

New Paradigm of Lean Six Sigma in the 4th Industrial Revolution Era

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ABSTRACT

Purpose: In early 2000s Six Sigma and Lean were combined into Lean Six Sigma (LSS), which has been one of the major strategic quality initiatives all over the world. Now, we are in the era of the 4th Industrial Revolution (IR), which changes almost everything including LSS and quality management (QM) in the companies. We need new paradigm of LSS to boost LSS activities in this 4th IR era. In this paper, the typical characteristics of the 4th IR are investigated, and desirable new paradigm of LSS is presented.

Methodology/Approach: The changing characteristics of production strategy, quality goal and quality strategy with regard to QM in the 4th IR are discussed and presented. Then the new and emerging paradigm of LSS in this 4th IR era is discussed in detail. Also 9 success factors for this new paradigm of LSS are shown for practitioners in the industry.

Findings: The direction of the new paradigm of LSS will be ‘simple, speedy and smart’, which may be called ‘3S paradigm’. Simple open procedures and simple statistical modelling tools will be mainly used. Speedy on-site improvement based on Open Data, Big Data and artificial intelligence (AI) will be favoured. Also smart mass customized ‘Smart Factory’ method will be emphasized.

Research Limitation/implication: Since we are in the beginning stage of the 4th IR, there are not many research papers which study the impact of this revolution to LSS and QM, which is the major research limitation.

Originality/Value of paper: This paper suggests some new and emerging paradigm of LSS, which could be of high value.

Category: Conceptual paper

Keywords: Six Sigma; Lean; Lean Six Sigma; 4th industrial revolution; quality responsibility

1 INTRODUCTION

Six Sigma and Lean are two quality management approaches that have received much attention and publicity to improve management processes over the past few decades. Six Sigma was first developed at Motorola in 1987 with remarkable results. In early 1990s, some leading electronic companies such as IBM, DEC, and Texas Instruments launched the Six Sigma approach. From 1995 when GE and Allied Sigma adopted Six Sigma as strategic initiatives, a rapid dissemination took place in non-electronic industries all over the world. Harry (1998), who is a well-known expert in Six Sigma, defines Six Sigma to be “a strategic initiative to boost profitability, increase market share and improve customer satisfaction through the use of statistical tools that can lead to breakthrough quantum gains in quality”. Later, Six Sigma was expanded to Design for Six Sigma (DFSS) for R&D and service activities. A good reference for DFSS is Park and Antony (2008). For a complete handbook for Six Sigma, see Pyzdek (2001), and to understand Six Sigma for quality and productivity promotion, see Park (2003). A recent literature review on Six Sigma can be found in Sony et al. (2019).

Lean manufacturing or Lean production, often simply called ‘Lean’, is a systematic method for waste minimization and value management within a manufacturing system without sacrificing productivity. Mass production systems based on work flow and the conveyer belt inspired Ohno (1978) to develop the Toyota Production System (TPS). The TPS was later coined as Lean in 1988 by Krafcik (1988), and then later by Womack, Jones and Roos (1990). The goal of Lean is to increase speed through the relentless elimination of waste and reduction of non-value-added activities from the processes. Womack and Jones (2003) define Lean as a tool for waste banishment and value creation. Recent references for literature review on Lean manufacturing are Bhamu and Sangwan (2014), Jasti and Kodali (2015) and Psomas and Antony (2019).

Both Six Sigma and Lean focus on customer satisfaction and improved business performance, and they use project management to improve results. However, if we compare both initiatives, we can find the clear differences as shown in Table 1 below. Good references to compare Six Sigma with Lean production are Dahlgaard and Dahlgaard-Park (2006), Andersson, Eriksson and Torstensson (2006), Arnheiter and Maleyeff (2005), Bendell (2006), Nave (2002) and Pacheco et al. (2015). Those references also show a detailed and historical analysis of Six Sigma, Lean production and Total Quality Management combined with a focus on the human factor and the needed corporate culture.

Table 1 – Comparison between Six Sigma and Lean

Initiative	Six Sigma	Lean
Theoretical Basis	Reduce variation	Remove wastes
Application guidelines	<ol style="list-style-type: none"> 1. Define 2. Measure 3. Analyse 4. Improve 5. Control 	<ol style="list-style-type: none"> 1. Identify value 2. Identify value stream 3. Flow 4. Pull 5. Perfection
Focus	Problem focused	Flow focused
Primary effect	Uniform process output	Reduced lead time
Criticism	<ul style="list-style-type: none"> • System interaction not much considered • Process improved independently 	<ul style="list-style-type: none"> • Statistical or system analysis not valued

The theoretical basis and focus of Six Sigma is the reduction of variation (of products/ product components) in the process, while that of Lean is the removal of wastes in the process. The major application guidelines for Six Sigma are DMAIC (Define, Measure, Analyse, Improve and Control), but those of Lean are IIFPP (Identify value, Identify value stream, Flow, Pull and perfection). The focus of Six Sigma is ‘problem’, but that of Lean is ‘flow’. The primary effect of Six Sigma is uniform process output by reducing variations of the process, but that of Lean is reduced lead time in the process. However, both initiatives have some criticisms. Six Sigma is criticized in that system interaction is not much considered, and, since each process is improved independently, the overall process may not be improved. Lean is criticized for not paying high importance to statistical and system analysis of each process.

Combining the theoretical bases, application guidelines and focuses of these two improvement approaches, the concept of LSS was first created by Wheat, Mills and Carnell (2001), and explained in detail by George (2002) and George (2010). LSS is a synergized managerial concept of Six Sigma and Lean (see also Hoerl and Gardner (2010), and Jugulum and Samuel (2008)). It combines the strengths of Six Sigma and Lean, and becomes more powerful for solving many practical problems.

As shown in the house of LSS of Figure 1, the goal of LSS is achieving ‘high value and quality, minimum waste and variation’ to be a world class company for stakeholder satisfaction. In order to achieve this goal, two big pillars are needed. The first is the Lean approach by speed acceleration and waste reduction for process innovation. The second is the Six Sigma approach by reducing variation, defects reduction and efficient process flow using continuous improvements and innovation. For these two pillars, project team efforts for continuous improvement are necessary. The base of the house is standardization and creating

facts by data. Therefore, a sound data management system is absolutely necessary for a good LSS management.

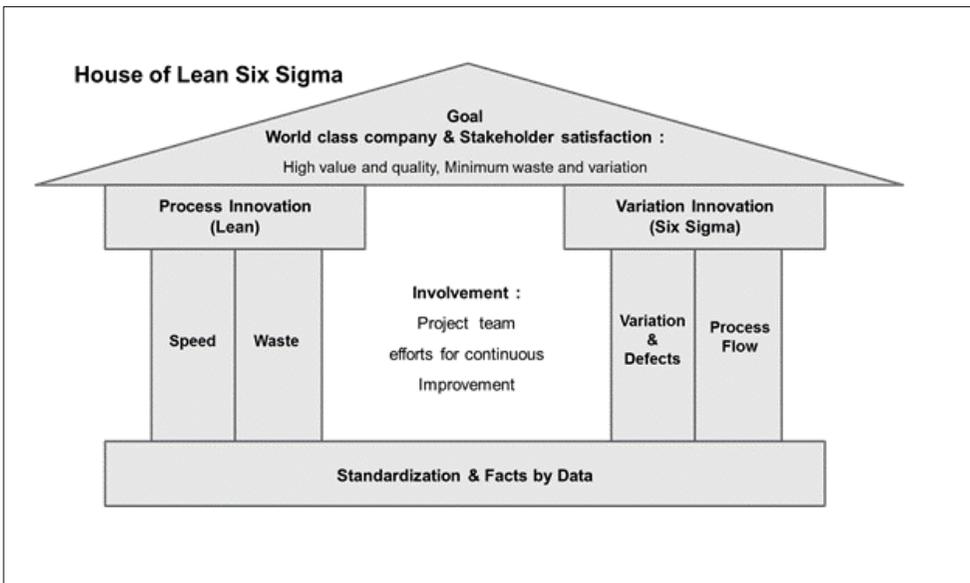


Figure 1 – Combining Lean and Six Sigma - House of Lean Six Sigma

Another point of view for LSS is that LSS allows not only process innovation with speed and waste reduction (by Lean), but also process efficiency with variation & defects reduction and efficient process flow (by Six Sigma). This concept may be called ‘Lean Design for Six Sigma’ which goes to ‘LSS Process Management’. This concept is graphically shown in Figure 2 for the essence of LSS.

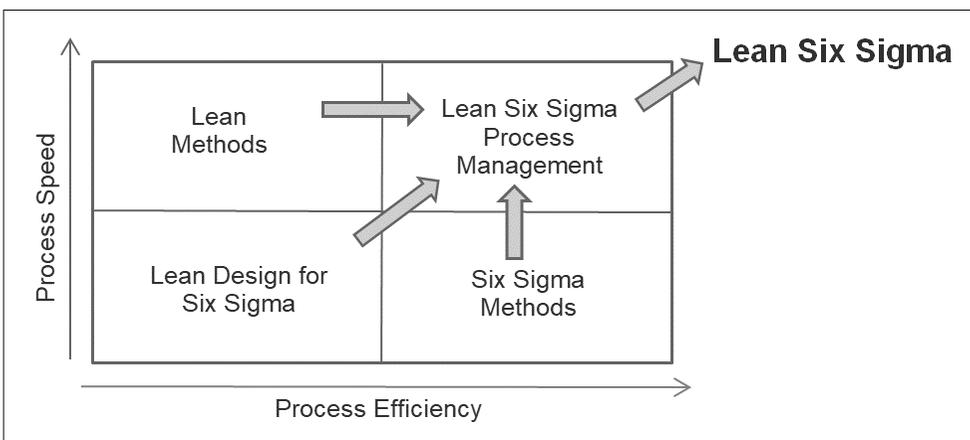


Figure 2 – The Essence of Lean Six Sigma for its Process Management

2 THE 4TH INDUSTRIAL REVOLUTION AND ITS IMPACT ON QUALITY MANAGEMENT

The 4th IR is now with us, and it is characterized by a convergence of physical and cyber technologies to produce intelligent digital transformation. While the term Industry 4.0 has been used since 2011 for referring and addressing the widespread integration of advanced information and communication technology for industrial purposes, Professor Schwab (2015) first introduced the term of 4th IR, and the major theme of the 2016 World Economic Forum was the impact of the 4th IR. However, we can also find cases where other people ‘warned’ the arrival of a new industrial revolution. For instance, prior to Schwab (2015), Cameron (2014) delivered a speech referring to the emergence of internet of things (IoT), ‘a new industrial revolution that will boost productivity, keep us healthier, make transport more efficient, reduce energy needs and tackle climate change’.

While previously recognized, industrial revolutions are all characterised by their significant capability to transform businesses, industrial structures, workforces, and even society in broad aspects, we are now witnessing a new wave of industrial revolution. We now live in a world in which billions of people can be connected to each other through mobile devices with unlimited access to knowledge with the help of emerging technologies such as artificial intelligence (AI), Big Data, robotics, IoT, cloud computing and more. The 4th IR is really changing all aspects of human life including the culture of Quality Management in industry as mentioned in Park et al. (2017).

The 1st IR began in England in the late 18th century, and introduced steam-powered and mechanized production. The Second began in the U.S. in the early 20th century, and introduced electric power and mass-production processes. The Third, which also began in the U.S. in the middle of the 20th century, introduced computers and the digitalization of technology. The 4th IR, which began in the early 21st century, and its characteristics with regard to QM, are shown in Figure 3. As far as production strategy is concerned, mass customization and personalized production will be popular in the 4th IR, since fast IT, customer Big Data and smart factory implementation become available. Before the 4th IR, machine production, mass production and lean production were the major production strategies. In the 4th IR, the speed of production, after delivery service, feedback of customer demands and others, will become increasingly important factors in QM.

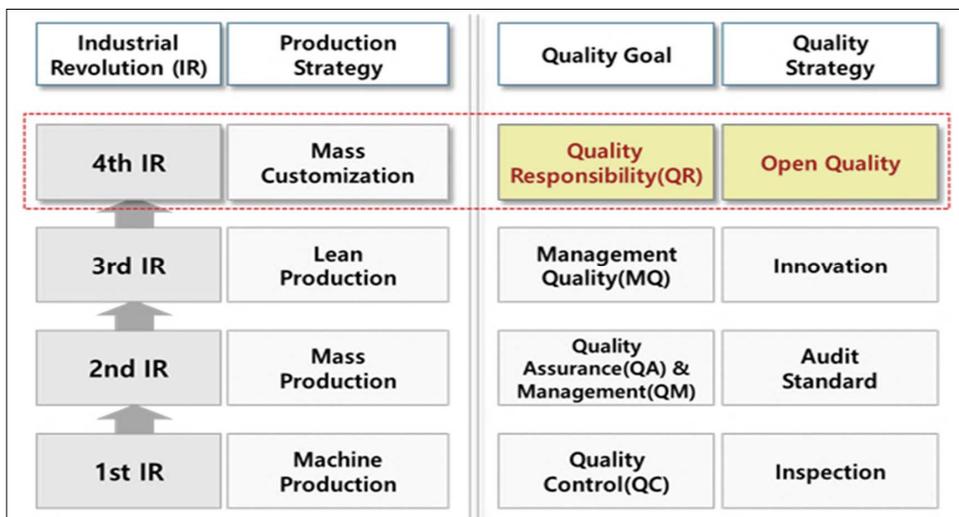


Figure 3 – The Four Stages of IR, Production Strategy, Quality Goal and Quality Strategy

From the evolution of quality in Figure 3 we have observed that the quality goals, scopes and focusing areas have been changing constantly in accordance to the environmental and technological changes (Dahlggaard and Dahlggaard-Park, 2006). For example, Quality Goals was changed or expanded from the 1st IR to the 4th IR as follows: Quality Control (QC), Quality Assurance (QA) and Quality Management (QM), Management of Quality (MQ), and finally we may say that the goal of quality in this 4th IR includes Quality Responsibility (QR). In the 4th IR era, not only the personalized service quality, but also the design, safety and brand quality become more important than before. With innovative technology for connectivity and smart computation, the ability to trace quality for each customer is being maximized in all product and service characteristics. Quality responsibility (or accountability) to all customers, the environment and society are required. For this purpose, the concept of social responsibility, introduced by ISO 26000, is added to quality responsibility. Also the concept of ‘green’ LSS will be pursued to make the world be a better living place. More explanation about “green LSS” is required.

The changes/ evolution in quality strategies according to the four stages of IR are from inspection, audit and standards, innovation, to Open Quality for the 4th IR. The changes in quality goals and strategies are results of purposeful efforts paid by organizations in order to improve both the internal processes and the external relationships of organizations. The managerial framework of TQM that emerged in the last part of the third stage can be considered as a kind of culmination that provided comprehensive tools and techniques, and principles for achieving organizational wide improvements. For instance principles of customer focus, relationship with suppliers, competitors, communication and deal with quality improvements specifically in relationships outside the organization, while other

principles such as top management commitment, leadership, focus on employees, process management focus on the improvement of internal aspects of organizations are basic principles (Singh and Smith, 2004). When combining all TQM principles, tools and techniques, the organizations can be equipped with a managerial framework, which can be applied to strengthen efficiency as well as effectiveness and due to that TQM has been considered to be a holistic management framework (Dahlgard-Park et al., 2013).

Chesbrough (2011; 2012) referred to closed innovation when the processes, products and services are the results of internal organizational innovation. That's why closed innovation is also called as vertical development because the innovation is happening within the organizational boundary. However open innovation is characterized by the integration of external knowledge with the internal knowledge of the organization, and due to that the issue of continuously identifying and measuring customer needs and desires in a cost effective way has been recognized to be one of the biggest challenges when implementing open innovation (Van de Vrande et al., 2009). Encouraging the customers and involving other external stakeholders in the innovation processes along with encouraging, motivating and involving employees has been equally emphasized, since the innovation process requires a combination of internal and external knowledge (West and Gallagher, 2006). The close relationship with the customers and the constant work with them have been emphasized as a critical success factor of the open innovation, not only in production but also in services (Chesbrough, 2003; 2012).

Identifying customers' needs and desires and thereby involving customers for gaining customer satisfaction has long been recognized to be the most important goal, and internal process improvements, focus on employees as well as other internal improvements activities have been targeted to support that goal within the TQM framework. In this way we can say that there are many similarities and close relationship between TQM and open innovation approaches. In many ways, the implementation of TQM nurtures and creates a proper organizational culture that is also recognized to be necessary for open innovation (Maistry, Hurreeram and Ramessur, 2017). Based on this background we propose using the term, 'open quality' as a new quality strategy. The open quality will be a good and proper solution for organizations in responding to multiple challenges emerged by not only the rapid technological development but also by the increasing globalization.

Open quality accounts for all quality characteristics of any product and service that are designed, produced, marketed, and sold based on open and transparent approaches. The word 'open' is used here to guarantee that the data generated in each section of a company are open to the other sections of the company. Furthermore, the data generated for a particular product of a company are open to external stakeholders/companies to openly promote the overall quality and productivity of the product. This goal can be attained through an open quality system where key factors such as speed, creativity, data analytics, and AI are

combined to provide a comprehensive approach for meeting dynamic consumer requirements.

Quality of data and software will be a critical issue in the 4th IR era, because most technologies such as Big Data, AI and IoT are all based on data and software. Eventually, the data and QM supporting software becomes more important; simple and smart QM systems will be necessary. A well designed simple and smart QM system for handling data and software may have the highest value in the 4th IR era.

3 NEW PARADIGM OF LEAN SIX SIGMA AND ITS ENABLERS

It is the authors' belief that the new paradigm of LSS will be '3S LSS' where 3S means 'Simple, Speedy and Smart'. The new directions of the '3S' are summarized in Figure 4 together with their innovation enablers. For the simple LSS, we need an easy problem-solving roadmap, and simple and open procedures. Use of traditional easy tools of Six Sigma and Lean such as DMAIC phases, project team activities of green belts and black belts, value stream mapping, 5S (Sort, Set in order, Shine, Standardize and Sustain), etc. Also simple statistical modelling for prediction is much simpler by using statistical software such as R, SAS, Minitab and so on.

We can observe that the speed itself has become an important characteristic of Quality Management which we believe will be even more important in the future. To achieve speedy LSS, speedy on-site improvements based on 'Open Data' will be necessary. Also project activities should provide speedy improvement in short time. The use of new methodologies such as Big Data, AI and IoT will be introduced, and some type of business customer platforms will be extensively practiced.

For the *smart* LSS, mass customized 'Smart Factory' methods for business improvement will be adopted, and LSS associated with smart 'green' initiatives will be introduced. Also AI and Big Data assisted LSS activities for quick and correct action will be used.

There are many 3S LSS innovation enablers, and some of them are listed in Figure 4. The first one is 'IT based open quality system for speedy multi-way information flow', which emphasizes that the open, speedy and multi-way simultaneous information (quality, productivity, customer demand, waste, value stream, etc.) flow among all stages (plan, design, production, marketing, sales, etc.) of company business is an important 3S LSS innovation enabler. The lastly listed one is 'intensive use of the 4th IR technologies such as Big Data, AI and IoT'.

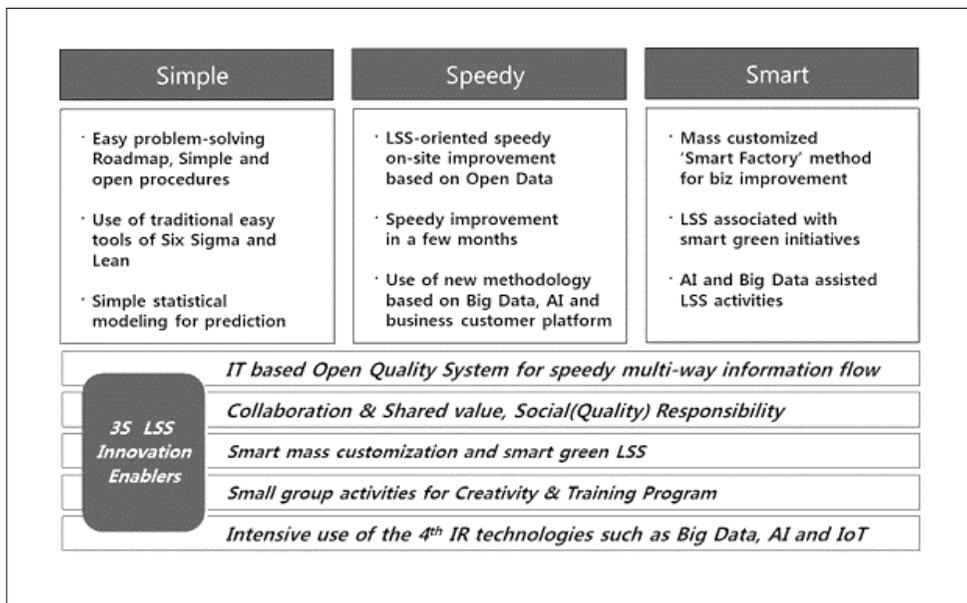


Figure 4 – The Four Stages of IR, Production Strategy, Quality Goal and Quality Strategy

In the 1990s the internet technology was the most powerful in changing the society. It seems that in the 4th IR, AI will become the most powerful technology to change almost everything including the industry. For instance, AI in a hospital can read several thousand MRI pictures in a few minutes, and can diagnose the patients much better than the doctors. There are at the moment no limits for the number of possible AI related LSS projects which LSS may handle and many countries have announced new intended or already initiated AI initiatives. In USA for example, the Trump administration has announced that the most important technology in a generation is AI, and announced the Executive Order on 'Maintaining American Leadership in AI' (issued on February 11, 2019).

Table 2 – The Simple Approach for the DMAIC Process in the New Paradigm of Lean Six Sigma

Phases	Standard 15 steps in the past LSS	Simplified 5 steps for '3S LSS'
Define	<ol style="list-style-type: none"> 1. Project selection 2. Project definition 3. Project approval 	1. Problem definition
Measure	<ol style="list-style-type: none"> 4. Confirm Y's 5. Confirm Baseline of Y's 6. Confirm potential causes(X's) 	2. Goal setting and confirmation of Y's and X's
Analyse	<ol style="list-style-type: none"> 7. Collect data 8. Analyse data 9. Select vital few X's 	3. Analysis of data and selection of true causes

Phases	Standard 15 steps in the past LSS	Simplified 5 steps for '3S LSS'
Improve	10. Establish improvement plan 11. Optimize vital few X's 12. Validate improved results	4. Optimization and Improvement
Control	13. Establish control plan 14. Execute control plan 15. Documentation	5. Standardization and control plan

As an example of simple LSS, we propose an easy problem-solving roadmap for DMAIC to be used in all business areas. In the past the standard of 15 steps have been used for the DMAIC process, but in the simple LSS much simpler 5 steps may be used as shown in Table 2.

Figure 5 shows another example of a 'simple, speedy and smart' manufacturing management process based on IT infra, in which LSS activities can work to reduce wastes and variability. Any LSS project team may work on this process to make the management simple and transparent, and to build speedy decision systems based on sound ethics and group innovation culture. In the process, several management systems are involved such as product data management (PDM), supplier relationship management (SRM), manufacturing execution system (MES), global logistics system (GLS), customer relationship management (CRM), advanced planning system (APS) and enterprise resources planning (ERP), and SCM.

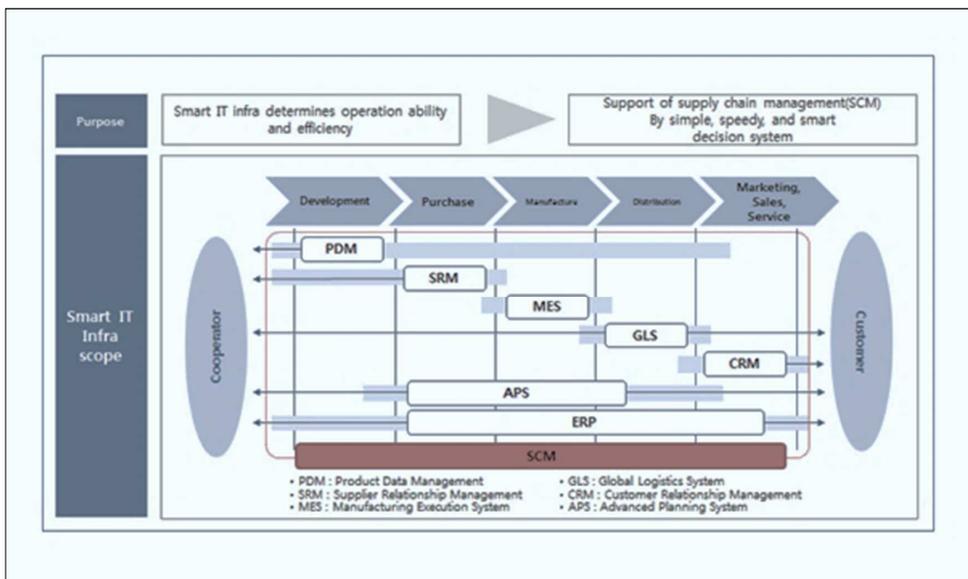


Figure 5 – An Example of Integrated Field Management Processes which 3S LSS Can Work on

4 A CASE STUDY OF 3S LSS IN KOREA

In this section the authors will shortly introduce a case study from Korea, where the 3S LSS concepts are practiced. Amore Pacific, which is the leading cosmetics company in Korea, started to implement Six Sigma in 2003 to “strengthen itself as a global company which satisfies the customers essential needs, and to attain a higher level of management capacity” (Amorepacific, 2020).

Kim and Ree (2017) explained that Amore Pacific introduced Lean manufacturing in 2016 to optimize not only process innovation with speed and waste reduction but also the ways to work for all business areas. The company combined Six Sigma with Lean and called the combined strategy ‘Lean Sigma’.

Table 3 shows the ways of LSS implementation in Amore Pacific. The typical methodologies of Six Sigma, DMAIC and DFSS are modified to Lean concepts (Lean DMAIC, Lean DFSS, Lean Sales), and Lean QSS (Quick Six Sigma) is proposed and implemented by Amore Pacific. Table 3 also shows that the two concepts of ‘speedy’ and ‘smart’ are reflected in the ‘Lean Sigma’ framework. Amore Pacific also argues that it combines Six Sigma and Lean to make a simpler version of process management called ‘Lean Sigma’. The company also declares that IT supported management makes Lean Sigma activities simpler than before. The authors found out, that the basic concepts of ‘3S LSS’ are already been practiced in Amore Pacific, and Amore Pacific has achieved a big success in management innovation by using the new concept of LSS.

Table 3 – The new Concept of Lean Six Sigma in Amore Pacific

Business Area	Lean Six Sigma (speedy and smart improvement)				
	Lean DMAIC	Lean DFSS	Lean Sales	Lean QSS	Remarks
R&D	○	○			R&D process improvement New product development
Marketing (Sales)	○	○	○		New concept design for marketing and Lean-oriented sales services improvement
Manufacturing/Logistics	○	○		○	Lean-oriented on-site improvement in two-month
Management Support/IT	○	○			Lean-oriented 6 sigma improvement, and IRT supported smart management

5 IMPORTANT ASPECTS OF THE 3S LSS AS A NEW PARADIGM OF LEAN SIX SIGMA

Some of the important aspects of the new paradigm of LSS explained above are as follows.

- (1) The important characteristics of the 4th IR such as mass customization, quality responsibility, open quality and smart factory will be incorporated into the 3S LSS. In practice it will be necessary for the 3S LSS activities to be simple, speedy and smart to match well to the characteristics of the 4th IR.
- (2) The use of AI, Big Data and IoT will be more emphasized in the 3S LSS. Also the quality of data and software system will be of significant value.
- (3) Corporate Social Responsibility (CSR) and Creating Shared Value (CSV) will become important concepts of the 3S LSS, and they will be combined to reflect quality responsibility.
- (4) Speedy multi-way information flow for the 3S LSS activities will be more popular in all stages of production system (plan, design, production, marketing, sales) by use of IT, Big Data, AI and IoT.
- (5) The 3S LSS experts will be more likely also data scientists in the future, because quality information can be mostly controlled by data analytics.
- (6) Business platform companies will occupy more markets. The 3S LSS activities to improve the quality of platform will be more focused. AI platform software such as Google's 'AI Assistant' will be more powerful for business handling.
- (7) Combining AI, Big Data, IoT and Cloud will begin to dominate the world market. The 3S LSS activities to improve the quality of such convergent technologies will be a major issue of quality management in the future.

To make the 3S LSS activities successful in the future, we need 9R success factors for the new paradigm LSS. They are as follows.

- (1) Right style: Develop simple, speedy and smart style LSS which is suitable for the 4th IR.
- (2) Right leadership: Get the top managers involved.
- (3) Right participation: Keep the message simple and clear, and request the participation of all employees.
- (4) Right project: Select the right projects and train capable black belts to concentrate on project team efforts.
- (5) Right result: Focus on speedy (short-term) results and long-term growth.
- (6) Right communication: Communicate, publicize and award results, and admit setbacks.
- (7) Right link: Link customers and your processes.

- (8) Right training: Make learning an ongoing activity, and make an investment to make it happen.
- (9) Right tool: Use LSS tools wisely including Big Data, AI and IoT of the 4th IR technologies.

6 CONCLUSION

The 4th IR is changing the concept of QM as well as the concept of LSS. If a company is not well aware of the big change influenced by the 4th IR, the future prospect of its QM and LSS is not bright. It is suggested that the direction of the new paradigm of LSS will be 'simple, speedy and smart', which may be called the '3S LSS' paradigm. Simple open procedures and simple statistical modelling will be mainly used. Speedy on-site improvement based on Open Data, and Big Data and AI assisted new methodology will be favoured. Also mass customized 'Smart Factory' method and LSS focused on smart green initiatives will be emphasized. For successful implementation of the new paradigm of LSS, 9R success factors are suggested.

The promotion of Six Sigma, Lean or Lean Six Sigma all over the world has been stabilized, and is somewhat decreasing. It is the authors' belief that LSS quality initiatives and practices need to be changed to accommodate the trend of the 4th IR. It is our hope that this article may give some valuable insights to many quality experts for quality and innovation management promotion in this rapidly changing society. Also, since we are in the beginning stage of the 4th IR, there are not many research papers which study the impact of this revolution to QM and LSS. The authors expect that the near future will bring many challenging issues for the new directions of QM as well as LSS.

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S.H.P. – preparation of the first draft paper; S.M.D.-P. – reading the draft paper and revising the draft paper; D.-CH.K – preparation of all figures.

CONFLICTS OF INTEREST

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