share and profit growth.

Limitations in Six Sigma

Maintaining customer satisfaction and profitability in the real world through Six Sigma is unlikely to be an easy job and there could be many problems. Six Sigma is a complex and time-consuming exercise (Chakrabary and Chuan 2009) and therefore it was reported that it cannot be recognised as a "quick fix" (Dahlgaard 2006). Over-focusing in two elements, including "cost down" approach (Bendell 2006) and Infrastructure-based training (De Mast 2006) is a challenging factor which could happen in any Six Sigma project and must be avoided as much as is possible. Ambiguity in purpose (Raisinghani et al. 2005) and certification (Laureani A. and Antony J. 2012), difficulty in data collection (Chakrabary and

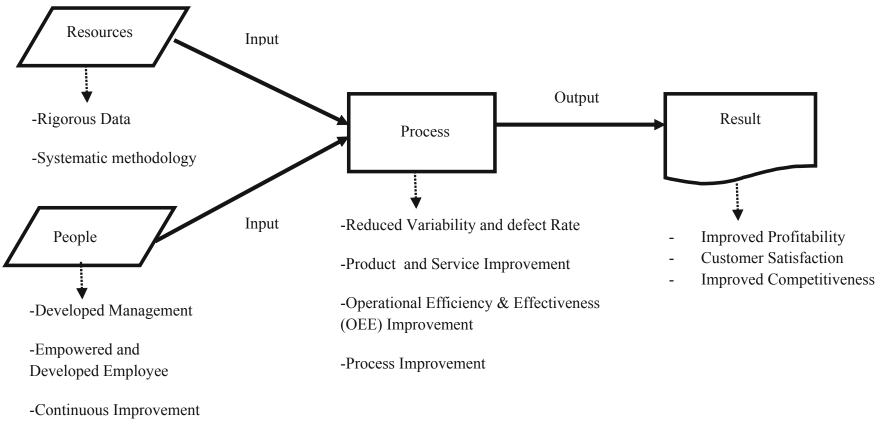

Fig. 5 Six Sigma benefits associated with people, processes and results

Chuan 2009), application in service organisations (Antony 2006), lack of theoretical understanding behind Six Sigma concept (Kumar et al. 2008) and lack of unified standard training (Antony 2008) are other challenges in Six Sigma application. Ignorance to process-based business (Swinney 2006), complexity in tools and techniques (Chakrabary and Chuan 2009), refusal to change (Swinney 2006), lack of interest (Fotopoulos and Psomas 2009) and internal Limited resources (Antony and Desai 2009), lack of knowledge (Chakrabary 2009), significant start up investment (Antony 2006), lack of process understanding (Kwak and Anbari 2006), lack of tangible result (Antony and Desai 2009) and poor project management skills (Miguel and Anderietta 2009) are more technical barriers which could happen before, during and even after any Six Sigma implementation. These barriers are also subject to the size and type of the organisation and there are plenty of opportunities to minimise or remove these barriers in any organisation. It is believed that all of these challenging elements could be tackled through consideration of Six Sigma KSFs, applying required and sometimes simpler tools or application of some supportive tools and techniques to practice technical Six Sigma tools.

Infrastructure Team Deployment and training in Six Sigma

Infrastructured team building in Six Sigma programme might be one of its distinguishing elements in comparison with other quality initiatives (Manville et al. 2012; Hilton and Sohal 2012 and Brun 2011). However, this factor is also not solid and may be changed based on the size of the industry. There are some elements that must be considered in deployment elements. Number of employees, methodology and criteria of selection, level of involvement, content and number of projects (Thomas 2006) and the capabilities of the involved people in deployment (Pfeifer et al. 2004) are critical elements in team building. Team infrastructure in Six Sigma programme is normally based on the "Belt System". The constructing belt members of this deployment and their roles and characteristics are described in Table 1. It is believed that BBs (full-time project managers) and GBs (part-time project managers) are the most critical members of any Six Sigma project in any size.

Training in the six sigma initiative is critical for productivity improvement, cultural change and organisational modification and must be team-based, practical, purposeful and effective for all top managers and relevant employees. It could be tailored to specific industry, process or problem (Raisinghani et al. 2005). Six Sigma training could be provided in three different tool sets: team tools, process tools and statistical tools (Antony et al. 2007). It is important to have an effective blend of all these tools in any type of organisation with any size. There is no evidence for massive training sessions by training providers under different trading names for every organisation that wants to implement a Six Sigma programme. For instance, the level, amount and even structure of training for smaller organisations are not the same as bigger counterparts and it is in lower profile.

Six Sigma Methodology
The Six Sigma methodology can be presented as a systematic structure with the configuration of various flexible tools and techniques. The Six Sigma methodology is linked to continuous improvement due to the systematic selection and continuous implementation of improvement projects (Savolainen and Haikonen 2007 and Antony et al. 2012) and formulates the main body of Six Sigma programme. The most common methodologies are: Define, Measure, Analyse, Improve, Control (DMAIC), Define, Measure, Analyse, Design, Verify (DMADV) and Design for Six Sigma (DFSS). DMAIC is the most common and popular Six Sigma methodology, which has systematic, rigorous, cost effectiveness, disciplined and scientific approach towards problem solving and process improvement. DMADV and DFSS are mainly used for innovations and in any project that a new process or product design is required. The summary of key activities and tools of each phase in DMAIC road map are depicted in Fig. 6.

Table 1 The Six Sigma team deployment and their roles based on the belt system

Six Sigma team member	Role	Responsibilities
Executive	Senior management	Strategic decision making and setting up the objectives
Champion	Process owner	Sponsorship, leading the deployment, removing road blocks, providing resources, project selection
Master black belt (MBB)	Black belt support	Mentoring, coaching and consulting
Black belt (BB)	Project leader	Methodology execution, project management
Green belt and yellow belt (GB and YB)	Team member/ Project leader	Methodology execution, project management and support

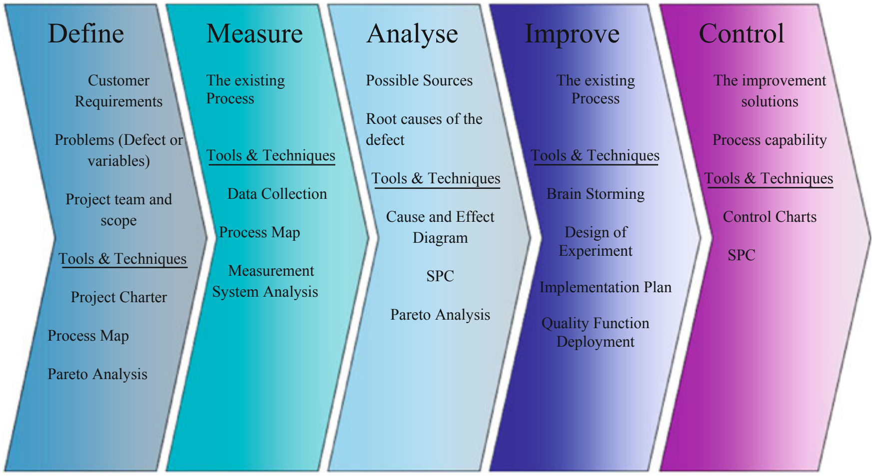

Fig. 6 Key activities, tools and techniques of five phases in DMAIC methodology

5 Six Sigma Methodology in SC

Fung (1999) and Sila et al. (2006) stated that QM initiatives can lead to dramatic changes in SC through analysis of upstream. Six Sigma is not limited to the downstream and can be adopted in a proactive approach by any organisation to identify any defect or variability of the supplier, which might affect the overall performance of the customer or whole SC. Six Sigma can add value to order processing, storage, transport, purchasing, sales and lean operation as SC practices. The continuous improvement is one of the principles of Six Sigma programme for any company in any size. The presence of control stage in DMAIC methodology, which promotes the sustainability of improvement strategies, can guarantee the continuous improvement philosophy in undertaking any Six Sigma project. Flynn (2005) put emphasis on reducing the process variation in any SC process as the result of implementing any QM programme. Variation within any SC process or activity could be related to the quality of service, speed, flexibility and dependability, which results in higher COPQ. Six Sigma aims to reduce the variability within any manufacturing and service processes.

In regards to logistics management, Mentzer et al. (2008) suggested the new set of conceptual dimensions of a contemporary logistics era as the result of logistics evolution. Cost efficiency, customer satisfaction and competitiveness, which were indicated as these important conceptual dimensions, could carry various measures in any business within SC. Six Sigma methodology of DMAIC can be stated as an appropriate approach towards improvement in these dimensions since these dimensions were theoretically capsulated in Six Sigma programme. Six Sigma programme aims to focus on key SC and logistical measures with dramatic strategic and financial impact. This means that Six Sigma projects must focus on key metrics or critical-to-quality (CTQ) metrics, which represent the strategic objectives of the business improvement in SC and logistics. Sum et al. (2001) stated the key logistical objectives or CTQs as “meeting customer special requests”, “reduced delivery lead time”, “low cost operation” and “value adding to the service”. In respect to project selection in Six Sigma application, any defect or measure associated with these strategic objectives will be desirable, since small improvement in these measures could result to significant impact of overall financial and strategic performance of the logistics and SC.

The Six Sigma integration with SC and logistics can be studied through four different perspectives. In respect to the Six Sigma principles, methodology and tools and techniques, which are utilised, it could be applied as a performance measurement tool or problem solving methodology and quality improvement programme in starting point and then it could change the whole culture of the organisation or SC and can be established as the business strategy (Fig. 7). This depends on the level of profile that Six Sigma is practiced and the experience of any organisation or SC that is practicing Six Sigma. Moreover, if any organisation is practicing Six Sigma in either of these perspectives, the business partners in upstream and downstream can also be affected and experience this practice. It is intended to introduce the impact of Six Sigma in SC through these four different perspectives separately by providing some information including case studies, which were conducted in food SC and logistics as an example of a complicated and competitive SC with various quality improvement, and customer satisfaction requirements in a sustainable and systematic way in recent years.

There are various SC measures and practices that can be targeted by Six Sigma as a performance measurement tool, problem solving methodology and quality improvement programme. These measures and practices are mainly quantitative and process based, which have opportunity to produce products and services with variability and defect. Figure 8 represents some of these SC measures.

The role of Six Sigma methodology will be specifically evaluated in regards to four different perspectives as following to indicate the real benefits of Six Sigma into SC. In fact, the conducted qualitative research methodology, which is a series of case studies has been summarised as the following to provide some findings as benefits of applying Six Sigma into food SC and logistics.

The methodology, which was used in this study, was a triangulation approach of research methodology through using both case studies and questionnaires. The following sections have been provided as the result of implementing five different case studies and seven questionnaires to promote adoption of Six Sigma in food distribution SC within 3.5 years. However, the purpose of this study is not just to present the result of any case study or questionnaire specifically and it is rather to present the role of Six Sigma aspects in dealing with issues and problems in food SC. Therefore, the methodology of this research output here is a secondary data analysis on a PhD thesis to present Six Sigma application and its benefits to logistics and SC via different perspectives.

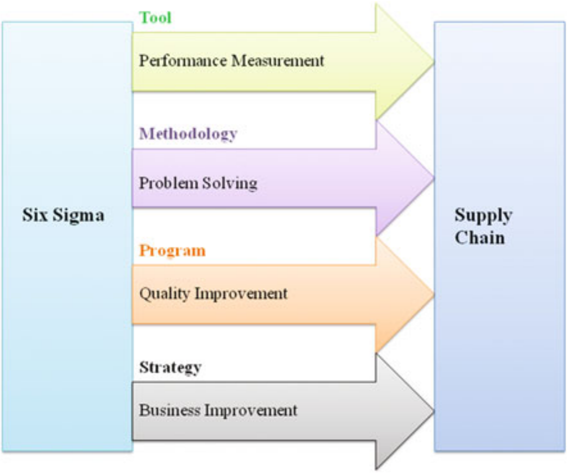

Fig. 7 Holistic view of Six Sigma roles in supply chain through different approaches

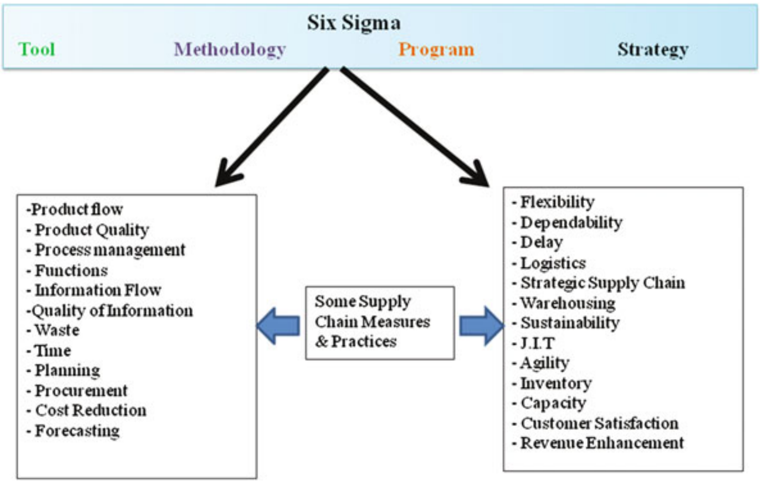

Fig. 8 Six Sigma role in some supply chain measures and practices

5.1 Six Sigma as a Performance Measurement Tool in SC

The continuous performance measurement practice of the Six Sigma implementation could be considered as one of the most common activities that could be undertaken in any organisation. This practice does not oblige organisations to follow the Six Sigma principles. It means that measurement tools and practices in DMAIC methodology can be undertaken by any organisation; as the starting point of Six Sigma journey, or the practical stage of the Six Sigma project or even as a performance measurement process isolated from any Six Sigma programme.

Performance measurement role of Six Sigma is mainly associated with methodology stage of the Six Sigma. There are many activities, tools and techniques that are undertaken to measure the existing performance of the organisation and performance after the implementation of the project. It means that performance measurement in Six Sigma is one of the most critical and fundamental tasks during the project utilisation. Data collection and benchmarking are two major performance measurement activities in Six Sigma methodology, which can indicate the current performance of any SC measure. This could include the target setting and gap analysis. Performance measurement in SC is difficult and complicated in terms of data collection and benchmarking. If the specific SC measure is an internal or inter-departmental measure, the data collection and benchmarking will be easier than data collection and benchmarking for inter-organisational SC measures. This would also depend on the level of SC measure; if the measure is strategic and data is required from top managers and senior executives, the data collection is difficult in terms of availability and willingness to share the information with other SC network firms. Data for tactical and operational measures can be collected in connection with medium level managers or shop floor employees. This would increase the availability, but can also increase the bias, which results in less precision and accuracy. The repeatability and reproducibility of data in data collection of SC measures is another issue, which can be more problematic in collecting the inter-organisational or even national and international SC measures.

Data collection can happen in all five stages of the DMAIC or any other Six Sigma methodologies. Identifying the most critical defects in "Define" stage, measuring the current performance of the organisation in relation to that defect in "Measure" stage, identifying the most important cause or source of the defect in "Analyse" stage and finally monitoring the improved performance in "Control" stage needs the set of rigorous data collection.

There are some examples of different tools or techniques that have been used in "Measure" or "Define" stage of the DMAIC for different purposes. Some examples of using these tools and techniques in measuring SC activities or processes will be presented as follows. However, these tools and techniques could also be used in any performance measurement practice isolated from Six Sigma methodology.

"Target setting" is one of the common activities in "Measure" and "Define" stage of the Six Sigma methodology in which the required measures from customer or management team are set in order to identify the defect and the gap. These target values are used to monitor the performance and effectiveness of the Six Sigma methodology and also the performance of the organisation or department in relation to the specific performance measure. Table 2 represents a "measuring criteria" in logistics as part of "Define" stage of one of the Six Sigma case studies that was conducted in relevant research programme. It was designed by a UK-based food wholesaler to increase the awareness of the supplier's performance in global logistics and transport. This model was produced through this case study in a UK-based food wholesaler as the result of monitoring the performance of the third party logistics and to increase the awareness of the global packaging manufacturer as a supplier. Containers of palletised goods have been delivered by cargo ships from outside the Europe to the UK-based food wholesaler with more concern in quality transport and shipment. This table can provide the customer's requirement in terms of what the very good or very poor performance in each category means.

The packaging manufacturer could simply measure its performance in packing, palletising, wrapping, loading and transport to the customer by receiving the feedback from customer based on this measuring target, which is used as the measuring criteria for quality of service and product.

Performance measurement also happens in "Control" stage of any Six Sigma methodology to check the impact of the solutions to reduce the defect level. Data will be collected from the same measure or performance to indicate the effectiveness of the methodology to reduce the level of the defect within the same number of opportunities. This data could be processed in the Excel to provide the graphic version of the effectiveness, and there would be no requirement of more complicated data analysis tools.

Figure 9 represents the effect of the Six Sigma methodology as a case study on performance of that packaging manufacturer in a global SC network. This figure indicates the delivery performance of the logistics aspects of the packaging products before and after implementing Six Sigma methodology in integration with supplier development practice with the packaging manufacturer. It is evident from this figure that Six Sigma project helped the food distribution company and the packaging manufacturer to remove the causes of the problems in five different logistics aspects and improve their performance. It is clear from this figure that the overall performance on delivery has transformed from poor and very poor to good and very good condition as the result of Six Sigma implementation. The rest of the Six Sigma methodology stages were applied as the result of identifying the key areas of the defect and also the level of non-conformance through this performance measurement practice. The first set of data was collected from a certain number of inward containers before implementing the Six Sigma methodology and the second set of the data was collected from exactly the same number of containers after implementing Six Sigma. It is clear that performance of the manufacturer could be measured in different stages of the methodology to ensure about the effectiveness of the solutions and also check them against the targets.

The performance related to any product or process in Six Sigma methodology needs to be translated in Six Sigma language, in which the Sigma level value indicates how the performance is. It means, the closer the Sigma value to six, the better the performance. This Sigma value can also be calculated after implementing the solutions from the new sets of data from the same product or process to evaluate the effect of the Six Sigma methodology on the product or process.

Figure 10 represents the process Sigma calculation for an "order taking" process as one of the SC activities. This Sigma calculation has happened during the "measure" stage of another case study in the relevant research programme in

Table 2 The measuring criteria for a packaging supplier using 3rd party logistics

	Very good	Good	Average	Poor	Very poor
Pallet condition	Impressive	No poor quality	≤10 % Poor quality	10–30 % Poor	≥30 % Poor quality
Wrapping of the pallet	Impressive tight and multi layered wrap	No loose, damaged or poor wrap	≤10 % loose, damaged or poor wrap	10–30 % loose, damaged or poor wrap	≥30 % loose, damaged or poor wrap
Stacking condition	Strong, straight and top level stacking	No poor or leaning stacking	≤10 % poor or leaning Stacking	10–30 % poor or leaning stacking	≥30 % poor or leaning stacking
Packaging	Tight, strong and perfect packs	Not tight but no obvious damages or holes on packs	Not tight and very few obvious damages or holes on packs	Not tight and few obvious damages or holes on packs	Not tight and many obvious damages or holes on packs
Product quality	Perfect and impressive quality in every issue	Less than 5 obvious damages on the pizza boxes	5–10 cases obvious damages to discarded the products	Few uncommon obvious damages to discard the products	Too many uncommon obvious damages to discard the products

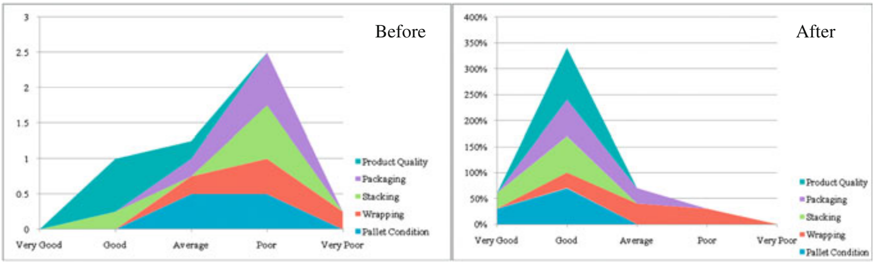

Fig. 9 Measurement of the logistics performance before and after implementing Six Sigma

which the defective order processing in a UK-based food wholesaler and distributor had been analysed through Six Sigma project. The number of processed units indicates the number of samples or collected data. The number of defect opportunities per unit has indicated as one opportunity for one invoice. The total number of defects per collected sample, defect per million opportunities (DPMO) and finally Sigma value were also presented in this tool. It is indicated in Fig. 10 that process sigma level for the current process (order processing) is 4.42 and target value must be a figure more than that. The gap between target and existing sigma value depends on process and number of units in the process. The processes with less samples or less units have lower jump on sigma value than more complicated processes with more units. This tool can simultaneously indicate the performance of the product or process with different languages. But, Six Sigma practitioners are usually concentrating on Sigma value. This tool is available online and can be used in both Six Sigma projects and any other complicated project to review the performance.

Benchmarking is another performance measurement activity that can be undertaken in different stages of any Six Sigma methodology. It can be applied in

Process Sigma Calculator - Discrete Data		
Number of Units Processed	**N**	**692**
Total Number of Defects	**D**	**1.21**
Number of Defect Opportunities per Unit	**O**	**1**
Defects per million opportunities	**dpmo**	**1748.6**
Defects as percentage		**0.17%**
Process Sigma Level	**Sigma**	**4.42**

Fig. 10 Process sigma level for the existing process of the order taking referred to the defect

"Measure" stage, where the gap between current performance and best-in-class target or an internal or external target is calculated. It can also be applied in "Define" and "Improve" stages, where inter- or intra-focused SC measures can be compared with others in terms of meeting the customer requirements or VOC. House of quality or QFD is one of the most common Six Sigma tools that can be used for benchmarking. It is usually used to translate the most critical VOC to the most critical VOB or technical requirements in the customisation and benchmarking context. This will be embedded with benchmarking process in which the performance of the organisation will be compared with a few other organisations in the same SC and for the same product or service. Project prioritisation matrix is a key component of the QFD in which the relationship between customer requirements and technical requirements alongside to presenting the most critical requirements will be presented.

Figure 11 is the example of project prioritisation matrix of a house of quality which represents the QFD analysis in a food SC. Key customer attributes of a UK-based food distributor and wholesaler have been collected through data collection and affinity process in another Six Sigma case study relevant to the PhD research programme. Then, the technical requirements of voice of business were identified and the relationship between these two sets of data was analysed to measure the level of relationship and finally identify the most critical customer and technical requirements. The benchmarking process was carried out based on studying the performance of two other organisations and scoring their performance. This process can be recognised in Fig. 11.

There are some other tools that could be used to monitor the performance of any Six Sigma project for any SC measure or process. Control or monitoring charts are used to monitor the performance of the Six Sigma project or capability of the product or process. Figure 12 represents an example of monitoring chart for the reverse logistics in a food distributor and wholesaler, which was part of another Six Sigma case study. This case study was conducted to identify the reasons for significant number of quality-related reverse logistics or rejects in that organisation. This tool is to indicate the occasions that the process went out of control in the logistics process, when the number of returned goods was more than the upper limit. This tool was used in a reverse logistics process of SC and can be used in any SC process or activity.

Failure mode and effect analysis (FMEA) is another tool that can be used to measure the severity of any problem, defect or even cause of the defect in Six Sigma project. This tool could be used to measure the SC risks in relation to quality improvement and customisation and in order to focus on the most significant risk. Table 3 represents an example of assessing the severity of different potential failure modes of a food supplier in food SC in relation to the reverse logistics case study based on the level of impact and effect that they can generate for the process failure.

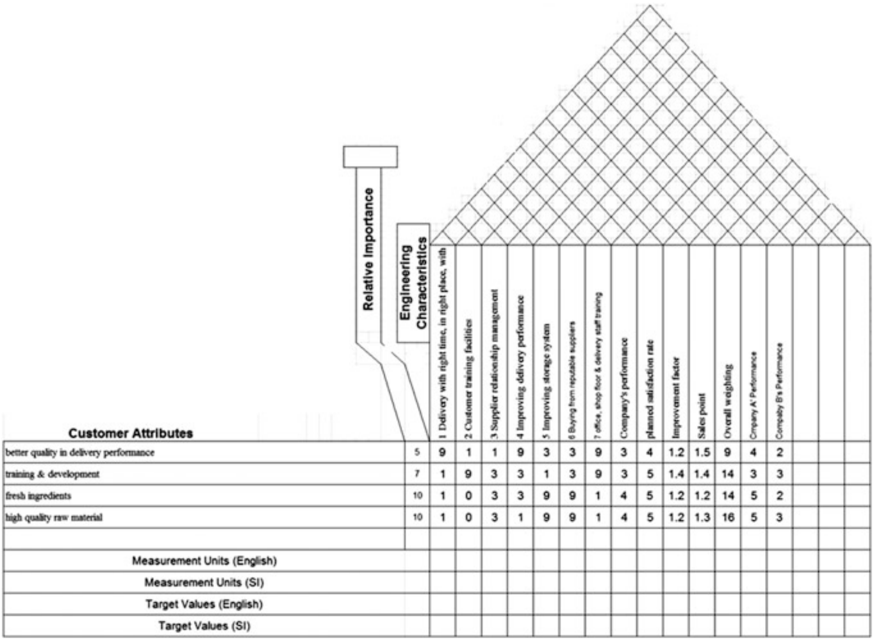

Fig. 11 The QFD analysis to benchmark the performance of the company in a food SC

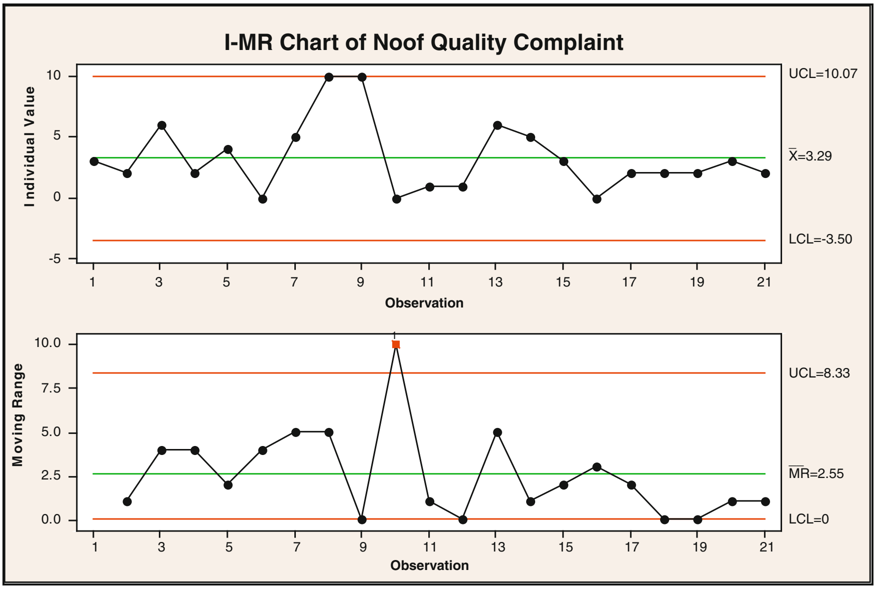

Fig. 12 Monitoring chart for a reverse logistics process

5.2 Six Sigma as a Problem Solving Methodology in SC

The Six Sigma methodology is one of the few quality improvement tools that has the ability to practically drill the problems through systematic, rigorous and data-driven approach. Six Sigma project can be applied in both proactive and reactive approaches and problem solving is the key task of the reactive approach (Shokri et al. 2010). There are various problem indicators in any process or product, which could be targeted by the Six Sigma methodology. These indicators in any SC process, sub-process or activity could be associated to time, quality, reliability, dependability and cost.

There are many SC issues that could be dealt with as the defect or variability. These issues will generate problem, if happen in any SC network; and Six Sigma methodology has ability to remove or minimise these problems. Some common SC-related problems with drastic effect on SC performance, which could be resolved by the Six Sigma methodology are presented in Table 4. It is clear from these examples that many of these problems have multi-effects on the SC performance in any organisation. It is also indicated that most of the problems have impacts on cost, while they can improve other performance indicators.

Figures 13 and 14 depict two practical examples in relation to one of the previous case studies stressing problems generated by third party logistics, hired by the packaging manufacturer to supply the UK-based food distributor and wholesaler. Figure 13 represents the poor warehousing within SC network in which the pallet of the whole product batch was damaged. This could happen in storage, loading, off loading or transport processes in warehousing. Figure 14 represents an example of poor transport, in which the pallet was tipped over as the result of poor planning in freight transport of the 40 ft container. These two problems are amongst the series of problems that have been raised and transferred to the supplier through designed measurement criteria (Table 2) resulting in rework and increased process cycle time. Here, the connection of two aspects of the Six Sigma methodology as performance measurement and problem solving tool can be identified. This would also highlight the mutual interaction between supplier development practices and Six Sigma project, in which Six Sigma project can improve supplier development practices by removing strategic problems with financial impact, while supplier development activities could also facilitate any Six Sigma project to be implemented for upstream side of the SC.

The general systematic approach of the Six Sigma methodology from performance measurement towards problem solving and improvement in any SC process, sub-process or activity is depicted in Fig. 15.

Six Sigma is identified as a process-based methodology to solve any problem. It means that if there is any intention to carry out the Six Sigma project to solve any SC problem, the process must be studied as the very first stage. If any defect or variability is observed in any SC process as the result of performance measurement tool, process mapping is a wise step to understand the current situation of the

Table 3 FMEA analysis to assess the severity of the SC risks

Process steps or product functions	Potential failure mode	Potential effects of failure	Severity (1–10)	Potential cause(s) of failure	Occurence (1–10)	Current controls	Detection(1–10)	Risk priority number(RPN)
Gods return	Irregular product failure	Recalling, customer complaint, food poisoning, customer loss	8	Machine, environment, personal, material, sudden cause	9	Data base, traceability system, monitoring, stock control, rotation	10	720
Gods return	Supplier function failure	Recalling, customer complaint, food poisoning, customer loss	8	Machine, environment, personal, material, sudden and common causes	9	Data base, traceability system, monitoring, stock control, rotation	10	720
Gods return	Live products	Recalling, customer complaint	5	Material common cause	10	Rotation, stock control monitoring, temperature control	10	500
Gods return	In consistency	Recalling, customer complaint	5	Material sudden cause	9	Supplier development, sampling, customer feedback	10	450
Gods return	Buying from inreputable supplier	Recalling, customer complaint, customer loss, malfunction	8	Personal, method, environment material, common cause	8	Supplier selection, supplier assessment, supplier development	1	64

Table 4 Examples of SC problems and their performance indicators

SC problem	Performance indicator				
	Time	Cost	Quality	Dependability	Flexibility
Logistics transfer Cost		√			
Forecasting inaccuracy	√			√	√
Excess and obsolete inventory		√			
Damaged and returned products		√	√		
Inaccurate bill of material		√		√	√
Excess of cycle time	√	√		√	
Lead tim	√	√		√	
Shipping errors		√	√	√	
Billing errors		√	√	√	√
Handling time	√		√		
Scrap and rework		√	√		
Energy cost		√			
Distribution cost		√	√	√	√
Line-item unavailability	√	√		√	√
Poor scheduling	√	√		√	√
Poor storage			√		
Poor delivery performance			√		

Fig. 13 Poor warehousing quality

process and also identify the potential steps that could have possible effect to occurrence of the defect or variability.

Process Map could be adopted as the very first step of the DMAIC methodology after identifying the defect. This would help to generate more idea for next steps. Figure 16 depicts a process map of a "Delivery" process in the food SC as part of previous presented case studies in the PhD research programme, where the "Delivery Lead Time" as one of the key SC problems is reported as the critical measure and reason of many customer complaints. This activity was carried out in

Fig. 14 Poor transport quality

the "measure" stage of a Six Sigma project as another research case study to reduce the delivery lead time in the UK-based food distributor and wholesaler.

The Six Sigma methodology was carried out as a problem solving project in a food distribution organisation to reduce the number of customer complaints related to the late delivery. The process steps that could be associated to the "Delivery Lead Time" were assessed in order to identify the defect. The average of delivery lead time for different delivery routes was calculated as the result of data collection and data analysis for the period of time. Then, any delivery lead time more than average were indicated as the defect. This would present the quantitative measure as the defect in which its reduction can represent the reduction of number of complaints in the delivery process. So, the problem identification, defect identification and data collection were carried out during two stages of the "Define" and "Measure" in the DMAIC methodology.

Then, the defect was analysed to identify the key sources or causes of this defect. The result of carrying out a statistical process control (SPC) analysis for all routes with recorded delivery lead time of certain amount of time indicated whether the routs are under control or not. The normal distribution and also high process capability of the process can allow the project team to rule out any possibility of sudden or special causes. This will also oblige the project team to look for the source of the defect within the processes of the organisation. Brainstorming will provide number of potential sources of the defect, which need refinery to select the most critical sources. The prioritisation strategy can be adopted in this stage in order to strategically select the most critical sources of the defect. "Pareto Analysis" will enable the project team to select these critical sources through prioritisation practice. Figure 17 presents a "Pareto Chart", in which the most counted sources of the defect were prioritised in order to focus on the most important options.

The Pareto Analysis indicated that the first three sources of the defect (spent loading time, late afternoon loading and too many shops) count for 61 % of total

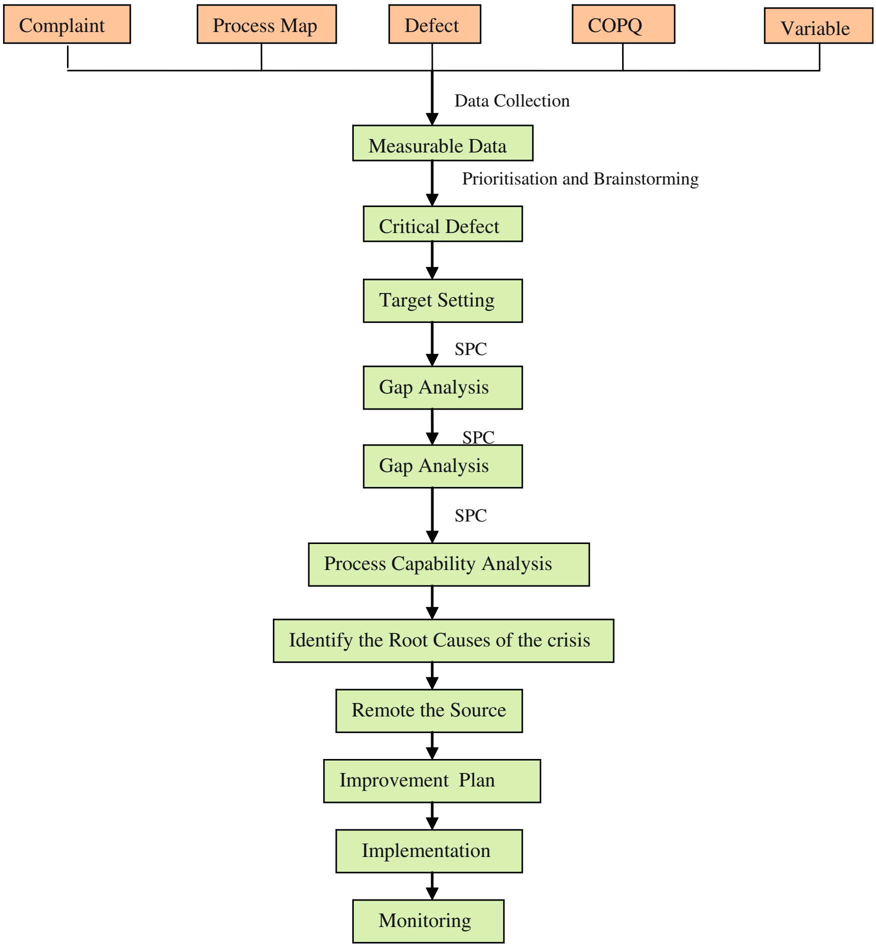

Fig. 15 Six Sigma systematic approach towards any crisis

number of sources as the result of brainstorming and data analysis, and therefore can be selected as the key variables, which need further investigation. This means that other variables would be avoided to be investigated at this time as the purpose of strategically focusing on critical measures, although they cannot be ruled out as the sources of the defect. However, if any changes happen to these variables, it means that the number of defects and ultimately number of customer complaints in delivery must be reduced significantly.

Then, it is important to deploy the further analysis in order to identify the critical causes of these variables. In fact, it is the distinguishing characteristic of the Six Sigma programme to dig to deeper sources and identify the most critical causes of the defect, which their removal or minimisation would provide significant improvement to the process. Therefore, a more quantitative tool can be

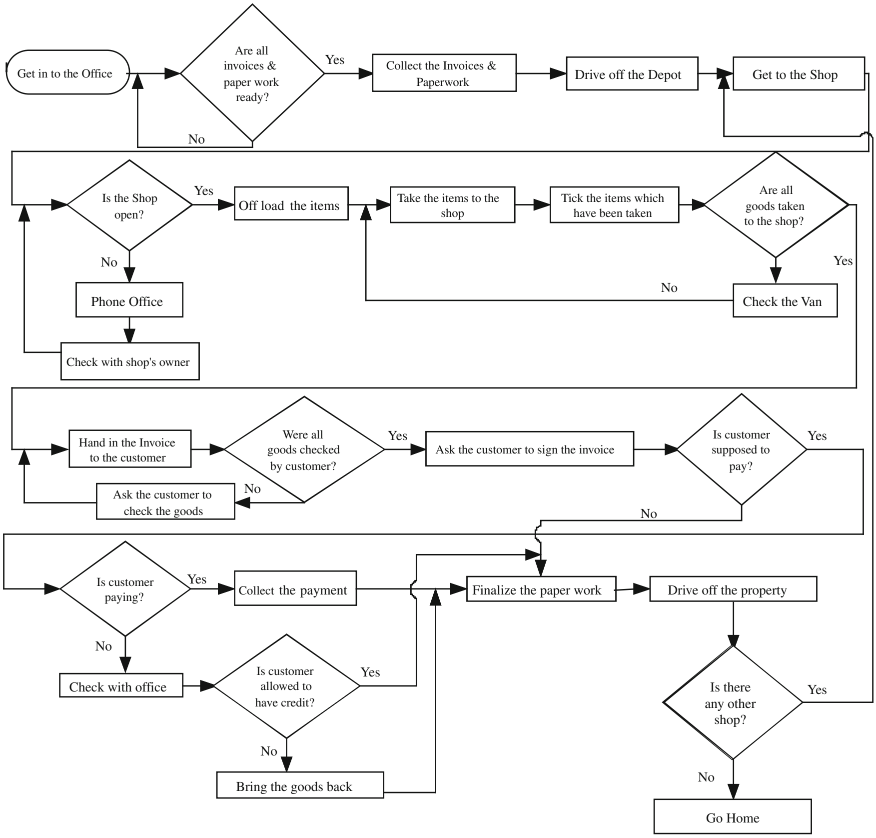

Fig. 16 Process map of a delivery process in a food SC

adopted in "Analyse" stage of the DMAIC to investigate the root causes of the variables and defect. This will enable the project team to identify the most important root causes of the defect in order to focus on them to generate more cost effective and strategic solutions. The possible root causes of three important variables in delivery lead time defect are presented in "root cause and effect XY matrix" (Table 5).

The possible sources of the three important variables were quantitatively analysed after generated by the relevant people and through brainstorming. This happened through scoring style to the effect of relationship between possible causes and three variables. Then, the most important causes with highest weighted score were selected. This was then discussed and analysed through brainstorming and cost/benefit analysis to decide about feasibility of the sources in order to be prepared for next steps. It is clear that the whole flow of methodology is going towards solving the problem, although the problem is yet to be resolved. The step-

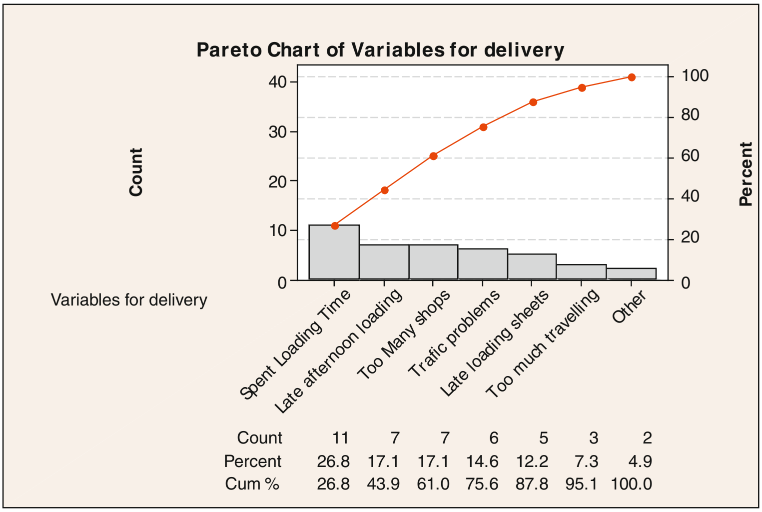

Fig. 17 The Pareto Analysis to select the most important sources of defect to be focused

by-step, deep drilled, data-driven and scientific approach of Six Sigma methodology towards solving the problem could be clearly observed by this point.

Having identified the root causes of the defect, the initialising of potential solutions is the next step in problem solving methodology of the Six Sigma. It is very important to make sure about the involvement of all relevant people in SC network and to buy their interest and willingness in order to participate in initialising any possible solution. Therefore, the SC collaboration, leadership and communication skills play an important role in this stage in order to envisage the chance of resistance to change, conflict of interest, political decisions and also fear of losing the job as the result of comments. It is clear that organisational values outweighed the technical intakes in here as one of the most important and critical stages of the Six Sigma problem solving methodology. Then these recommendations will be brainstormed through the whole individuals, departments and firms that are involved in the SC to select the most practical, sensitive and effective solutions.

The result of brainstorming will be possible bunch of recommendations and initials, which could be in the technical, organisational or even strategic nature. Then, these recommendations must be refined through the process of prioritisation in order to select the most optimum solution that not only solve the problem, but is practical and feasible for the organisation. There might be many recommendations in the SC issues which are inter-organisational and must be dealt with care and cautious. In contrast, there might be some basic internal recommendations that were always there but ignored and could have potential impact on the whole SC performance. It is important to make sure that all these recommendations are through prioritisation and selection channel to avoid any failure in the future.

Table 5 The root cause and effect XY matrix for delivery lead time

Output variables (Y's)	Late afternoon loading	Spent loading time	Too many shops at route	
Importance score (1–10)	6	9	3	
Input/process variables (X's)	Table of association scores (X's to Y's)			Weighted score
Bad loading planning	9	3	0	81
Bad route planning	3	3	9	72
Warehouse layout	9	9	1	138
Staff shortage	9	9	3	144
Late morning start	9	0	3	63
Number of shops at each run	1	9	9	114
Loading method	9	9	3	144
Van discrepancy	3	3	9	72
Late depot leaving	0	0	3	9
Lack of internal communication	9	9	3	144
Warehouse space	3	9	0	99
Goods In delivery distraction	9	9	0	135
Tonnage of orders	3	9	3	108
Failure in specific days	9	9	9	162

"Affinity diagram" is a tool in which different potential solutions could be categorised to make the decision making easier. The categorisation of different solutions for the previous case, which was "Delivery Lead Time", is presented in Fig. 18 and Table 6. The affinity diagram in Fig. 18 categorises potential solutions under 5 different headings and then these categories were brainstormed with all stakeholders in that food SC to select the most effective practical and strategic category based on various factors (see Table 6). However, there could be some occasions that one single recommendation from one category could be selected to be compared with other categories.

Then, each category or any individual solution from any category could be selected for the next step, which is final prioritisation. This prioritisation process deals with reviewing the effect of each solution or category of solutions to the causes of the defect in a comparative approach. It means that the number of potential solutions will be assessed in pairs through a prioritisation analysis in order to indicate the level of effectiveness and importance of that specific solution or strategy on the causes of the defect. This will enable the project team to be more focused and select the most optimum solution which will results in high significance in outcome and more competitiveness in implementation. In the case of reducing the delivery lead time case study, the category prioritisation could be helpful in terms of giving more transparency in decision making process and brainstorming. This was happened between different firms in SC network to ensure cross-functionality of solutions and also holistic approach towards all SC members.

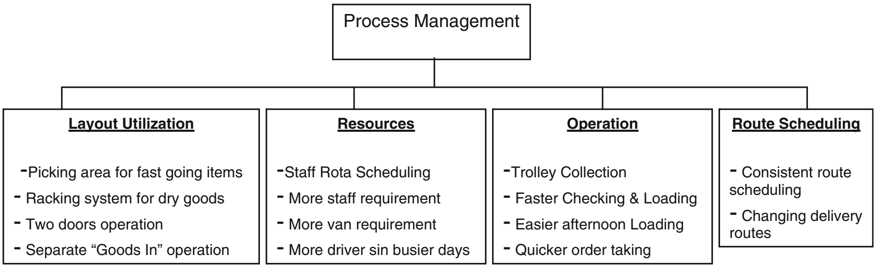

Fig. 18 Affinity diagram for the potential solutions in delivery lead time

Table 6 Prioritising the categories as the result of brainstorming

Header	Status	Priority
Layout utilisation	Consistent, practical, highly beneficial, costly, timely, low risk, Asset	1
Resources	Available, highly beneficial, complicated, expensive, high risk, overhead	3
Operation	Practical, low cost, complicated, high risk, high dependency, value adding	2
Route scheduling	Low cost, high risk, low practicality, complicated, high dependency	4

Analytical hierarchy process (AHP) is one of the most common tools to be used in the process of prioritisation through comparative approach. The few most effective solutions will be selected to be analysed by AHP through comparing their level of effectiveness on the cause of the defect in pairs. In the case of delivery lead time, the following solutions from category of "layout utilisation" were selected:

– Picking area for fast going items (A1)
– Racking system for dry goods (A2)
– Quicker Order Taking (A3)
– Separate "Goods In" operation with two doors in the warehouse (A4)

Each solution was tagged with a letter and number prior to be analysed in AHP. The analysis is based on a matrix comparison in which the level of importance of each individual solution will be scored in comparison with other individual solutions as the result of intensive and cross functional brainstorming within the SC. This will end up with selecting the most optimum solution to target the cause of the defect. Figure 19 represents the AHP for the delivery lead time in which the solution from another process of SC (loading process) was selected as the most optimum solution to reduce the number of defects. It means that "designing a picking area for fast going items" (A1) can be selected as the most optimum solution (with highest score) to reduce the spent loading time which was selected as the key cause of the defect (delivery lead time). The instruction over the calculation and analysis in AHP could be found in the internet or any statistical specific book.

$$\begin{array}{c} \\ A1j \\ A2j \\ A3j \\ A4j \end{array}\begin{array}{c} \begin{array}{cccc} Ai1 & Ai2 & Ai3 & Ai4 \end{array} \\ \begin{pmatrix} 1 & 5 & 5 & 7 \\ 1/5 & 1 & 1/3 & 1/5 \\ 1/5 & 3 & 1 & 7 \\ 1/7 & 5 & 1/7 & 1 \end{pmatrix} \end{array} = \begin{pmatrix} 1 & 5 & 5 & 7 \\ 0.2 & 1 & 0.333 & 0.2 \\ 0.2 & 3 & 1 & 7 \\ 0.143 & 5 & 0.143 & 1 \end{pmatrix} \quad \begin{array}{c} \\ A1j \\ A2j \\ A3j \\ A4j \end{array}\begin{array}{c} \begin{array}{cccc} Ai1 & Ai2 & Ai3 & Ai4 \end{array} \\ \begin{pmatrix} 1 & 5 & 5 & 7 \\ 1/5 & 1 & 1/3 & 1/5 \\ 1/5 & 3 & 1 & 7 \\ 1/7 & 5 & 1/7 & 1 \end{pmatrix} \end{array} = \begin{pmatrix} 1 & 5 & 5 & 7 \\ 0.2 & 1 & 0.333 & 0.2 \\ 0.2 & 3 & 1 & 7 \\ 0.143 & 5 & 0.143 & 1 \end{pmatrix}$$

$$W = \begin{bmatrix} 0.559 & 0.066 & 0.24 & 0.184 \end{bmatrix}$$

Fig. 19 AHP for selecting the most optimum solution to reduce the cause of the defect

Then, implementation plan could be adopted in the purpose of cost and benefit analysis. The level of risk, sensitivity, effectiveness, cost and actual benefit of this optimum solution can be presented in implementation plan to be discussed with different members of the SC. This solution was implemented in the case study resulted in £50,000 actual profit for the food distribution company and also other potential financial benefits for other SC stakeholders. The Six Sigma project could be more difficult to be carried out in inter-organisational level of food SC network. This is due to difficulty and complexity in information exchange, secrecy and also conflict of interest. But, it is important that the project team and especially the project manager focus on the bottom line which is customer and SC strategy rather than benefit for any individual firm within SC.

5.3 Six Sigma as a Quality Improvement Programme in SC

Six Sigma programme can be promoted as a quality improvement programme following an effective and continuous application of the Six Sigma projects in any organisation. Six Sigma programme embeds Six Sigma principles, success factors, training, methodology and tools and techniques. It means that if any SC sector considers Six Sigma projects in a complete version with some tangible results, Six Sigma can be labelled as the quality improvement programme for this SC. Therefore, application of some problem solving Six Sigma projects reactively in regular bases and through systematic and rigorous approach within SC possibly provides the platform for the whole SC entities to claim that they have successfully established Six Sigma quality improvement programme in their organisation. This would also cover some proactive approaches in the SC network to improve the performance. Six Sigma programme was the result of everlasting evolution in quality management and quality improvement initiatives. The requirement for more rigorous and systematic quality improvement programme to solve more complicated problems in complicated SC processes is the key motivation behind Six Sigma development in SC.

Six Sigma programme could improve the SC competence by focusing on quality, efficiency, effectiveness, reliability, and value-adding. It can reduce the variability in quality of delivered goods, delivery time, forecasting and scheduling. This will increase the chance of JIT application or service quality improvement. It means that Six Sigma can be used as a driving factor to improve the quality of service and achieve JIT in any SC activity through identifying and reducing the variability. There are number of time-related defects or variability in any SC process or sub-process, which can be targeted by Six Sigma. The systematic, rigorous and data-driven approach of Six Sigma can ensure the effectiveness, reliability and efficiency in any quality improvement project that is under taken in SC networks. Previous research case studies have indicated the role Six Sigma methodology in removing causes of the defect and therefore improving the equality of SC performance in delivery, supplier development and also order processing.

There are many hidden costs involved in SC activities that could be targeted by the Six Sigma as the cost of poor quality. For instance, reworking in relation to returned goods, poor transport and logistics in previous research case studies could be considered by Six Sigma project in reverse logistics. There are some waste measures related to the SC activities and processes that could be reduced through Six Sigma project to improve the quality and add value. Delivery lead time in one of the research case studies is a time-related measure, which is considered as a waste in any SC network. Six Sigma programme can be adopted, as it was indicated before to reduce the delivery lead time and add more value to the SC and logistics. Defect-free orders and deliveries in those case studies added more value to the SC by reducing the chance of inspection and rework. Six Sigma can also be used to reduce the process cycle time (refer to previous case studies) and also improve the agility of the SC. Lean SC can also be developed through identifying the lean-related measures to be improved through Lean Six Sigma (LSS) projects.

There are various quality-related SC measures that any improvement in their performance can result in SC quality improvement. Some of these measures have been adopted in these research case studies for a food distribution and wholesale company in a food SC. These measures, which are related and generalised to different SC processes, can be targeted by the Six Sigma project as the process of quality improvement. It means that if the Six Sigma programme is established in any organisation within any SC as quality improvement programme, these measures could be immediate targets by the project teams that need to be measured and improved. These measures could also be expanded to other entities in the SC to improve the inter-organisational measures in the SC. It means that cross-functionality and cross-integration in the SC to select these measures is a key success factor. Some of these SC measures were cited in Shepherd and Gunter (2006) and are listed in Table 7.

Table 7 Quality related supply chain measures (Shepherd and Gunter 2006)

Stages in supply chain	Measure	Quantitative (QN) or Qualitative (QL)
Plan	Fill rate	QN
	Order entry method	QN
	Accuracy of forecasting techniques	QN
	Autonomy of planning	QL
	Perceived effectiveness of departmental relations	QL
	Order flexibility	QN
	Perfect order fulfilment	QN
	Deviation from schedule	QN
Source	Buyer–supplier partnership level	QL
	Supplier defect-free deliveries	QN
	Supplier rejection rate	QN
	Mutual trust	QL
	Satisfaction with knowledge transfer	QL
	Satisfaction with supplier relationship	QL
	Supplier assistance in solving technical problems	QL
	Extend of mutual planning cooperation leading to improved quality	QL
	Extend of mutual assistance leading in problem-solving efforts	QL
Make	Distribution of decision competences between supplier and customer	QL
	Quality and frequency of exchange of logistics information between supplier and customer	QL
	Quality of perspective taking in supply network	QL
	Information accuracy	QL
	Information timeliness	QL
	Information availability	QL
	Inventory accuracy	QN
	Percentage of wrong products	QN
	Defect-free product	QN
Delivery	Delivery performance	QL
	Delivery reliability	QN
	Number of on-time deliveries	QN
	Effectiveness of distribution planning schedule	QL
	Effectiveness of delivery invoice method	QN
	Driver reliability for performance	QN
	Quality of delivered goods	QL
	Achievement of defect-free deliveries	QN
	Quality of delivery documentation	QL
Return (customer satisfaction)	Customer satisfaction	QL
	Level of customer perceived value of product	QL
	Customer complaint	QN
	Rate of complaint	QN

5.4 Six Sigma as a Business Strategy in SC

Six Sigma programme can be established as the part of business improvement strategy within and between all organisations and departments of the SC. It is required to practice Six Sigma in smaller projects and lower profile and gradually make the implication wider within organisation to inject it as a part of any strategy or policy setting in every single decision making within SC.

Collaboration, integration and inter and intra-team building is necessary to be adopted alongside other key success factors of Six Sigma to make the Six Sigma as a business improvement strategy. Its application originally needed top management and some commitment and support from relevant people to the process. However, wider spread commitment and involvement, deeper cultural transformation and broader view are required in order to establish the Six Sigma programme as a part of business strategy. It means that Six Sigma must be developed as the "mind-set" within SC in order to make it more effective in longer term as a business strategy. This is challenging in SC and needs more collaborative network of SC firms in order to communicate their strategic decisions, data and finally conduct a multi level and integrated Six Sigma team to be able to have a cross-functional and broad view in every single process involved in the SC.

This indicates the necessity of a partnership approach between firms in SC in order to facilitate to develop the Six Sigma programme as the business strategy for all relevant firms within SC and looks at the problems as the whole SC problem and work together to remove it. This also needs a valuable and distinctive cultural transformation equally and with the similar aspiration in spite of different power level within SC.

Figure 20 depicts that Six Sigma must be established as a mindset to keep all organisation within SC together and work with each other. This can set up a collaborative strategy within SC, which could be adopted to make the SC network stronger. It means that four elements of partnership, integration, collaboration and cultural transformation across any SC are required as pre-requisites to successfully

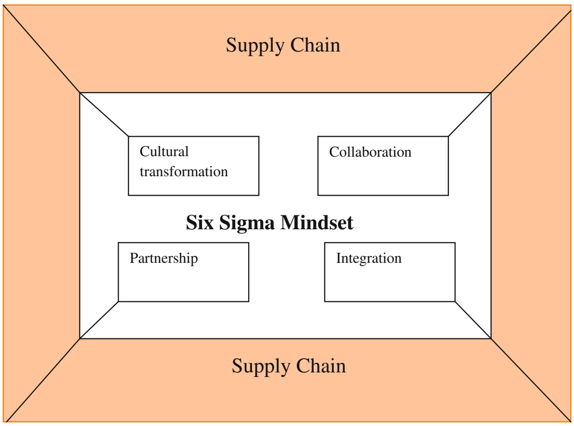

Fig. 20 The Six Sigma strategy within supply chain

implement Six Sigma programme as business strategy. However, this is as a matter of full implemention which results in establishing Six Sigma culture within any organisation and any SC.

6 Conclusion

This research article addressed the gap between practical aspects of Six Sigma programme and SC practices and measures. It was found that Six Sigma programme would be beneficial to any quantitative SC measure in terms of measurement, improvement and monitoring in a systematic and rigorous fashion. The result of research methodology and case studies highlighted the role of Six Sigma programme into practical aspects of SC such as supplier development, order processing and logistics. It is concluded that application of Six Sigma methodology in any SC process would not necessarily need the comprehensive model and it may be applied for targeting specific process or defect. The key finding of this research programme is that Six Sigma can be used as a single reliable and systematic package to measure and improve the SC processes by focusing on key measures with financial and strategic impact in whole SC. The biggest limitation of this research was focusing of the methodology on one specific SC as food SC and also focusing on just handful of SC measures in case studies, but the result can be generalised for any other SC and there is opportunity for further research programmes to review the role of four different aspects of Six Sigma on their measures. This research programme also highlighted more opportunity of Six Sigma and SC integration.

The managerial implication of this chapter relates to the integration of a systematic business improvement methodology into practical elements of SC and logistics to improve the efficiency and profitability in any organisation. The financial benefit of application Six Sigma methodology of DAMIC in SC and logistics is substantial, which will result in more competitiveness in market. Six Sigma applications in SC generate more opportunity for collaboration and reduce the chance of market failure. It is critically important to transform the culture, involve management team and to sustain the improvement via a cross-functional view in SC in order to establish any Six Sigma benefit in internal or external SCs.

Future studies are required to develop the effectiveness of Six Sigma methodology in SC and logistics through more practical approaches such as case studies and also research outputs. It is a great necessity to investigate the effect of Six Sigma implementation in SC for different sectors. This could be established through series of inter-related research studies and activities that can fill the gap in studies related to Six Sigma integration with SC. Further research studies can also focus more on specific logistics and SC measures in different types of industries and SCs as the process of problem solving methodologies.

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