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Operations Management and Systems Engineering

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Lecture Notes on Multidisciplinary Industrial Engineering

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About This Book

This volume contains extended research work of researchers who participated in the Fifth International Conference on Production and Industrial Engineering (CPIE) 2018. Manuscripts with analytical models, reliability and maintenance engineering, supply chain management, human factor engineering, decision-making case studies with simulation approaches in the area of operations management and systems engineering have been included.

The Conference on Production and Industrial Engineering (CPIE) series, from which this special issue has been derived, was started by the Department of Industrial and Production Engineering, Dr. B.R. Ambedkar National Institute of Technology Jalandhar, India, in March 2007. Subsequently, CPIE 2010, CPIE 2013 and CPIE 2016 were organized which attracted renowned academicians/researchers, noted industry representatives and delegates from countries like Canada, UK, France, Australia, Russia, Singapore, Iran, Egypt, Algeria, Bangladesh, Israel, Mauritius, Turkey and India. We would like to express our gratitude towards all the authors for contributing their valuable articles for our Conference. Finally, we would like to acknowledge the reviewers for their painstaking and time-consuming effort in reviewing manuscripts and providing their thorough evaluations for improving the quality of the articles.

We would also like to express our sincere gratitude towards the Springer team. Last but not least, we would also like to express our sincere gratitude towards our worthy Director (Professor) Lalit Kumar Awasthi for his wholehearted support for the smooth conduct of the conference.

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About the Editors

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Chapter 1
Tolerance Analysis of Mechanical Assemblies Using Monte Carlo Simulation—A Case Study

Pradeep K. Singh and Vaibhav Gulati

Abstract Different parts of a mechanical assembly are usually manufactured at different units so as to be assembled later. The assembled parts must fit together without any interference or unnecessarily large clearance. This paper presents the study of the effect of variation in dimensions of individual parts on the assembly response using Monte Carlo simulation. This technique represents the process distribution of the dimensions of individual parts, which helps in determining the assembly response and yield estimation of successful assembly. A case study on a cylinder-piston assembly has been attempted. The simulation has been carried out using MATLAB 7.0 with different theoretical process distributions (uniform, normal, and beta) and yield has been estimated. The aim of this study is to establish a simple yet powerful technique (Monte Carlo simulation) for tolerance analysis and yield estimation of mechanical assemblies. This approach quantifies and handles both the normal and non-normal process distributions.

Keywords Tolerance analysis · Monte Carlo simulation · Assembly · Yield

1.1 Introduction

An engineering assembly is characterized by a critical parameter or critical dimension, commonly called assembly dimension or assembly response (Y). The relationship between the assembly dimension (Y) and the individual dimensions (X_i) is called assembly response function "$Y = f(X_i)$". Any variation in individual dimensions will directly affect the assembly dimension, and hence the performance of the assembly. In mass production, the individual dimensions have their own distributions. The random assembly of these dimensions gives rise to the distribution of the resultant assembly dimension. Tolerance analysis is the methodology to estimate the resultant

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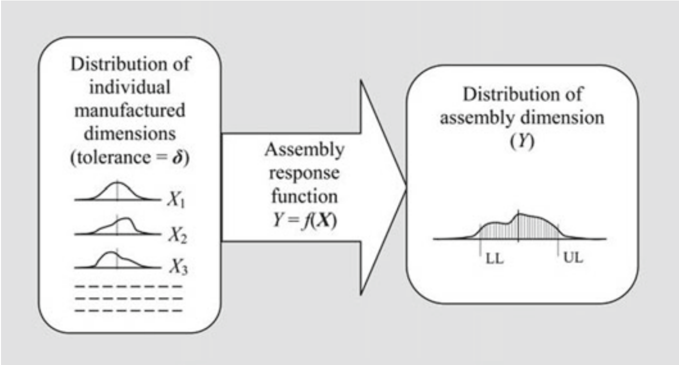


Fig. 1.1 Tolerance analysis of mechanical assemblies [18] LL and UL: Lower and upper limits on assembly dimension

variation of the assembly dimension, given the tolerances associated with individual dimensions (δ_i), and the assembly response function [1]. If the limits of variation of assembly dimension are set, the fraction of successful assemblies meeting the design requirements, called yield, can also be estimated (Fig. 1.1).

Tolerance analysis establishes a procedure to estimate (i) the resultant variation of the assembly dimension, (ii) distribution of the assembly dimension, and (iii) fraction of successful assembly (i.e., assembly yield), given the tolerances associated with individual dimensions, the assembly response function, and the specifications of the assembly dimension(s). Different approaches to tolerance analysis have been proposed over the decades. Traditional approaches to tolerance analysis, viz., the worst case, and the root sum square are based on a few unrealistic assumptions, and hence do not fulfill the requirements of the real-world assembly design. The importance of tolerance analysis in assembly design attracted the attention of a large number of researchers, with the result the topic has been addressed in depth. A brief account of these approaches has been presented by Singh et al. [18].

In this study, an effort has been made to demonstrate tolerance analysis of mechanical assemblies using Monte Carlo simulation with the help of a case study on a cylinder-piston assembly. The random sampling of the cylinder-bore and piston diameter has been carried out for three different theoretical process distributions (uniform, normal, and beta). The range of variation of assembly dimension (diametric clearance between the cylinder and the piston), mean, standard deviation, and yield of successful assembly have been estimated for all three cases. Effect of tightening of the tolerance (specified for the assembly dimension) on the yield of successful assembly has also been analyzed.

1.2 Literature Review

The tolerance design of mechanical assemblies has widely been explored in the research. With the increased interest in the tolerance design problem, various approaches to classical tolerance analysis and synthesis were evolved. A few survey articles on the topic have been reported by Gerth [6] and Ngoi and Ong [13]. Hong and Chang [9] present the most comprehensive discussion on tolerancing research covering various aspects. However, their focus on tolerance analysis and synthesis has been very limited. Singh et al. [18] seem to have presented a detailed and updated discussion fully dedicated to tolerance analysis.

A number of commercial and noncommercial software packages have been developed to make the tolerance design practice easier with a focus on tolerance analysis. With the help of software packages, tolerance synthesis can indirectly be carried out, by attempting tolerance analysis in an iterative manner. This is done by changing the input parameters (tolerances associated with individual dimensions) and estimating the accumulated tolerance and the yield, but without consideration of manufacturing cost.

Commercial software packages offer tolerance analysis capability either through add-ons to existing spreadsheet applications or integration with CAD packages [3]. Many of these are based on the application of Monte Carlo simulation. A brief review of the software packages has been presented by Singh [17].

According to the published literature, a large number of approaches to tolerance analysis have been proposed for tolerance analysis. The Monte Carlo simulation appears to be the most popular tolerance analysis approach because of its simplicity and versatility of application, and the unlimited achievable precision. The research applications of this approach include Gerth and Hancock [7], Bruye‘re et al. [2], Dantan and Qureshi [4], Gulati [8], Qureshi et al. [14], Yan et al. [20], etc. A detailed discussion on these researches shall not be useful. This approach is the basis of most of the tolerance analysis software, and has been applied in research as a reference (yardstick) for evaluating the performance of other approaches [5, 10, 15, 21].

1.3 Design of Simulation Methodology—Monte Carlo Simulation

The Monte Carlo simulation approach is based on stochastic sampling technique, and is useful to simulate the randomly occurring natural phenomena. Since the actual dimensions obtained in manufacturing are random in nature with a definite pattern, the approach can be applied to study an engineering assembly for statistical tolerance analysis. The approach appears to be simple to estimate the variation in the assembly response; and is applicable to both the linear and nonlinear assembly response functions, and, the normal and non-normal process distributions. This approach directly yields the distribution of assembly response, which makes it more useful [16]. The statistical tolerance analysis problem can be attempted through the simulation following a systematic procedure given below.

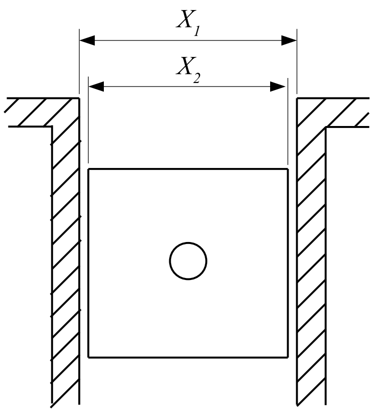
a. Identification of assembly dimension(s), individual dimensions, and dimension chain(s) in the assembly.
b. Formulation of the assembly response function(s) "$Y = f(X_i)$".
c. Specification of the probability density function (pdf) to individual dimensions.
d. Random sampling of individual dimensions and simulation of assembly, i.e., forming a virtual assembly to obtain assembly dimension(s).
e. Estimation of yield—the proportion of successful assembly, out of the total simulations.
f. Estimation of statistical parameter of distribution—spread (range), mean, standard deviation, etc. of the distribution of assembly dimension(s).

The accuracy of the results obtained with this approach is proportional to the square root of the sample size. This makes the approach highly computationally expensive for better results. In spite of this, a few authors explored the application of this approach in the tolerance design [5, 11, 12, 19]. With the availability of highly efficient modern computers at an economical rate, the application of the approach is no more a problem.

1.4 Case Study–Cylinder-Piston Assembly

The simulation-based computer-aided system for the tolerance analysis has been presented with the help of a numerical example of the cylinder-piston assembly (Fig. 1.2). The tolerance analysis has been carried out with the help of MATLAB 7.0.

Fig. 1.2 Engine (cylinder-piston) assembly



Assembly response function: $Y = X_1 - X_2$

Table 1.1 Dimensional details for cylinder-piston assembly (Courtesy: FMGI Ltd., Bahadurgarh)

S. No.	Cylinder-bore diameter (mm) ($X_1 \pm \delta_1$)	Piston diameter (mm) ($X_2 \pm \delta_2$)	Specified assembly clearance (mm) (Y)
1	95.042 ± 0.010	94.912 ± 0.010	Worst-case assembly tolerance (0.130 ± 0.020)
2	95.042 ± 0.010	94.912 ± 0.010	Reduced assembly tolerance (0.130 ± 0.015)
3	95.042 ± 0.010	94.912 ± 0.010	Reduced assembly tolerance (0.130 ± 0.010)

The need for tolerance analysis is especially prevalent in assemblies where some assembly features are more critical to the functioning of the product than others. An example of a critical design feature is the assembly clearance (Y) in the cylinder-piston assembly. In order to make the cylinder-piston assembly function properly, the assembly clearance must be larger than zero to prevent jamming, and smaller than a specified value to perform the axial motion between the cylinder and the piston satisfactorily.

This assembly clearance (Y) is not a manufactured feature, i.e., the actual size and shape of this gap is not directly controllable in manufacturing. Rather, it is an aggregate property of the assembly which results from the interaction between the mating features of the components when assembled. The size of the gap can be expressed in terms of component dimensions X_1 (cylinder diameter) and X_2 (piston diameter), (Eq. 1.1). The tolerance of Y is the sum of the tolerances associated with the component dimensions X_1 and X_2, regardless of whether the component dimensions are added or subtracted (Eq. 1.2).

$$Y = X_1 - X_2 \tag{1.1}$$

$$Tol_Y = Tol_{X1} + Tol_{X2} \tag{1.2}$$

Based on either experience or adopted practices, the product designer assigns appropriate tolerance values to X_1 and X_2. The tolerance analysis can thus ensure the product functionality while allowing the widest allowable tolerances to be assigned to the component dimensions/features for economic production. The dimensional data of the cylinder-piston assembly for the proposed case study has been obtained from an automobile parts manufacturing company [Federal Mogul Goetze India Ltd. Bahadurgarh (Patiala)]. The same has been presented in Table 1.1.

1.4.1 Random Sampling of Dimensions

(a) Cylinder-bore diameter (X_1)
For the calculation of the sample size for cylinder-bores, a set of 2000 samples was generated in the specified tolerance range (95.042 ± 0.010) following a uniform distribution. After a set of 205 samples, the sample mean became almost constant within ±5% of the specified tolerance (i.e., 0.0005 mm) which is very close to the true mean (95.042 mm). Details have been presented in Fig. 1.3.

(b) Piston diameter (X_2)
For the calculation of the sample size for pistons, a set of 2000 samples was generated in the specified tolerance range (94.912 ± 0.010) following a uniform distribution. After a set of 100 samples, the sample mean became almost constant within ±5% of the specified tolerance (i.e., 0.0005 mm), which is very close to the true mean (94.912 mm). Details have been presented in Fig. 1.4.

In the same way, the practical approach has been used following normal and beta distribution. For the normal distribution, the approach estimates a sample size of 126 for cylinders and 25 for pistons. For beta distribution, the approach estimates a sample size of 56 for cylinders and 115 for pistons. For better accuracy of the results, $N_{simulation} \geq N$. Thus, tolerance analysis has been carried out for 500 assemblies by applying Monte Carlo simulation.

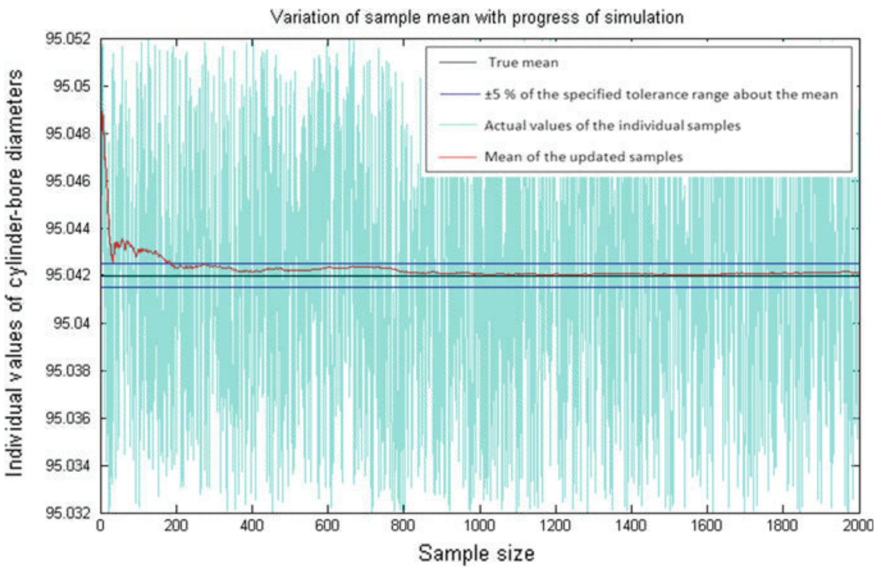


Fig. 1.3 Variation of sample mean with progress of simulation (X_1)

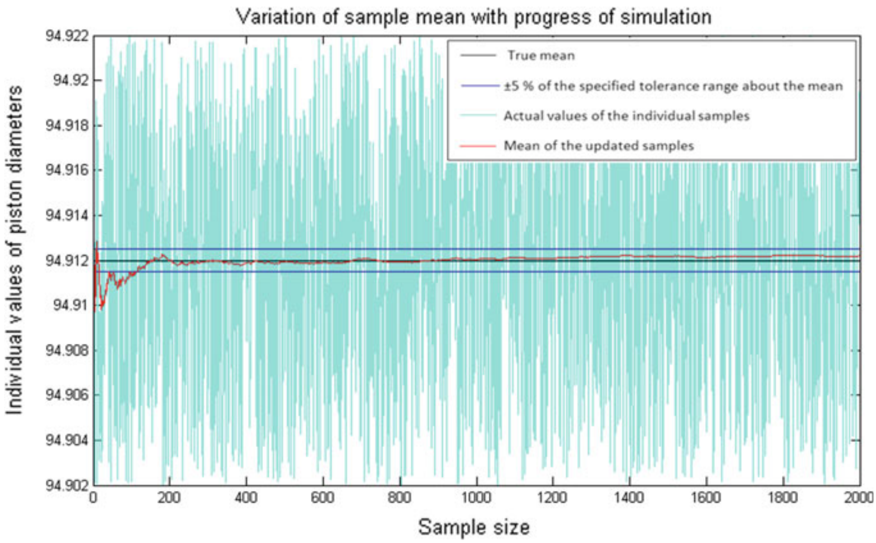
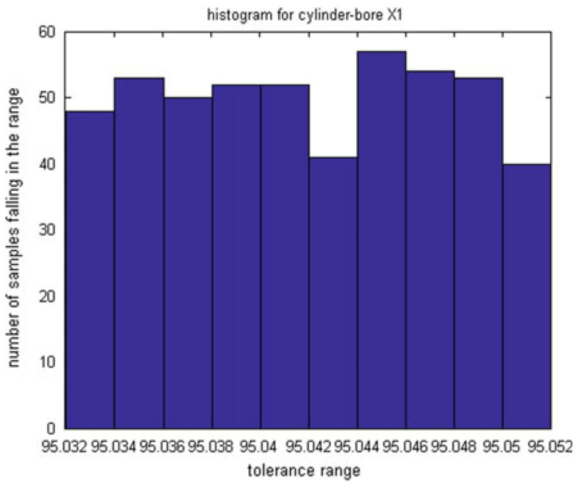


Fig. 1.4 Variation of sample mean with progress of simulation (X_2)

Fig. 1.5 Histogram for distribution of cylinder-bore diameter (X_1) (uniform distribution)



1.4.2 Tolerance Analysis and Yield Estimation

Tolerance analysis for assembly clearance has been carried out for 500 assemblies applying Monte Carlo simulation. Histograms showing distribution of the clearance between the cylinder-bore and piston have been drawn based on uniform (input) distribution. Similar histograms can be obtained for the normal and beta distributions as well.

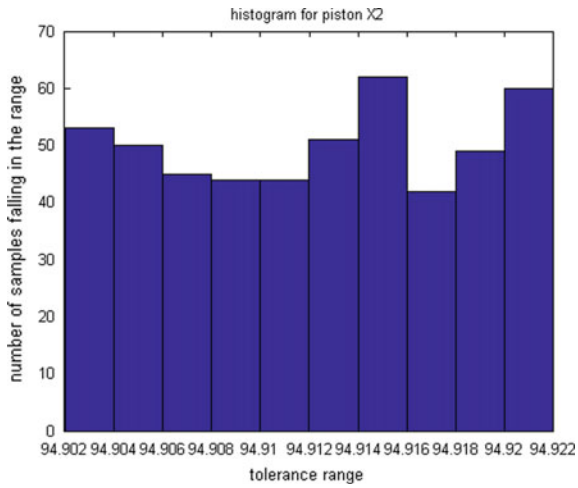


Fig. 1.6 Histogram for distribution of piston diameter (X_2) (uniform distribution)

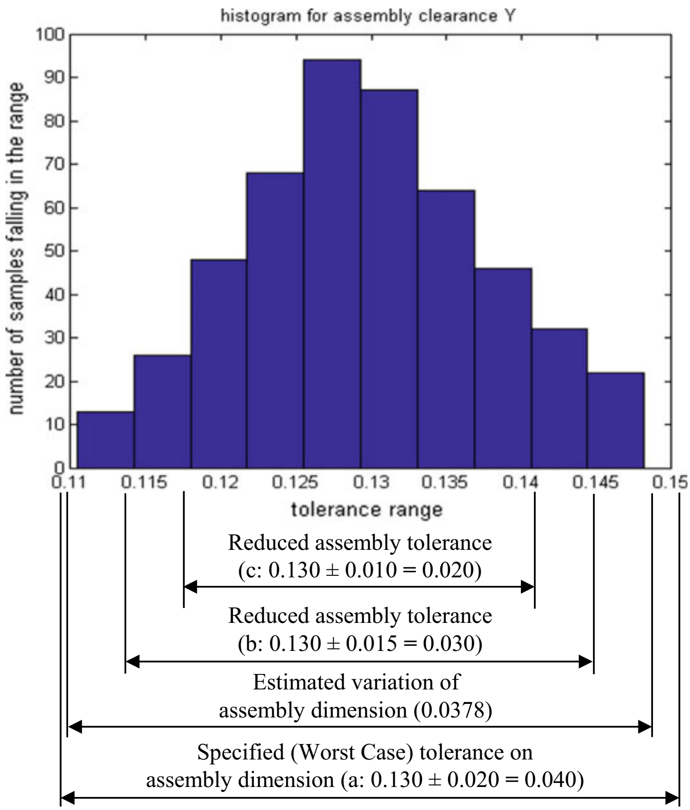


Fig. 1.7 Histogram for distribution of assembly clearance (Y) (uniform distribution)

1.4.2.1 Uniform Distribution

A set of 500 random samples for each of cylinder-bore (X_1) and piston (X_2) has been generated in the specified dimension range following uniform distribution and the assembly clearance (Y) has been obtained. The histograms for distribution of cylinder-bore diameter, piston diameter, and assembly clearance have been represented through the Figs. 1.5, 1.6 and 1.7. With the help of these histograms, it is easy to determine quickly that the current process is able to produce successful product assemblies with good yield percentage. The statistics of the tolerance analysis for the three cases, viz., worst-case tolerance on assembly clearance (0.130 ± 0.020), reduced tolerance on assembly clearance (0.130 ± 0.015) and (0.130 ± 0.010), has been presented in Table 1.2.

1.4.3 Normal Distribution

A set of 500 random samples for each of cylinder-bore (X_1) and piston (X_2) has been generated in the specified dimension range following a normal distribution and the assembly clearance (Y) has been obtained. The histograms showing distribution of cylinder-bore diameter, piston diameter, and assembly clearance can also be presented as in case of uniform distribution. The statistics of the tolerance analysis for the three cases, viz., worst-case assembly clearance (0.130 ± 0.020), reduced tolerance on assembly clearance (0.130 ± 0.015), and (0.130 ± 0.010), has been presented in Table 1.3.

1.4.4 Beta Distribution

A set of 500 random samples for each of cylinder-bore (X_1) [beta (2, 3)] and piston (X_2) [beta (3, 4)] has been generated in the specified dimension range following beta distribution and the assembly clearance has been obtained. The histograms for distribution of cylinder-bore diameter, piston diameter, and assembly clearance (Y) can also be presented as in the case of uniform distribution. The statistics of the tolerance analysis for the three cases, viz., worst-case assembly clearance (0.130 ± 0.020), reduced tolerance on assembly clearance (0.130 ± 0.015) and (0.130 ± 0.010), has been presented in Table 1.4.

1.5 Discussion

The results of the simulation study have been presented and analyzed in the previous Section (Figs. 1.5, 1.6 and 1.7 for uniformly distributed constituent dimensions,

Table 1.2 Tolerance analysis of the assembly for uniform distribution of dimensions

Worst-case tolerance on assembly clearance Y (0.130 ± 0.020)	Specified tolerance range = 0.150–0.110	= 0.040
	Estimated variation = 0.1482–0.1104	= 0.0378
	Mean	= 0.12967
	Standard deviation	= 0.0081875
	Number of simulated assemblies	= 500
	Number of successful assemblies (within the specification limits)	= 500
	Number of failed assemblies (beyond the specification limits)	= 0
	Yield	= 100%
Reduced tolerance on assembly clearance Y (0.130 ± 0.015)	Specified tolerance range = 0.145–0.115	= 0.030
	Estimated variation = 0.1482–0.1104	= 0.0378
	Mean	= 0.12967
	Standard deviation	= 0.0081875
	Number of simulated assemblies	= 500
	Number of successful assemblies (within the specification limits)	= 463
	Number of failed assemblies (beyond the specification limits)	= 37
	Yield	= 92.6%
Reduced tolerance on assembly clearance Y (0.130 ± 0.010)	Specified tolerance range = 0.140–0.120	= 0.020
	Estimated variation = 0.1482–0.1104	= 0.0378
	Mean	= 0.12967
	Standard deviation	= 0.0081875
	Number of simulated assemblies	= 500
	Number of successful assemblies (within the specification limits)	= 381
	Number of failed assemblies (beyond the specification limits)	= 119
	Yield	= 76.2%

Table 1.3 Tolerance analysis of the assembly for normal distribution of dimensions

Worst case tolerance on assembly clearance *Y* (0.130 ± 0.020)	Specified tolerance range = 0.150–0.110	= 0.040
	Estimated variation = 0.1445–0.1180	= 0.0265
	Mean	= 0.13033
	Standard deviation	= 0.0044625
	Number of simulated assemblies	= 500
	Number of successful assemblies (within the specification limits)	= 500
	Number of failed assemblies (beyond the specification limits)	= 0
	Yield	= 100%
Reduced tolerance on assembly clearance *Y* (0.130 ± 0.015)	Specified tolerance range = 0.145–0.115	= 0.0300
	Estimated variation = 0.1445–0.1180	= 0.0265
	Mean	= 0.13033
	Standard deviation	= 0.0044625
	Number of simulated assemblies	= 500
	Number of successful assemblies (within the specification limits)	= 500
	Number of failed assemblies (beyond the specification limits)	= 0
	Yield	= 100%
Reduced tolerance on assembly clearance *Y* (0.130 ± 0.010)	Specified tolerance range = 0.140–0.120	= 0.0200
	Estimated variation = 0.1445–0.1180	= 0.0265
	Mean	= 0.13033
	Standard deviation	= 0.0044625
	Number of simulated assemblies	= 500
	Number of successful assemblies (within the specification limits)	= 486
	Number of failed assemblies (beyond the specification limits)	= 14
	Yield	= 97.2%

Table 1.4 Tolerance analysis of the assembly for beta distribution of dimensions

Worst case tolerance on assembly clearance Y (0.130 ± 0.020)	Specified tolerance range = 0.150–0.110	= 0.040
	Estimated variation = 0.1449–0.1150	= 0.0299
	Mean	= 0.12925
	Standard deviation	= 0.0053477
	Number of simulated assemblies	= 500
	Number of successful assemblies (within the specification limits)	= 500
	Number of failed assemblies (beyond the specification limits)	= 0
	Yield	= 100%
Reduced tolerance on assembly clearance Y (0.130 ± 0.015)	Specified tolerance range = 0.1450–0.1150	= 0.0300
	Estimated variation = 0.1449–0.1150	= 0.0299
	Mean	= 0.12925
	Standard deviation	= 0.0053477
	Number of simulated assemblies	= 500
	Number of successful assemblies (within the specification limits)	= 500
	Number of failed assemblies (beyond the specification limits)	= 0
	Yield	= 100%
Reduced tolerance on assembly clearance Y (0.130 ± 0.010)	Specified tolerance range = 0.140–0.120	= 0.0200
	Estimated variation = 0.1449–0.1150	= 0.0299
	Mean	= 0.12925
	Standard deviation	= 0.0053477
	Number of simulated assemblies	= 500
	Number of successful assemblies (within the specification limits)	= 467
	Number of failed assemblies (beyond the specification limits)	= 33
	Yield	= 93.4%

Table 1.5 Estimated yield (percentage) under different conditions

	Distribution of independent dimensions (cylinder-bore and piston diameter)		
Assembly dimension or clearance (Y)	Uniform	Normal	Beta
0.130 ± 0.020	100	100	100
0.130 ± 0.015	92.6	100	100
0.130 ± 0.010	76.2	97.2	93.4

Tables 1.2, 1.3, and 1.4 for all three cases—uniform, normal, and beta distribution). The results have further been summarized in Table 1.5 for better clarity. The following points are observed.

1. When the independent dimensions (or variables) are normally distributed. The resultant dimension (or assembly response) also appears to be normally distributed.
2. In case, the independent dimensions are not normally distributed (for uniform distribution and beta distribution of the cylinder-bore and piston dimensions), the resultant dimension appears to be normally distributed. The observation is in accordance with the Central Limit Theorem. According to the theorem, a sampling distribution always results in significantly less variability, as measured by standard deviation, than the population it is drawn from. Thus, the distribution of assembly dimension will look more and more like normal distribution as the length of the simulation run is increased, even when the population itself is not normally distributed.
3. The specified tolerance on the assembly dimension based on the worst-case criteria results in 100% yield. As the specified tolerance on the assembly dimension is tightened, the yield varies accordingly because of reduction in fraction of accepted assemblies. Tightening the assembly tolerances, though results in better precision of the assembly characteristics, yet with the corresponding reduction in assembly yield.
4. In case of normally distributed dimensions, tightening of the tolerance on assembly dimension results in smaller variation in assembly yield, because of relatively less variability of the assembly dimension. In case of other distributions of independent dimensions, the assembly yield suffers more variation, because of the relatively larger variability of the assembly dimension. The maximum reduction in assembly yield occurs with the uniformly distributed individual constituent dimensions.

1.6 Conclusion

The objective of this study has been to estimate the distribution of the assembly response for a given set of dimensions of individual components, and the mathematical relationship among the dimensions of individual components and the assembly response. Monte Carlo simulation has been used for this purpose. A computer-aided system for tolerance analysis of mechanical assemblies has been presented in this work with the help of a numerical example of cylinder-piston assembly. The results have been presented as the histograms for uniformly distributed constituent dimensions, followed by tabulated data for the tolerance analysis for all three cases—uniform, normal, and beta distribution of dimensions of individual components. Salient features of the study have been presented in the previous section. The work can further be extended in the following directions.

- The assembly attempted in this study involves only two independent dimensions with simple dimension chains. More complex problems for assemblies with a large number of independent dimensions involving interrelated dimension chains, and two-dimensional cases can be attempted.
- In this study, only size tolerances have been considered. Tolerance analysis can also be carried out considering geometrical dimensioning and tolerancing (GD & T).
- This study makes use of only a particular probability density function, which has been considered for all the components of an assembly at a time. It is also possible to consider different probability density functions for different individual dimensions at a time.
- This study presents a mechanical assembly of rigid components. The work can be extended to include flexible and elastic components.

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Chapter 2
Operationalization and Measurement of Service Quality in Manufacturing Supply Chains: A Conceptual Framework

Anish Sachdeva and Surjit Kumar Gandhi

Abstract Service and service activities are perishable, complex, and multifunctional in nature, because of which the production and delivery of services are inseparable. Services in manufacturing, however need to be treated in a different manner. In a manufacturing organization, while early market leaders focus on innovation, the quality of services rendered along the supply chain would help in developing loyal customers, resulting in enhanced business performance. Research demonstrates that service quality (SQ) has strong linkages with business performance, cost reduction, feeling of delight, trust, and loyalty among partners and consequently leads to profitability. However, the service dominance perspective that establishes the importance of intangible aspects such as service and relationship is still to be widely embraced in the manufacturing sector. The scholarly attention accorded to service quality in manufacturing is still in its nascence. Against this preamble, this chapter aims to bring out a tailor-made framework to evaluate SQ at different interfaces of a manufacturing supply chain. This chapter conceptualizes SQ as a multidimensional construct, which operates at interfaces of supplier–manufacturer, manufacturer–employee, and manufacturer–distributor.

Keywords Service quality · Supply chain management · Small-medium manufacturing enterprises

2.1 Introduction

The fierce competition of today's marketplace is driving small-medium manufacturing enterprises to reshape their strategies in order to curtail overall cost and cut

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down inefficiencies. To ensure their operational and financial benefits, manufacturing enterprises are working closely and maintaining backward linkages with the suppliers and forward linkages with its distributors besides realizing their employees as the most valuable asset [32].

Once known as purchasing, supply chain management (SCM), today, has evolved to include a number of functions related to the supply activities of organizations, such that it has assumed strategic importance. The application of the tools and techniques of operations management, such as world-class manufacturing, benchmarking, and business process reengineering, no longer suffices to optimize internal production. The introduction of lean manufacturing, including techniques such as supplier tiers, collaboration, joint design and development, and supplier associations or alliances has broadened the SCM canvas. SCM has borrowed concepts from a range of academic disciplines, such as transaction cost economics (TCE), resource-based view (RBV) [66], and social capital [45], and enabled scholars to explain supply activities of organizations from varied theoretical lenses.

The body of SCM literature generated in recent times includes strategic issues in supply chain planning, and principles and practices of effective supply chain management [44]. Supply chain orientation can foster innovation, facilitate removal of complexity, help eliminate waste, streamline processes, and enhance efficiency [37]. The supply chain lens can help in designing the value chain and facilitate the creation of the resilient enterprise [61]. Focusing on the supply chain triggers organizational turnaround [70] and provides impetus to the merger and acquisition process [36].

Supply chains do exist in all manufacturing units, and several scholars have taken cognizance of the influence of the actions of one member of the supply chain on the profitability of all the others in the chain [26]. Despite these benefits, Indian small-medium manufacturing units are unable to understand the role of each member in the supply chain and in the entire delivery system and find it difficult to change their focus from immediate customer to all downstream and upstream members in the supply chain. By delivering the superior value to ultimate consumers, the chain as a whole achieves the objective of differential advantage. This enhances the performance of the chain as a whole as well as delivers results to the individual members of the chain [51].

By delivering the superior value to ultimate consumers, the chain as a whole achieves the objective of differential advantage. This enhances the performance of the chain as a whole as well as delivers results to the individual members of the chain [64]. Earlier the Indian small-medium manufacturing units were in dormant stage shielded by the government policies of reservation, quota, license, etc., but due to globalization, this once flourishing sector is facing several challenges. Thus, this sector needs to adopt the best practices in all their activities so as to compete in the backdrop of global competitiveness. Although, many studies have been carried out in the developed countries in the aspects of interfirm linkages, little or no studies have been reported on studying their supply chains in India. Studies on

Indian SMEs are largely confined to competitive priorities, manufacturing strategies, capacity building, and innovation trends. However, the service dominance perspective [48] that establishes the importance of intangible aspects such as service quality is unexplored.

Service quality (SQ) is, "a way of thinking about how to satisfy customers so that they hold positive attitude toward the service they are receiving. Delivering quality service is considered to be an essential strategy to succeed in a competitive business environment. Firms, which offer superior services, achieve higher growth in the market and increase profits [40]." Researchers suggest that service quality is positively associated with customer satisfaction [2, 62]. Studies establish a positive relationship of service quality with customer loyalty [17, 27] too. Service quality is also linked to behavioral outcomes as word-of-mouth (WOM), complaint, recommending, and switching [76].

Intrinsic service quality is defined as, "how well the manufacturing organization is working towards the suppliers, employees and distributors," while extrinsic service quality is defined as, "quality of services delivered by supplier, employees and distributors to the manufacturing organization."

For the purpose of this chapter, supply chain may be broken into three basic segments of sourcing, manufacturing, and delivery and involves its associated flow of material/service, funds, and information among them. To overcome the above challenges, the small-medium manufacturing units need to develop effective strategies and should frame the policies and constantly review them to meet their long-term objectives. The managers of these units often consider these problems independently and develop solutions. In reality, these issues need to be addressed and evaluated in the supply chain perspective. The concept of service quality bridges scientific and humanistic management philosophies by focusing on areas such as coordination, collaboration, commitment, communication, trust, flexibility, dependence, joint engineering, integration, and training and development of employees.

2.2 Manufacturing Supply Chains

A simple manufacturing supply chain comprises three components, i.e., the supplier, the manufacturer, and the distributor, as shown in Fig. 2.1.

A manufacturing supply chain may vary in size and complexity, depending on the number of members and their linkages. Though the management of service quality in a service environment is difficult from that in manufacturing, both service organizations as well as manufacturing organizations need to pay attention to service and how service quality can be achieved, controlled, and improved [68]. The underlined theme of the manufacturing supply chain is to focus on process management, enabling capacity through the use of ICTs and measure performance, while staying customer-centric. Consequently, manufacturing organizations aim to develop value-added processes which deliver innovative, high-quality, low-cost products,

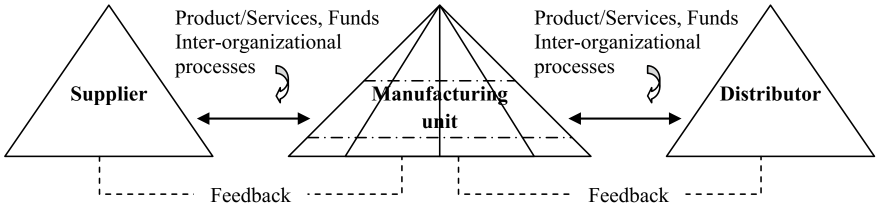

Fig. 2.1 A simple manufacturing supply chain

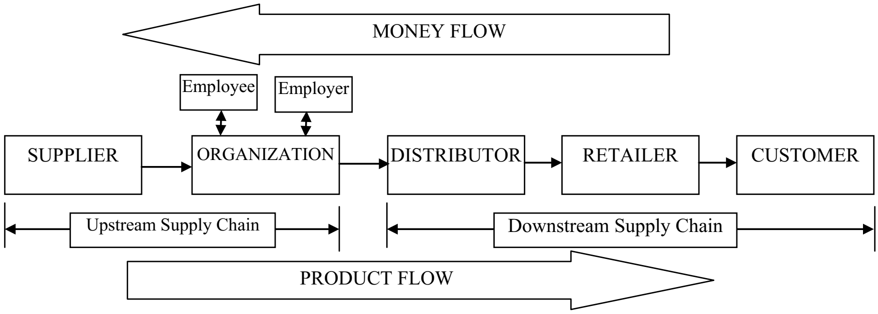

Fig. 2.2 Drivers of supply chain

with shorter development cycles and greater responsiveness in serving the market [21].

Though redundancy involves cost, however manufacturing organizations build redundancy as it enables flexibility and helps an organization to enhance its ability to recover from disruption. Building flexibility across procurement–conversion–distribution process enables supply chain to build organic capabilities that can sense environment and respond quickly and helps in moving from forecast-driven supply chains to a demand-driven supply chains. The total offering of a manufacturer must evolve gradually from mostly tangible to include services, and finally, develop into a relationship-focused offering. Industrial services refer to services offered by a manufacturer to other organization at pre-purchase, at-purchase, and after-sales service stages or only after-sale stage [41]. Figure 2.2 shows the drivers of supply chain management. It shows that product moves from supplier to customer after value addition at every level while finance moves from customer to supplier and every driver keeps its part.

Service thus gets highly influenced by four factors: the immediate response of service provider, the time and way of the delivery of service, the behavior of the service provider, and the knowledge and skill of the service provider. The focus on service quality in the manufacturing supply chain is of recent origin and the body of knowledge is still nascent. Here, the focus is on issues related to service which are embedded in various processes in the manufacturing supply chain. Amad et al.

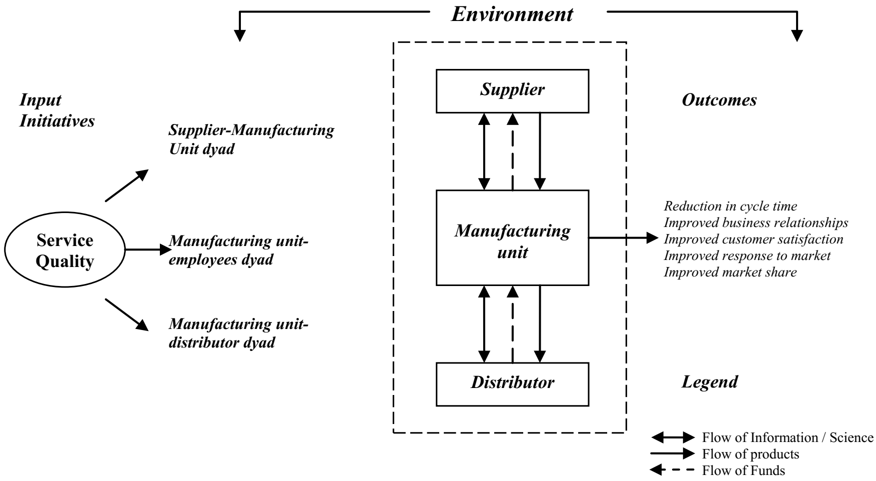

Fig. 2.3 Service quality in a manufacturing supply chain

[1] have found that a higher level of service quality among intrinsic suppliers and intrinsic customers lead to better extrinsic service quality as illustrated in Fig. 2.3.

2.3 Different Perspectives of Service Quality

The Grönroos–Gummesson Quality Model [30] integrated product and service quality perspectives from the customer's viewpoint. It described four sources of quality, i.e., design, production, delivery, and relations. Design quality refers to how well the combination of goods and services are developed and designed. Production and delivery quality refer to how well services and goods are delivered compared to design. Relationship quality refers to how the customer perceives quality during the service processes.

In the same vein, Philip and Hazlett [60] developed a hierarchical structure of SQ consisting of overlapping areas of pivotal, core, and peripheral attributes. By combining the models of [8, 13, 56] a hierarchical and multidimensional model of perceived SQ was developed that comprises the primary dimensions of interaction, environment, and outcome, each of which has three subdimensions. This model has greater explanatory power of customer perceptions of SQ as it explains what defines service quality perceptions, how SQ perceptions are formed, and how service experience occurs.

Chaston and Mangles [11] suggested that core capabilities are the main predictors for the growth of small firms. They observed that areas of competency concerned with new product development, organizational productivity, and management of service quality were extremely crucial for the growth of the small firms.

Thus, physical facilities and processes, people's behavior, their professional judgment [35], and potential and actual customer's perception affects service quality [10]. Service quality is perceived as value received [50] and operates through sequential elements of antecedents, consequences, and mediators and plays a significant role in post-purchase decision-making process [73]. Expectations about SQ leads to disconfirmation felt in service received [71]. Disconfirmation arises because of gaps in seeker's perception and provider's expectation, gaps in service specifications and actual service delivery and gaps in the receiver's expectation and the provider's perception [23].

Another set of models deals with e-service quality, which is defined as the role of SQ in cyberspace and have incubative (good design, easy access, etc.) and active (support, speed, maintenance, etc.) dimensions [67] and rely on ICTs. On this channel expectations, image and reputation, service setting, service encounter, and customer participation affect the perception of service quality [9]. In cyberspace service, quality consists of website process quality, outcome quality, and recovery quality and these constructs in turn influence user satisfaction and their behavioral intentions [12]. Therefore, service quality offered is determinant of success of e-commerce [58, 67]. has developed a 22-item scale, E-S-QUAL to measure web service quality. Electronic service quality also has a hierarchical and multidimensional structure that comprises primary dimensions of environment quality, delivery quality, and outcome quality, each of which consists of various subdimensions [19, 63].

Information availability and content, ease of use, security, graphic style, and reliability are key issues relevant for e-service quality perception [77] and timeliness, availability, condition, and return are identified as key attributes of e-distribution service quality [75]. Though reliability of information is an important facet, the availability and depth of information is believed to improve the use of information, [3] and this necessitates alignment and coordination of service quality and information system strategies [7].

In technology-based self-service (TBSS) context, service quality is cognitive evaluation of attributes associated with technology-based service options and affective evaluation through overall predispositions [13]. However, forced use of TBSS results in negative evaluations, which may improve when service provider offers manual interaction and that previous experience with TBSS (in general) leads to more positive attitudes toward the offered self-service, which can offset the negative effects of forced use to some extent [59, 65].

Bala Subrahmanya [5] presented the declining trends of SMEs in the globalization period. He has also highlighted the importance of developing interfirm linkages among supply chain partners and horizontal cooperation across the supply chains of such firms to overcome the traditional barriers.

In the recent years, Nor and Musa [55] proposed the loyalty program SQ (LPSQual) model and identified program policy, tangibles, rewards, information usefulness, courtesy, personalization, and communication as factors leading to loyalty. [39] proposed E-S-QUAL model with efficiency, system availability, fulfillment, privacy, loyalty, perceived value, and control variables as underlying dimensions. Sultan and Yin Wong [72] put forward 'Integrated process SQ model' with infor-

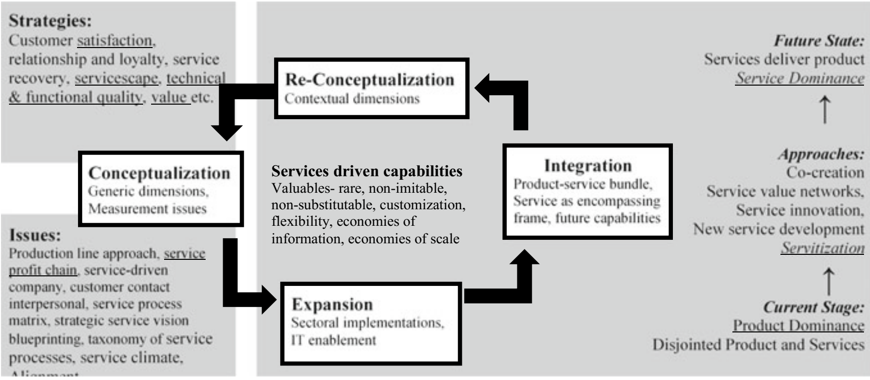

Fig. 2.4 Phases of SQ literature along strategic imperatives

mation, past experience, perceived SQ, trust, brand, behavioral intentions as factors. Bakti and Sumaedi [4] identified comfort, reliability, tangible, and personnel as determinants of P-TRANSQUAL—a service quality model of public land transport services. Teeroovengadum et al. [74] determined five attributes of administrative quality, support facilities quality, core quality, transformative quality, physical environment quality influencing SQ in higher education SQ (HE-SQUAL) model.

It can be concluded that literature is replete with re-(conceptualization), contextual adaptations, and measurements. Nonetheless, service quality remains to be elusive and multidimensional. SQ literature has evolved across overlapping phases of conceptualization, expansion, reconceptualization, and integration. Evolution of service-driven capabilities may be structured along concepts of adaptation with strategic drivers and imperatives, learning and alignment, and problem structuring (such as analysis of current state, the design of future state, and transformation). Evolution of SQ literature along these strategic imperatives is depicted in Fig. 2.4.

Conceptualization phase of SQ-initiated alignment with strategic drivers. Themes associated with SQ constructs such as customer satisfaction, relationship and loyalty, service recovery, service failure, servitization, etc., are evolving as strategic levers. The level of analysis is shifting from customer-level analysis to strategic-level offerings [24]. Service characteristics such as servicescape, service quality, quality, and value provide cost leadership and enable strategic differentiation [53] and result in customer satisfaction and retaining market share.

Expansion phase of SQ involves the application of service-driven approaches across various sectors. Production line approach to service, service profit chain, and service-driven company have been service design paradigms. Effective service design has been supported by approaches such as customer contact, interpersonal, service process matrix, strategic vision, blueprinting, taxonomy of service processes, and service climate [25].

Technology is emerging as a key enabler of service-driven offerings. Technology has created service industries of a scale, sophistication, complexity, and value-adding potential to match any manufacturing industry [15]. The SQ is becoming more broad and interdisciplinary and requires diverse expertise [57]. This results in a lack of agreement on terms, concepts, assumptions, theories, and methods [54]. Themes like service design, service modeling, service-dominant logic, service adaptation, cross-cultural impacts on service quality are getting more attention. Service value networks, service innovation, new service development, and servitization are emerging as key paradigms.

Models for operationalization of SQ range from personalized services to technology-enabled services. On one hand, these models enable measurement of SQ in quantitative terms and on the other hand links SQ constructs with customer's behavioral intentions [76]. Quality-driven organizations focus on the effectiveness of SQ-driven intraorganizational relationships and their impact on serving customers [28]. Capability to create a unique value proposition requires service innovations, which are based on dynamic capabilities to simultaneously exploit and explore [18] and adaptive capabilities [79] of stakeholders across embedded value chain network [31]. Services are substituting manufacturing functions and operations strategies are exploring how services can contribute to productivity, value creation, growth, flexibility, and output quality.

2.3.1 Partnership, Coordination, and Collaboration

Exchange in the traditional economic sense entailed single-product transaction with limited information sharing. However, present-day supply chains that are based on repeated transactions, information sharing, and collaboration have high performance. Information sharing on its own or through the redesign of supply chain processes improves supply chain performance [46]. Supply chain processes driven by a seamless information system include quick response, vendor-managed inventory (VMI), and collaborative planning, forecasting and replenishment (CPFR) [6]. CPFR, which comprises three stages, namely, basic CPFR, developing CPFR, and advanced CPFR, is a new form of collaboration that is based on the exchange of information between the partners, as well as common planning and synchronization of activities and business processes.

Supply chain collaboration may be defined as two or more independent organizations jointly working to align their supply chain processes in order to deliver value to their end customers with greater success than acting alone [38, 69] and overcoming constraints [29]. The different cost and revenue structures of supply chain partners require co-performance evaluation, decision synchronization and incentive alignment [69]. Therefore, for effective collaboration supply chain performance metrics such as reliability, flexibility and responsiveness, expenses, and assets/utilization must be similar among the members [43]. Collaboration with upstream and downstream partners translates into efficient inventory management, mutual benefits, and matching demand with supply [22], which improves the return on investment and gains a competitive advantage. From a process perspective, collaboration entails joint redesigning of supply chain operations and streamlining interorganizational processes, resulting in lower costs, higher quality, and faster operations [34]. Collaboration also enables organizations to focus on key supply chain processes such as customer relationship management, demand management, order fulfillment, and returns.

Many collaborative initiatives end up in failure [20] due to a number of reasons. Forced collaboration may result in the exit of the uninterested member if the opportunity emerges [52]. Power asymmetry among the supply chain members, such as in the aerospace [47] and automobile industries [16], and the misuse of such power leads to dissension and underperformance in the supply chain [49]. Kampstra et al. [42] suggest that understanding the position of power and division of roles such as collaboration leader, collaboration coordinator, and remaining collaboration members can serve as the basis for defining collaborative processes and laying down the future course of action. For successful collaboration in the supply chain, we need to take a strategic chain-wide perspective rather than focus at the individual entity. Synergies created through collaborative relationships determine long-term competitiveness of organizations [20, 33].

2.3.2 Enterprise-Wide View of the Supply Chain

This enterprise-wide view of the supply chain depicting linkages of the manufacturing organization with its suppliers and distributors is presented in Table 2.1.

Summarizing the review of service quality measurement tools and debates, it can be revealed that the total offering of industrial units may evolve gradually from mostly tangibles to include services [14], and finally, develop into a relationship-focused offering with the focus on issues related to service which are embedded in various processes in the supply chain. Based on the discussion ensuing above, we have culled out from the literature, key issues that need to be addressed for the enhanced level of service quality in the supply chain. A select list of key issues is summarized in Table 2.2.

2.4 Major Research Findings

Empirical exploration has been the dominating theme and the interview schedule/survey method is the most popular method for conducting SQ research. Multivariate statistical methodologies such as exploratory factor analysis (EFA), multiple regression and correlation, structural equation modeling (SEM), analytic hierarchical process (AHP), decision-making trial and evaluation laboratory (DEMATEL), multi-attribute utility theory, fuzzy logic, graph-theoretic approach (GTA), interpre-

Table 2.1 Coordination mechanisms in the supply chain

<table>
<tr><th colspan="2">Coordination mechanism</th><th>Supplier</th><th>Manufacturer</th><th>Distributor</th></tr>
<tr><td colspan="5">A. Approaches</td></tr>
<tr><td>Centralized</td><td>Individual</td><td colspan="3">System is managed by a single person</td></tr>
<tr><td>Decentralized</td><td>Team based, nexus-of-contract</td><td colspan="3">Cooperative effort among supply chain members at functional, cross-functional, and interorganizational levels</td></tr>
<tr><td colspan="5">B. Problem type</td></tr>
<tr><td>Structured/unstructured</td><td>Decision domain</td><td colspan="3">Standards, rules, schedules, and plans</td></tr>
<tr><td>Formal/informal</td><td>Roles and responsibilities</td><td colspan="3">Design of role, mechanism to synchronize activities and flows, mutual adjustment</td></tr>
<tr><td colspan="5">C. Task specification</td></tr>
<tr><td>Input</td><td rowspan="4">Define tasks to be performed, skill sets needed, and coordinate through norms</td><td colspan="3" rowspan="4">Flexibility, solidarity, mutuality, conflict resolution, restrain in use of power, reputation, information sharing, and collaborative product design</td></tr>
<tr><td>Processes</td></tr>
<tr><td>Output</td></tr>
<tr><td>Skillset</td></tr>
<tr><td colspan="5">D. Policies</td></tr>
<tr><td>Price related</td><td rowspan="3">Clearly laid down policies to govern various forms of transactions</td><td colspan="3">Quantity discount, Two-part tariff, buyback and return contract</td></tr>
<tr><td>Non-price related</td><td colspan="3">Quantity flexibility contracts, promotional allowances, allocation rules, cooperative advertising, exclusive dealing</td></tr>
<tr><td>Flow related</td><td colspan="3">Vendor-managed inventory (VMI), quick response (QR), collaborative planning forecasting and replenishment (CPFR), efficient consumer response (ECR)</td></tr>
<tr><td colspan="5">E. Flow of information</td></tr>
<tr><td>Intra-organization</td><td rowspan="2">Types of implementation technologies and applications</td><td colspan="3">Voice mail, off-the-shelf application packages, ERP, etc.</td></tr>
<tr><td>Interorganizational</td><td colspan="3">EDI, shared databases, network applications, electronic markets, CAD/CASE data interchange and repositories, and mobile computing</td></tr>
</table>

Source Seth et al. [68], Prakash et al. [64]

tive structural modeling (ISM), neural network, etc., have been extensively used. Review articles constitute much of the qualitative studies. Confirmatory factor analysis has been the dominating method. Recent years have seen the rise of fuzzy and

Table 2.2 Key issues pertaining to service quality in the supply chains

Key issue	Description
A. Service quality	
Intrinsic service quality • *Intra-organizational*	Employees of various functional departments treat each other as their customers
• *Interorganizational*	Treating supplier and distributor as valuable partners and developing strong linkages with them
Extrinsic service quality	Levels of service offered by external entities, i.e., suppliers and distributors to the manufacturing unit
B. Satisfaction	
• Product/service	Satisfaction with the product and the embedded service
• Financial benefits	Tradeoff of product/service received with expense incurred
C. Loyalty	
• Future perspective	Patronage of the product and the manufacturing unit
• Recommendation	Recommendation of the products/manufacturing unit to others
• Switchover	No switchover to competitors
D. Competitive advantage	
Quality • *Specification*	Delivering excellent service as per specifications Conformance to specifications, and delivery as per schedule
Responsiveness of supply chain • *Production lead time* • Speed • Reliability	Time taken to fulfill an order, lead time, order fill rate, etc. Time related to supply of raw material and distribution of products
	How swiftly demand is fulfilled
	Fulfilling demand with the right product and as per agreed schedule
• Lead time in supply	Time taken to fulfill a customer order
• Customer service level	Customers should be satisfied with the product received and the way demand was fulfilled

(continued)

Table 2.2 (continued)

Key issue	Description
• Information flow	Sharing of information by all supply chain stakeholders
• Adaptability	How supply chain stakeholders adapt to environmental changes and changes in end customers' preferences, etc.
Flexibility	
• *Service flexibility*	Ability to meet special/ sudden demand
• *Order flexibility*	Ability to adjust order
• *Location flexibility*	Meeting demand from alternative sources
• *Time flexibility*	Ability to meet time-based demand
E. Organizational performance	
• Market share	Continuous increase in market share and becoming a market leader
• Financial performance	Financial performance reduction in cost incurred, and increase in profit margin

neural network based approaches. Exploration of neurological aspects of human brain and its linkages with customer satisfaction is on the rise.

2.4.1 Actionable Framework

Summarizing the analysis and the findings of the research data, an actionable framework is proposed for improving the efficiency and effectiveness of the supply chain. The framework is shown in Fig. 2.5.

2.4.2 Managing Service Quality in Manufacturing Supply Chains

Service quality in the manufacturing supply chains is a multidimensional construct. Conceptually, SQ dimensions address performance standards, expertise, and physical elements of the stakeholder organizations as well as employees' willingness to assist in a timely manner with their knowledge and sensitivity. The services literature recognizes that there are two perspectives of service quality namely, the functional/process (i.e., how) and the technical/outcome (i.e., what) perspectives. Moreover, service quality evaluation is not based only on the outcome of service, but also involves evaluation of the service-delivery process. Though scholars have still not completely identified the attributes of technical quality, they are in agreement that technical quality significantly affects customer's perceptions of service quality.

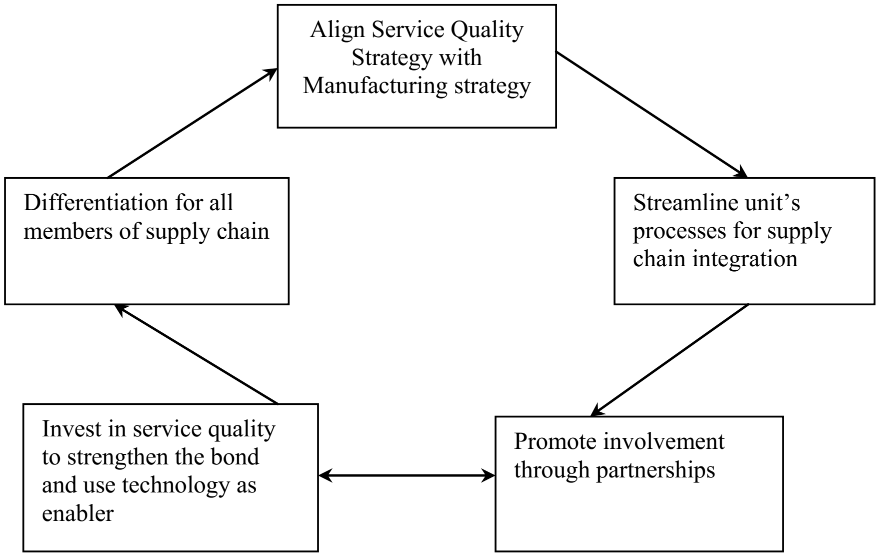

Fig. 2.5 Framework for improving efficiency and effectiveness of supply chain

Against this backcloth, this chapter puts forward a three-pronged framework for the conceptualization of service quality strategy in an organization's supply chain. The building blocks of the proposed framework include supply chain strategy and service quality strategy. Therefore, as depicted in Fig. 2.6, managing service quality in the supply chain is the vector sum of the manufacturing unit's working toward its suppliers, employees, and distributors.

The proposed framework is schematically represented in Fig. 2.7, and its components are laid out hereunder.

The components of the supply chain strategy are the following:

- Supply chain objectives
- Supply chain processes
- Manufacturing unit's focus

The components of the service quality strategy are the following:

- Service quality objectives
- Service quality processes
- Supply chain focus

The above-mentioned components constitute the axes of the three-dimensional Cartesian coordinate system. The optimum service quality strategy is crafted by mapping it with supply chain strategy. As the supply chain of a manufacturing unit involves all the activities undertaken to fulfill a customer order, the imperative, therefore, would be to align the supply chain objectives with the objectives of the manu-

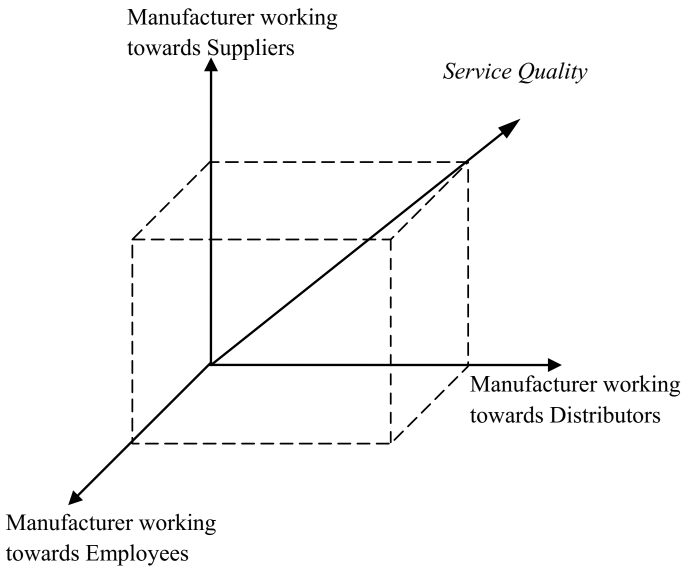

Fig. 2.6 Components of service quality in the supply chain

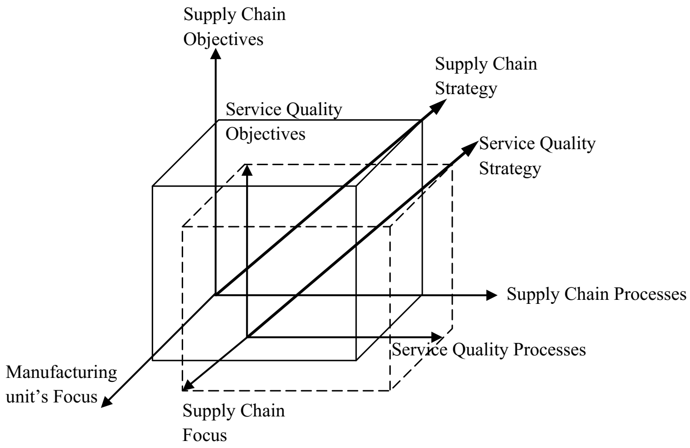

Fig. 2.7 Supply chain strategy vis-a-vis service quality strategy

facturing unit. Along similar lines, the objectives of service quality initiatives in the supply chain should be integrated with the objectives of the supply chain.

The review of literature and findings of this research identify that service quality is linked to loyalty primarily through operations and the market. Operations improve process and design quality, reduce waste, fine-tune internal processes, and develop synchronized linkages with suppliers and distributors, and thereby achieve operational efficiencies. By way of cost reduction and increase in product and service reliability, these operational efficiencies improve the attractiveness of the products and services. In the market, improved service quality enhances satisfaction and loyalty of suppliers, employees, and distributors, and lures them away from competitors who are perceived low in service quality.

2.4.3 Recommendations

SQ-based processes need to be incorporated in the supplier–manufacturer, manufacturer–employees and manufacturer–distributor interfaces of the supply chain. A focus on the singular link may not represent the holistic perspective. Service quality based processes need to be incorporated at various dyads of the supply chain as per the following recommendations:

i. **Supplier–manufacturer dyad**: Honest sharing of operational information, integrating supply chain strategy, promptness in handling queries or failures attention to each other's requirements, maintaining confidentiality in dealings, flexibility in terms and conditions as per requirements, and preference for a long-term collaborative relationship.
ii. **Manufacturer–employee dyad**: Mutual commitment to best serve one another, developing employees' skillfulness through training, maintaining a pleasant work environment, encouraging workplace hygiene through recognition, open communication, and friendliness.
iii. **Manufacturing unit–distributor dyad**: Endeavoring ease-of-doing-business (EODB) and customer relationship management (CRM) by honest and timely exchange of information, and developing trust, value and reciprocal benefits with one another, making adjustments as per changes in the extrinsic environment to market signals by mutual adjustment with distributors.

Thus, to achieve supply chain objectives it is vital for supply chain stakeholders to coordinate, synchronize and integrate their activities to produce desired outputs by incorporating service quality initiatives.

2.4.4 Concluding Remarks

An attempt was made to study service quality in the simple supply chain of manufacturing unit. Service quality has a special role to play in continuous improvements. It provides a useful framework to explore the consequences of service quality for both upstream and downstream the chain and reports a strong significance.

The results of this study have demonstrated that for Indian manufacturing organizations, orientation to service quality is one of the means through which they can strategize their supply chains. The results of this study confirm that service quality at all sections (supplier, manufacturing unit, and distributor) of the supply chain can be used as a differentiation strategy. For example, improving service quality may lead to a reduction in lead time, improved delivery reliability, less reworks, etc., and thus contribute to improvements in supply chain differentiation parameters, viz., flexible design, timely delivery, and patronage intention.

This study and analysis of assessment and modeling of service quality for different sections in supply chain highlights that manufacturing organizations have to focus not only on their own service quality but also service quality of both upstream and downstream partners. A focus on the singular link may not represent the holistic perspective.

From this study, the key factors to manage service quality are identified as follows:

(a) Focus on both technical and functional quality,
(b) A pool of motivated employees,
(c) Know-how of service quality attributes operating in the supply chain,
(d) An effective feedback and implementation system,
(e) “Knock-their-socks-off” treatment among supply chain partners.

It may be noted that service quality is a continuous journey to a manufacturing unit’s success and will act as an essential step in the enhancement of supply chain management initiatives.

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Chapter 3
A Novel Framework for Evaluation of Failure Risk in Thermal Power Industry

Dilbagh Panchal, Mohit Tyagi and Anish Sachdeva

Abstract The aim of this research work is to develop a novel integrated framework for improving the availability of Water Circulation System (WCS) of a thermal power industry located in the northern part of India. Qualitative information related to system's operation has been collected on the basis of feedback from maintenance experts/log book record and using that information, Failure Mode and Effect Analysis (FMEA) sheet was generated. Fuzzy ratings have been assigned by the experts on the basis of designed linguistic scale for three risk factors, namely occurrence probability (O), severity probability (S), and detection probability (D). Fuzzy Risk Priority Number (FRPN) has been computed for each failure cause and ranking was done in descending order. Further, for testing the stability and robustness of ranking results fuzzy Evaluation Based on Distance from Average Solution (EDAS) approach has been applied within fuzzy FMEA approach. Appraisal score values have been computed as EDAS output and ranking of failure causes was done. Ranking results were compared for effective decision-making of critical failure causes. The implork shows its effectiveness in overcoming the limitations of rule base FMEA approach. The ranking results would be supplied to the maintenance manager of the plant for developing an effective maintenance program for WCS. The analysis result will be highly useful in minimizing the total operational cost of the considered unit.

Keywords Thermal power industry · Water circulation system · Fuzzy FMEA · Failure · EDAS · Availability

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3.1 Introduction

In India, coal-fired thermal power plants are the main source of power generation. The economy of India is totally based on these thermal power plants as they contribute nearly 70 percent of the total power supply generated from different sources. For fulfilling the demand of power supply to each and every sector, availability of these power plants plays a key role. Operation of heavy process plant like thermal power industry is very complicated and due to this complexity failure prediction is a tough ask from the system analyst. Failure is a common phenomenon for an industrial system and has a serious impact on the operational/production cost of industry. Sudden failure in the plant operation not only results in raising the operational cost of the plant, but may also lead to serious accidents in the plant. For the decrease in production cost of a process plant, it is essential to minimize its maintenance cost which contributes more than 15% to the total production cost [10, 12, 21]. Hence, for this decrease, a quality maintenance policy is needed to be developed for which identification of critical failure causes/critical equipment of a system is a must. Furthermore, the identification of critical components of a complex industrial system is a difficult task for the maintenance management of a plant. It is due to the issues like vagueness of operational information/data, human error, etc. [13, 15, 19]. Hence, for addressing these issues it is essential to develop a knowledge-based decision support system for the considered system. For the accuracy in the identification of critical failure causes/critical equipment of a system operational knowledge of a plant is highly useful. Therefore, considering the operational knowledge of experts as a key factor, knowledge-based risk analysis of an industrial system is essential to be carried for improving plant availability and profitability.

3.2 Research Background

In the past, it has been reported that various researchers have implemented different frameworks for performing risk analysis in different sectors. Xu et al. [22] developed Fuzzy MATLAB Toolbox based framework for carrying the risk analysis of an automobile engine system. Sharma et al. [16] presented the application of fuzzy FMEA approach for analyzing the risk associated with the paper plant [20]. Sharma et al. [17] again expounded the application of fuzzy-based decision support system for identifying the critical component of the paper industry. Adar et al. [1] presented the application of fuzzy FMEA for performing the risk analysis of water gasification subsystem of a sewage treatment plant. Panchal and Kumar [9] presented the application of fuzzy methodology based framework for analyzing the risk issues of water treatment plant of thermal power plant. Panchal and Kumar [12] developed an integrated framework for the risk analysis of compressor house unit in a thermal power industry. The framework so developed in the above studies prove to be very useful for studying the risk issues of complex industrial system and the results so

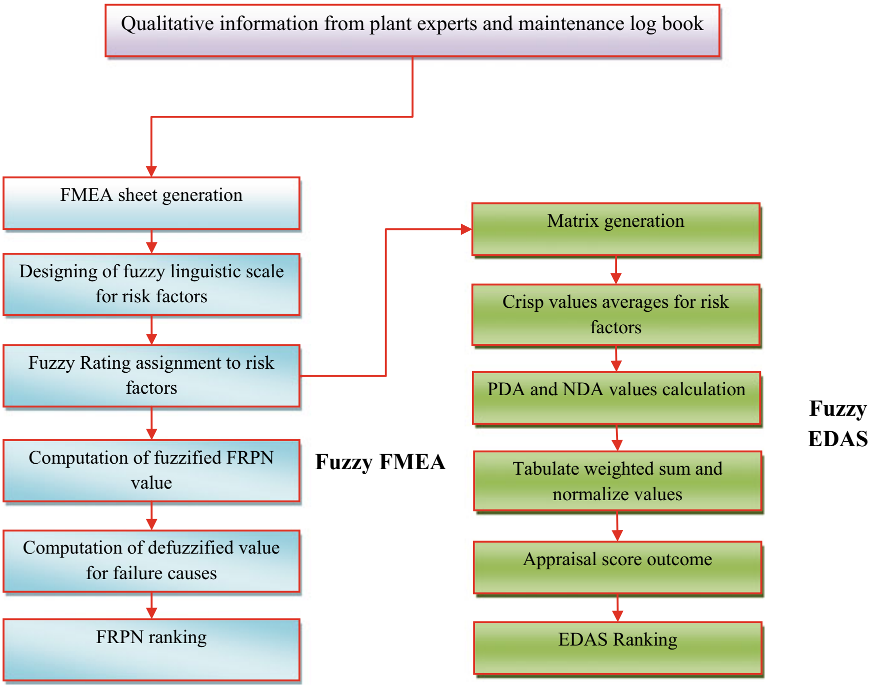

Fig. 3.1 Integrated framework

obtained with the implementation of these frameworks are very helpful for designing the maintenance policy for the system. In the above-cited work, IF-THEN fuzzy rule based FMEA approach based framework has been implemented for studying the risk issues of industrial systems. Although, the proposed framework is very useful there are some other limitations which are associated with this framework like similar ranking for more than one failure cause? Complete dependency on the quality of IF-THEN rules is also a big concern for the accuracy of decision-making results. Direct involvement of experts was also missing here. Considering these issues as a scope for further improvement there is a need to develop a new decision-making framework, which can overcome these limitations in an effective and efficient manner.

From the above-cited works, it has been noticed that the proposed framework is not developed yet and its application is not found in any area. Current research work presents a novel framework with its application on a WCS of a coal-fired thermal power plant located in the northern part of India. The proposed integrated framework with it layout is represented in Fig. 3.1.

First, qualitative information collected from the experts and log book record has been used to generate fuzzy linguistic scale for three risk factors (O, S, and D). Using expert's knowledge FMEA sheet has been generated; fuzzy ratings were assigned to tabulate the FRPN for each failure cause. Second, fuzzy EDAS approach was implemented within improved fuzzy FMEA and matrix were generated for each set of failure causes listed under a subsystem. Positive Distance from Average (PDA) and Negative Distance from Average (NDA) values were tabulated. Relative weight values for three experts have been considered for computed weighted sum values for PDA and NDA. Further, appraisal score values were tabulated, and on the basis of these values, ranking of failure causes was done and compared with improved FMEA approach based result for judging the stability of the risk results.

3.3 Fuzzy Concepts and Decision-Making Methods

3.3.1 Triangular and Trapezoidal Membership Functions

Membership functions under fuzzy set theory play an important role in considering the vagueness or uncertainty in the expert's judgment. Triangular and trapezoidal membership functions have been used in the present work because of its ease and a wide range of consideration of the uncertainty in the collected information. The equations for triangular and trapezoidal membership functions are represented as [11, 14, 17, 23–25].

$$\mu_{\check{S}}(t) = \begin{cases} \frac{x-a_0}{b_0-a_0}, & a_0 \le t \le b_0 \\ \frac{c_0-x}{c_0-b_0}, & b_0 \le t \le c_0 \\ 0, & \text{otherwise} \end{cases} \tag{3.1}$$

$$\mu_{\check{S}}(t) = \begin{cases} \frac{x-a_0}{b_0-a_0}, & a_0 \le t \le b_0 \\ 1, & b_0 \le t \le c_0 \\ \frac{d-x}{d-c}, & c_0 \le t \le d_0 \\ 0, & \text{otherwise} \end{cases} \tag{3.2}$$

where $\mu_{\check{S}}(t) \rightarrow$ membership function with triangular and trapezoidal fuzzy number represented as (a_0, b_0, c_0) and (a_0, b_0, c_0, d_0), respectively.

3.3.2 Improved Fuzzy FMEA

FMEA, first developed by NASA in 1963 since then it has been used effectively for the system and safety analysis of various systems in different sectors such as thermal power industry, paper industry, aerospace, medical, automotive, and nuclear [2, 7, 8, 14–16, 18]. To overcome the limitations of traditional FMEA and rule base FMEA as mentioned in Sect. 3.2, there is a need to develop an improved FMEA approach. The various steps of the improved FMEA approach are as follows.

Table 3.1 Defined linguistic terms for O

Linguistic terms	Probability of failure	Fuzzy ratings
Very high (VH)	Nearly unavoidable failure	(8,9,10,10)
High (H)	Failure recur	(6,7,8,9)
Moderate (M)	Rare failures	(3,4,6,7)
Low (L)	Few failure	(1,2,3,4)
Remote (R)	Improbable failure	(1,1,1,2)

Table 3.2 Defined linguistic terms for S

Linguistic terms	Failure probability	Fuzzy ratings
Risk without warning (RWOW)	High severity without any warning	(9,10,10)
Risk with warning (RWW)	High severity with warning	(8,9,10)
Very high failure (VH)	System unavailability with grave failure	(7,8,9)
High damage (H)	System unavailability with equipment damage	(6,7,8)
Moderate damage (M)	System unavailability with minor damage	(5,6,7)
Low damage (L)	System inoperable without damage	(4,5,6)
Very low (VL)	Significant degradation in system's performance	(3,4,5)
Minor (MR)	Slight degradation in system's performance	(2,3,4)
Very minor (VMR)	Inoperable system with a few minor problems	(1,2,3)
None (N)	No effect	(1,1,2)

Step 1 Assign fuzzy ratings on the basis of defined linguistic terms (Tables 3.1, 3.2, and 3.3) for three risk factors O, S, and D [23].

Step 2 The equations for computing the aggregated fuzzy ratings for three risk factors are represented as

Table 3.3 Defined linguistic terms for D

Linguistic terms	Severity effect	Fuzzy ratings
Completely uncertain (CU)	No possibility	(9,10,10)
Very remote (VR)	Very remote possibility	(8,9,10)
Remote (R)	Remote possibility	(7,8,9)
Very low (VL)	Very low possibility	(6,7,8)
Low (L)	Low possibility	(5,6,7)
Moderate (M)	Moderate possibility	(4,5,6)
Moderately high (MH)	Moderate–high possibility	(3,4,5)
High (H)	High possibility	(2,3,4)
Very high (VH)	Very high possibility	(1,2,3)
Almost certain (AC)	Almost sure	(1,1,2)

$$\check{T}_i^o = \sum_{j=1}^{k} p_j \check{T}_{ij}^o = \left(\sum_{j=1}^{k} p_j \check{T}_{ijL}^o, \sum_{j=1}^{k} p_j \check{T}_{ijM_1}^o, \sum_{j=1}^{k} p_j \check{T}_{ijM_2}^o, \sum_{j=1}^{k} p_j \check{T}_{ijU}^o \right) \tag{3.3}$$

$$\check{T}_i^S = \sum_{j=1}^{k} p_j \check{T}_{ij}^S = \left(\sum_{j=1}^{k} p_j \check{T}_{ijL}^S, \sum_{j=1}^{k} p_j \check{T}_{ijM_1}^S, \sum_{j=1}^{k} p_j \check{T}_{ijM_2}^S, \sum_{j=1}^{k} p_j \check{T}_{ijU}^S \right) \tag{3.4}$$

$$\check{T}_i^D = \sum_{j=1}^{k} p_j \check{T}_{ij}^D = \left(\sum_{j=1}^{k} p_j \check{T}_{ijL}^D, \sum_{j=1}^{k} p_j \check{T}_{ijM_1}^D, \sum_{j=1}^{k} p_j \check{T}_{ijM_2}^D, \sum_{j=1}^{k} p_j \check{T}_{ijU}^D \right) \tag{3.5}$$

where $\check{T}_{ij}^o$, $\check{T}_{ij}^S$ and $\check{T}_{ij}^D$ $\rightarrow$ fuzzy rating of n failure mode for three risk factors O, S and D

$p_j \rightarrow$ relative importance weights for k experts with satisfying the condition $\sum_{j=1}^{k} p_j = 1$ and $p_j > 0$.

Step 3 Equation for computing FRPN output is represented as

$$FRPN_i = \left(\check{T}_i^o\right)^{\varphi_O} \times \left(\check{T}_i^S\right)^{\varphi_S} \times \left(\check{T}_i^D\right)^{\varphi_D}, i = 1, 2, 3 \ldots n \tag{3.6}$$

where φ_O, φ_S and φ_D $\rightarrow$ risk factors fuzzy weights.

The $FRPN_S$ are computed using alpha-level sets equations for each risk factor as

$$(FRPN_i)_\alpha^L = EXP\left(\varphi_O.ln\left(\check{T}_i^O\right)_\alpha^L + \varphi_S.ln\left(\check{T}_i^S\right)_\alpha^L + \varphi_D.ln\left(\check{T}_i^D\right)_\alpha^L \right), \text{where } i = 1, 2 \ldots n \tag{3.7}$$

$$(FRPN_i)^U_\alpha = EXP\left(\varphi_O.ln\left(\check{T}^O_i\right)^U_\alpha + \varphi_S.ln\left(\check{T}^S_i\right)^U_\alpha + \varphi_D.ln\left(\check{T}^D_i\right)^U_\alpha\right), \text{where } i = 1, 2 \ldots n \tag{3.8}$$

Step 4 Equation for computing the defuzzified values of fuzzified FRPN is given as [4, 15]

$$\bar{y}_0\left(\tilde{Q}\right) = \frac{\int_b^c y\rho_{\tilde{Q}}(y)dy}{\int_b^c \rho_{\tilde{Q}}(y)dy} \tag{3.9}$$

where $\bar{y}_0\left(\tilde{Q}\right) \rightarrow$ defuzzified value.

Step 5 Prioritize the failure causes in decreasing order of FRPN values.

3.3.3 EDAS Method

EDAS method is another effective decision-making approach. This method is useful to deal with the conflicting criteria. This method is useful in comparison to other decision-making method such as Technique for Order of Preference by the Similarity to Ideal Solution (TOPSIS) and VIseKriterijumska Optimizacija I Kompromisno Resenje (VIKOR), because under it best alternative is selected on the basis of average solution rather than the Negative or Positive ideal solution values [5, 6]. In the present work, this method is applied because alternative selection becomes easy as less calculation is required to be done [6]. Procedural steps of EDAS approach are as follows [5, 6].

Step 1 Defuzzify fuzzy rating values obtained for three risk factors (O, S, and D) under improved fuzzy FMEA approach. Trapezoidal and triangular fuzzy ratings are converted into crisp values [3].

Step 2 Generate a decision matrix (A) for the set of failure causes associated with each subsystem and is represented by equations as

$$A = \left[A_{ij}\right]_{n\times m} = \begin{bmatrix} A_{11} & A_{12} & \cdots & A_{1m} \\ A_{21} & A_{21} & \cdots & A_{2m} \\ \vdots & \vdots & \vdots & \vdots \\ A_{n1} & A_{n2} & \cdots & A_{nm} \end{bmatrix} \tag{3.10}$$

where $A_{ij} \rightarrow$ crip value of the ith failure cause of the particular subsystem on jth risk factor.

Step 3 Compute the average of the crisp values under each risk factor as

$$AV = \frac{\sum_{i=1}^{n} A_{ij}}{n} \tag{3.11}$$

Step 4 Tabulate positive and negative distances from average (PDA, NDA) according to the type of risk factor (beneficial and non-beneficial). The equations according to the required criteria are shown as

$$PDA = \left[\widetilde{pda}_{ij}\right]_{n \times m} \tag{3.12}$$

$$NDA = \left[\widetilde{nda}_{ij}\right]_{n \times m} \tag{3.13}$$

Since in the current study, three risk factors are considered as non-beneficial, therefore, under such condition PDA and NDA are computed as

$$PDA_{ij} = \frac{max\left(0, \left(AV_j - A_{ij}\right)\right)}{AV_j} \tag{3.14}$$

$$NDA_{ij} = \frac{max\left(0, \left(A_{ij} - AV_j\right)\right)}{AV_j} \tag{3.15}$$

Step 5 Compute the weighted sum of PDA and NDA for each failure cause by using equations as

$$WP_i = \sum_{j=1}^{m} g_j \times PDA_{ij} \tag{3.16}$$

$$WN_i = \sum_{j=1}^{m} g_j \times NDA_{ij} \tag{3.17}$$

where $g_j \rightarrow$ relative importance weight values of three risk factors.

Step 6 Normalize WP and WN values for all failure causes by using equations as

$$NWP_i = \frac{WP_i}{max_i(WP_i)} \tag{3.18}$$

$$NWN_i = 1 - \frac{WN_i}{max_i(WN_i)} \tag{3.19}$$

Step 7 Compute appraisal score ($\widetilde{as}_i$) for all failure causes by using Eq. 3.20 and rank the failure causes on the basis of $\widetilde{as}_i$ values in ascending order.

$$\widetilde{as}_i = \frac{1}{2}(NWP_i + NWN_i) \tag{3.20}$$

where $0 \leq \widetilde{as}_i \leq 1$.

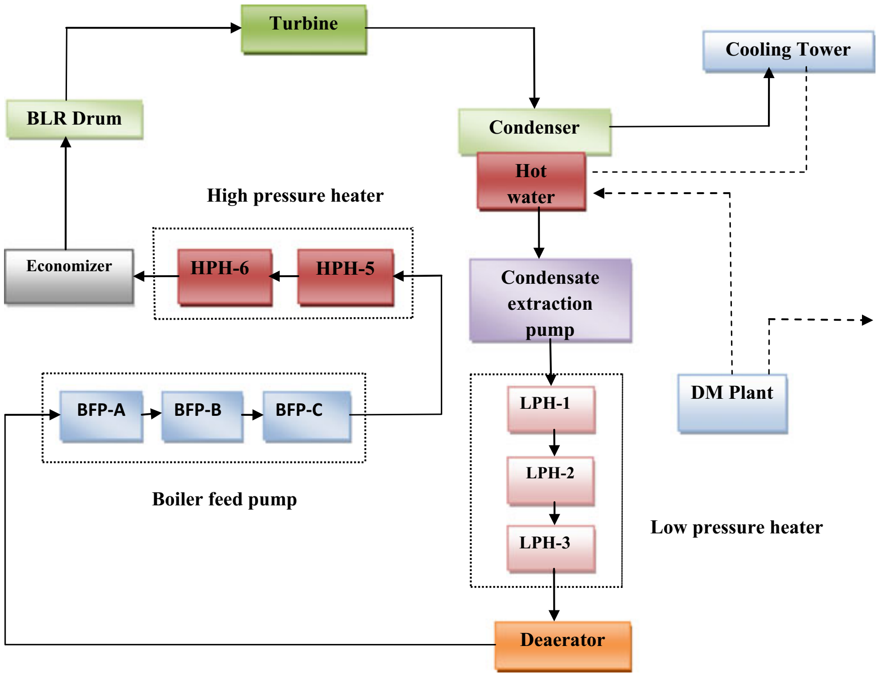

Fig. 3.2 Schematic diagram of WCS

3.3.4 Case Study

For the application of the proposed framework, WCS an important functionary unit of a coal-fired thermal power plant (Capacity-1368.8 MW) located in the northern part of India has been considered in the present work. WCS of considered industry consists of five main subsystems namely Condensate extraction pump, Low-pressure heater, Deaerator, Boiler feed pump, and High-pressure heaters. The schematic diagram of the Water Circulation System is shown in Fig. 3.2.

3.4 Proposed Framework Application

3.4.1 Improved FMEA Application

Under improved FMEA, various failure causes associated with different subsystems of the considered system have been listed by carrying a brainstorming session with the plant's operational experts. FMEA sheet has been prepared (Table 3.4) in which three experts were asked to allocate fuzzy ratings (on the basis of defined linguistic terms shown in Tables 3.1, 3.2, and 3.3) to three risk factors. Due to space limitation, FMEA sheet with the fuzzy rating provided by Expert-1 is shown in Table 3.4.

Further, considering risk factors (O, S, and D) fuzzy ratings, weight values as $\varphi_O = 0.45, \varphi_S = 0.35$, and $\varphi_D = 0.20$ and expert's relative importance weights as ($p_1 = 0.25$, $p_2 = 0.35$, and $p_3 = 0.40$) aggregate fuzzy rating were computed

Table 3.4 FMEA sheet

Components	Function	Potential failure mode	Potential effect of failure	Potential cause of failure	O	S	O
Condensate extraction pump	To pump out the condensate	Leakage	Operational efficiency loss	Seal failure **[CP_1]**	**M**	**VH**	**VH**
				Gland failure **[CP_2]**	**M**	**M**	**M**
		Jamming		Bearing seizure **[CP_3]**	**H**	**MR**	**MH**
				Rotor jamming **[CP_4]**	**H**	**VH**	**VH**
				Improper greasing **[CP_5]**	**M**	**RWOW**	**M**
Low-/high-pressure heater	To increase the temperature of the condensate	Leakage	System efficiency decrease	Tube puncture **[PH_1]**	**M**	**H**	**H**
				Gas kit failure **[PH_2]**	**L**	**RWW**	**VH**
		Chocking	System efficiency decrease	Improper cleaning of safety valve **[PH_3]**	**H**	**H**	**M**
Deaerator	To remove the dissolved gases from the feed water	Blocking	Operational efficiency decrease	Improper cleaning of spray nozzle **[DT_1]**	**L**	**L**	**L**
				Presence of foreign particles **[DT_2]**	**VH**	**H**	**R**

(continued)

Table 3.4 (continued)

Components	Function	Potential failure mode	Potential effect of failure	Potential cause of failure	O	S	O
		Valve failure	Operational efficiency decrease	Safety valve wear/tear **[DT_3]**	**L**	**M**	**L**
Boiler feed pump							
Filter	To filter the water	Blocking	Efficiency decrease	Filter chocking **[BP_1]**	**VH**	**VH**	**VH**
Buster pump	To increase the flow of water	Leakage	Operational efficiency decrease	Mechanical seal leakage **[BP_2]**	**M**	**VH**	**H**
				Hydraulic coupling leakage **[BP_3]**	**H**	**M**	**M**

using Eqs. 3.3–3.5. Here expert's relative importance values have been considered on the basis of their seniority in terms of their experience, whereas weights values for three risk factors were considered on the basis of expert's feedback. Further, by using Eqs. 3.7 and 3.8 upper and lower bound values for different α cut (range lies between 0 and 1) were computed for each failure causes and are used in Eq. 3.6 for computing FRPN outputs. The fuzzified FRPN values so obtained has been defuzzified by using Eq. 3.9 and the priorities were allocated to listed failure causes in descending order as shown in Table 3.5.

3.4.2 Fuzzy EDAS Application

Further, for testing the stability of the ranking results, fuzzy EDAS approach has been applied. Under the EDAS approach, fuzzy ratings assigned under improved fuzzy FMEA approach has been used in fuzzy EDAS and are converted into crisp values by using the relations [3]. Using crisp value for the defined linguistic term matrix was developed (using Eq. 3.10) for the set of failure causes listed under each subsystem of WCS. Using Eq. 3.11, the average of the crisp values has been tabulated under three risk factors (O, S, and D). Here, the three risk factors have been considered as non-beneficial criteria and PDA and NDA values were computed for the listed failure causes by using Eqs. 3.12 and 3.13. Further, considering expert's relative weight values the same as used under improved fuzzy FMEA weighted sum PDA and NDA values have been tabulated for each failure causes (considering risk factor

Table 3.5 Improved FRPN and fuzzy EDAS approach based ranking

Sr. No	Failure causes	FRPN score values	FMEA ranking	$\widetilde{as}_i$ values (EDAS output)	EDAS ranking
1	CP_1	4.6189	4	1.0000	5
2	CP_2	5.6585	3	0.3755	3
3	CP_3	6.5817	2	0.2966	2
4	CP_4	4.2017	5	0.7240	4
5	CP_5	7.4095	1	0.0000	1
6	PH_1	4.4109	3	1.0000	3
7	PH_2	6.1027	1	0.1127	2
8	PH_3	5.3853	2	0.0474	1
9	DT_1	5.2359	3	1.0000	3
10	DT_2	6.5433	2	0.4881	2
11	DT_3	6.8841	1	0.1420	1
12	BP_1	6.4457	3	1.0000	3
13	BP_2	6.8553	1	0.1193	1
14	BP_3	6.2545	2	0.3087	2

as non-beneficial criteria) by using Eqs. 3.14 and 3.15. Using Eqs. 3.16 and 3.17, normalized values for weighted sum PDA and NDA values have been computed. Using these values in Eq. 3.20, appraisal score ($\widetilde{as}_i$) values for each failure cause have been tabulated and ranking of failure causes was done in ascending order and comparison of results has been done as shown in Table 3.5.

3.5 Result Discussion

Table 3.5 compares the raking results given by fuzzy FMEA and EDAS analysis. From comparison, it has been observed that the causes CP_5, DT_3, and BP_2 of condensate extraction pump, deaerator, and boiler feed pump have been prioritized/ranked as 1 with improved FMEA outputs (4.6189, 6.8841, and 6.8553) and fuzzy EDAS outputs (1.0000, 0.1420, and 0.1193), respectively. Comparison of ranking results clearly shows that out of total 14 listed failure causes only 4 failure causes are with different rankings, whereas 10 failure causes show similar ranking. The similarity in ranking results shows the stability of ranking results and thus the robustness of the proposed integrated framework is also confirmed in this work.

3.6 Conclusion

The current study focuses on the application of the proposed framework on WCS of a coal-fired thermal power plant under uncertain environment. Triangular and trapezoidal membership functions are used with the proposed framework for considering uncertainty/vagueness in the collected information/experts feedback. Causes CP_5, DT_3, and BP_2 are identified as the most critical one as they have been ranked as first. A similarity in ranking results validates the application of the proposed framework. Table 3.5 results show no overlapping of ranking with the proposed framework, which means that the limitations of traditional FMEA, fuzzy rule base FMEA–Grey Relation approaches based framework has been overcome in an effective and efficient manner. As the analysis ranking results show consistency, therefore framework proves to be highly useful for the management of the considered thermal power industry and there would be no confusion for maintenance managers in designing the time interval for an optimal maintenance policy. The proposed framework-based analysis results totally depend upon the correctness of the data obtained from different sources. For considering the point of the correctness of information fuzzy set, theory-based concepts have been incorporated within the proposed framework. In future, the proposed framework could be implemented on other real industrial systems of different process industries and also it can be modeled with other mathematical theories for further improvements.

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Chapter 4
Modeling and Analysis of Critical Success Factors for Implementing the IT-Based Supply-Chain Performance System

Mohit Tyagi, Dilbagh Panchal, Ravi Pratap Singh and Anish Sachdeva

Abstract The key concern in competitive market is to maximize the performance as well as growth of the organization. To perform better among their competitors, every industry/company is trying to identify the critical success factors (CSFs) which will enable them to implement the latest technology changes in order to set a long-term sustainable edge. The present research identifies the critical success factors to enactment of Information Technology (IT) structure for better supply-chain performance system in auto industry particularly under Indian context. The aim of present research work is to recognize and examine the CSFs for implementing the IT-enabled supply-chain performance system. To achieve the aim, various success factors (SFs) were recognized on the basis of literature review/expert's opinions and "Interpretive Structural Modeling" (ISM) with preference rating has been applied as a hybrid approach. Through ISM, interrelationships among the identified SFs have been determined. To know the driving and dependence behavior of considered success factors, this model was developed and to visualize the "driving power" and "dependence power" relations, MICMAC analysis was accomplished. After that based on ISM model leveling (through cluster), a list of "critical success factors" (CSFs) was formulated in order to prioritize them using preference rating approach. The findings of the present research work may be helpful for managers in forming strategies/policies for implementing the IT-enabled supply-chain performance system effectively and efficiently.

Keywords Supply-chain management · Information technology · Critical success factors · ISM approach · Preference rating approach

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4.1 Introduction and Background

Indian automobile industry is one of the key contributors to National Economy; it accounts for 7.1% of the GDP, 45% of the manufacturing GDP, contributed 4.3% to exports, and 13% to excise revenues. Indian government with "Make in India" program is designed to simplify asset, adoptive innovation, improve skill enlargement, defend intellectual property, and form best in period manufacturing setup. Auto industry is giving lot of thrust to become more competitive and to use best in class processes and practices.

Many authors have defined supply-chain management (SCM) in different contexts. According to Womack and Jones [37], SCM is a crucial module to build organization more operative and competent in current business environment. To stay with competitive environment, most of the companies are putting lot of efforts and time to expand their supply-chain recital in order to reduce the overall operational cost. Tyagi et al. [32] defined Information Technology (IT) as equipment used to support information gathering, processing, and distribution, with composition of hardware and software technologies. Bayraktar et al. [3] found that firms are concentrating to build an IT-based platform in order to achieve the SCM training to improve their performance in worldwide viable marketplace.

According to Chen and Paulraj [4], application of information technology is emitting the positive effect on performance system of an organization in order to enhance their competitiveness and being more effective toward financial structure improvement because supply-chain performance system contains the various extents like "cost, quality, flexibility, and delivery." Pereira [29] stated that IT is a competent instrument which improves the info stream and also builds a vigorous and resistant supply-chain network. The IT-based system takes proficiency toward equal superior performance of the main organization and its associates of supply-chain network [13].

In the recent years, IT takes grew a higher visibility and effectiveness toward improving the supply-chain performance system under different contexts. In current visualizing practices, SCM-based actions are altered from "electronic data interchange (EDI) systems" and "enterprise resource planning systems" to internet–intranet to care supply-chain management [6]. Mentzer et al. [21] detected that practice of contemporary skills in supply chain can clue to gains like price saving, superiority enhancement, transfer and maintenance, and better cheap gain. Du et al. [7] stated that IT-based supply chain is very beneficial in terms of providing a flexible platform for better responsiveness and dynamic competitiveness [33].

The role of IT system inter-organizational factors is becoming more important in favor to integrate the companies on both sides, upstream and downstream. Efficacious execution among different organizational systems entails the cooperation and promise of exchange associates [5]. Therefore, it is easy to say that amiable relationships and partnerships form the basis of successful implementation (Gunasekaran and Ngai [11]; Panchal and Kumar [27]). Based on literature review, it has also been found that IT-enabled supply chain gives a visualized picture of trusting relationship among the trading partners which works as the main success factor in order to build a long-term relationship. Its implementation helps in creating the clear vision and strategy for a company in order to satisfy the stakeholders and customers as well. Leidner and Kayworth [17] found that success rate of an organization may be enhanced with the implementation of IT system [28]. Soliman and Janz [30] developed a model in order to visualize the trusteeship relationship based on IT system among the organizations.

4.2 Proposed Methodology

In this research work, a combination of "Interpretive Structural Modeling (ISM)" and "Preference Rating Approach" has been applied as a hybrid platform in order to achieve the objective.

4.2.1 Interpretive Structural Modeling Approach

ISM is an approach which is useful in analyzing the intricate socio-fiscal system [36]. It is an erudition practice that frequently recycled to provide vital kind of intricate conditions, as well as to place composed a passage of achievement for resolving the problems [16, 15].

There are various existing phases of interpretive structure modeling [14, 34] as summarized below: first recognize and conscript the success factors/issues related to IT-based supply-chain management and develop an appropriate association for each couple of factors recognized earlier. Further, it is mandatory to cultivate the structural self-interaction matrix (SSIM) for factors/issues based on pairwise interactions among the considered factors. After that based on SSIM a reachability matrix is structured with a check of transitivity rule, which follows the concept "Zeroth law of thermodynamics." Then, flow graphs have been formulated without indicating transitive links, and then ISM model has been developed by converting the resulting diagraphs. For one sight understanding, a flowchart of ISM approach has been structured as shown in Fig. 4.1.

4.2.2 Preference Rating Approach

The preference rating approach is newly developed method by Nahm et al. [24] to govern the comparative importance scores among the considered factors/issues. Under this method, graph theory-based representations are to be used to exemplary the human's imperfect or indeterminate preference edifice, and these graphical representations are known as preference graphs (PGs) Nahm and Ishikawa [22, 23]. As

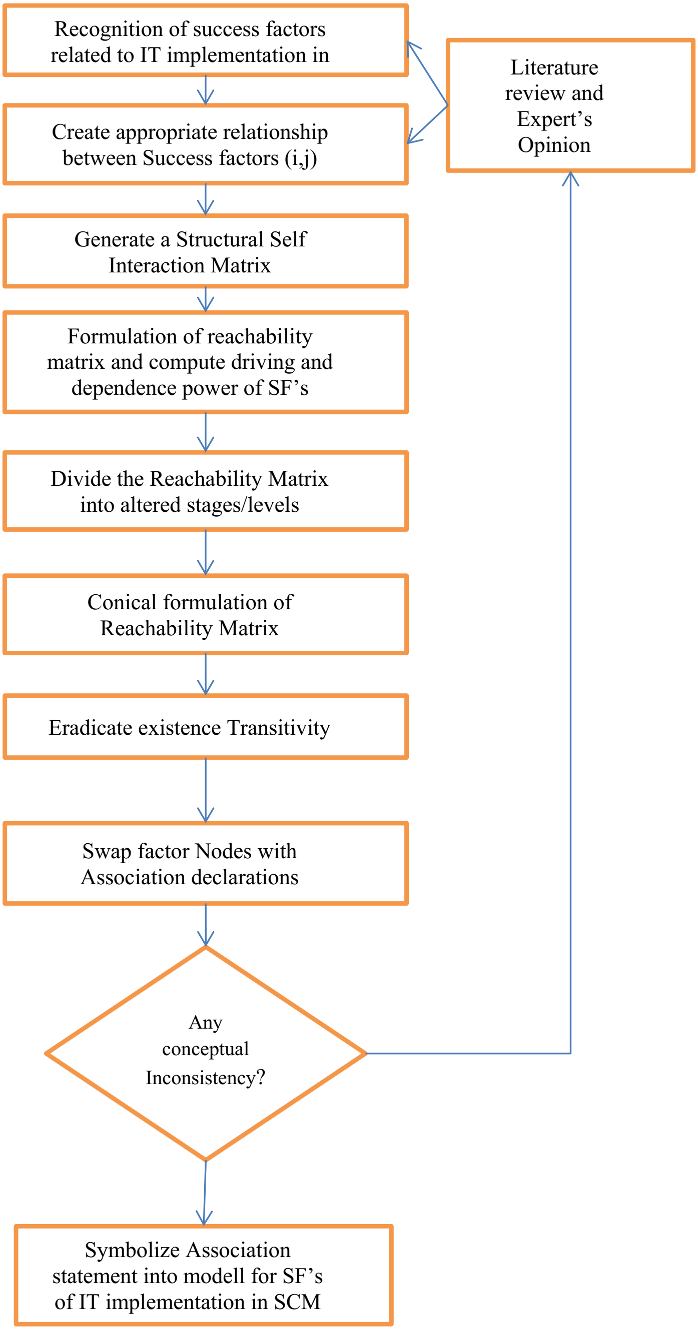

Fig. 4.1 ISM flowchart

Table 4.1 Set of recognized success factors (SFs)

Sr. no.	Factors impacting IT implementation	Authors
1	Top management commitment/support	Wang and Elhog [35], Gunasekaran and Ngai [10]
2	Clear vision and business strategy	Griffin [9]
3	Effective project management	Al Khalil [2]
4	Organizational culture	Cheng [5], Hartono et al. [12].
5	Change management	Magnan et al. [20]
6	Effective communication	Devaraj and Kohli [6]
7	Education and training	Okur et al. [25]
8	Focused performance measures	Okur et al. [25], Olugu et al. [26]
9	Cooperation and commitment of trading partners	Gunasekaran and Ngai [11]
10	Trust among channel members	Akkermens et al. [1]
11	User support and involvement	Ellram [8]
12	Project team composition	Lohman et al. [19]

an advantage, this method provides degree of dominance of each factor over another factor which helps in prioritizing the considered factors. A step-to-step route of this approach is explained in the next section with numerical illustration.

4.3 A Case Illustration

To drive the implementation of the present methodology, an example of auto industry situated at National Capital Region (NCR) of India was considered. The various substantial critical success factors related to IT-enabled supply-chain performance system were recognized on the root of previous work done and conversation by park professionals and are set as in Table 4.1.

In this present work for recognizing the appropriate relationship among the SFs of IT implementation in SCM, twofold groups of experts from college circles and four groups of experts from auto industry have been referred, each group having three to four experts. The selected experts (academia and industry) have appropriate

Table 4.2 Structural self-interaction matrix (SSIM)

	Factors	12	11	10	9	8	7	6	5	4	3	2
Top management commit-ment/support	1	V	X	A	V	X	V	A	V	V	V	V
Clear vision and business strategy	2	V	A	O	V	V	A	A	V	O	V	
Effective project management	3	V	V	A	X	X	O	A	V	A		
Organizational culture	4	V	A	X	V	O	X	A	V			
Change management	5	O	A	A	A	V	A	A				
Effective communication	6	V	V	V	V	X	O					
Education and training	7	O	X	O	O	A						
Focused performance measures	8	A	A	A	A							
Cooperation and commitment of trading partners	9	A	X	A								
Trust among partners	10	O	V									
User support and involvement	11	O										
Project team composition	12											

knowledge toward the IT-based supply-chain system in Indian auto industry. On the basis of appropriate relationship among the factors, Structural Self-Interaction Matrix (SSIM) has been established. There are standard symbols to represent the track of association between the factors (i and j) (Table 4.2):

V Feature i will help to accomplish factor j
A Feature j will help to accomplish factor i
X Feature i and j will help to accomplish each other and
O Feature i and j are disparate

Based on SSIM, an initial reachability matrix was established using the following instructions:

- If the $\{i,\ j\}$ cell value in the SSIM is V, then fix the $\{i,\ j\}$ score 1 in the reachability matrix and the $\{j,\ i\}$ score to 0.

- If the $\{i, j\}$ cell value in the SSIM is A, then fix the $\{i, j\}$ score 0 in the reachability matrix and the $\{j, i\}$ score to 1.
- If the $\{i, j\}$ cell value in the SSIM is X, then fix the $\{i, j\}$ score 1 in the reachability matrix and the $\{j, i\}$ score to 1.
- If the $\{i, j\}$ cell value in the SSIM is O, then fix the $\{i, j\}$ score 0 in the reachability matrix and the $\{j, i\}$ score to 0.

After that by applying the rule of transitivity, final reachability matrix has been structured as exposed in Table 4.3. To determine the reachability set, partitions have been made in final reachability matrix. For level partition, the factors have equal reachability set and intersection set subsists at level "I" and conquer the highest level in ISM-based model [14]. The factors established at "level-I" are superfluous from the next process, which have been made with the lasting factors and by retelling the above procedure and make these repetitions continuous till the stages/levels of each factor were finalized. A summary of level partition is exposed in Table 4.4.

Based on level divination rule, an ISM-based model has been structured for the success factors of IT-based supply-chain performance system. The model shows relationship among the success factors. Using final reachability matrix, an organized model is formed and diagraph is developed. The diagraph was converted into ISM model as exposed in Fig. 4.2, which displays the driving and dependence behavior of the considered factors.

From Fig. 4.2, it is clear that top management commitment practices the ground of ISM ladder and is the main success factor for IT-enabled supply chain. ISM hierarchy helps to explain mutual relationship among SFs. Top management commitment/support drives organizational culture, effective communication, and trust among channel partners which form the level II at ISM hierarchy. These three SFs are interrelated that is effective communication helps to achieve trust among channel members. Similarly, organizational culture helps in effective communication and vice versa. These three SFs help to achieve clear vision and business strategy formed by top management at level III of ISM hierarchy. Then, vision and business strategy forms the base for cooperation and commitment of trading partners, education and training, and project team composition at level IV. At level IV, SFs have mutual relationship that is based on project team composition education and training is decided. The SFs exist on level IV helps to achieve SFs of level V that is user support and involvement, effective project management and change management. Effective project management helps user support and involvement, which in turn helps to change management. At Level V, SFs help to achieve focused performance measures set for IT implementation, which is at level VI of ISM ladder.

4.4 MICMAC Analysis

MICMAC analysis reveals the classification of factors on the basis of driving and dependence power in four segments as shown in Fig. 4.3. To determine the value

Table 4.3 Final reachability matrix

	SF 1	SF 2	SF 3	SF 4	SF 5	SF 6	SF 7	SF 8	SF 9	SF 10	SF 11	SF 12	Driving power
SF 1	1	1	1	1	1	1	1	1	1	1	1	1	**12**
SF 2	1	1	1	0	1	1	1	1	1	0	1	1	**10**
SF 3	1	1	1	1	1	1	1	1	1	0	1	1	**11**
SF 4	1	1	1	1	1	0	1	1	1	1	1	1	**11**
SF 5	1	0	1	0	1	1	1	1	0	0	0	0	**6**
SF 6	1	1	1	1	1	1	1	1	1	1	1	1	**12**
SF 7	1	1	1	1	1	0	1	1	1	1	1	1	**11**
SF 8	1	1	1	1	1	1	1	1	1	1	1	1	**12**
SF 9	1	1	1	1	1	1	1	1	1	0	1	1	**11**
SF 10	1	1	1	1	1	1	1	1	1	1	1	1	**12**
SF 11	1	1	1	1	1	1	1	1	1	1	1	1	**12**
SF 12	1	0	1	0	1	1	1	1	1	0	1	1	**9**
Dependence power	**12**	**10**	**12**	**9**	**12**	**10**	**12**	**12**	**11**	**7**	**11**	**11**	

Table 4.4 Level partition (Iteration II–VI)

CSFs	"Reachability set"	"Antecedent set"	"Intersection"	"Level"
1	1, 2, 3, 4, 5, 6, 7, 9, 10, 11, 12	1	1	VI
2	2, 3, 5, 7, 9, 11, 12	1, 2, 4, 6, 10	2	IV
3	3, 5, 9, 11, 12	1, 2, 3, 4, 5, 6, 7, 9, 10, 11, 12	3, 5, 9, 11, 12	II
4	2, 3, 4, 5, 6, 7, 9, 10, 11, 12	1, 4,6, 10	4, 6, 10	V
5	3, 5, 9, 11,	1, 2, 3, 4, 5, 6, 7, 9, 10, 11, 12	3, 5, 9, 11,	II
6	2, 3, 4, 5, 6, 7, 9, 10, 11, 12	1, 4, 6, 10	4, 6, 10	V
7	3, 5, 7, 11, 12	1, 2, 4, 6, 7, 10, 12	7, 12	III
9	3, 5, 9, 11	1, 2, 3, 4, 5, 6, 9, 10, 12	3, 5	III
10	2, 3, 4, 5, 6, 7, 9, 10, 11, 12	1, 4, 6, 10	4, 6, 10	V
11	3, 5, 9	1, 2, 3, 4, 5, 6, 7, 9, 10, 11, 12	3, 5, 9	II
12	3, 5, 7, 9, 11, 12	1, 2, 3, 4, 5, 6, 7, 10, 12	3, 7, 12	III

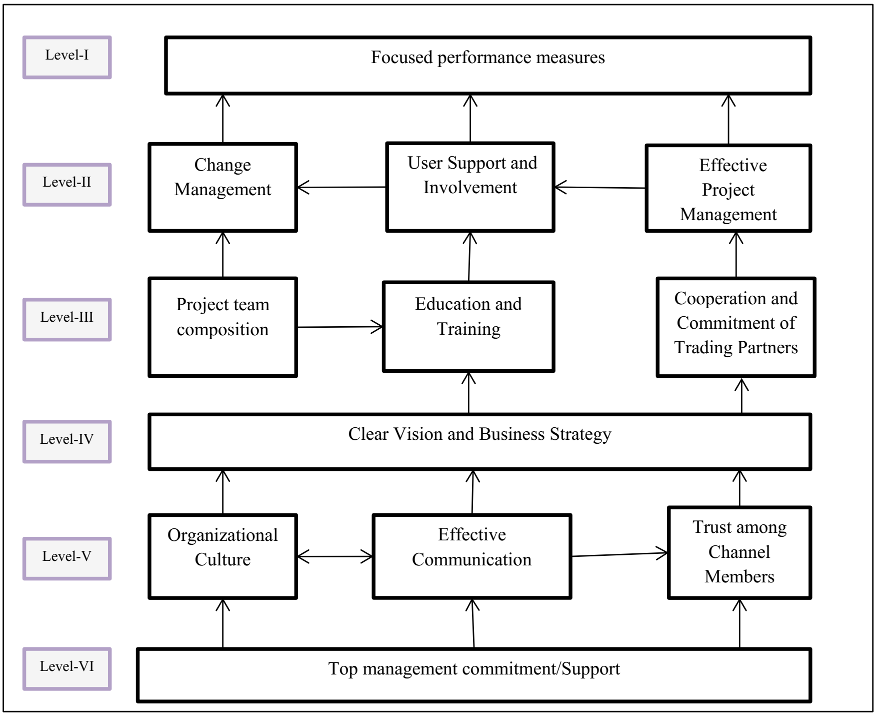

Fig. 4.2 ISM-based model

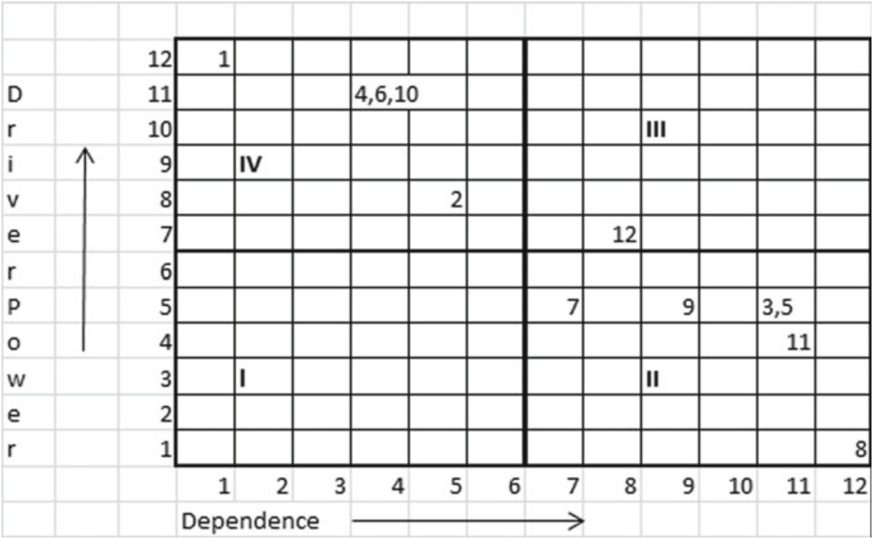

Fig. 4.3 Driver and dependence power graph

of "driving" and "dependence" power of considered success factors, final reachability matrix was used. Classification of segments under MICMAC analysis is as follows: Segment 1: independent factors; Segment 2: dependent factors; Segment 3: association factors; and Segment 4: driver factors. The SFs have weak driving, and dependence power occurs in the Segment 1. These types of SFs have rare links with the additional SFs existing in another segments and also disengaged from the classification. The SF's devouring weak driver power and strong dependence power will exist in Segment 2. The SFs have strong driver power as well as dependence power will exist in Segment 3 and in last SFs that have resilient driving and weak dependence power occurs in Segment 4 [14].

As CSFs of Segment 4 contain high driver power, they strongly touch the SFs of another segment. Therefore, it is needed to focus more toward SFs that conquer the upper place in ISM model to accomplish the improved outcomes.

Based on Fig. 4.3, it is observed that no success factor exists in Segment 1. The six SFs explicitly effective project management, change management, education and training, cooperation and commitment of trading partners, focused performance measures, and user support and involvement lie in Segment 2. Hence, these SFs require low driver power and strong dependence power. In Segment 3, only one SF's project team composition has high driver power and dependence power. Five SF's top management commitment/support, organizational culture, effective communication, clear vision and business strategy and trust among channel members lie in Segment 1, which has robust driver nature and low dependence nature. Hence, they formed the top levels in ISM hierarchy.

Further on the basis of ISM leveling (cluster of SFs exist on same level), a set of six "critical success factors" (CSF's) was arranged. Those are, namely, as top management commitment support (CSF6), trust among organization through effective communication (CSF5), clear vision and business strategy (CSF4), cooperation and commitment among team members based on their education and training (CSF3), project management through user support and involvement (CSF2), and focused performance measures (CSF1). The coding of CSFs has been done as per their level existence.

Based on brainstorming session, three groups each having four to six experts have been structured. The three groups considered are represented as GP_1, GP_2, and GP_3, and preference graphs represented by these groups may be represented as PG1, PG2, and PG3 as exposed in Fig. 4.4.

The preference graph (PG_1) over "N" CSFs (in this case, N = 6) can be structured by group one. Let us say, a PG to be denoted by "r" groups, GP_r. In order to that, suppose PG_r be nearest matrix for the preference graph and "N" be a optimistic number. Hence, the item pg_{ij} (i, j = 1, 2,…, n,…., N) of PG_r^N offers the amount of "N" step supremacies of element i over j.

Hence, dominance matrix D^r is structured as

$$D^r = PG_r^1 + PG_r^2 + \ldots PG_r^n \ldots + PG_r^N \tag{1}$$

The summation of items (d_n^r) in row "n" of dominance matrix means the entire amount of conducts that n is dominant over 1, 2,…, N stages [31, 18]. In this study, dominance stages are considered as (N−1) for the PG. Based on ISM model leveling, six CSFs were considered; hence, five dominance stages will occur. The nearest matrix of PG_1 can be represented by

$$PG_1^1 = \begin{bmatrix} 0\,0\,0\,1\,0\,0 \\ 0\,0\,0\,1\,0\,0 \\ 1\,1\,0\,0\,0\,0 \\ 0\,0\,0\,0\,0\,0 \\ 0\,1\,0\,0\,0\,0 \\ 0\,0\,1\,0\,1\,0 \end{bmatrix} \tag{2}$$

In this case with N = 6, the dominance matrix (D^1) of PG_1 can be calculated by

$$D^1 = PG_1^1 + PG_1^2 + PG_1^3 + PG_1^4 + PG_1^5 \tag{3}$$

From Eq. 3, dominance matrix (D^1) of first preference graph is found as given below:

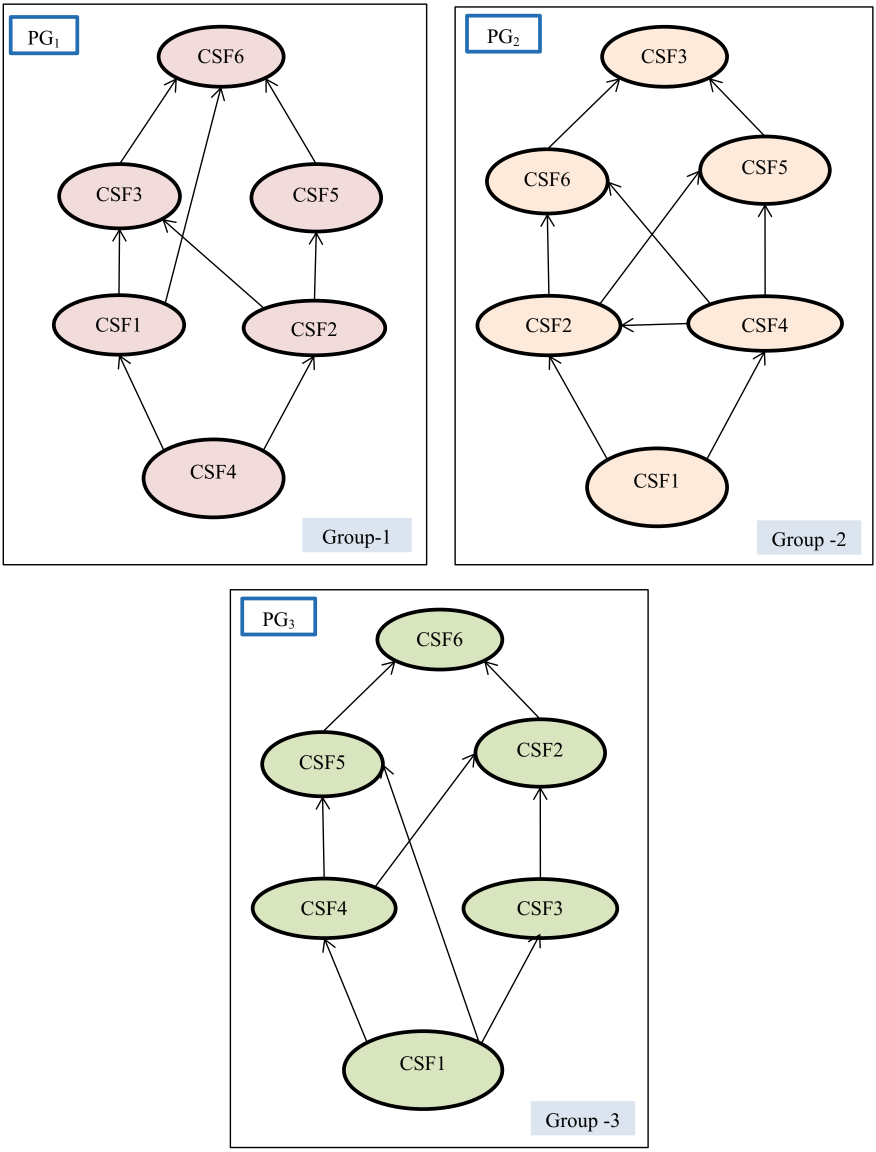

Fig. 4.4 Demonstration of relative prominence of CSFs

$$D^1 = \begin{bmatrix} 0 & 0 & 0 & 1 & 0 & 0 \\ 0 & 0 & 0 & 1 & 0 & 0 \\ 1 & 1 & 0 & 2 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 1 & 0 & 1 & 0 & 0 \\ 2 & 2 & 1 & 4 & 1 & 0 \end{bmatrix} \tag{4}$$

Based on the above equation, the degrees of dominances of one critical success factor have been deliberate as "$d_1^1 = 1$, $d_2^1 = 1$, $d_3^1 = 4$, $d_4^1 = 0$, $d_5^1 = 2$ and $d_6^1 = 10$. It can be visualized as CSF1 is dominated in 0 + 1 + 0 + 0 + 0 + 0 = 1 way." CSF3 may be dominated in four ways, similarly CSF6 in ten ways. The above computation procedure is repeated similarly for other preference graphs PG_2 and PG_3.

Dominance matrix (D^2) of second preference graph is determined as

$$D^2 = PG_2^1 + PG_2^2 + PG_2^3 + PG_2^4 + PG_2^5 \tag{5}$$

From Eq. 5, dominance matrix (D^2) of second preference graph is found as

$$D^2 = \begin{bmatrix} 0 & 0 & 0 & 0 & 0 & 0 \\ 2 & 0 & 0 & 1 & 0 & 0 \\ 6 & 2 & 0 & 4 & 1 & 1 \\ 1 & 0 & 0 & 0 & 0 & 0 \\ 3 & 1 & 0 & 2 & 0 & 0 \\ 3 & 1 & 0 & 2 & 0 & 0 \end{bmatrix} \tag{6}$$

In order to visualize the degree of dominance based on preference group (PG_2), a matrix has been structured as shown in Eq. 6, "$d_1^2 = 0$, $d_2^2 = 3$, $d_3^2 = 14$, $d_4^2 = 1$, $d_5^2 = 6$, and $d_6^2 = 6$. Similarly, for PG_3, degree of dominances has been obtained as follows: $d_1^3 = 0$, $d_2^3 = 4$, $d_3^3 = 1$, $d_4^3 = 1$, $d_5^3 = 3$, and $d_6^3 = 9$."

The "relative degree of preference" (RDP) of every group (r) can be found by the following mien to be the extreme of one using formula as given below:

$$\mathrm{Rdp}_n^r = \frac{(1 + d_n^r)}{\max\limits_{m=1....N} (1 + d_n^r)} \mathrm{r} = 1 \ldots \mathrm{R} \tag{7}$$

For the explanatory suitability, RDP symbolization of each company (k) is a vector:

$$\mathrm{RDP_r} = \left(\mathrm{rdp}_1^r, \ldots \mathrm{rdp}_n^r, \ldots \mathrm{rdp}_N^r\right) \tag{8}$$

Relative degree of preference for PG_1, PG_2, and PG_3 are as follows:

$$\mathrm{RDP_1} = \left(\frac{2}{11}, \frac{2}{11}, \frac{5}{11}, \frac{1}{11}, \frac{3}{11}, \frac{11}{11}\right)$$

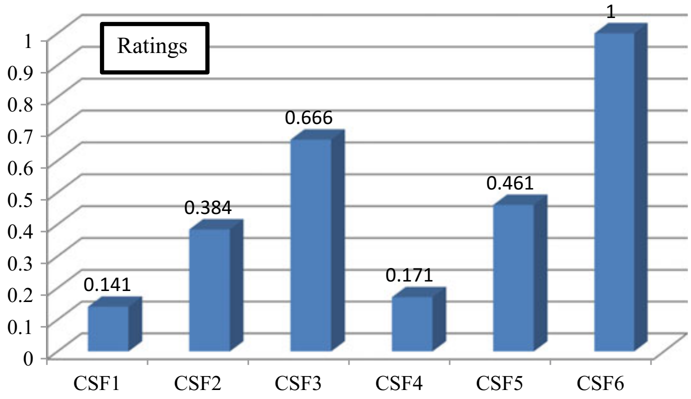

Fig. 4.5 Rating of critical success factors

$$\mathrm{RDP}_2 = \left(\frac{1}{15}, \frac{4}{15}, \frac{15}{15}, \frac{2}{15}, \frac{7}{15}, \frac{7}{15}\right) \text{ and}$$
$$\mathrm{RDP}_3 = \left(\frac{1}{10}, \frac{5}{10}, \frac{2}{10}, \frac{2}{10}, \frac{4}{10}, \frac{10}{10}\right) \tag{9}$$

On the basis of RDP of each group, relative importance ratings of the CSFs may be determined easily. Since "R" firms are occupied into description, the relative importance rating (RIR) of each CSF can be examined through normalization process by using the expression as given below:

$$\mathrm{RIR_n} = \frac{\sum_{r=1}^{R} rdp_n^r}{\max\limits_{n=1.....N}(\sum_{r=1}^{R} rdp_n^r)} \tag{10}$$
$$\mathrm{RIR} = (\mathrm{rir_1},\ \mathrm{rir_2}, \ldots \mathrm{rir_m}, \ldots, \mathrm{rir_N}) \tag{11}$$

In this research work, computation was made to get the RIR value through Eq. 9, and then normalization has also been in order to reduce the variation among the ratings of considered CSFs which comes as follows:

$$\mathrm{RIR} = (0.141,\ 0.384,\ 0.666,\ 0.171,\ 0.461,\ 1.000) \tag{12}$$

From above computation, it has been observed that the critical success factor "six" (CSF6) has higher value of relative importance rating as compared to the other CSFs and "CSF1" seems least desirable with a relative importance rating of 0.141 among all considered CSFs. For ease in comparative understanding of the ratings of CSFs, a bar diagram is made as exposed in Fig. 4.5.

4.5 Results and Discussion

MICMAC analysis directs the comparative prominence and interdependencies of critical success factors. The analysis reveals many outcomes as deliberated below:

- Among considered critical success factor, no one lies in independent group, i.e., in Segment 1, this delivers an optimistic immoral for learning, and this means all the factors considered are consistent and play an significant role in implementation of IT in supply-chain management.
- SF's effective project management, change management, education and training, cooperation and commitment of trading partners, focused performance measures, and user support and involvement lie in Segment 2, which means they have strong dependence and low on driving power.

It may be accomplished based on critical success factors which have high driving power. As depicted in ISM model, they are being driven by other factors which lie below them in model.

- Success factor project team composition lies in Segment 3, which means they have strong dependence and driving power; project team composition plays an important role in implementation as it gets driven by the factor and it also drives other factors for successful implementation.
- SF's top management commitment/support, organizational culture, effective communication, clear vision and business strategy and trust lie in Segment 1 which contains high driver power and low dependence power. It means they drive other CSFs and plays most important role for implementation of IT for SCM.

On the other corner, based on degree of dominance and relative importance of structured critical success factors, it is pragmatic that "top management commitment" support comes out with a high relative importance rating and focused performance measures with lower relative rating as shown in Fig. 4.5.

4.6 Conclusion

In this research work, a hybrid approach as a combination of interpretive structural modeling (ISM) and preference rating was applied in order to analyze the considered success factors well along with critical success factors. Through ISM, driver and dependence nature of considered factors have been visualized while preference rating approach was applied in order to arrange them constructed on grade of dominance. From Fig. 4.2, it was noted that "top management commitment and support" plays a role of driver in order to focus on the performance measures through various considered factors those exist on in-between levels. Equation 12 summarizes the relative importance ratings (RIR) of all structured critical success factors. The periodization of these factors can be shown as CSF6 > CSF3 > CSF5 > CSF2 > CSF4 > CSF1.

From Fig. 4.5, a clear view of these ratings can be envisioned. Hence, it is easy to say that "top management commitment support" with a higher RIR and "Focused performance measures" with lower RIR plays their significant part in implementing the IT-based supply-chain performance system effectively and efficiently.

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Chapter 5
Lean-Sigma for Product Improvement Using the VoC for Enhancing the Product Competitiveness

Aldo Salcido-Delgado, Li Zhou and Noé G. Alba-Baena

Abstract Managers are using metrics such as productivity, quality and low costs, to reach their objectives and keep companies success; however, customer expectations in the twenty-first century are not only including deliveries on time, good quality, and low costs; but they are also looking for values such as long term commitment, strategic integration and innovation as competitive values. For the mentioned conditions, today's managers need to learn how to adapt to such challenges by using flexible methodologies that help them to integrate more qualitative requirements to the conventional metrics. For this challenge recently, Lean-Sigma has proven to be a flexible and adaptable methodology that can incorporate such requirements. For proving this concept, this chapter describes a case study in which the initial valuation of the metrics shows that a product has been delivered as expected with the quality and productivity values in the best levels. However, the customer perception is different and product competitiveness is at risk, signals that the operations management presented as a priority requiring actions and a later solution. Using the Voice of the Customer (VoC) and Lean-Sigma, this study focuses in an operation framed in the automotive industry. The assembly process is the target in specific in the cutting step of rubber hoses, which have to measure different lengths depending on the product models. At first sight, with a production rate of 1000 pieces per hour, the 7

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complains in a year looks as expected for the variability in the process. However, the quality perception and confidence of the customer are at risk. Actions were taken and in two weeks the team incorporated the qualitative requirements to the operations' quantitative targets and responded to the customer concerns and kept the product competitiveness. The adjustments and implementations results are reflected in the measured values at the cutting process, achieving an 80% reduction in the process' variation, and an increment in the capability index (Ppk) from 0.97 to 1.97.

Keywords Lean-Sigma · Variation reduction · Production process

5.1 Introduction

In the world-class manufacturing and actual competitive environment, the difference between a profitable operation and the bankruptcy can be decided by the customer perception, moreover, having a well balanced factors in the managerial triangle (productivity/delivery, quality/functionality, and costs/profit) is not a measurement of a successful operation. Today, the more efficient processes and profit margins are just mere base for entering the market; the success is now a mirror of the ability of the company to influence the customer's perception, trust and reliability as advantages over other competitors. Such strategy is based in the customer service offered for fast responding to the customer concerns. A successful relationship then, is defined by the ability of the companies to balance between customer-care concessions and the profit resulting from this relationship. The challenge for the managers is to integrate the mentioned market reality into the operations' goals, actions and measure targets. However, actual approaches consider only the management triangle (quality, productivity, and costs) for their decision-making process and goals in the operations strategies. Moreover, operations managers can dissect actions and reactions in their management programs using approaches in three different categories: problem-solving, improvement, and optimization processes. Such programs may include Lean manufacturing as a response methodology for process challenges, Six Sigma can be used for improvement projects, and the Taguchi approach or surface respond method (RSM) for optimization ventures and more recently, Lean-Six Sigma variations for solving complex problems [18]. In the search for an efficient methodology for including more actively the VoC in the operations management, Lean-Sigma is presented as a feasible option. This chapter describes the use of the Lean-Sigma approach and its adaptability for solving problems at different managerial levels and for different conditions. Lean-Sigma has been developed from the principles of Six Sigma and Lean manufacturing that have been extensively used successfully companies around the globe, especially in Japan and the USA. For this purpose, a brief description of these managerial strategies will help us to describe the key factors that make the integration of these strategies in the Lean-Sigma approach.

5.1.1 The Six Sigma Strategy

The Six Sigma term is attributed to Bill Smith who helped Motorola Corporation to achieve an estimated $16 Billion in savings during the 1980s. After, several USA companies, including GE and Allied signal, have successfully implemented this philosophy and methodology. According to Arnheiter and Maleyeff [3], the concepts behind Six Sigma can be traced to C. Gauss who introduced the normal curve and its statistical meaning; followed by the works of W. Shewhart in the Western Electric Company, who introduced in 1924 the Control charts as visual representation of defective items in the Hawthorne facilities. Later, his work sets the bases for the statistical quality control, and to the total quality management (TQM) approach and the Six Sigma statistical metric originated at Motorola Corporation. Today, the use of Six Sigma helps to effectively identify and eliminate the variability in the production processes, and has grow to the point that companies around the world have built entire cultures around this founding concept. Moreover, according to Dahlgaard and Mi Dahlgaard-Park [6], Six Sigma is more than a narrowly focused quality management program, but is extended to a definition of a methodology, later a philosophy, and broad long-term decision-making business strategy. Literature reports have shown that the use of the Six Sigma approach has taken many organizations to operate at very high levels of efficiency. As mentioned by Brun [5] who also lists several of the factors for a successful in implementation of Six Sigma and those for limiting the benefits. Among them, the main considerations are the management involvement, linkage to the customer and business plan, training, and cultural change. In this terms, Del Angel and Pritchard [8] highlighted the importance of the listed and potential failure factors. The same author refers that the majority of all corporate Six Sigma initiatives (60%) fail to yield the desired results due to these factors. As an example, the management acceptance and incorporation of the Six Sigma culture as successful factor for impulse the implementation to its maturity. However, contradicting this rationale, managers have discovered that the very culture of little to no variance that allowed them to achieve their efficiency goals can be the main factor for suffocating their growth potential as the process variance is essential for promoting the innovation and growth of the business [18]. In other hand, the influence of the cultural effects is exemplified by a case in the 3 M corporation, where the initial profits grew approximately 22% a year, but then languished drastically. Such reduction was attributed to the strategy that emphasized on efficiency, strangling 3 M's employees' creativity and innovation initiatives [8].

5.1.2 Lean Manufacturing Strategy

From a historical perspective, Lean manufacturing has been evolved and used exponentially, since Krafcik [12] introduces the term Lean production system in the USA. Krafcik describes the importance of the transition process from the Fordist production system and the further enhancements the largely efficient adaptation into the Toyota Production System (TPS). This highly efficient constant-flow production process was also characterized by its flexibility for producing a variety of products. Among its practices, this system included smaller inventories and less preparation areas, it also increases dramatically the teamwork approach even for the work standardization processes. The increment of the teamwork and data analysis characterized the Lean approach and has been contributed to the "Leanness" of the production management policies and to increase the manufacturing facilities' performance and productivity of a variety and flexible models' mix and complexity. From such experiences, western companies were attracted to the Lean practices having reported successful implementations [12]. The 2007 manufacturing census [4] revealed that almost 70% (69.6%) of the US companies that successfully used Lean manufacturing had improved their target values. Lean then, has become the most common approach in the operations management field, which is twice popular of the second in use (Total Quality Management with 34.2%). However, Blanchard [4] also points out that such popularity does not correspond to successful implementations. 2% of the responding companies achieved their goals using a Lean approach and 24% have significant achievements; however, for the left 74%, the results were not as expected. Quoting James Womack, Blanchard attributes these results to several misconceptions, such as, "Lean management is not a quick solution for cost reduction." Moreover, other consulting practitioners such as Pay [16] and McMahon [14] have not only highlighted the Lean Manufacturing approach failure rates but the common causes for such results. First, they point out that managers must analyze if the Lean approach will contribute directly to reinforce the company's strategy, avoiding with this the failures due to management commitment and Lean principles implementation. The second point is to match and agree the management practices to the team decision-making approach practiced in Lean manufacturing. Then, to be aware of the internal and surrounding culture, which determines the impact and change-resistance when the managers incorporate the Lean principles and practices in the company. And finally, to keep use customer focus and avoid to have conflicting metrics among other suggestions.

In the struggle for avoiding the negative impacts and failure rates in the implementation processes, practitioners consider to merge both approaches attempting to using the best practices of both approaches. If we consider that the general strategies of Six Sigma and Lean manufacturing started from two different needs: Lean from the need to increase product flow and productions speed by the elimination of all non-value-added activities (*mudas*), and Six Sigma from the need to ensure the final product quality; focusing in achieving high product conformance or less defective products [3], the integration seems difficult, however higher quality at increased speed is the promised land.

5.1.3 Merging Lean and Six Sigma

Considering that the original methodologies differ by the structure and objectives, while Six-Sigma project considers that the "improvement happens project-by-project and in no other way" [18]. Lean management focuses on the reduction of the production times and variation by establishing standardized work procedures and a single-piece flow approach to achieve improvements. Tools and decision processes in Six-Sigma quality systems are characterized by deep statistical analysis and the use of statistical process control (SPC). For measuring the quality and variation of the process, Six-Sigma uses acceptance sampling procedures for batches of the final products. On the other hand, Lean approach used fixtures and other mistake proofing (Poka-Yoke) sources, for achieving higher quality and by these means a 100% inspection of the final products. In the Lean approach, the Zero Quality Control (ZQC) characterize the incorporation of the Poke-Yokes to the production process as value-added activities [3] instead of a delay and costly dedicated inspection stations in the production process (as seen in the Six Sigma approach). As described by Arnheiter and Maleyeff [3], the Lean manufacturing philosophy is more suitable when the production process is simple with few components. However, the tendency for the personalization of the products and the diversification of the markets, the production processes are now characterized by the increment of components and increased complexity in actual products. Actual productivity strategies requires that components come from different vendors using different materials and processes' variation; creating a complex interaction of components and variables in the product increasing the potential of quality and later, reliability problems. In this context, the Lean decision-making process fails due to the limited approach to quality analysis, however, the use of statistical tools can be borrowed from the Six Sigma experience. In the case of Six Sigma, the rigid sequenced methodology and the statistical analysis reduces the flexibility in the solution process makings use inefficient for cases where the main goal is to keep the flow or for fast reaction to an unexpected condition. In order to find the middle way, Pepper and Spedding describes the integration of Lean and Six Sigma [17], the authors mentions how researchers have looked several models and approaches for finding and determining the theoretical compatibility or mutual content for implementing a combined methodology or method. Among the attempts that have been reported since 2003 for creating specific Lean/Six-Sigma subcultures reports shown that some have been successful, but also reported that can cause a conflict of interest and a drain on resources of the organizations. The literature reveal that academic reports and documented practical results are few as compared to the originating philosophies documentation. Pepper and Spedding [17] emphasizes that there is an opportunity for practitioners and academic researchers to take find integrations to make Lean-Sigma to reach its full potential. Among the attempts that have been reported since 2003 for creating specific Lean/Six-Sigma subcultures which can be successful, but also can cause a conflict of interest and a drain on resources of the organizations.

5.1.4 Lean-Sigma Approach

Taking advantage of both approaches, Lean-Sigma has been defined as a methodology for improving the speed, quality, and cost of manufacturing and service industries. Such operations are characterized by the high-frequency or repetitive events and a fix variety of products and/or services [15]. For demotivating this, Pavlovi and Božani reported several cases, benefits and successful implementations in their review for the pharmaceutical industries [15]. Snee [18] also concludes that several benefits can be reported of the use if this combination of Lean and Six Sigma, showing that the beneficiary companies can expect economic returns of $50 k for each green belt project and $175 k per black belt project, also to expect to pass the break-even point in an average of 6–12 months. Moreover, companies are expected to get returns from 1 to 4% sales/year, depending on the operation sizes: for large companies, is expected an average return of 1–2% in sales/year, and for the small-to medium-sized companies, a return of 3–4% in sales/year. Finally, Snee [18] considers that the key for the success in merging Lean and Six Sigma is to use a holistic improvement process, a continuous improvement culture, and the leader development by increasing the use of Lean-Six Sigma to become an expert. The synergy between Lean and Six Sigma was discussed by Estrada-Orantes and Alba-Baena [9] describing Lean-Sigma as the strategy for solving a problem in the shortest time as possible creating a synergy between the quick-fix approach of the "Lean strategy" and the deep statistical analysis of the "Six Sigma strategy".

For the last two decades, Lean-Sigma has been used and applied successfully in companies all around the world. Several examples have been reported describing successful implementations of Lean-Sigma resulting in economic growth, quality, and, however, the response to the competitive markets, and other considerations like commitment, service, and response to the customer concerns have barely reported as implicit consequence of such implementations. Lean-Sigma success has been used in world-class companies and in the developed countries and in restrictive environments such as in Latin America. Such approach has been reported in several documents, especially in the restrictive Latin-America industrial conditions. Among the reported successes Gracia et al. [11], De la Cruz-Rodríguez et al. [7], and Alba-Baena et al. [2] are the more representatives. In the referred documents, Lean-Sigma is presented as a flexible solving problem strategy, the goals for each project may be different depending on the process needs, however, Lean-Sigma steps can be used in the same way following a well defined methodology (see Estrada-Orantes et al. [10]). The project goals may be the production flow speed-up or to bring the variability of the process back to control, or to an specific value such as a process' performance to a specific Sigma level. The flexibility of this approach can be seen, for example, if the goal is to achieve a quality level, this Lean-Sigma strategy uses an incremental-step approach to move the process' quality to the desired level through several kaizen or improvement events.

An example has been reported by Alba-Baena et al. [1], who used this strategy to solve a problem in the assembly of outdoor lamps, focusing on the variation of colors and tones resulting from a patina process. By applying Lean-Sigma, the team was able to increase from 50 to 97.2% the probability of obtaining product that meets the customer's specifications. Also, the same group [2] reported the case in a process of insertion of fuse covers reporting that by the use of a Lean-Sigma methodology, the productivity and quality of the product moves from a quality level of 683,576 per million pieces produced (ppm) to 33.35 ppm. Also, Kumar et al. [13] reported with a different metric a successful implementation savings in $140,000 dollars per year when applying the Lean-Sigma in a die-casting operation in India. These reports, which are coming from restrictive conditions, exemplify the potential adaptability of Lean-Sigma to the different managerial conditions and approaches. Moreover, the practice and use of Lean-Sigma has proven to be an efficient approach that can be improved and there are opportunities to define new strategies and tool combinations to make more efficient use of Lean-Sigma in other industrial settings. It is possible to develop other methods and tool sequences for solving situations and give solutions in a short, mid, and long-term spans.

Furthermore, this Lean-Sigma approach can help managers in the adaptation to the XXI century competitiveness. As mentioned before, in this century, the "classical" metrics (quality, Productivity and Costs) efficient as they are, keep the manager's vision limited to measuring internal outputs and metrics in acceptable levels, and justify the responses in the operations' level, while the reality in the markets for the product expectative is moving faster into other directions and to more sensible levels. Then a slow reaction to other metrics such as customer perception, satisfaction, and competitors' service improvements, for example, can create challenges or weaknesses and gaps up to the point where the product can be expelled and drained from the markets. These metrics challenges are given an opportunity to attend the customer needs, to convert such concerns and expectative to an opportunity for improvements in the operations. It is an opportunity for, at the same time, learn how to convert a competitive challenge (or external problem) into an internal opportunity (by listening to the voice of the customer) and take positive actions for improving the internal operations. It is possible to act in consequence of the market pressures and challenges without sacrificing the revenue and having a fast return on investment (ROI) after any correction, or improvement to the operations using the Lean-Sigma strategy.

Alba-Baena et al. [1] proposes to change the focus of these strategies and methodologies from measuring the success and profits based on the trilogy: costs, quality and productivity (management triangle), and use the same principles to include variables that defines the actual competitiveness. Managers can make more efficient decisions, if include other elements such as the customer's perceived quality or the product competitiveness as the product is compared to the leading or close following competitors, and have the ability to fast react to the customer concerns and needs. If we consider this phenomenon, managers are now facing challenges which includes more qualitative (attribute) values in addition to the described tangible, short term economic (profitable) values. Then, the VoC is critical in operations management and it is necessary to adapt more efficient strategies. There is need for adapting the strategies for attending the market needs, and extending the objectives of the methodologies in use.

The described examples and others have shown that Lean-Sigma is an approach flexible enough to be adapted to the strategies for the XXÏ century industries. Its methodology and tools can be extended to include the market's conditions and to convert the VoC in actions at the operations areas. Lean-Sigma tools are adaptable and flexible not only for keeping the operations flow but for finding deep root causes and describing the statistical conditions of the processes. However, each case requires the management to use a series of flexible Lean-Sigma toolkits that according to the experience in the process and use of the tools, the manager will choose the tools and sequences that more effectively help to address the case.

For better describe this concept and to illustrate the ability of Lean-Sigma strategy for adapting to such conditions, the following case study presents an example of the situation where a customer is highlighting the presence of nonconforming product units coming from the manufacturing facility (seven unit complains). The management perception is that the seven occurrences (from a total of 1.6 M sold pieces) have been found in the 100% inspection at the customer site, reflecting a high-quality performance or a sigma level close to Six Sigmas (5.95). Such levels must reflect that the internal controls and metric goals are as best as possible, and these occurrences are as expected from the production system. However, the initial data analysis reflects a different scenario; this chapter also presents the methodology and solution for the given case study. The team addressed this situation and used a methodology based on Lean-Sigma approach for, first, converting the customer complain into an internal solution process, then, by using a sequence of tools for achieving the metric goals and in consequence, improving the customer satisfaction and keeping the product competitiveness.

5.2 Case Study

5.2.1 Introduction

A manufacturing company in the automotive sector prepares and assembles vent hoses for different automobile models. The cutting area has a process of cutting rubber hoses which are prepared to specific lengths depending on the model number. Such procedure begins with a hose reel. The reel is supplied as is it by a vendor and consists of a 500 m hose rolled into a cardboard core. The process has an average production rate of 1000 pc/Hr. The hose is feed to the cutting area using a pair of feeding bands (see Fig. 5.1) the rubber bands help in controlling the feeding rate by exerting friction axially on the hose. As a control, the feeding system includes an decoder that serves as device for measuring the hose length feed. The function of this control is to provide feedback for comparing the input to the desired distance and to signal the cutting knife and do the cut. The cutting device consists in a stainless steel

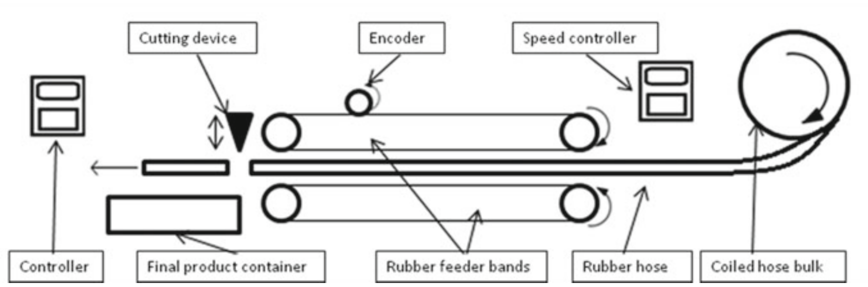

Fig. 5.1 Scheme of the hose cutting machine

knife which cuts the hose in a single movement. Also, for input the hose parameters, the system has two controllers, one for the speed at which the operator sets the feeding rate of the hose and the main controller in which the desired length of the hose is configured.

In order to operate this equipment, the operator enters the distance at which the hose is to be cut in the controller, enters the desired speed in the speed controller, and makes a modification of the vertical distance between the bands to be able to exert a friction on the hoses, then feed the hose from the reel and starts try outs for the verification and validation process. Once the operator start the continuous cutting process, takes the first sample of four hoses, measures them, and compares them with the specifications; if these samples comply with the established measures, the process keep continued; otherwise, the process is stopped and the parameters are adjusted.

5.2.2 Problem Description

During the last year, and according to the customer, this hose cutting process has produced several complaints (seven) due to the short-length of the hose which stops the assembly of this hose assembly in the final product (automobiles) for which it is intended. These complaints are one sided because the product which is larger or above the specifications allows to make some adjustment in the final assembly process, Throughout the year, there were seven complaints related to this cause. If consider the reported sales volume (1.6 million pieces/yr) and the previously valued performance level is close to 5.95 Sigma level. With the given information, the operations management consider these as normal outliers from this process. However, the perception and confidence of the customer has been diminished considering that robustness of the process is not acceptable, looking for a corrective action and a problem solving procedure. Even that from the customer's perspective this is a problem, it is necessary to "translate such complain to an opportunity at the operations level and prepare such actions as an opportunity for optimize the process and give,

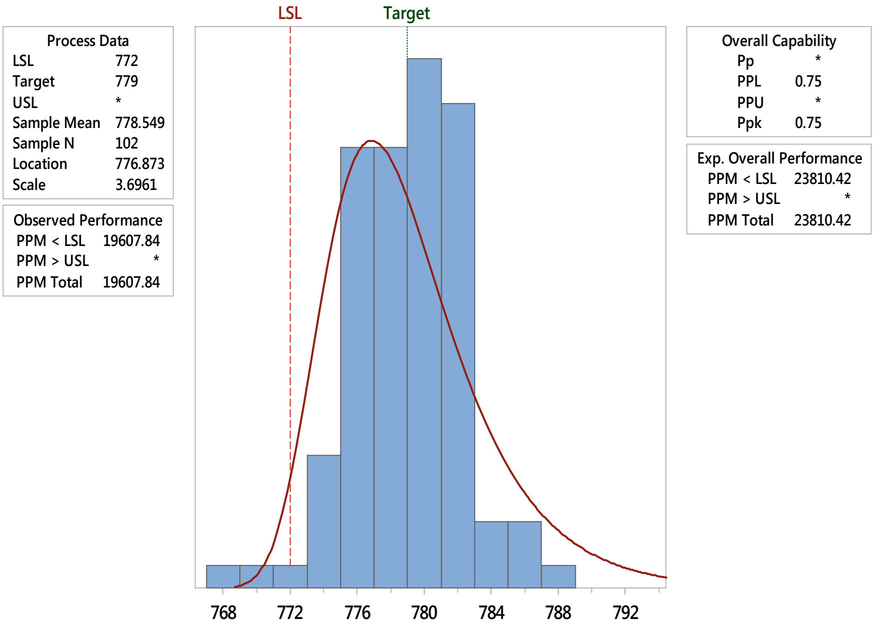

Fig. 5.2 Initial data for the hose lengths, sampled from the received product at the customer's warehouse

at the same time, a corrective procedure for the customer complaint. This seems contradictory, if we consider that in the operations management a solution is normally given for conditions that represents unexpected costs and optimizations are part of the continuous improvement process, meaning, to increase the profits from the operations. For this, the manager in charge gathered a multifunctional team to give the solution to this situation, highlighting the need for finding the root cause of this variation and at the same time to establish an efficient solution for increasing the customer confidence in the robustness of this process, via pushing the operations to the next level in terms of quality goals. An initial diagnosis was conducted at the customer's front door measuring only the length of the hoses of the received product (Fig. 5.2). The performance the process has a capability index, Ppk in 0.75 and an expected rejection rate in 19608 parts per million. Data also show that the process is not reliable as expected and the variation in the cutting process is large enough to reduce the confidence in the process, then it is possible to determine the objective, to identify the root cause for the variation, to find a solution, and bring the process in control in the shortest possible time.

5.3 Methodology

The methodology used consists of a series of steps based on Lean-Sigma; the sequence is presented in Fig. 5.3. In this diagram, the first step emphasizes the need for truly identify the problem, understanding the VoC and "convert" his needs or perspective in terms of the operations' measurable variables. Then, it is necessary to do a comparison between the specifications of the product, design and characteristics with the data provided (or expected values) by the customer. Determining in this way the strategic actions that will follow. However, in general the first action is to measure the actual values (input variables and outcomes) coming from the process. With the inputs coming from the process it is possible to have a comparison triangle that will determine the focus and goals of the forthcoming project. In this case, such data will help in determine the problem and the project goal that is to reduce the variation in the cutting process. For accomplish this goal, a series of tools can be used in sequence, in this case: for listening the VoC we have used the QFD, check lists, the design and product specifications; and from the process main variables identification and measurements we used charts, descriptive statistics normality test for the data and the calculated process capability. The description of the initial conditions by the descriptive statistics not only allows the understanding of the behavior of the critical characteristic of the product (hose length) but give measure values to use and monitor while achieving the targets and with the normality test, it is possible to determine the statistical values to consider. The process capability also helps in determine the directions for achieving the goal, actions followed will look for centering the outcomes to an expected value, then, to adjust the process variation to a span controlled in a range expected for the cutting process. After setting target (quantitative) goals, it is possible to find actions that will take the process to the proposed goals, for this it is necessary to determine the "causes" for having the process in the actual state. In this case, by understanding the effect of the different input variables (say in this case cutting conditions, feeding speed and feeder conditions among others) it is possible to adjust them ordered by the impact that they have in outcome (hose length, in this case). For the input variables-identification step we used the brainstorming and 5 Whys techniques as core tools. Following the described process, once the causes of the variation and the input variables were identified, a sequential DOE was used for measure the effect and impact of the input variables in the outcome. First, a fractional design allows the measuring of each effect for then discriminate the less impacting ones from the main variables. The later step may use the main variables for running a full factorial design and determine the best possible outcome with the given equipment and conditions. With the data provided by the sequential DOE, the relationship of the system inputs with the characteristics of the product could be quantified and in turn, stratified the impact on this characteristic, which allowed the team to propose various solutions to the problem or to achieve the proposed target. Actions were taken for implementing the most promising solution (based in the possible impact in the main input variable). After analyzing the design of the machine, the feasibility the solution was implemented. After the stabilization period, data of the outcomes

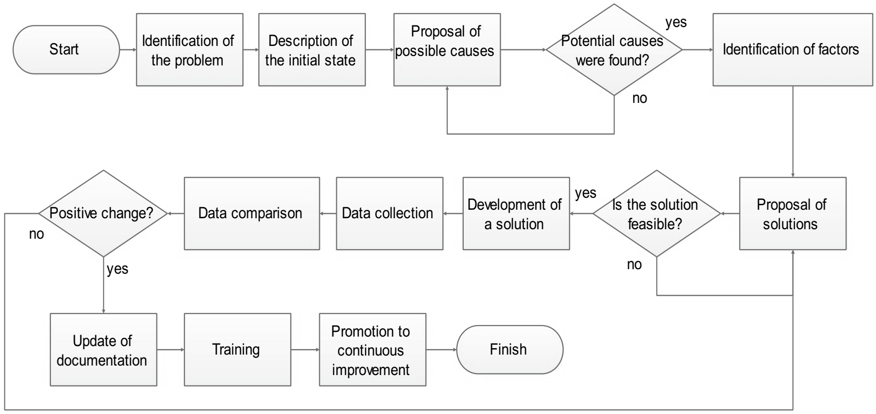

Fig. 5.3 Steps of the methodology used in the solution of the described case

was collected to later use the mentioned statistical tools for presenting the results and then for making an statistical comparison to the initial process conditions and to the target values. In the case when the comparison shows that the goal is not reached, the team has to use the next feasible solution and continue the cycle up to the point of reaching the expected goal. Once the target is achieved, the composed solution is documented, the changes are also standardized for the process and training is programmed for the operative team. The final statistical values and comparisons are gathered for measuring the effect and benefits of the implemented solutions, also costs and ROI is reported to the management and to the customer. Finally, a kaizen even is used for transfer the knowledge and for officially close the project. In the case presented, the knowledge is transferred to a twin process that assembly different models of the same product.

5.4 Problem Analysis

Because this product is processed in two different cutting devices, it is necessary to decide for which machine (identified as "A" and "B") the team will do the analysis and adjustments for later transfer the knowledge to the second one. For such comparison, data from machine "A" is used for calculating the process capability level (see Fig. 5.4), indicating a Cpm index of 0.56 showing a large data dispersion; in addition to this, the same Figure evidence a Ppl distance of 0.54 supporting the Cpm index. The data obtained from these indices in conjunction with a Cpk of 0.58 and a ppm value of 53,840, indicating that machine "A" doesn't have the sufficient robustness to keep the process in statistical control; on the other hand, the indices obtained from the machine “B” shows a distance Ppl of 0.97, and a Cpk of 0.93. The resulting ppm value of 1838 is not within the expected robustness, but machine “B” is more stable as compared to the machine “A” then, the team focuses the project in the process that includes the cutting machine “A”.

Once the decision was made, a different sample is taken considering only the product and model in observation. A normality testing was carried out on the data which can be observed in Fig. 5.5. The test indicates a P-value of 0.024 which indicates that the data do not follow a normal distribution, so it was necessary to find the curve to which they fit more accurately and describe better the data behavior. After, the Largest Extreme Value curve was used for describing the data and to be used as the characteristic representative curve, of this data. An index of capability (Ppk) was calculated (Fig. 5.6) considering the target value of 310 mm for this specific model. The data obtained from the capability analysis results in a Ppk of 0.83 which confirms that the process is not able to meet specifications, also shows a ppm of 10770 which indicates potential defective parts for this process. Then, such data will be used for comparison after using the different solutions and the final implementation.

5.4.1 Root Cause Analysis

The team used brainstorming, an Ishikawa diagram and 5 whys as a combination of tools for finding the root cause of the hose length variation. Firstly, the brainstorming to identify possible factors that could affect the length of the hose. Then the Ishikawa diagram for arrange the potential causes using as branches the 6Ms, Fig. 5.7 shows a representative image of the Ishikawa filling process. The 5 Whys technique helped in finding deeper and the main causes and later to determine the root cause of the problem. With the analysis after the use of the 5 Whys, the team found that a combination of factors in the cutting machine, was the root cause of the problem. To detect the principal variables that affect the variation on the characteristic of the product, a second brainstorming session was used for obtaining a list of six input variables: feeding speed, encoder position, the use of a locking device for vertical distance adjustment between the bands, hose diameter, hose length, and the human factor and one response variable: hose length. To weight the input variable and its effect in the response variable, the team decided to run a sequential two-level fractional design of experiments (DOE), a fractional design and later a full factorial design. The first one for determining which of these variables are more impacting on the variation in the cutting machine. The second one for determine the interaction dependency among the components of the machine. Table 5.1 presents the arrangement of the factors used in the experiment, with the used levels and the response variable results obtained (in mm). The results of the analysis of the effect evaluation of the first DOE can be seen in Fig. 5.8. The chart reveal that the factor that contributes most to the variation is the length of the hose (or model). This effect is attributed to the variation and slipping of the hose during the feeding process. Then, the larger the hose the

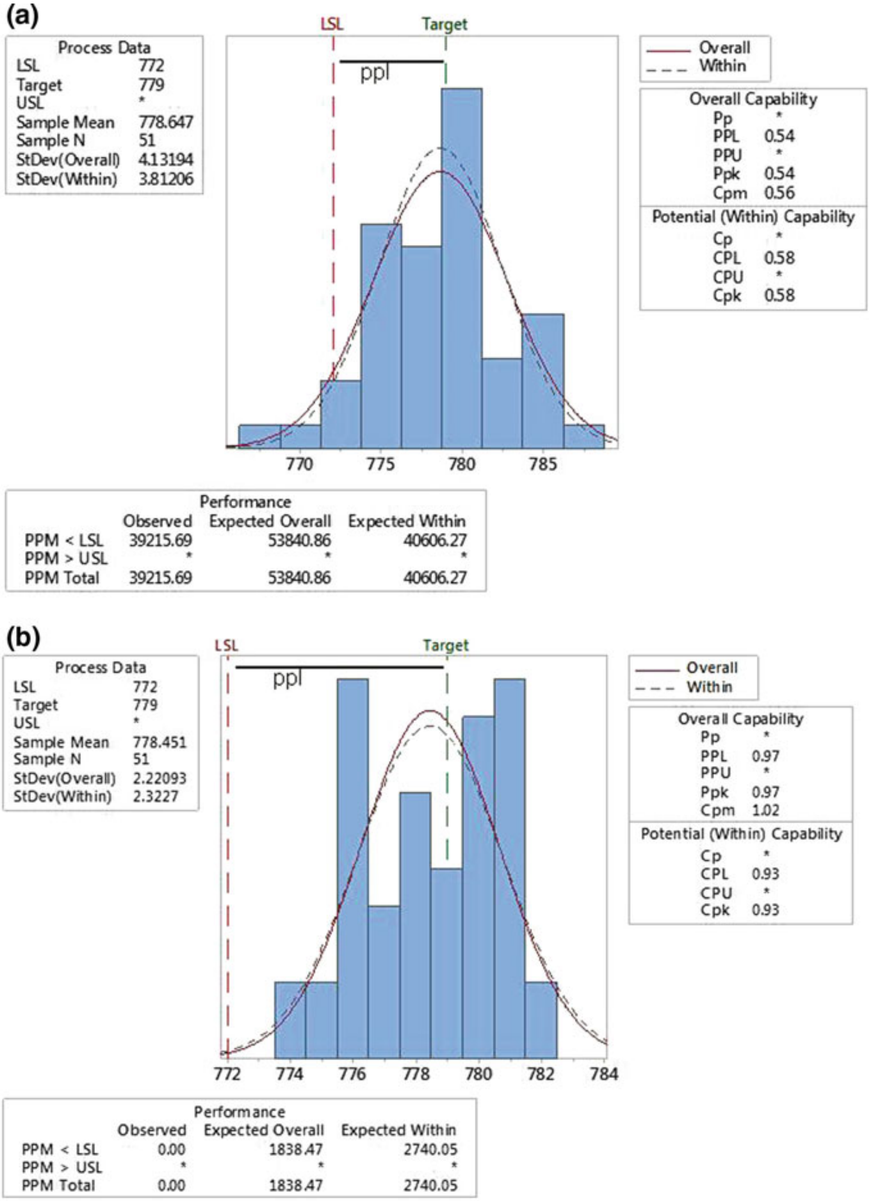

Fig. 5.4 **a** Process capability study for data obtained from (**a**) Machine "A" and (**b**) Machine "B"

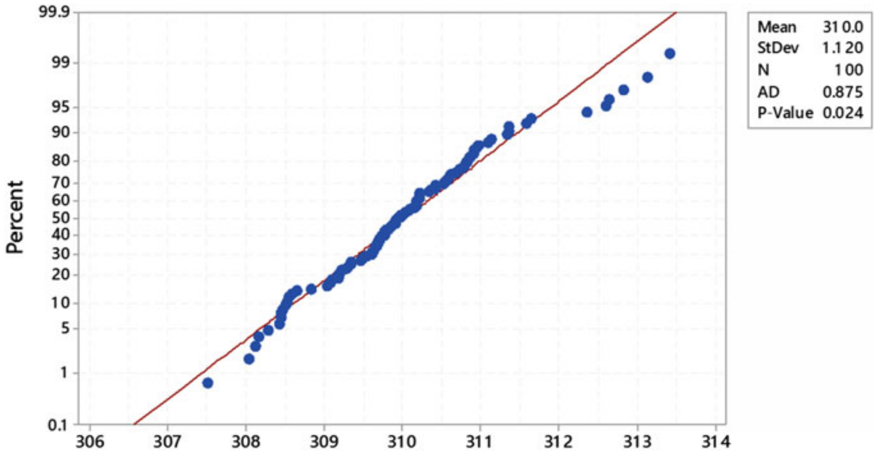

Fig. 5.5 Results for the normality test on the product and model under observation coming from the cutting process in Machine "A"

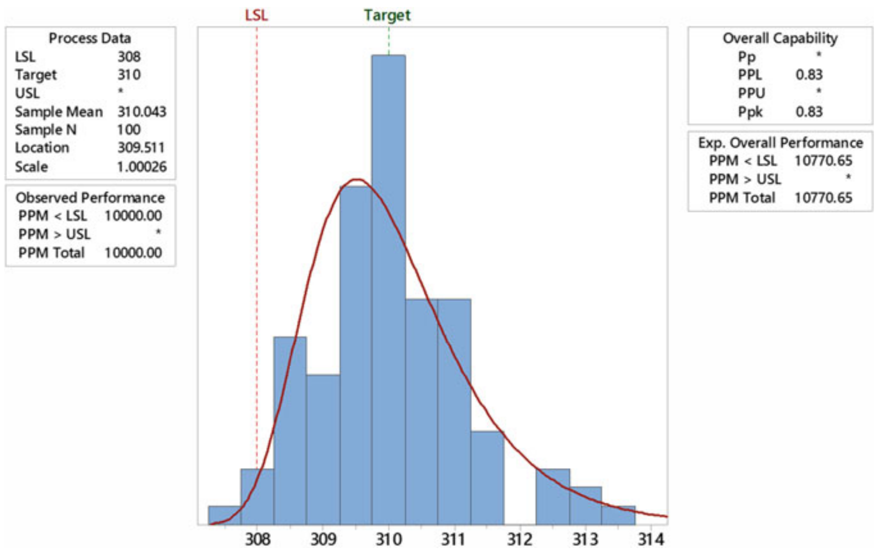

Fig. 5.6 Process capability index (Ppk) for Machine "A"

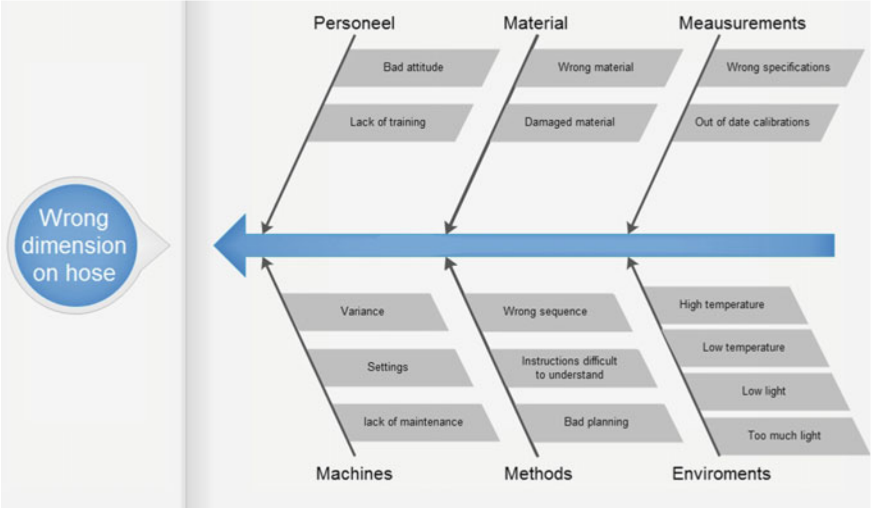

Fig. 5.7 Representative Ishikawa diagram for the process of finding the root cause

Table 5.1 Fractional design arrangement for the selected factors and response outcome

Input variables						Response variables
Speed (rpm)	Encoder position	Lock	Diameter (mm)	Hose length (mm)	Operator (shifts)	Hose length output (mm)
210	2	2	8	1467	1	1432
30	1	2	8	310	2	315
30	2	1	10	1467	2	1442
210	2	1	8	310	2	288
210	1	1	10	310	1	304
30	1	1	8	1467	1	1491
30	2	2	10	310	1	304

larger the variation, resulting from the components' conditions of the process. To better understand the effect that the components of the machine have on the variation of the length of the final product, the team decided to consider only factors related to the equipment and leave the operator off, because this factor depends in a training procedure (which will be integrated to the solution after the mechanical component are adjusted). The team decided to fix the solution to one model and reduce the input variables to three, the feeding speed, the locking device and the encoder position.

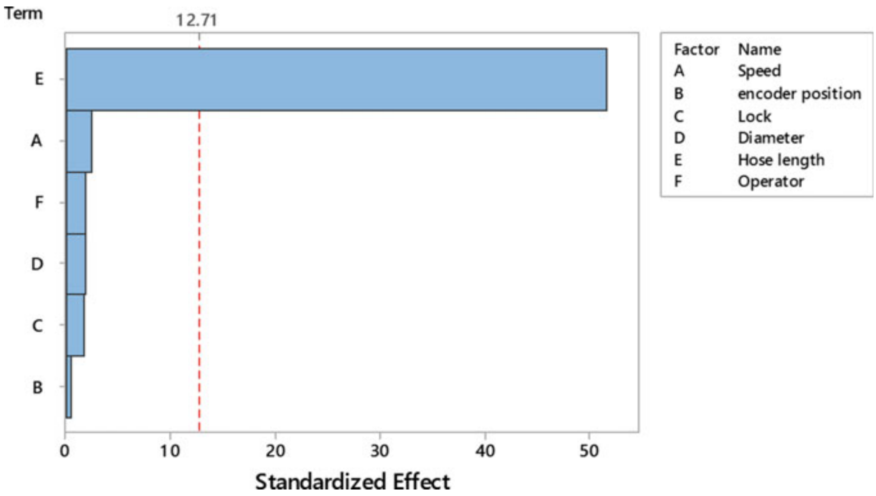

Fig. 5.8 Chart of effects resulting from the first fractional DOE used in the stratification of the input variables of the cutting process

For the second experiment, the interaction of the remaining factors is considered as it is shown in Fig. 5.9. In addition, it was decided to adjust the conditions and perform trainings so that the operator is not a serious factor in the study; Also, the interaction between the remaining factors was included, and a new sequential DOE was performed with only the factors of feeding speed, encoder position, the use of a locking device for vertical distance adjustment between the bands, and the interaction between them; the results of this implementation can be seen in Fig. 5.9. The results obtained indicate that from the mechanical components, the feeding speed is the main contributing factor to the hose length variation. However, the interaction of the lock use and encoder position have to be tracked and have to be considered in the solution, because its importance and effect in the hose length response.

5.5 Developing a Solution

Data indicates that the feeding speed is the variable contributing largely to the variation of the product, so a mechanical analysis and controlling components calibration was proposed. The machine components that affects the hose feeding are identified as: Speed controller, electric motor, power transfer bands, pulleys and feeder belts. According to the documented instructions, preventive and corrective maintenance activities were programmed and executed. When performing the analysis and efficiency of the components, it was found that even after the maintenance, they were not able to maintain a constant speed. Deeper mechanical and electrical adjustments were made for reducing the components and its interaction effects in the obtained data.

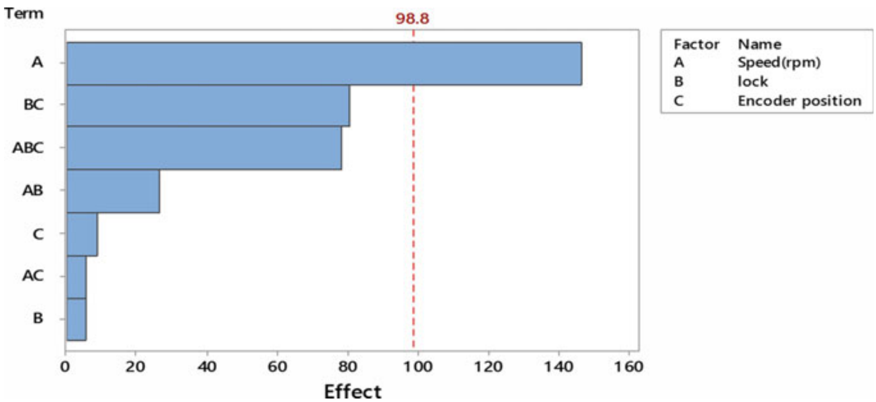

Fig. 5.9 Chart of effects from the DOE using the feeding speed, the position of the encoder, the use of a locking device, and the interaction between them

Later, new data is collected. As seen in Fig. 5.10, descriptive statistics were calculated and for visual comparison the image includes the target and lower limit determined by the customer. Next Figure shows for comparison the initial (Fig. 5.11a) and the calculated capability index, Ppk (Fig. 5.11b) after modifications. Comparing data it can be noticed that the mean length of the hoses shift from 310.04 to 310.81 mm moving away from the lower limit. Also the comparison reveals that the standard deviation shrinks from 1.12 to 0.66. Also Fig. 5.11, is showing the change in the capability index of the process, an increase in the Ppk index from 0.83 to 1.97, and a decrease of the opportunities for defective from 10.7 to 0.0001% nonconforming parts, which reflects an increase in the robustness of the process and a decrease in the variation close to 80%.

5.6 Verify the Solution

An I-MR chart is composed for monitoring the process (Fig. 5.12) and for observing the outcome behavior. In the Figure, the I-MR chart plots the individual values of the observations and moving ranges from the initial and after the implementation of the adjustment. Illustrated by the visual comparison, it is noticeable the mean shift in the hose lengths and the reduction of ranges. For exemplifying the mentioned shift in the product lengths, initial data section in Fig. 5.12 shows three data points outside the specifications (see the left side of the graph "M"), this is reflecting an instability of the process and potential for customer complains. Comparing this to the second section in the same graph, the mean values move away from the lower limit, showing no outsider points and exhibiting the stability achieved after the modifications. If a comparison is exercised in the second graph of the same Fig. 5.12, the graph "R" also shows three data points of data

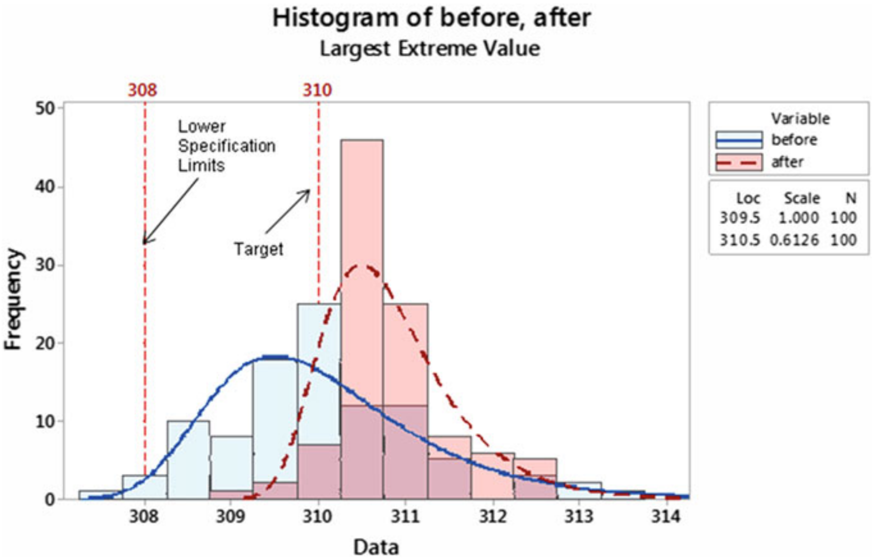

Fig. 5.10 Descriptive statistics comparing data behavior before and after the mechanical and electrical adjustments

Table 5.2 Two-sample t test, comparing the initial conditions and data after the implementations

Two-sample T for after versus before				
	N	Mean	St Dev	SE mean
After	100	310.81	0.661	0.066
Before	100	310.04	1.12	0.11
Difference = μ (After) − μ (Before)				
Estimate for difference: 0.768				
95% CI for difference: (0.511, 1.025)				
T-Test of difference = 0 (vs≠): T-Value = 5.90 P-Value ≤ 0.001 DF = 160				

outside the range limits in the initial data section (left side of the graph). After the implementation, the ranges shown to be reduced and there are no points out of specification, presenting an aleatory distribution in a reduced range. In order to statistically validate the mean shift and the decrease in the variation, two sample t testing for equal variances (Fig. 5.13) and mean comparisons (Table 5.2) were calculated by using and comparing the initial data and data after the implementation. Results indicate that the variance was modified after the implementations, it is smaller and shifted as seen in the Figure. Since the calculated p-values was ≤ 0.05, the testing demonstrates that by statistical means, there is not enough evidence to consider that the compared means remain equal, then, it is also expected a shift in the means.

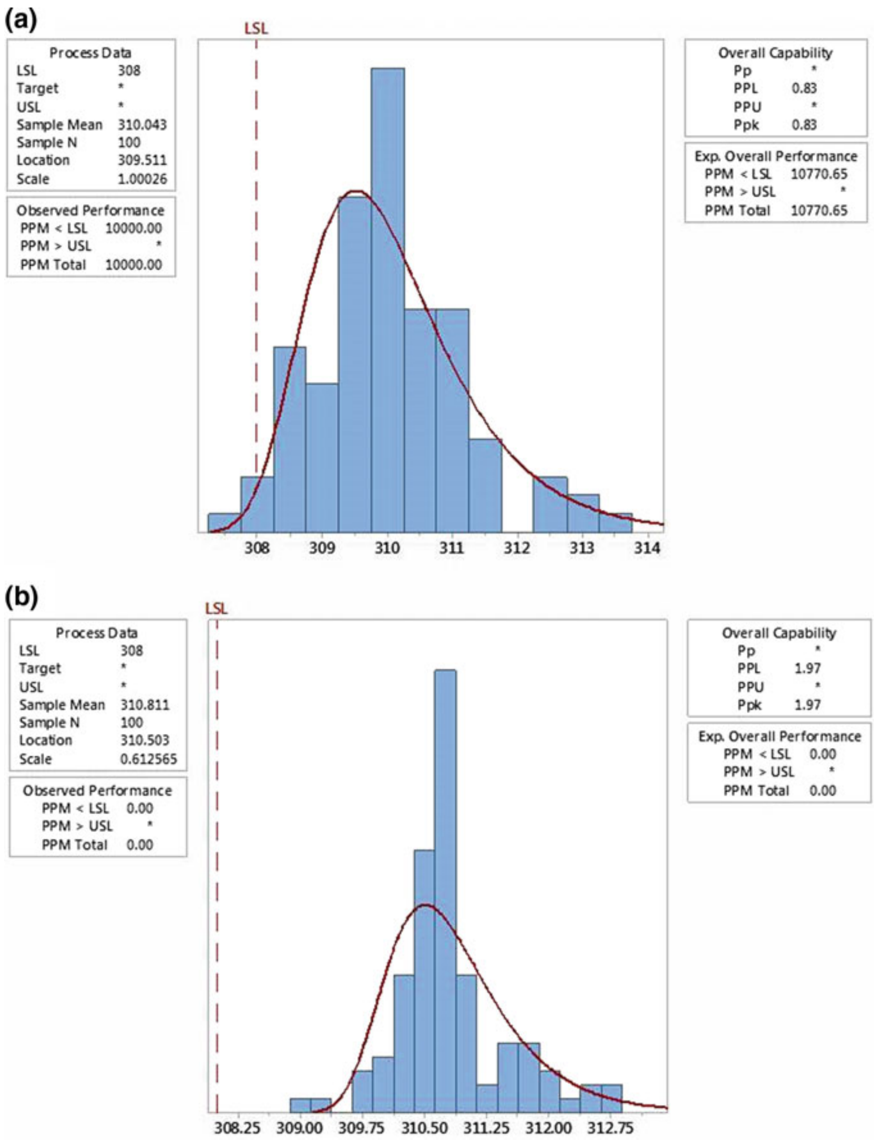

Fig. 5.11 Graphical representation of the Capability Index and data performance for two process conditions: (**a**) initial data and (**b**) after mechanical and electrical adjustments

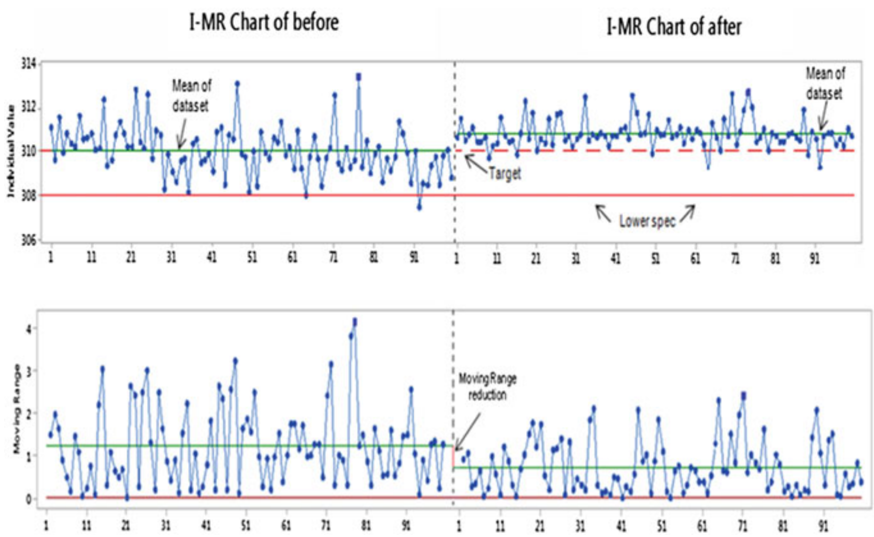

Fig. 5.12 I-MR graph showing data from the initial and after the implementation conditions

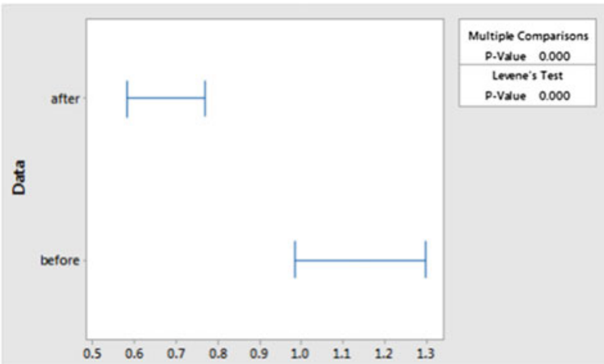

Fig. 5.13 Variances comparison for the initial and after the implementation conditions

5.7 Control Plan

Once the target conditions are achieved, the last step of the proposed methodology is to monitor and follow up the process behavior and the outcome data, then, to document the knowledge acquired and to disseminate this information across the organization. Adjustments in the quality control charts were made, the maintenance instructions were updated, and a new preventive maintenance routine was incorporated to the general maintenance plan. The main changes were in the adjustments in the values of the reliability life time of the mechanical components, as well as the changes in the calibration methods for the electrical components and their calibration frequencies. Also these actions had other non targeted impacts such as the relocation to other activities in the plant of three collaborators (from the department of quality) that were stationed in this area as support, helping in the contention plan activities, inspection process, and the selection and reprocessing. Several studies were proposed for move the maintenance goals from corrective and preventive maintenance to actions towards reaching the stage of predictive maintenance. A kaizen event was implemented in which these actions and plans were presented to the organization. Explaining the importance of the preventive maintenance and pro-positive actions for keeping the equipment components in good condition. The consequences of having variations in the machine was addressed and in the same event were clarified how to apply the corresponding measures on each of the elements and the interpretation of the results obtained. Finally, after two weeks of receiving the customer complain, the team presented the final report and achievements to the customer. Then, with the approval of the customer, the operations manager congratulated the team for the effort and the achievements.

5.8 Conclusions

The use of Lean-Sigma for solving problems has been proven by different authors, however, its use can be extended to solve problems where the final goals includes qualitative targets along with the well used quantitative targets (Cost, Quality, Production). The described case study is used as an example of the combination of the fast Lean strategy along with a selection of efficient tools and Six-Sigma methodology a solution was achieved in two working weeks. Results show a process capability change from the initial capability index (Ppk) of 0.54 for the general outcome of the productions process (changing for each different model). Focusing on the leading model and after applying the proposed Lean-Sigma methodology, data show a Capability Index moving from the cutting process show an increment of the Capability Index from 0.83 to 1.97. The outcome data show a change in the mean and standard deviation, the reduction from 1.12 mm (standard deviation) to 0.66 mm means an increase of the robustness of the process and the reduction of the variation in about 80%. The process was validated by the comparison shown in Sect. 5.6. The customer received a satisfactory response to his qualitative and competitiveness concerns. The management reached the proposed objective for the project. Secondary benefits included the resulting maintenance improvements, and to work towards the predictive maintenance of this equipment as next the step in the continuous improvement plans. Other benefit is the relocation of the personnel in charge of inspection and reworking processes. In summary, it can be concluded that the Lean-Sigma methodology is a highly efficient way of solving problems with inherent positive results, such as the robustness of the process, not only for quantitative targets, moreover, for a combination go qualitative and quantitative goals.

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Chapter 6
Structural Equation Modelling Application to Assess Environmental Aspects in Implementing Sustainable Manufacturing

Keshav Valase and D. N. Raut

Abstract Manufacturing industries consume different types of resources while manufacturing their products as well as offering services. This consumption of resources, particularly diminishing natural resources, has been hazardous and causing serious losses to the environment and hence to the earth as well as animal and plant life. Most of the manufacturing organizations have realized the need of corrective actions towards this destruction. They have also realized the importance of adopting sustainable practices for their manufacturing activities to survive in the intense competition at local as well as global level. Thus, the Sustainable Manufacturing (SM) has been gaining increasing importance. Research so far in SM does not offer an easy to adopt, integrated and holistic approach towards implementing SM. Most of the researchers have mentioned the need of a comprehensive framework or a model for the adoption of SM practices with due importance to 'manufacturing and technology' domain over to three conventional domains of sustainability, i.e. economic, social and environmental. The main aim of this paper is to address this need by proposing a basic framework of four domains and hence to develop a Partial Least Square—Structural Equation Modelling (PLS-SEM) model validated using SmartPLS software for the analysis of empirical data of Indian Engineering Manufacturing industries. The results of model fit analysis revealed quite satisfactory performance of the 'manufacturing and technology' domain with acceptable level of control over the adverse impact on environment and a need for enhanced attention towards social domain. Authors of this paper expect that this study will provide a systematic approach for the implementation of SM in manufacturing industries so as to enhance the decision-making towards controlling adverse impact of manufacturing-related activities.

Keywords Environmental · Manufacturing and technology · PLS-SEM · Structural equation model · Sustainable manufacturing

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Nomenclature

AMOS	Analysis of Moment Structures
AVE	Average Variance Extracted
CR	Composite Reliability
MCDM	Multi-criteria Decision-Making
MODM	Multi-objective Decision-Making
PLS	Partial Least Square
SEM	Structural Equation Modelling
SM	Sustainable Manufacturing
SMEs	Small and Medium Enterprises
SMP	Sustainable Manufacturing Practices
UNSD	United Nations Statistics Division

6.1 Introduction

The advancements in fast-growing manufacturing technology, communication technology and continuously changing demand patterns are some of the major reasons having a deep impact on manufacturing industries across the world. This situation has led to ever-increasing competition making it very difficult for manufacturing organizations to survive. These manufacturing industries from any nation have significant contribution towards the economy of that nation. On the other hand, they consume huge amounts of variety of resources such as men, machines, different materials, money, energy, etc. This consumption has a multifaceted impact—wherein the first and foremost is that most of the materials consumed are diminishing the stock levels of natural resources, particularly non-renewable resources. Second, the consumption of resources generates tremendous amount of variety of wastes, harmful gases, leading to poisoning of the biosphere. This in turn causes acid rain, global warming and a bunch of similar environmental hazards. The fast depleting natural resources have made it a further grave situation. Additionally, increasing awareness of these facts by stakeholders has been developing unrest in the demand situations in the market. Manufacturing organizations are compelled to attend and address the seriousness of this state, and hence they are bound to show their concern towards enhancing sustainability in manufacturing.

Almost all the manufacturing industries have adverse environmental impacts of their manufacturing activities in varying degrees, contributing towards the destruction of the mother earth. Manufacturing organizations are trying to enhance their concern over adopting practices of sustainability in manufacturing to reduce adverse environmental impacts of their activities, which plays a crucial role in deciding the economies of their nations [5, 11].

An international programme for a sustainable society was organized by United Nations Statistics Division (UNSD) in 1992. During this programme, the need was recognized to address unsustainable lifestyle and their side effects [37]. During similar programme organized after 10 years, it was realized that for a sustainable development, it is essential to change the unsustainable patterns of production and consumption. It was also noticed that for achieving this goal, there is a need for further intense research, business models and community initiative [37]. With traditional approaches followed by many organizations, the product development is carried out with cost/profit models. Most of these organizations have a delayed concern over environmental assessment and are not integrated with their existing development activities [33]. The manufacturing organizations need to consider the interactions of their products, processes and allied activities to understand and control their effects on environmental pollution. Manufacturing firms can offer these things with efficient and effective consumption of manufacturing resources without compromising the standards and health of upcoming generations [46]. Further to this, with changing market conditions, manufacturing firms are expected to recognize the relationship between manufacturing operations and the natural environment for the sustenance of manufacturing businesses [5, 38]. This fact is leading to the considerations of multifaceted aspects of manufacturing activities while adopting sustainability. Despeisse et al. [14] mentioned in their paper that the research in Sustainable Manufacturing (SM) is crossing disciplinary boundaries. This adoption of SM practices has become more challenging as most of the times these authorities from industry are in a state of confusion basically for wherefrom to begin and second they do not know how to handle the enablers and barriers of SM. They are required to be provided with the comfortable ways and means of adopting and hence maintaining the SM practices. Thus, simple to grasp and easy to practice information on SM is essential for the industries and their managers to enhance sustainability in manufacturing. Following sections deal with the literature review and proposed Structural Equation Model (SEM) with results and future scope.

6.2 Literature Review

The changing global scenario has made it almost inevitable for the manufacturing firms to adopt information technology, communication technology as well as advanced manufacturing technologies [3] to sustain in the intense business competition. This can be well achieved basically by adopting effective and efficient ways of consumption of resources [5] for incorporating sustainability in manufacturing. However, adopting SMP has been challenging for organizations since most of them are unaware of how to utilize the enablers and mitigate the effect of barriers of SM [4]. Moreover, the research so far in this field has been confined to three domains of sustainability, i.e. economic, social and environmental. There is a vital need for addressing sustainability issues in manufacturing with additional domains so as to establish a fine correlation amongst various parameters. The research in the field of SM provides the principles for making manufacturing sustainable but it covers very little practical guidance on their applications [2, 20]. The literature review is grouped under two heads of SM and SEM.

6.2.1 Sustainable Manufacturing

The definition of SM given by U.S. Department of Commerce is 'the creation of manufactured products that use processes that minimize negative environmental impacts, conserve energy and natural resources, are safe for employees, communities and consumers and are economically sound' [2, 4, 18, 30, 38]. All the major elements of this definition are required to be well focussed and addressed by the concerned authorities in manufacturing organizations. Manufacturing establishments from developing countries are trying to inculcate new approaches towards the activities of production and consumption [9]. The overall supply chain as well as product life cycle should be thought properly so that due considerations to variety of predominant elements are offered while adopting SM practices. Further to this, organizations intending to practice environmentally friendly products and operations are required to understand that they can recover costs quickly contributing to competitive advantage rather than suffering a burden [46]. Very few quality reports are available on levels of SM activities exercised by the manufacturing organizations [13]. Despeisse et al. [14] have explored the need to address different challenges in adopting SMP, from manufacturer's point of view. Following Table 6.1 gives the compilation of the literature review.

Thus, Table 6.1 highlights ample potential for research in the field of SM implementation in manufacturing industries that provide a standard and comprehensive reference model. It also indicates the need for the consideration of manufacturing and technology domains to be duly valued in the developing the framework. Research gap also projects the importance of empirical studies with the survey data from manufacturing industries.

6.2.2 Structural Equation Modelling (SEM)

There are plenty of techniques in statistics for studying the relationships between dependent and independent variables. Regression models establish the relationship between one dependent variable and one or more independent variables, whereas structural equation modelling can be considered as an application of regression analysis to multiple latent variables defined by the researchers [31, 47]. These latent variables may represent a set of dependent and independent variables. It can also be said as a multivariate technique for the analysis of direct and indirect effects of different variables in the model, using multiple regression analysis. de Carvalho and Chima [12] have provided an overview of SEM for testing relationships between indicator variables and latent variables with its scope beyond conventional field of

Table 6.1 Compilation of research papers for identifying the research gap

SN	Major gap for SM implementation	References
1.	Development of standard/comprehensive reference model or systematic approach for SM	Bhanot et al. [4], Chun and Bidanda [8], Despeisse et al. [14], Gunasekaran and Spalanzani [20], Vinodh and Joy [50], Zubir et al. [52], Kibira et al. [34]
2.	Identifying and addressing proper critical variables such as safety, health, recycling, manufacturing capability, remanufacturing, etc.	Dawal et al. [11], Ghazilla et al. [19], Bhanot et al. [4], Dewangan et al. [15], Singh et al. [45], Kibira et al. [34], Rusinko [39], Ijomah et al. [28]
3.	Need of empirical studies for the implementation of SM with different/developing countries	Dubey et al. [17], Dubey et al. [16], Dewangan et al. [15], Gunasekaran and Spalanzani [20], Jovane et al. [32]
4.	Different qualitative/quantitative approaches for SM implementations like SEM, MCDM/MODM*, etc.	Dewangan et al. [15], Trianni et al. [49], Dubey et al. [16], Mittal and Sangwan [36], Chun and Bidanda [8], Shi et al. [43], Gungor and Gupta [21]
5.	Limited work on integrating product and process design with sustainability	Jayal et al. [30], Jawahir et al. [29], Kaebernick et al. [33]
6.	SM improvement opportunities in view of manufacturer/manufacturing operations	Sen et al. [41], Despeisse et al. [14]
7.	Less work on sustainable production–consumption	Gunasekaran and Spalanzani [20], Clark et al. [9]
8.	Research to improve understanding of SM; enhancing considerations of technology	Rosen and Kishawy [38], Chow and Chen [7]
9.	Less focus on effective technologies, manufacturing flexibility	Dewangan et al. [15]
10.	To address unsustainable lifestyles with socio-technical approach	Mont et al. [37]

social sciences. In recent times, SEM has emerged as a viable tool for most of the research problems requiring statistical analysis in almost all fields like social science, management, production and operations management, etc. The model fit depends on the fit indices selected during the analysis which has been discussed by Daire Hooper [10] and Hox and Bechger [25]. A structural equation model has been developed by Sen et al. [41] for testing the relationship between environmental pro-activity and financial performance of manufacturing industries from India and UK. Singh and Khamba [44] proposed SEM model providing focus on factors of manufacturing competency and strategic success for automobile industry. Hussey and Eagan [27] used SEM technique for validating environmental performance improvement model for SMEs in plastics manufacturing industries highlighting the need to move beyond just complying with environmental regulations.

Structural equation model has been developed by Vinodh and Joy [50] for analysis of the factors in SM implementation in manufacturing industries from Tamil Nadu, India. Thirupathi and Vinodh [48] have used PLS-SEM for the analysis of SM factors from auto-component sector of Tamil Nadu. The relationship between skill levels of employees, manufacturing flexibility and business performance has been studied by Mendes and Machado [35] applying SEM to the data collected from automotive sector of different countries.

PLS-SEM has been used by Dubey et al. [17] for studying impact of institutional pressures on implementation of sustainable production and consumption with the survey of industries in India. Similar efforts were put by Dubey et al. [16] in developing World-Class Sustainable Manufacturing framework with PLS-SEM approach. Zeng et al. [51] and Severo et al. [42] also used SEM for the analysis of relationship between cleaner production and business performance parameters. Thus, SEM in its various forms has proved to be a tool which offers plenty of inroads for studying the relationships of multiple variables of statistical models practically from all walks of life. Hair et al. [22] have presented the scope of PLS-SEM in their paper, highlighting its advantages and limitations. PLS-SEM can handle a non-normal data even with small sample size as against AMOS and other SEM tools.

These discussions reveal that SEM has its applications in the field of SM with wide scope for the development of an approach that is easy to understand and apply for SM implementation. Thus, the main problem identified by authors for study is:

To develop a systematic approach for the application of SEM to SM implementation in Indian engineering manufacturing industries to study the environmental issues with due focus on manufacturing- and technology-related aspects.

6.3 Methodology

It is very much essential for the manufacturing organizations to recognize the importance and prioritization of variables in SM implementation so as to address the environmental impact of their manufacturing activities. For this, an integrated and comprehensive framework for SM is necessary, which can offer an ease to understand and practice for the industry personnel. Thus, the major objectives of the study are as follows:

- To propose a simple to grasp framework for the implementation of SM;
- To develop PLS-SEM model for the awareness, ease of acceptance and implementation of SM, while addressing environmental issues.

In view of this, the flowchart for the research methodology is depicted in Fig. 6.1. With due considerations of the proposed framework (discussed in the next section), a questionnaire is designed for the collection of data from the survey of engineering manufacturing industries from India. To meet the requirements of the industrial practitioners and to bridge the gap between academics and industrial practices, it is very much essential to have a liaison among experts from both the fields. Hence, the questionnaire developed has been validated by personally interacting with the experts from industry as well as academics. This resulted in alterations of the initial

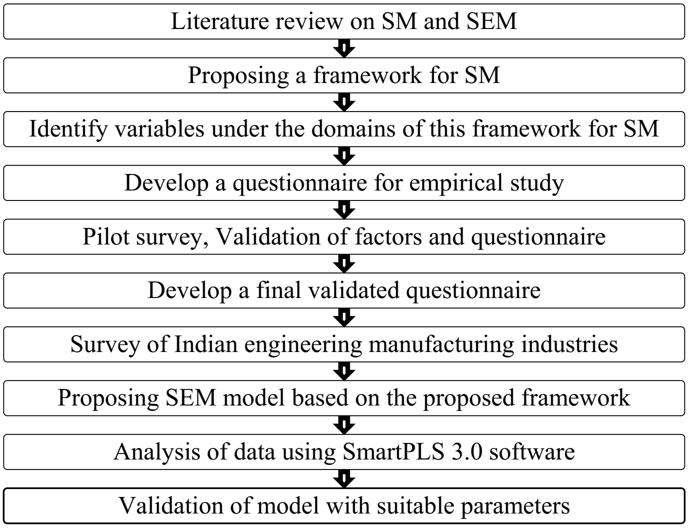

Fig. 6.1 Flowchart for research methodology

set of variables and their grouping under various domains. Particularly, due to the basic intention of addressing ‘manufacturing- and technology’-related aspects, these interactions proved to be very fruitful in view of developing final proposed model. The selection of respondents was very challenging as the questionnaire has a widespread field referred, demanding an exposure of respondents to various fields in four domains of the framework. Moreover, they were expected to correlate the issues with three basic domains of sustainability. These experts from industry have been holding the designations of Director, General Manager, Assistant General Manager, etc. Some of them are the consultants in the field of statistical analysis which is a crucial part of the study. The manufacturing industries covered included automobile sector, motor and pump manufacturing industries, electrical/electronic equipment manufacturing, machine tool manufacturing industries and others. Heterogeneity is expected based on the type of industry, so as to avoid focus on only certain sectors of industry, which covered large scale as well as SMEs. The survey was conducted via ‘Survey-Monkey’ platform for which annual subscription was also paid to avail better options in the survey. In addition to the basic survey data as against the questionnaire, it provided the data on IP addresses of the respondents, time for response (to the accuracy level of seconds), some results on basic statistical analysis with charts and graphs and many more options. This increased the validity of the survey which is the prime requirement in empirical study and analysis type of research work. The survey data was analysed using SmartPLS 3.0 software for testing the model fit.

6.4 Proposed Model and Hypotheses

Manufacturing industries across the world are facing the problems of continuously changing the state of competition, and hence the paradigms and challenges [24]. The awareness of stakeholders is also contributing more towards the unrest. Additionally, government regulations have been imposing environmental restrictions on their manufacturing and related activities. This has led to constraining the research efforts in SM, thereby demanding efficient utilization of overall resources [8]. The research work carried out so far has largely referred to three-domain framework in sustainability including social, economic and environmental domains [2, 6, 7, 38, 50]. Recently, some of the manufacturing industries have started attending environmental issues of sustainability also [38], as against earlier state of addressing only economic issues. Following paragraphs brief about the proposed framework for SM implementations as well as SEM model along with the hypotheses.

6.4.1 Proposed Framework for SM

To address the sustainability aspects in manufacturing, it has now become crucial to address these issues at micro-level with a wide scope for addressing the maximum extent possible by considering more manufacturing activities which have high impact of the environment. Hence, there has been an ever-increasing need to consider SM implementation beyond conventional three domains of economic, social and environmental aspects with more comprehensive and integrated approach [38]. Kibira et al. [34], Chun and Bidanda [8] and Sen et al. [41] have proposed considerations of additional 'Manufacturing'-related activities, whereas Jovane et al. [32], Chow and Chen [7], Shi et al. [43], Ghazilla et al. [19] have referred 'Technology' domain-related variables in their overall frameworks. Technology is very much related to manufacturing and is affected by products, processes and practices [38] in manufacturing. With this, the authors of this paper propose a framework for SM implementation, with additional domain of 'Manufacturing and Technology', as shown in Fig. 6.2. The intention in proposing an additional domain of 'manufacturing and technology' is to address the issues in view of the authorities in manufacturers and to duly value their perceptions while facing the practical difficulties, and hence taking proper decisions towards sustainability.

6.4.2 Proposed Inner (Structural) Model and Hypotheses

The proposed inner model (Fig. 6.3) has four domains, based on the proposed framework shown in Fig. 6.2, considered with the intention of defining environmental domain as the target endogenous construct. The aim is to understand the impact of

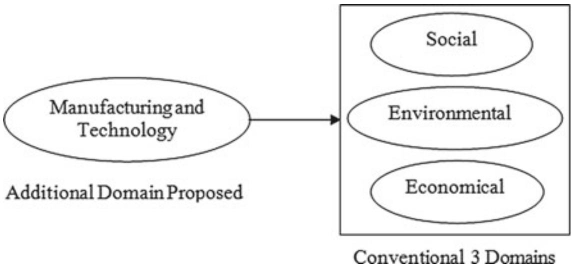

Fig. 6.2 Proposed framework of SM

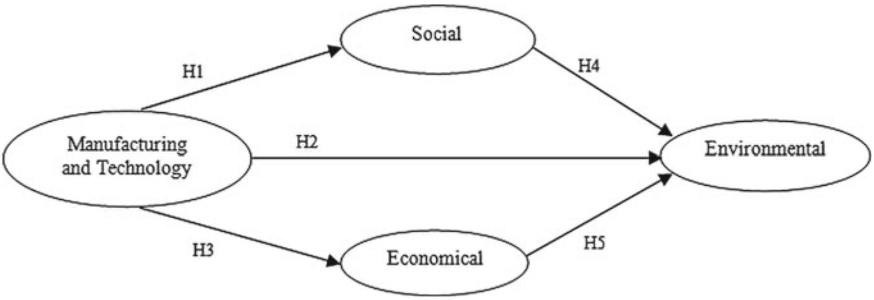

Fig. 6.3 Proposed inner model and hypotheses

Table 6.2 List of proposed hypotheses

H1	'Manufacturing and Technology' domain activities and social domain are correlated
H2	'Manufacturing and Technology' domain activities and environmental domain are correlated
H3	'Manufacturing and Technology' domain activities and economical domain are correlated
H4	Social domain activities and environmental domain are correlated
H5	Economical domain activities and environmental domain are correlated

'manufacturing- and technology'-related decision-making ultimately on the environmental aspects.

Based on this SEM model, Table 6.2 gives five hypotheses defined which are then tested for the model fit. These hypotheses define the associations of different domains in the model, and hence their performance in relation to each other.

Table 6.3 provides the list of variables under each domain referred in the proposed model. In addition to the references of the researchers, these variables have been validated by personally interacting with consultants, academicians and experts from manufacturing field with the designations of Vice-presidents, Directors, General Managers, etc., representing various engineering manufacturing industries. These variables are the parameters deciding the state of manufacturing firms while addressing the environmental impacts of their manufacturing-related activities. The model fit analysis establishes the correlation of these variables as well as the domains represented by them. Authorities from industry are expected to understand the priorities for these variables so that they can strategically handle them so as to trade off the variables in availing the best results in adopting SM practices, thereby surviving in the heavy business competition. In this view, the selection of variables becomes very much critical in the overall study. The groping of variables under new proposed domain of 'manufacturing and technology' offers a due scope in dealing with the issues in SM practices.

6.5 Results and Discussions

The proposed model has one exogenous construct of 'Manufacturing and Technology' (MAT in Fig. 6.4) and three endogenous constructs (Environmental, Economical and Social, i.e. ENV, ECO and SOC in Fig. 6.4), wherein the environmental construct is a target endogenous construct. After running the model, for outer (measurement) model evaluations, output from PLS algorithm is shown in Fig. 6.4, which indicates the variables finally retained in the model fit analysis.

The values of outer loadings for the final observed variables under different latent variables are presented in Table 6.4, which indicates satisfactory values (>0.7) for most of the shortlisted variables. For four variables, these values are around 0.6 but they are retained to study their effect on other parameters. The variables with these values less than 0.4 must be eliminated as that level of values indicates no worth for studying the association of such variables.

For construct reliability and validity, the values of Composite Reliability (CR), Average Variance Extracted (AVE) and Cronbach's alpha are determined and presented in Table 6.5, which all indicate satisfactory levels compared to recommended values, i.e. Cronbach's alpha and composite reliability values are all greater than 0.7 and AVE greater than 0.5 [23], except one value of AVE for MAT is little less than 0.5.

Discriminant validity is tested by two ways of Fornell–Larcker criterion and cross-loadings. In Fornell–Larcker criterion, the AVE of each latent construct is higher than the constructs highest squared correlation with any other latent construct [23]. These values of model evaluations are given in Table 6.6 and they satisfy the requirements. Cross-loading evaluations are provided in Table 6.7 which clearly indicates that the indicator loadings within the construct are higher than indicator values for other construct, satisfying the validity requirements.

Under inner (structural) model evaluation, R-square for three endogenous constructs ECO, ENV and SOC are 0.407, 0.619 and 0.389. R-square values of 0.75, 0.50 and 0.25 for endogenous constructs can be taken as substantial, moderate and weak, respectively [23]. Here, all R-square values are moderate as they are near 0.5 which can be taken as quite satisfactory and justifying in manufacturing- and technology-

Table 6.3 Domain-wise list of variables

Variable	References
Manufacturing and Technology Domain	
1. Inventory quantity	Amrina and Yusof [2], Kibira et al. [34]
2. Labour turnover	Singh et al. [45], Amrina and Yusof [2], Kibira et al. [34]
3. Material waste	Singh et al. [45], Amrina and Yusof [2], Feng et al. [18], Kibira et al. [34], Seidel et al. [40]
4. Internal material handling	Abdulrahman et al. [1]
5. Non value-adding time (NVAT) elements	Amrina and Yusof [2]
6. Technology awareness	Ghazilla et al. [19], Bhanot et al. [4], Abdulrahman et al. [1], Mittal and Sangwan [36], Shi et al. [43],
7. Skill/expertise	Ghazilla et al. [19], Abdulrahman et al. [1], Mittal and Sangwan [36], Shi et al. [43]
8. Training and education	Bhanot et al. [4], Ghazilla et al. [19], Singh et al. [45], Amrina and Yusof [2], Shi et al. [43]
9. Research and development	Ghazilla et al. [19], Dewangan et al. [15], Amrina and Yusof [2], Jovane et al. [32]
10. Flexibility	Ghazilla et al. [19], Dawal et al. [11], Singh et al. [45], Amrina and Yusof [2]
11. Information and communication technology (ICT)	Dewangan et al. [15], Trianni et al. [49], Shi et al. [43], Jovane et al. [32]
Social Domain	
1. Customer satisfaction	Singh et al. [45], Rosen and Kishawy [38], Amrina and Yusof [2], Jovane et al. [32]
2. Employee satisfaction	Ghazilla et al. [19], Amrina and Yusof [2]
3. Health, safety, security of employees	Rosen and Kishawy [38], Amrina and Yusof [2], Feng et al. [18], Jovane et al. [32]
4. Work culture	Ghazilla et al. [19], Rosen and Kishawy [38]
5. Corporate social responsibility (CSR)	Ghazilla et al. [19], Singh et al. [45], Rosen and Kishawy [38], Amrina and Yusof [2]
Environmental Domain	
1. Pollutants	Singh et al. [45], Rosen and Kishawy [38], Amrina and Yusof [2], Feng et al. [18], Kibira et al. [34]
2. Energy saving/generation	Trianni et al. [49], Singh et al. [45], Vinodh and Joy [50], Rosen and Kishawy [38], Amrina and Yusof [2], Feng et al. [18], Kibira et al. [34], Jovane et al. [32]

(continued)

Table 6.3 (continued)

Variable	References
3. Environmental regulations	Ghazilla et al. [19], Bhanot et al. [4], Mittal and Sangwan [36], Kibira et al. [34]
4. Recycling, remanufacture, reuse	Ghazilla et al. [19], Abdulrahman et al. [1], Rosen and Kishawy [38], Hu and Hsu [26], Jovane et al. [32]
5. Suppliers	Ghazilla et al. [19], Amrina and Yusof [2], Kibira et al. [34]
Economical Domain	
1. Profitability	Bhanot et al. [4], Kibira et al. [34], Jovane et al. [32], Seidel et al. [40]
2. Financial constraints	Ghazilla et al. [19], Bhanot et al. [4], Mittal and Sangwan [36], Abdulrahman et al. [1], Vinodh and Joy [50], Kibira et al. [34], Jovane et al. [32], Shi et al. [43]
3. Government incentives	Ghazilla et al. [19], Rosen and Kishawy [38], Shi et al. [43]
4. Manufacturing costs	Singh et al. [45], Amrina and Yusof [2], Jovane et al. [32]
5. Quality costs	Dawal et al. [11], Singh et al. [45], Rosen and Kishawy [38], Amrina and Yusof [2]

related decision-making. The recommended values for 'F-square' are 0.02, 0.15 and 0.35 for weak, moderate and strong effects. Model evaluations for F-square indicate that MAT $\rightarrow$ ECO $=$ 0.687 and MAT $\rightarrow$ SOC $=$ 0.637 are having strong effect; MAT $\rightarrow$ ENV $=$ 0.163, ECO $\rightarrow$ ENV $=$ 0.245 have moderate effect, whereas SOC $\rightarrow$ ENV $=$ 0.136 value indicates weak effect.

Bootstrap analysis was carried out for 5000 subsamples, and the data analysed for T-statistics and P-values corresponding to five proposed hypotheses are given in Table 6.8 for the confidence level of 1%.

Considering the results from the above table and the complete model fit analysis, one hypothesis of SOC $\rightarrow$ ENV is not supported by the empirical data, whereas rest four hypotheses are well supported. It can be inferred from these results that there is a need to enhance the decision-making towards social domain for the satisfactory performance of the proposed SEM model while implementing SM to study the environmental issues.

Table 6.4 Outer loading evaluations

	ECO	ENV	MAT	SOC
ECO-1	0.824			
ECO-2	0.689			
ECO-3	0.772			
ECO-4	0.770			
ECO-5	0.841			
ENV-2		0.654		
ENV-3		0.826		
ENV-4		0.718		
ENV-5		0.807		
MFG-4			0.577	
MFG-5			0.606	
SOC-1				0.740
SOC-2				0.790
SOC-3				0.835
SOC-4				0.868
SOC-5				0.715
TEC-1			0.713	
TEC-3			0.783	
TEC-5			0.677	
TEC-6			0.706	

Table 6.5 Construct reliability and validity

	Cronbach's alpha	Composite reliability	Average variance extracted (AVE)
ECO	0.841	0.886	0.610
ENV	0.750	0.840	0.570
MAT	0.767	0.837	0.463
SOC	0.850	0.893	0.626

Table 6.6 Discriminant validity—AVE values

	ECO	ENV	MAT	SOC
ECO	0.781			
ENV	0.736	0.755		
MAT	0.638	0.682	0.681	
SOC	0.725	0.619	0.624	0.791

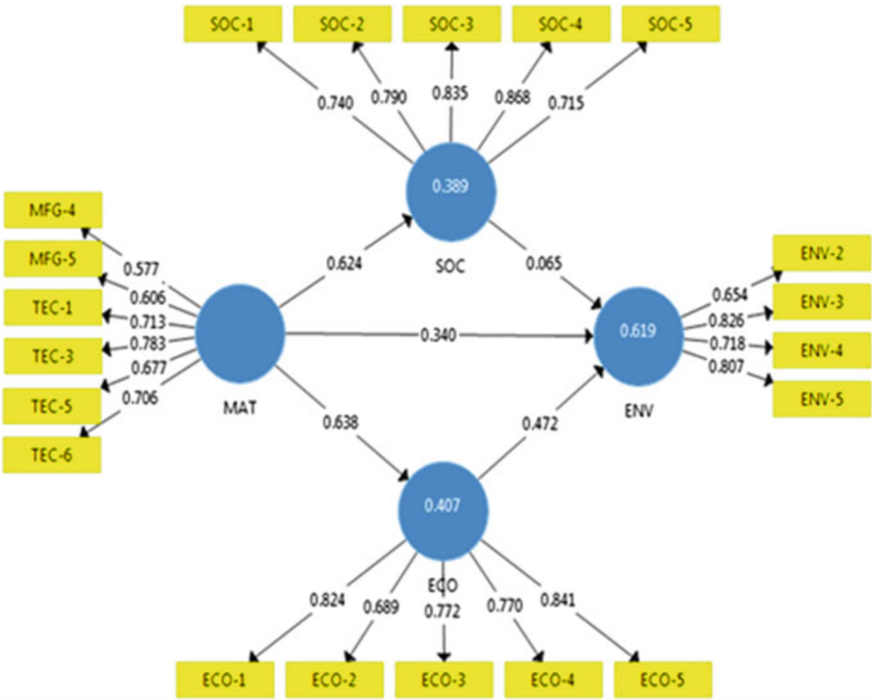

Fig. 6.4 PLS algorithm evaluations for SEM model

6.6 Conclusion

Even in the state of intense survival issues in the local as well global market, decision-makers from majority of the manufacturing industries have realized the importance of controlling the unsustainable practices of manufacturing so as to minimize the adverse effects of their manufacturing activities. Literature review has reflected that there has been a need to further enhance the research activities towards addressing environmental issues related to decision-making in 'manufacturing- and technology'-related domains in industries. This paper basically proposes a four-domain framework for studying environmental impacts of SM practices with a focus on 'manufacturing- and technology'-related issues.

The empirical data required for the model fit analysis is collected from Indian engineering manufacturing industries using 'Survey-Monkey' platform and is analysed using SmartPLS 3.0 software. The model fit parameters in outer (measurement) model are quite satisfactory. 'Manufacturing and technology' domain-related parameters in inner (structural) model evaluations also reveal satisfactory results, and corresponding three hypotheses (H1–H3) are supported by the data. Hypothesis H4 is not supported which reflects the need to enhance the social domain-related decision-making for enhancing the environmental domain-related issues, whereas

Table 6.7 Discriminant validity—cross-loadings

	ECO	ENV	MAT	SOC
ECO-1	**0.824**	0.607	0.545	0.598
ECO-2	**0.689**	0.375	0.394	0.469
ECO-3	**0.772**	0.618	0.600	0.563
ECO-4	**0.770**	0.521	0.432	0.564
ECO-5	**0.841**	0.690	0.486	0.620
ENV-2	0.438	**0.654**	0.472	0.363
ENV-3	0.565	**0.826**	0.614	0.608
ENV-4	0.357	**0.718**	0.340	0.191
ENV-5	0.750	**0.807**	0.565	0.572
MFG-4	0.340	0.270	**0.577**	0.371
MFG-5	0.463	0.297	**0.606**	0.407
SOC-1	0.737	0.572	0.599	**0.740**
SOC-2	0.528	0.372	0.451	**0.790**
SOC-3	0.524	0.443	0.462	**0.835**
SOC-4	0.544	0.423	0.484	**0.868**
SOC-5	0.468	0.576	0.424	**0.715**
TEC-1	0.368	0.519	**0.713**	0.386
TEC-3	0.542	0.456	**0.783**	0.600
TEC-5	0.413	0.563	**0.677**	0.297
TEC-6	0.456	0.616	**0.706**	0.451

Table 6.8 T-statistics and P-values

Hypothesis	T-statistics	P-values	CL*	Hypothesis
H1 = MAT → SOC	9.905	0.000	1%	Supported
H2 = MAT → ENV	2.842	0.004	1%	Supported
H3 = MAT → ECO	9.031	0.000	1%	Supported
H4 = SOC → ENV	0.468	0.640	1%	Not supported
H5 = ECO → ENV	3.16	0.002	1%	Supported

*CL = Confidence Level

another hypothesis H5 is supported by the data. It can be concluded from this that engineering manufacturing industries from India need to enhance their decision-making in social domain-related issues towards improving its correlation with the 'Environmental' domain.

The future scope is observed in studying the mediating effects of various latent variables as well as moderating effects of SMEs and large-scale manufacturing organizations. The SEM applications may be extended to different combinations of critical variables under each domain depending upon the eventual trade-off requirements.

This research work will provide an easy-to-grasp approach for SEM application to SM implementations in manufacturing organizations to study environmental impacts of their ‘manufacturing- and technology’-related decision-making.

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Chapter 7
Service Quality Through the Lens of SAP-LAP Methodology: A Case Study

Ajay Gupta, Rajeev Trehan and Surjit Kumar Gandhi

Abstract In the customer-centric marketplace, it is getting increasingly important to add value in services being delivered to customers. The service quality rendered to consumers results in developing loyal customers, which helps to yield enhanced business performance. The present study tries to study the service quality being imparted to stakeholders by a well-established group of technical institutions located in North India established since 2001. This study is carried out through a specific case study tool named as SAP-LAP (Situation-Actor-Process–Learning-Action-Performance) methodology from the stakeholders' point of view. The analysis brings out six service quality factors, namely, leadership, process management, people management, resource management customer satisfaction, and customization to influence the outcome in terms of placements, reputation, growth, and sustainability of such institutions.

Keywords Service quality (SQ) · Technical education · DSMG model · SAP-LAP methodology

7.1 Introduction

The concept of TQM in higher technical education is rapidly gaining ground since its outcomes are the human resources, who are the most valuable assets particularly for the third world [13]. Abdullah [1] pointed out that there exist "invisible" competitions between countries, and "quality of education" is the key deciding factor

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to emerge as winner. Thus, the quality assurance and associated determining factors need to be explored [22]. Feigenbaum (1993) addressed the quality issues to suit industrial environment for effective execution of quality management into the critical dimensions of quality management strategies [10].

India has not yet registered its presence to World Trade Organization w.r.t. technical education sector. However, liberalization and globalization of knowledge leave no option for technical institutions of developing world except changing mindsets and enhancing the quality [28]. Academic institutions need to continuously invigorate their traditional structures and develop innovative ways of serving their customers more effectively thereby delighting them. If an education provider has to obtain a sustainable competitive advantage, it must understand customer satisfaction especially in terms of perceptions of services quality [27].

Researchers have identified a number of attributes affecting SQ of higher/technical education, namely, knowledgeable teachers [8], quality of lectures [38], relevant and industry-oriented syllabus [35, 36], emphasis on soft skills [36], prompt evaluation and feedback of students [1], effective classroom management [4], internal quality feedback programs [32], affordable fee [37], placement opportunities [40], ideal campus location [11], layout [39], reputation (), hostel and recreational facilities [16], and modern state-of-the-art technology [21] to name a few.

Given the importance of technical education, particularly the emerging economies like India, and appreciating the critical junctures at which they find themselves today, research effort to bring out SQ factors specific to their present dynamic circumstances is well justified. The findings of the study would be useful for the management of these institutions to continuously improve the quality delivery of services to their stakeholders.

The purpose of an SAP-LAP model is to help analyzing and creating workable ideas on the situation, actors, process, and their mutual interactions. SAP-LAP structure generates generic as well as specific models for managerial inquiry and problem-solving [34]. The framework ultimately synthesizes the situation and facilitates the action and learning process to consolidate the knowledge gained through the study. SAP-LAP brings out the strengths and weakness of the system, in its paradigm. The main difference between the SWOT (Strength–Weakness–Opportunities–Threats) and SAP-LAP analysis is that latter comes out with possible suggestions and expected performance of a system through the key learning issues [17].

The study aims at answering the following questions: What are the expectations of top management of education organizations from the quality management function? How can a service organization sustain and develop its systems? How effective can the management strategy be in fostering the innovation culture within an institution? The study addresses these questions under the analysis of SAP-LAP. The methodology covered the following features: legacy of the institution, philosophy, quality management strategy, interdisciplinary teamwork, collaborate industrial alliances, clarity in purpose of organization, innovation, flexibility in administration, research projects and productivity, resources generation, relationship with neighboring institution, technology transfer, stakeholder development, and social responsibility.

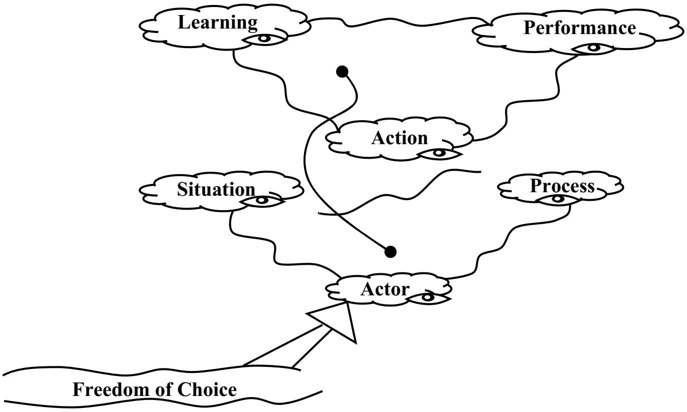

Fig. 7.1 SAP-LAP architecture (*Source* Husain and Pathak [12], Sushil [34])

The scope of the study has been identified in ABC Group of Institutions (original name disguised) in Punjab. The roles played by various individuals and associated people involved have been described. The present situation of the institution and the prevailing environment have also been highlighted. The takeaways from the study in form of learning points have been charted out, the possible futuristic roadmap has been suggested, and expected outcomes have been visualized. Figure 7.1 shows the interaction of entities in the SAP-LAP architecture.

7.2 Literature Review

Table 7.1 tries to capture the multifaceted conceptualization of literature on service quality in technical education in the twenty-first century.

Sushil [34] pointed the need for a framework which supports flexibility and adaptability in enquiring the situation of technical education in the changing environment. The flexibility in the management operates through the interaction in learning, action, and performance. The implementation of the SAP-LAP models can be done through a group exercise by considering multiple perspectives of various actors. The SAP–LAP models have been characterized for general problem-solving, change, and flexibility [34]. Change and flexibility are inevitable in modern organizations, which ideally suits SAP-LAP. In view of that, this case study introduces the Situation-Actor-Process (SAP)–Learning-Action-Performance (LAP) as the framework for developing models of managerial inquiry. Husain et al. [12] conducted a case study using SAP-LAP analysis of the technology management strategy on the three Indian automobile industries. They observed that flexibility in managerial enquiry is not reported in the conventional case study process; however, the SAP-LAP methodology helps to analyze the change and flexible situations in an organization.

Table 7.1 Studies on service quality in higher/technical education

Author and year	Factors considered	Academic parameters
Datta [7]	Tangible, empathy, attitude	Responsiveness, reliability, outcome quality
Sohail and Shaikh [31]	Physical evidences, access to facilities	Curriculum, responsiveness, contact personnel, reputation
Lagrosen et al. [18]	Campus facilities, ITC effectiveness, best practices	Intrinsic and extrinsic evaluations, IT facilities, e-resources in library resources, industrial collaboration
Joseph et al. [14]	Campus servicescape, facilities, social prestige, fee	Size/schedule, peer group
Sahney et al. [26]	Attitude, content	Competence, delivery, reliability
Abdullah [1]	Nonacademic aspects academic aspects, access	Program issues, reputation
Mahapatra and Khan [20]	Personality development, responsiveness	Learning outcomes
Angell et al. [2]	Cost, leisure	Academics, industry links
Singh et al. [29]	Supplementary processes, financial resources	Teaching–learning process, infrastructure, tangibles, institutional governance
Tsinidou et al. [36]	Infrastructure, location, administration service	Carrier prospects, curriculum structure, library services, academic staff
Sumaedi and Bakti [33]	Supporting facilities, social activities	Academic content and knowledge center, class program and facilities
Jain et al. [13]	Academic facilities, input quality, curriculum, industry interaction, support facilities. Extracurricular activities, interaction quality	Outcome, reputation
Kamakoty et al. [16]	Learning resources, teaching resources, infrastructure, faculty competence, faculty development	Training and placement, curriculum delivery, curriculum design

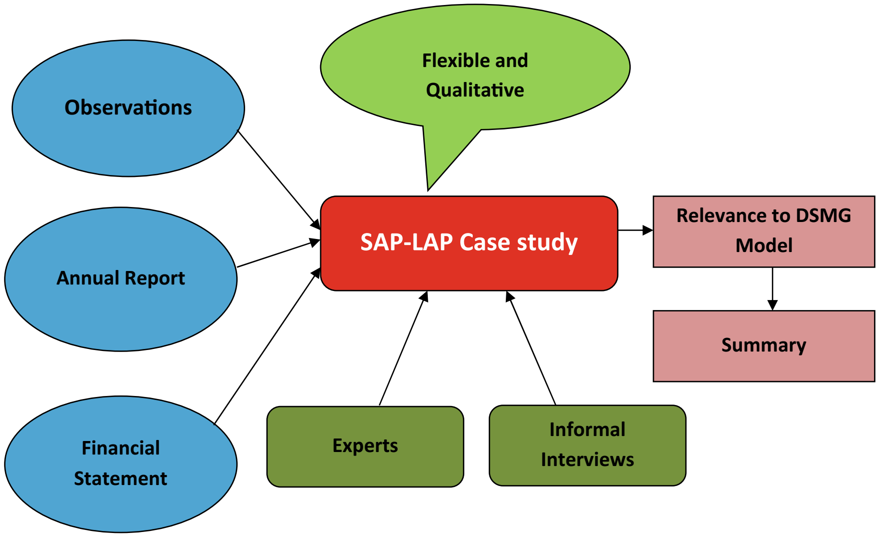

Fig. 7.2 Methodology adopted for SAP-LAP case study

In general, the effectiveness of a case study depends on the deep-rooted understanding and creative group learning about the important aspects of the problem. The purpose of an SAP-LAP model is to help in the process of analysis and for creating an idea on the situation, action and process, and their interactions. SAP-LAP framework can be used to generate generic as well as specific models for managerial inquiry and problem-solving. The model ultimately synthesizes the framework and facilitates the action learning process to consolidate the knowledge gained through the study. SAP-LAP facilitates the strengths and weakness of the system, in its paradigm. The main difference between the SWOT (Strength–Weakness–Opportunities–Threats) and SAP-LAP analysis is that latter comes out with possible suggestions and expected performance of a system through the key learning issues, e.g., in an engineering college, there may be more doctoral degree holders, and it may be claimed as a major strength, but in a real scenario, there may not be any further research contributions from the doctoral degree faculty members. This issue is highlighted with expected performance in SAP-LAP. Figure 7.2 shows the methodology adopted for the case study.

Relevance to Driver System Measure Goal (DSMG) Model

The critical success factors of service quality have been arranged in the order of DSMG model of service quality as perceived by the user. The major findings of this model are presented below:

(i) Leadership	(Driver)
(ii) Process management and people management	(System)
(iii) Measurement of resources	(Measure)
(iv) Customer satisfaction	(Goal)

The central hypothesis in DSMG model is that each dimension positively influences an individual's attitude toward using a new model, which in turn influences to use it. The objective of this research is to test the quality management model as presented by the DSMG. The independent factor in the model is leadership and measurement of resources. The dependent factors are process management, people management, and customer satisfaction.

In a nutshell, the Driver System Measure Goal (DSMG) model indicated the following:

DRIVER

Leadership: Administrative capability of the institution*, i.e., it examines how the institutions can achieve continuous quality, through the driving forces of the senior personnel and the involvement of all levels of the institution to achieve performance excellence.*

SYSTEM

Process management: How efficient the processes are being managed in the institutions? *That is, it examines how the various key processes, management, and evaluation are improved to achieve service excellence.*

People, management: How the human resources are being managed and made capable of doing things? *That is, it examines how the institution plans and develops its human resources to achieve the maximum potential of its employees.*

MEASURE

Measurement of resources: Effective creation, utilization, and sustenance of physical, human, and financial resources. *That is, it examines the management of various resources in the institution, namely, financial, physical, human, and technology in order to support and the effective operation of processes.*

GOAL

Customer satisfaction: Satisfaction on the process and effectiveness*. That is, it examines how the institution takes care of customer requirement and gets responsive to customer needs to maintain high levels of service through a variety of indicators.*

The following identification of components of DSMG model SAP-LAP is applied to capture the qualitative and quantitative aspect of the service systems and suggested actions for the expected performance.

The SAP-LAP methodology has been applied by various researchers to various applications as given in Table 7.2.

Table 7.2 Select SAP-LAP applications

Author and year	Issues	Application
Sushil [34]	Inquiry of flexible system management	MIS planning, i.e., evolve and implement the models
Duggal et al. [9]	Management of information technology	The impact in issuing driving license using smart cards
Husain and Pathak [12]	Handling technology management practice	Three Indian automobile firms
Chatterjee and Prabhakar [6]	Examines the experience of a number of internet portals in e-marketing	ICT deployment in agricultural marketing
Arshinder et al. [3]	Procurement in supply chain management	Explored the status of coordination supply chains
Karthikeyan et al. [17]	Improvement of placement activities in engineering education industry–institute interaction	Case study of engineering college
Charan [5]	Information sharing and technology, collaborative partnerships, and vendor management	Supply chain performance issues in an automobile company
Palanisamy [25]	Building information systems flexibility	SME sector
Mahajan et al. [19]	Performance parameters of SCM participants	Frozen corn manufacturing and its supply chain
Singh and Shalender [30]	Marketing flexibility	Success of Tata Nano car
Kabra and Ramesh [15]	Importance of information and communications technology (ICT)	Humanitarian supply chain management

7.3 A Case Study on Technical Institution Using SAP-LAP

7.3.1 Background of ABC Group of Institutions, Punjab

For over 17 years, the ABC Group of Institutions (original name disguised) has been in the forefront in technical education in Punjab. The institute came into existence in 2001 and began its philanthropic work on teaching and training. It delivered the first batch of technical graduates in 2005. Since then, the group has been contributing to the cause of engineering education, with a management commitment to process, technology, and quality. After a decade of its establishment, the group was in a strong position of continuous growth with an annual placement of 300+ students out of 480 in undergraduate education. To maintain a high level of harmony between faculty, students, and management, the group innovated its own processes, managed collaborations, and put efforts for the development of faculty and students.

The group stands not for just producing technical graduates, but aims to attain a high degree of philanthropy value for serving the society. This in the contemporary view is known as "participative management"—the concept of management includes student's cooperation, and faculty development through focused as well as interdisciplinary training and industry collaborations. The prerequisites for growth in today's business environment are cutting-edge technologies and result-oriented processes. Incorporating state-of-the-art technologies and process management into all teaching and learning processes, the group focused its quality strategy on developing campus facilities with high level of commitment.

7.3.1.1 Stakeholders

Students, parents, industry, and society in general are the important stakeholder for the institutions. Most of the students joining the ABC Group hail from rural and semi-urban areas through online counseling process of affiliating university. Parents are mostly literate, but predominantly hail from the rural areas. Reputed engineering industries are periodically visiting the campus for placement, training, students and staff internship, project work, etc.

7.3.1.2 Objectives

The objective of this case is to assess the quality management practices in Indian technical institutions with a special focus on the following aspects:

- Institutional management;
- Curriculum development;
- Capability of innovative teaching methodologies;
- Industrial collaborations—sponsored projects, testing, internship, and training; and
- Research projects and consultancy with external agencies.

7.3.1.3 Issues

- **Mission of the group of institutions**: The group's mission is for slogan sake, often misunderstood and for the management perspective, the group has achieved the mission and there is no real evidence in translating the mission through goals and objectives.
- **Institutional benchmarking**: Benchmarking with competitive institutions is highly regional one and the group has never attempted to benchmark the best practice with well- established and reputed institutions.
- **State-of-the-art technology for upgradation**: The ABC Group is under the notion that the technology upgradations are to be imposed from the regulatory bodies or

affiliating agencies. Institutions are not proactively coming forward to upgrade the laboratories and equipment, even though there are many schemes are through external funding agencies and industries.

- **Faculty development**: The group is least bothered about its faculty development academically, as there is no budgetary allocation for faculty development programs. Institutions are under the impression that faculty development is the responsibility of the university/regulatory bodies.
- **Innovations in quality improvement**: The top management is mainly involved in their routine exercise of budgeting and introduction of new programs rather than any innovation for quality improvement in their system.
- **Building competencies/skills of students**: The feedback from the industries is highly discouraging, about 75% of the graduates being "unemployable"; still the focus is not on developing the competencies and skills of technical students.
- **Research capability and productivity**: Though faculty members are sincere in teaching and associated activities, but when it comes to the research, the group is not in a position to tap the potential of their own faculty members due to the lack of leadership at every level.

7.3.2 Tool: Situation-Actor-Process–Learning-Action-Performance (SAP-LAP)

SAP analysis has been carried out covering for a period of 17 years for batches starting from 2001 to 2017. The methodology is based on study by Palani Natha Raja et al. [24].

7.3.2.1 Context

Making of an internationally renowned engineering institution through quality management.

Situation Prevailing

- The group has a mission and perspective plan for its growth.
- Multiple regulations are enforced by government agencies and affiliating bodies for retaining approval, obtaining accreditation, acquiring autonomy status, and affiliation of all the programs.
- Budget for the last financial year 2017–2018 was clearly framed out of the tune of Rs. 5 crores, which encompasses, staff salary, equipment, consumables, infrastructure development, training, travel allowances, skill development programs, and administrative expenses.

- Periodically, reviews are taking place through College Development Council and Departmental Advisory Committee for effective monitoring.
- The group has consolidated its human resource and financial strength being purely self-financing.
- There has been always a focus on teaching innovation due to changing needs of students being admitted.
- Resources generation efforts have been taken and collaborations on research and development projects with national and international automotive agencies are visible.
- Admissions to the group are no longer competitive as no differentiating strategy was employed.
- Collaborative tie-ups with few leading industries ensuring availability of state-of-the-art knowledge in terms of technology and management practices.
- Leading industrial partners ensure a long-term relationship with the group for their business solutions vide training, faculty and student internships, technical competitions, sponsored projects, and research tie-ups.
- Harmonious relations exist with stakeholders like parents and industrialists. Parents demand better institutional performance in terms of scholarship, placements, and skill development. Employable (technical and soft skill developed) students are being expected by the industries.
- Teaching and learning innovations through model creation, software management, industry defined projects, etc., create conductive opportunities to meet the dynamic industrial requirements.
- A rich resource of trained faculty exists to take the challenges posed by the industrial partners. The group has more than 125 faculty members involved in teaching and research. One-fifth of the total faculty members possess a doctoral degree. More than 60% of the remaining faculty has registered for doctoral degrees. The faculty–student ratio is 1:20.
- Head of the institution ensures the best practices from around the globe are implemented and also key learning in terms of quality issues, stakeholders' requirements, etc., are implemented.
- Institution funds approximately 2% of the total budget for the faculty development programs. Faculty development program includes attending short-term courses, conferences, seminars, symposia, industrial training internship visits, undertaking industry, and socially relevant projects.
- Appointment of consultants for carrying out specific initiative. (For instance, administrative reforms, ISO, 5S, TQM activities, and mock accreditation processes.)
- State-of-the-art information technology infrastructure in terms of high-end servers.
- The group is no longer on the preference list of admission seekers.
- The declining financial health of the group hinders in launching new initiatives.
- Introduction of contemporary areas/subjects is made by the university more effective by way of consultation with eminent researchers, industrial experts, alumni, and academicians through the academic council. The entire syllabi are revised every 5 years. The contemporary subjects are introduced as elective.

- New administrative setup has been effectively decentralized by appointing campus directors after 10 years of existence.
- There are around 20000 alumni and their database is maintained by each institution.
- Alumni chapters are functioning effectively. Alumni contribution toward the alma mater is in the form of counseling and mentoring to the students, live projects training, feedback on the syllabus, software development with the help of students, live projects, training, feedback on the syllabus, software development, etc.
- An outsourced MIS has been developed for the administrative automation.
- Student attendance and continuous assessment details can be accessed through the Internet portal of the institute.
- The institution is ISO 9001:2000 certified. It has procedure and processes for the entire activities of the college: general administration, teaching, and learning. Students' activities, industry collaboration, research and development, hostels are effective. However, monitoring of the processes is seriously lacking.
- The group could not get accredited even after graduating 13 batches of students.
- Long pending problem such as improvement in placements is plaguing the group.
- Academic calendar is available to know the schedule and cocurricular activities. Minor deviations are observed due to the improper planning as tests and examinations clash with the placements schedule.
- Classroom and lab ambience are conductive in nature for all the programs. Beyond working hours in laboratories are the culture embedded among the students to participate in the technical competitions and mini projects.
- Merit and means, single girl child, and deprived classes scholarships are available for about 50% of the students.
- Student's amenities such as canteen, transport, dispensary, nearby post office, stores, shops, and restrooms are in place.
- National-level student's symposium is being organized once in a year. Intra-department contest among the students too is organized as part of the interdisciplinary programs.

Actors

- The *management* of the charitable trust provides a clear strategy along with focused direction and facilitates to meet the requirements of the group. Commencement of new course, the establishment of new laboratories, physical infrastructure for classrooms, and manpower requirement are decided by the management.
- The *Board of Governors* comprises veteran academicians, corporate senior officials, government nominees, and regulator representatives. The BoG keeps pace with the stakeholder's demand and provides the requisite resources.
- The curriculum, subjects of study, and syllabi are developed and approved by the *Academic Council* of the affiliating university for a specified period. Eminent academicians, industrial experts, scientist from R&D organizations, university representatives, and heads of institutions are the members of the council. Periodically, new members are included in the council to have fresh ideas and suggestions

in academic development. The syllabus is continuously updated in tune with the modern need of industries and feedback received from the council members. Also, this council deals with all other academic related matters including discipline and malpractices.

- This *campus administration* includes all the heads of the department and institutional heads periodically. They review the progress of the institutional activities in the areas of planning and administration, academic issues and development and its interaction, and students' activities. It provides the input to the management for further development of the institutions such as array of new MoUs with other institutions based on the review and monitoring of professional activities.
- The *Heads of Institution* (Director/Principal) sustains the teaching–learning process, forecasted stakeholders' grievances, alleviate the student issues, draft the policies, and implements effective procedures. They receive feedback from alumni and involve them in academic processes, corpus generation for scholarship, mentoring the students for placements, and skill developments, research projects, and training. They also head technological incubations, entrepreneurial role models are the activities, mainly motivate and initiated by the institution.
- The *Head of the Department* works closely with faculty members and students to monitor the functioning of the department. HoD is responsible for creating a strategy for further expansion. She/he encourages faculty growth and guides the faculty to meet external demands. The external demands are in the form of research projects and industrial problems and testing the products.
- The *Department Advisory Committees* provide directions and advice to the department on the innovations and implementation issues relating to infrastructure development, teaching–learning process, industry–institute interaction, R&D, faculty development and students activities so as to achieve the mission and objectives envisioned in the policies of the institution.
- The *Faculty* acts as a facilitator for the students and mentors them to learn fundamental and newer technologies. They help the students to bring out their creativity through teaching and develop their skills and also inculcating the habits of self-study. The faculty also acts as an agent for behavior modification.
- The *Students* are actively involved in asynchronous learning of modern technologies. They are associated and involved with Special Interest Groups and societies like SAE, IE (India), ISTE, etc. Students participate in the innovative design contest, project exhibition, and various professional activities. Students are supportive in research projects undertaken by the faculty members. Each student is monitored personally by a mentor personally and academically once a student enters into the department discipline.
- The *Librarian* is responsible for issuing, ordering, procuring, and weeding out old books, journals, periodicals and proceedings, etc. She/he facilitates the students and faculty members in viewing the tele-education programs beamed by agencies like EDUSAT, NPTEL, UGC, and other institutions.
- The *Sports Officer is* responsible for talent scouting of various games. He conducts coaching camps for the students and proposes for infrastructure and equipment for procurement.

- *Consultants* from regulatory and accreditation bodies are also hired for quality improvement.

Process

- Any educational institutions fundamental duty is to conceptualize the teaching and learning processes and sustain the process with an effective monitoring mechanism. The university's Board of Studies (BOS) frames the learning objectives by understanding the changing industrial trends. The learning objectives are available for each subject.
- Most of the objectives are conversed with the creation of new knowledge, providing better content to the students, developing problem-solving ability, creative thinking and skills development through training, imparting information and educate weaker students, providing links with industrial and research organization, and institute of higher learning.
- Every department identifies theme areas and interest groups for accomplishing objectives for the same. Asynchronous learning of students has been visualized through mini projects and innovative design contests.
- Academic calendar is prepared well ahead of the commencement of classes. Classroom and lab ambience and infrastructures are conductive for teaching and learning. Basic teaching aids and models are available for teaching.
- Lecture videos/CDs are provided to the students by the faculty members in advance. Professional society activities had planned for the whole academic year and schedule for the activities are reflected in the academic calendar.
- Invited Lectures are being arranged by every department in association on their respective domain. Open source courseware is being collected from various reputed institutions to enhance their learning on recent topics.
- Industry interactions result in singing of MoUs, student internships, student exclusive contests, faculty exposed to specific training, involving the experts in boards of students, identifying futuristic projects, etc.
- The group has prepared blueprint for every activity associated with teaching and learning process. This includes planning and administration, quality system, enterprise resources planning for education system and support, faculty development activities, academic issues, admissions, amenities, continuous assessment examinations, academic and sponsored research, industry–institute interaction, professional society activities, department association activities, and student activities. Collaboration, student awards, and fellowships are implemented.

Learning Issues

- The study reveals that awareness about the importance of faculty and their contribution to the institution making is well recognized. However, the institutions need to develop focused approaches and strategy to harness and upgrade the knowledge more vigorously.

- Financial performance is under pressure due to non-release of post-matric scholarship meant for SC/ST students who comprise 40% of the total strength at campus.
- Top management commitment for collaboration strategy with industry giants has helped the institution in institutionalizing many collaborations. The collaborative workplace has proved to be most effective in the transfer of tacit knowledge in the area of high technological processes.
- Top management vision keeps the institution in learning mode and ready to embrace the change.
- People-centric policies, their effective participation, commitment, involvement, and creativity has kept the institutions in good stead. Rewards and incentive scheme started in 2006 has worked well for the group.
- The perspective plan of the institution needs to be translated to the faculty, supporting staff, and students. The effectiveness of quality initiatives depends on the organization's readiness for change.
- The revenue generation in the group institutions other than student's fee is nascent. More potential could be tapped for resources generation from industry in form of consultation.
- Public relations and press interface are seriously lacking for the outreach of the institution.
- Departmental budgets are overlapped.
- Benchmarking initiative in teaching and learning processes are insufficient and more renowned institutions could be consulted and implemented.
- The alumni database is ill-maintained. All addresses and their current positions are not in place. The group support is desired for alumni chapters since the deliberation had held sporadically. Feedback from alumni needs formal mechanism structuring. Alumni should be enthused to participate in the institutional activities and efforts should be taken to tap their interest.
- Accreditation by NBA, NAAC, etc., is missing. Efforts could be initiated to undergo the accreditation processes.
- The existing knowledge base of theme areas and Special Interest Groups (SIG) are to be continuously updated in different streams. As and when new groups are formed, the suitability of the group may be integrated for interdisciplinary or multidisciplinary areas. The Special Interest Groups should be in conformity with cutting-edge academic/industrial trends.
- In the process of evolving new educational models, constant stakeholders' feedback particularly industry is to be structured to redefine objectives of the institutions.
- Interest is not fully explored for assigning/procuring industry defined collaborative projects to develop academic interests of students and faculty.
- The basic functions like role prescription and role definition of faculty are not clearly spelt out.

- An existing mechanism needs more focus for dissemination of information with regard to college functions from the stakeholder to the stakeholder (parents, students, and faculty).
- Realizing the illustrious functioning of the group industries Volvo, MUL, etc., are coming forward to support academic research projects.
- More of the student placements are in the software development domain whereas in convention engineering discipline, it is very less.
- Best practice implementation and its sustainability need more strategic monitoring.

Action

- More focus is required on developing faculty and students by imparting recent knowledge in the respective field and skill through training schedule.
- More technological support should be provided for effective teaching and learning. The online assignment should be encouraged.
- Student's participation in laboratory performance may be encouraged. PG students shall be involved in the laboratory demonstration and exercises.
- Independent products development through industry defined projects need to be promoted. Innovative assignment and projects should be assigned to the students. Certain members are practicing it; however, it is warranted that many more faculty members should contribute to sustain the quality.
- Industry case studies need to be presented to have more practical experience to the student. In house case studies should be prepared by the students.
- Identify the domain companies for students and faculty training projects and research areas. At present, the decision on training to the students is decided by themselves. The respective HoD should identify the industries relevant to their Special Interest Groups (SIG) so that the students training and the faculty projects may be of the same interest to grow further.
- More exploration on the possibility to collaborate faculty/students exchanges with reputed higher learning institutions in India and abroad should be done.
- Develop a mechanism to get stakeholder feedback to improve the system. The present MIS does not have any follow up on the suggestions given by the stakeholder feedback.
- Involvement of nonteaching faculty is required in developing the projects.
- Predominantly more than 70% of the students are from semi-urban/rural areas. Their basic study has been in the local language. The group should formally address this issue, as many students are struggling to forge into the system in beginning, because the medium of instruction is in English.
- The growth of various technologies is in fact pace. Institutions should capture the recent trends with the present capabilities to accommodate in their theme areas.
- Since a number of technical institutions have mushroomed in region in the last decade, the healthy competition from upcoming is in place. The institutions should change the policies on various issues such as students' admissions, research areas, industry tie-ups, etc.

- Arrival of foreign universities is on the scene through General Agreement for Trade and Services (GATS) and globalization. Institute should revise the strategy to meet the anticipated fall in demand.
- Strategic planning is required to meet the increasing demand of Internet bandwidth by the students and faculty.
- More involvement of alumni is required to tap the potential know-how from the alumni. The mechanism for involvement of alumni (for instance, video conferencing mentoring, projects review, laboratory improvement, industrial trends, and mentoring leadership's qualities) should be evolved.
- Institutional image building and outreach of the institutions need more concentration since the national public magazines do not paint a rosy futuristic picture for the group.

Expected Performance

- The group has significant capabilities to emerge as a model for higher learning institutions.
- Institutions have high revenue from post-matric scholarship scheme and Skill India scheme, and there is a scope for investment in the quality management system.
- The group shall explore new industries for knowledge transfer on product development.
- Amount of revenue generated on sponsored research and consultancy may not increase sufficiently.
- Pass %age of students should increase beyond 70% in the next three years.
- Average placement of students in reputed companies has been 75% of eligible students in the last three years.
- The number of doctoral degree holder faculty shall increase by 25% in the next 3 years.
- International collaborations with reputed institutions under various schemes shall be exploited.
- Proper mechanism to be evolved to tap the university/industry supported R&D projects.
- More involvement is required in consultancy and testing for all the domains. It results in a continuous watch for current technologies. Capable laboratories shall aim for accreditation exclusively to have more projects consultancies and testing in recent areas.
- It is observed that in the past three years more than 80% of the passing out students have been placed in the information technology/information technology-enabled service. Students shall be educated to take up the job in core conventional discipline (mechanical design, hardware interface, projects management, and challenging engineering jobs) in addition to the software aptitude, since job market in core domain is starving for motivated and knowledgeable young engineers.
- Centers of excellence shall be set up in few strong domains of engineering.

7.4 Key Learning Issues

Quality initiatives are driven by top management commitment at ABC Group of Institution, Punjab. The learning issues on the quality attributes have been synthesized and are depicted in Table 7.3.

Influence of managerial concepts
Informal telephonic interviews were carried out with faculty at all levels, graduating students and parents for their feedback. A sample of 100 was selected. The interview covered 14 questions as enumerated in Table 7.4. The influence of managerial concepts in engineering institution has also been listed in Table 7.4 based on values (Mode) the informal interviews with the faculty, supporting staff, students, parents, and society in general.

7.5 Conclusions, Limitations, and Future Directions

In this study, SAP-LAP methodology has been applied in a group of Institutions to appreciate the roles played by various individuals and associated stakeholders. The key learning issues thus synthesized make an important contribution to theory and practice. SAP-LAP architecture of the service quality issues fills the gaps that exist in the conceptualization of SQ practices in professional institutions. The findings also help improve the understanding of how stakeholders in such institutions evaluate service delivery and performance. The identified parameters can act as diagnostic tools for identifying poor and/or excellent performance to benchmark across various cells or functional areas within a single institute. Furthermore, any of these parameters can also be compared across time. The findings are in line with those by [1, 13, 16, 23].

The findings of the study must be interpreted keeping in mind certain limitations. Being a case study only, it is not sufficient to set up a full structure for modeling service quality issues in technical education. Telephonic interviews conducted using a small convenience sample technique are another limitation of the study. Perhaps the use of one of the probabilistic techniques would provide the chance of generalizing the results more confidently. Studies with similar objectives and agenda with large sample size may be more beneficial for generalizations of the SAP-LAP items.

7.6 Learning from This Research

Education represents the main components of the society. From this case study, it is concluded that there are certain common quality parameters woven in a common thread in these service domains. Particularly, the processes and people management help to identify and prioritize the quality factors for education setup. For instance, in

Table 7.3 Synthesis of key learning issues in engineering institutions

S. No.	Quality factors	Status/implication
1.	Situation/environment	Competition pressure from private universities, mushroomed engineering institutions, and upcoming foreign universities
2.	Centers of excellence	Powerful futuristic concept to provide requisite focused knowledge and resources in particular identified domains of engineering
3.	Technical dimensions for quality	Institutions have built infrastructure for implementing quality initiatives. However, a centralized application center needs to be integrated
4.	Lifelong learning through training for faculty and students	Faculty development should be on a continuous basis. The usage of infrastructure needs to be enhanced
5.	Management of intellectual resources	The group has given explicit focus to further improve the management of resources for managing the skills and diverse knowledge skills of faculty
6.	Top management commitment	There is a high degree of commitment from top management for the effective sharing of information and forming strategies and following up their implementation
7.	Development of faculty-centric policies for creativity and commitment	The group believes in the role played by the tacit knowledge performance of its human resource. People-centric policies should remain in place for their overall development
8.	Readiness for change	Through flexible policy framework institutions has archived employee response capabilities keeps itself ready for change
9.	Interactions collaborating and networking with partners	Institutions have effectively managed their interactions with industries for sharing and promotions of knowledge and skills. It has successfully integrated the diverse knowledge for working in cutting-edge technologies. Faculty and students are effectively involved in its collaborative and sponsored projects. The participation by its students and its interactive industry should be on a continuous basis

(continued)

Table 7.3 (continued)

S. No.	Quality factors	Status/implication
10.	Regulations and compliance of quality policies	Formal rules and regulation and compliance policies for quality are needed to be strengthened. However, at informal level, these are effectively put in pace
11.	Formalizations and compliance of quality concept	Implicitly and explicitly, the group has formalized powerful concept for teaching and learning through various integrating mechanism and committees. The group should, however, develop a scheme and methodology to evaluate the outcome of development initiatives, optimum mix of people, process and technology needs to be evolved for the desired level of performance dimensions
12.	Rewards and recognition for faculty and staff	Institutions have developed schemes for rewarding the faculty, staff, and students. There need to be incentives for knowledge sharing and team efforts/performance
13.	Competitiveness—capability buildup and innovation	The quality imitativeness by ongoing commitment of top management keeping people at the center has helped the institution constantly improve its capability of managing knowledge resources. Involvement of internal and external stakeholders has provided the necessary capability of innovation, response, flexibility, commitment, and creativity leading to competitiveness
14.	Success through operational efficiently	The group has successfully managed the competition from the neighboring institutions, but is under pressure to update with world class features at par with global institutions. The group is making efforts by interaction, MoUs for improving its performance against internal and external benchmarking. This is a focus on new development and growth of the institution with new ideas

Table 7.4 Influence of managerial concepts in engineering education

S. No.	Item	Modal remarks
1.	Academic leadership	Good
2.	Social prestige of the group	Very good
3.	Change management	Good
4.	Degree of customization	More need to be done
5.	Degree of academic planning	Good
6.	Effectiveness of technical alliances	Good
7.	Research output	Good
8.	Investment in technology	More need to be done
9.	Technology availability	More need to be done
10.	Students' technology awareness	More need to be done
11.	Student's satisfaction	Good
12.	Conduciveness for making innovations	Good; proven
13.	Flexibility in system/procedures	Quite good
14.	Group's vertical growth	Saturated

the engineering education, there is an immediate response in different areas such as networking with experts, consortium approach, CBT, video conferencing/streaming, etc., which are initiated by the colleges. The DSMG measurement scales have been constructed for self-supporting engineering colleges (for lower level engineering colleges). The DSMG measurement scale can, however, be extended to IITs/NITs, nevertheless, by altering the weightages with respect to the leadership, process management, people management, measurement of resources, and customer satisfaction.

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Chapter 8
Selection of the Optimum Hole Quality Conditions in Manufacturing Environment Using MCDM Approach: A Case Study

Ravi Pratap Singh, Mohit Tyagi and Ravinder Kataria

Abstract In the current competitive structure of the manufacturing industries, the qualitative decision-making has become an issue of paramount prominence to solve the real-life industrial environment based problems. It becomes further more complex when the decision maker has to be in concern with the multiple constraints at one time. The present article has targeted to select the optimum hole quality conditions for performing ultrasonic machining of a selected composite material through multiple criteria decision-making (MCDM) approaches. The experimentation has been designed according to the Taguchi's methodology. The hole quality based attributes (out of roundness, hole over size and conicity) have been studied under the influential situations of several selected input variables namely; thickness of workpiece, cobalt content, tool profile, power rating, material of tool and grit size. In addition, two different MCDM approaches called as the additive ratio assessment (ARAS) technique, and the TOPSIS method have been attempted for the selection of the best optimum condition that can offer fruitful hole quality based outcomes for the considered manufacturing environment problem. The optimality function and the specific alternative to the perfect solution to observe the best available alternative have been computed as per the ARAS, and the TOPSIS techniques, respectively. Results revealed that, for both the explored MCDM methods, the 9th experimental run offers the highest value of the calculated hole quality attribute index. This particular conducted test is entailing of the parametric blend as; cobalt content—24%, workpiece thickness—3 mm, tool profile—hollow, material of tool—stainless steel, abrasive grit size—500 (mesh size) and power rating—80%.

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Keywords ARAS method · Decision-making · Manufacturing environment · MCDM approaches · TOPSIS method

8.1 Introduction

"Ultrasonic machining" (USM) is a nontraditional manufacturing method proficient to process both the non-metallic and metallic materials retains hardness more than HRC-40, i.e.; glass, ceramics, composite materials, silicon, semiconductors, ferrites, etc. [15, 16, 18]. Tungsten carbide has extensively been finely recognized for its incomparable wear resistance and hardness however inferior toughness. Mediums of ductile metals, explicitly; cobalt, nickel, etc., greatly recover its toughness. Therefore, WC–Co (tungsten carbide-cobalt) composite, which comprises of WC grains implanted in a metal binder level, shows superior hardness to contest wear and adequate toughness to endure intermittent cuts happening during the manufacturing process [15]. WC-Co is a material of excellent hardness, wear confrontation, decent-dimensional constancy and better mechanical forte. Due to these properties, it is becoming very desirable for a number of applications with expected growing application in the future [2–4]. USM is a practicable alternative method for the processing of WC-Co compounds, because the practice is free from several of issues allied with the thermal energy-based process.

8.2 Literature Review

USM is non-thermal kind practice, so the processed surface do not possess any unwished effects i.e.; HAZ, the creation of recast film, etc. [1, 7]. The accuracy of the hole produced in USM was affected due to different factors; the accuracy of the machine, grit size, the fixture used, the superiority of parts, transverse vibration effects, depth of cut and tool wear. In USM hole oversize arises owing to flooding of grains during the process.

The hole over size is the difference between the actual tool diameter before drilling and hole diameter at the entry side. Abrasive grit size has been found as a foremost significant variable which affects the accurateness of hole [15]. Adithan and Venkatesh [18] reported that a rise in the processing time and static load consequences in reduced over size of the hole. The four-sided tools produced more oversize than circular ones [13]. Jadoun et al. [4] enhanced the method variables for production accuracy in USM of ceramic-based composites using Taguchi approach. For hole oversize, the consequences showed that, the grit size was more momentous than other parameters. Ramula [7] reported that over cut increasing with decreasing the diameter of the abrasive particle and the over cut range from 1.4 to 12.8 times of mean grit size. Lalchhuanvela et al. [13] deliberated the influences of several method variables on hole accuracy with a hexagonal profile of tool. Healthier correctness of hexagonal type profile hole was attained at an inferior concentration of slurry (30–40%), and at a standard abrasive slurry flow. The grit size, tool feed and concentration of slurry were the main controllable factors which affect the accuracy of hole profile [2–4].

Out of roundness (OOR) is the type of form inaccuracy of the circular holes. In USM, OOR is first transpired on the tool and then trailed by the drilled hole [7, 12, 14]. Jadoun et al. [4] analysed conicity of the ultrasonically drilled hole in alumina. Results exhibited that the conicity increase with growing alumina in work material and the size of grit.

In the assessment of stated literature, for the valuation and selection of the optimum alternatives for the hole excellence attributes in USM of composite material, it is vital to inspect a range of method variables and their consequences on the hole quality measures. MCDM tactics also deal a resolution to the above-deliberated issue in an operative way [8, 10]. In addition, two different MCDM approaches called as the additive ratio assessment (ARAS) technique, and the TOPSIS method have been attempted for the selection of the best optimum condition that can offer fruitful hole quality based outcomes for the considered manufacturing environment problem. The ARAS and TOPSIS methodologies are one of the approaches accessible, which can suggest clarification to the above-conversed issue [5, 6]. The optimality function and the particular alternative to the ideal solution to observe out the best available alternative have been computed as per the ARAS, and the TOPSIS techniques, respectively.

8.3 Experimentation Work

The ultrasonic machining of WC-Co composite work samples has been performed to understand the influence of the certain method variables on the measures of hole quality. The work samples having Co-content of 24 and 6%, with 3 and 5 mm thickness, were selected for conducting the experimentation. WC-6%Co has 14.9 g/cm^3 density, 1580 HV hardness, 630 GPa elastic modulus and for, WC-24%Co has 12.9 g/cm^3 density, 780 HV hardness, 470 GPa elastic modulus. Table 8.1 displays the studied method factors considered for the study. The employed machine setup and the enlarged view of machining zone comprising tool, workpiece and fixture are shown in Fig. 8.2 (Fig. 8.1).

This work makes usage of Taguchi's L-36 OA for experimental strategy. The experimental design is demonstrated in Table 8.4.

8.3.1 Experimental Results

The two-level factors, such as; cobalt content, thickness of work and profile of tool, were assigned to first, second and third column of the array, respectively. The three-level factors, i.e. material of tool, size of grit and power rating were assigned to fourth, fifth and sixth column of the array, respectively. As per the designed plan

Table 8.1 Method variables taken for the study

Symbol	Parameter	Level 1	Level 2	Level 3
A	Cobalt content	6%	24%	
B	Work thickness	3 mm	5 mm	
C	Tool profile	Solid	Hollow	
D	Tool	Stainless steel	Silver steel	Nimonic-80A
E	Grit size	200	320	500
F	Power rating	40%	60%	80%

Persistent factors

Frequency	20 kHz	Slurry concentration	25%
Static load	1.63 kg	Slurry temperature	25 °C
Amplitude	25.3–25.8 μm	Slurry flow rate	50×10^3 mm^3/min

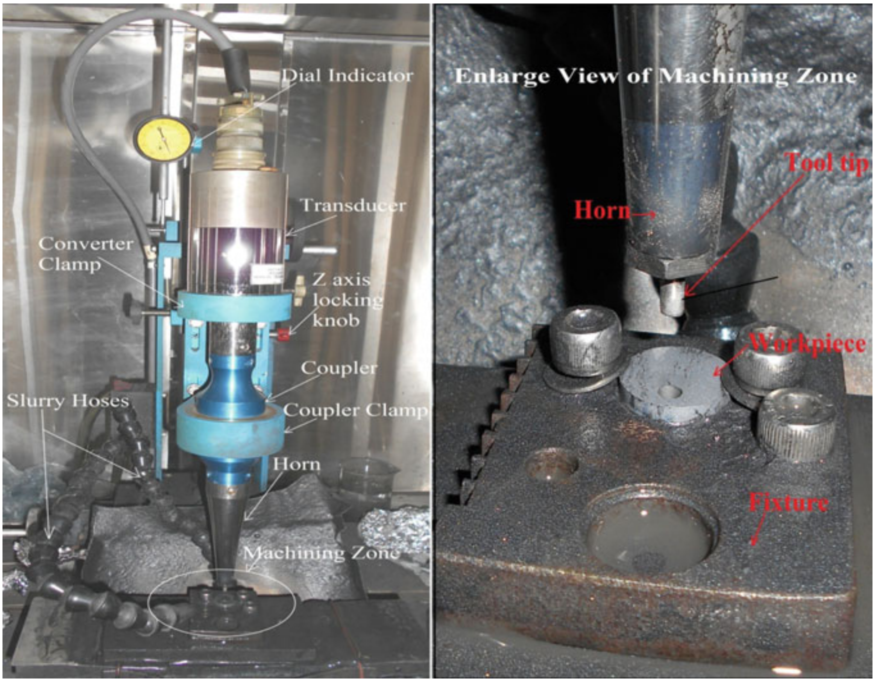

Fig. 8.1 Major components of USM set-up

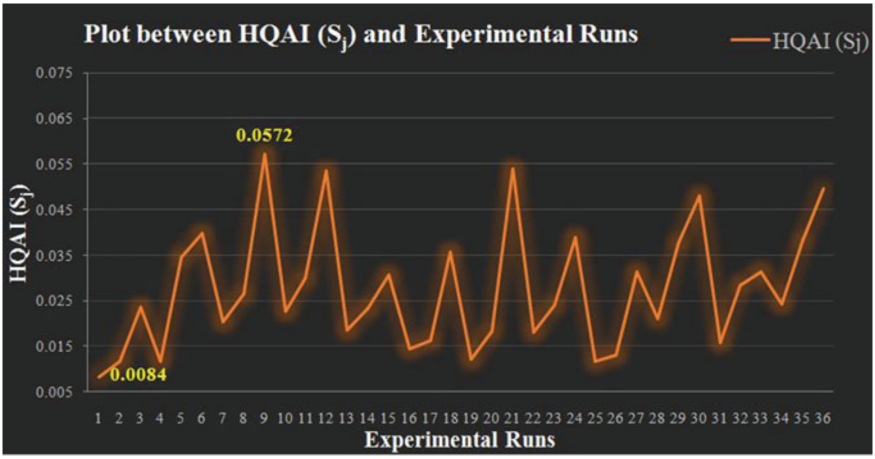

Fig. 8.2 Representation of computed S_j values versus experimental runs

exposed in Table 8.2, through holes were drilled in work pieces. The final obtained results for the studied outcomes has been reflected in Table 8.3.

8.4 Decision-Making With the MCDM Approaches

MCDM is an extensively employed decision procedure in innumerable grounds namely business, industrial sector, economy, energy and environment, manufacturing and many more [11, 17]. The MCDM methods and tactics advance the eminence of choices by generating the expansion more effectual and competent, balanced and explicit. A hefty sum of tactics and procedures has been familiarized in this capacity of study. In recent times, the progress of modular and hybrid approaches is flattering progressively imperative [9]. They are grounded on formerly developed renowned methods, for instance; SAW, AHP, graph theory & matrix approach (GTMA), ANP, ***technique for order preference by similarity to ideal solution (TOPSIS)***, VIKOR, ELECTRE, PROMETHEE, DEMATEL, DEA and their adaptation, by smearing fuzzy and grey theory. Moderately newly established MCDM procedures, for example, COPRAS, ***additive ratio assessment (ARAS)***, RUTA, GRIP, MULTIMOORA, SWARA, MOORA, UTADISGMS and WASPAS are swiftly industrialized and practiced to unravel the real-life industrial complications. However, for the present research work, two MCDM methodologies *(ARAS, and TOPSIS)* have been selected, explored and implemented for revealing and practice their capability to solve practical industrial problems. The description and implementing steps of these said methods are described below.

Table 8.2 Experimental design matrix based on L-36 OA

Experiment no.	A. Cobalt content	B. Work thickness	C. Tool profile	D. Tool material	E. Size of grit	F. Power rating
1	1	1	1	1	1	1
2	1	1	1	1	2	2
3	1	1	1	1	3	3
4	1	2	2	1	1	1
5	1	2	2	1	2	2
6	1	2	2	1	3	3
7	2	1	2	1	1	1
8	2	1	2	1	2	2
9	2	1	2	1	3	3
10	2	2	1	1	1	1
11	2	2	1	1	2	2
12	2	2	1	1	3	3
13	1	1	1	2	1	2
14	1	1	1	2	2	3
15	1	1	1	2	3	1
16	1	2	2	2	1	2
17	1	2	2	2	2	3
18	1	2	2	2	3	1
19	2	1	2	2	1	2
20	2	1	2	2	2	3
21	2	1	2	2	3	1
22	2	2	1	2	1	2
23	2	2	1	2	2	3
24	2	2	1	2	3	1
25	1	1	1	3	1	3
26	1	1	1	3	2	1
27	1	1	1	3	3	2
28	1	2	2	3	1	3
29	1	2	2	3	2	1
30	1	2	2	3	3	2
31	2	1	2	3	1	3
32	2	1	2	3	2	1
33	2	1	2	3	3	2
34	2	2	1	3	1	3
35	2	2	1	3	2	1
36	2	2	1	3	3	2

Table 8.3 Experimental results (average raw data)

Experiment runs	Average of two readings		
	HOS (mm)	ORR (mm)	Conicity
1	0.5082	0.1002	0.1759
2	0.2950	0.0683	0.1605
3	0.1916	0.0481	0.0540
4	0.4031	0.0817	0.1081
5	0.1702	0.0304	0.0321
6	0.1091	0.0315	0.0326
7	0.2516	0.0125	0.1915
8	0.1833	0.0140	0.0812
9	0.0560	0.0107	0.0470
10	0.5202	0.0088	0.1284
11	0.3190	0.0076	0.0799
12	0.2500	0.0034	0.0669
13	0.2274	0.0285	0.1008
14	0.1687	0.0395	0.0668
15	0.1783	0.0122	0.0618
16	0.3695	0.1130	0.0738
17	0.3490	0.0221	0.1112
18	0.1079	0.0288	0.0433
19	0.2904	0.0648	0.1545
20	0.2276	0.0212	0.1384
21	0.0491	0.0392	0.0442
22	0.4086	0.0212	0.0802
23	0.2369	0.0164	0.0721
24	0.1634	0.0096	0.0427
25	0.5284	0.0188	0.3369
26	0.5339	0.0184	0.2050
27	0.1205	0.0131	0.0906
28	0.4198	0.0112	0.1104
29	0.4001	0.0046	0.1039
30	0.1728	0.0069	0.0327
31	0.4375	0.0141	0.2179
32	0.3570	0.0061	0.2065
33	0.1993	0.0093	0.0712
34	0.2575	0.0188	0.0597
35	0.2019	0.0120	0.0336
36	0.1188	0.0094	0.0299

8.4.1 The ARAS Method

The ARAS technique is grounded on the measurable capacities and concept of utility. The steps involved in the implementation of ARAS technique are given as below

1. For advantageous characteristics;

$$r_{jy} = \left[x_{jy} - \min.\left(x_{jy}\right)\right] / \left[\max\left(x_{jy}\right) - \min.\left(x_{jy}\right)\right] (j = 1, 2, 3, \ldots, m;\ y = 1, 2, 3, \ldots, p) \tag{8.1}$$

For non-advantageous characteristics, the normalization process is of two stages. Perform primarily the reciprocal of individual condition w.r.t. involved substitutes as:

$$x^*_{jy} = \frac{1}{x_{jy}}, \tag{8.2}$$

and then compute the further values as:

$$R = \left[r_{jy}\right]_{m \times n} = \frac{x^*_{jy}}{\sum_{j=1}^{m} x^*_{jy}} \tag{8.3}$$

2 The weighted standardized matrix (D), as:

$$D = [f_{jy}]_{m \times n} = r_{jy} \times w_y \tag{8.4}$$

3 Computation for the ideal function (S_j) for jth substitute. Higher the S_j score, the superior is the substitute

$$S_j = \sum_{y=1}^{p} f_{jy} \tag{8.5}$$

4 Estimate the utility grade (U_j) for every substitute. It is resolute by an assessment of the alternative with the best effectual alternative (S_o). The rationalization employed for scheming the value of U_j is given as below:

$$U_j = \frac{S_j}{S_o} \tag{8.6}$$

The variant possessing the uppermost score for utility is taken the finest choice amid the available substitutions.

8.4.2 The TOPSIS Method

The TOPSIS technique was developed by Hwang and Yoon (1981). This method is grounded on the concept that the chosen substitute must possess the unswerving Euclidean distance from the ideal resolution, and the furthest from the undesirable ideal resolution. The steps involved in the implementation of TOPSIS technique are given as below

1 All the experimental results are represented in a decision matrix form.
2 Calculate the normalized decision matrix. The normalized value R_{jy} is calculated as

$$R_{jy} = m_{jy} / \left[\sum_{y=1}^{p} m_{jy}^2 \right]^{1/2} \quad (8.7)$$

3 Provide the corresponding importance score to the several attributes. The weight scores can be given as; w_y, i.e. $\sum w_y = 1$.
4 Calculate the weighted normalized decision matrix. The value V_{jy} is calculated as below

$$V_{jy} = w_y R_{jy} \quad (8.8)$$

5 Determine the worst and perfect resolution in this phase as:

$$\begin{aligned} V^+ &= \{(\max. V_{jy}/y \in Y), (\min. V_{jy}/y \in Y')\}; \\ &= \{V_1^+, V_2^+, V_3^+, \ldots\ldots\ldots V_n^+\} \end{aligned} \quad (8.9)$$

$$\begin{aligned} V^- &= \{(\max. V_{jy}/y \in Y), (\min. V_{jy}/y \in Y')\}; \\ &= \{V_1^-, V_2^-, V_3^-, \ldots\ldots\ldots V_n^-\} \end{aligned} \quad (8.10)$$

where Y = (y = 1,2,3….p)/y is allied with advantageous qualities, and Y' = (y = 1,2,3….p)/y is allied with non-advantageous characteristics.
6 Obtain the parting measures. The separation of every alternative from the perfect solution is given by the Euclidean distance in the following equations:

$$S_j^+ = \left\{ \sum_{y=1}^{p} \left(V_{jy} - V_y^+ \right)^2 \right\}^{1/2}, \quad j = 1,2,\ldots\ldots\ldots m \quad (8.11)$$

Similarly, the separation from the negative ideal solution is given as

$$S_j^- = \left\{ \sum_{y=1}^{p} \left(V_{jy} - V_y^- \right)^2 \right\}^{1/2}, \quad j = 1,2,\ldots\ldots\ldots m \quad (8.12)$$

7 The comparative nearness of a specific substitute to the perfect solution, P_i, can be articulated in this step as

$$P_j = S_j^- \Big/ \left(S_j^+ + S_j^-\right) \tag{8.13}$$

8 A bunch of substitutes is generated in the sinking order in this phase, as per the score of P_j reflecting the most favoured and least favoured feasible solutions.

8.5 Method 1: Implementation Steps of Aras Method for the Considered USM Case Study

The case study which has been considered for understanding the capability of selected MCDM approaches is related with the experimental investigation conducted to process the tungsten carbide based composite material with ultrasonic machining method using Taguchi's designed experiments. The output response data has been undertaken from the experimental work, which has been reflected in Table 8.3. The following are the implementing steps for practicing the ARAS method potentially. These are as follows.

8.5.1 Normalized Matrix for Raw Data

As the case study is having attributes of the non-beneficial category, the experimental raw data has been normalized as per the formulation discussed in Eqs. (8.2) and (8.3). The normalized response data is illustrated in Table 8.4.

8.5.2 Weighted Normalized Matrix

The considered case study is consisting of three different hole quality measures namely; hole oversize, out of roundness and conicity. The equal weightage has been provided to all the three attributes, i.e. 0.33 for each response. Then using Eq. (8.4), the weighted normalized matrix is attained as presented below in Table 8.5.

Table 8.4 Normalized matrix for response data

	Selected parameter levels						Normalized hole quality measures		
Exp. runs	A	B	C	D	E	F	HOS	OOR	Conicity
1	1	1	1	1	1	1	0.0106	0.0038	0.0109
2	1	1	1	1	2	2	0.0182	0.0055	0.0120
3	1	1	1	1	3	3	0.0280	0.0078	0.0356
4	1	2	2	1	1	1	0.0133	0.0046	0.0178
5	1	2	2	1	2	2	0.0315	0.0124	0.0599
6	1	2	2	1	3	3	0.0492	0.0119	0.0590
7	2	1	2	1	1	1	0.0213	0.0301	0.0100
8	2	1	2	1	2	2	0.0293	0.0269	0.0237
9	2	1	2	1	3	3	0.0959	0.0351	0.0409
10	2	2	1	1	1	1	0.0103	0.0427	0.0150
11	2	2	1	1	2	2	0.0168	0.0495	0.0241
12	2	2	1	1	3	3	0.0215	0.1106	0.0287
13	1	1	1	2	1	2	0.0236	0.0132	0.0191
14	1	1	1	2	2	3	0.0318	0.0095	0.0288
15	1	1	1	2	3	1	0.0301	0.0308	0.0311
16	1	2	2	2	1	2	0.0145	0.0033	0.0261
17	1	2	2	2	2	3	0.0154	0.0170	0.0173
18	1	2	2	2	3	1	0.0497	0.0131	0.0444
19	2	1	2	2	1	2	0.0185	0.0058	0.0124
20	2	1	2	2	2	3	0.0236	0.0177	0.0139
21	2	1	2	2	3	1	0.1093	0.0096	0.0435
22	2	2	1	2	1	2	0.0131	0.0177	0.0240
23	2	2	1	2	2	3	0.0227	0.0229	0.0267
24	2	2	1	2	3	1	0.0328	0.0392	0.0450
25	1	1	1	3	1	3	0.0102	0.0200	0.0057
26	1	1	1	3	2	1	0.0101	0.0204	0.0094
27	1	1	1	3	3	2	0.0445	0.0287	0.0212
28	1	2	2	3	1	3	0.0128	0.0336	0.0174
29	1	2	2	3	2	1	0.0134	0.0818	0.0185
30	1	2	2	3	3	2	0.0311	0.0545	0.0588
31	2	1	2	3	1	3	0.0123	0.0267	0.0088
32	2	1	2	3	2	1	0.0150	0.0617	0.0093
33	2	1	2	3	3	2	0.0269	0.0404	0.0270
34	2	2	1	3	1	3	0.0208	0.0200	0.0322
35	2	2	1	3	2	1	0.0266	0.0313	0.0572
36	2	2	1	3	3	2	0.0452	0.0400	0.0643

Table 8.5 Weighted standardized matrix for response data

	Selected parameter levels						Weighted normalized hole quality measures		
Exp. runs	A	B	C	D	E	F	HOS	OOR	Conicity
1	1	1	1	1	1	1	0.0035	0.0012	0.0036
2	1	1	1	1	2	2	0.0061	0.0018	0.0040
3	1	1	1	1	3	3	0.0093	0.0026	0.0238
4	1	2	2	1	1	1	0.0044	0.0015	0.0119
5	1	2	2	1	2	2	0.0105	0.0041	0.0346
6	1	2	2	1	3	3	0.0164	0.0040	0.0400
7	2	1	2	1	1	1	0.0071	0.0100	0.0205
8	2	1	2	1	2	2	0.0098	0.0089	0.0266
9	2	1	2	1	3	3	0.0319	0.0117	0.0572
10	2	2	1	1	1	1	0.0034	0.0142	0.0227
11	2	2	1	1	2	2	0.0056	0.0165	0.0301
12	2	2	1	1	3	3	0.0071	0.0368	0.0536
13	1	1	1	2	1	2	0.0079	0.0044	0.0186
14	1	1	1	2	2	3	0.0106	0.0032	0.0234
15	1	1	1	2	3	1	0.0100	0.0103	0.0307
16	1	2	2	2	1	2	0.0048	0.0011	0.0146
17	1	2	2	2	2	3	0.0051	0.0057	0.0165
18	1	2	2	2	3	1	0.0166	0.0043	0.0357
19	2	1	2	2	1	2	0.0062	0.0019	0.0122
20	2	1	2	2	2	3	0.0079	0.0059	0.0184
21	2	1	2	2	3	1	0.0364	0.0032	0.0541
22	2	2	1	2	1	2	0.0044	0.0059	0.0183
23	2	2	1	2	2	3	0.0075	0.0076	0.0241
24	2	2	1	2	3	1	0.0109	0.0130	0.0390
25	1	1	1	3	1	3	0.0034	0.0067	0.0119
26	1	1	1	3	2	1	0.0033	0.0068	0.0133
27	1	1	1	3	3	2	0.0148	0.0096	0.0315
28	1	2	2	3	1	3	0.0043	0.0112	0.0212
29	1	2	2	3	2	1	0.0045	0.0272	0.0379
30	1	2	2	3	3	2	0.0103	0.0182	0.0481
31	2	1	2	3	1	3	0.0041	0.0089	0.0159
32	2	1	2	3	2	1	0.0050	0.0205	0.0286
33	2	1	2	3	3	2	0.0090	0.0135	0.0314
34	2	2	1	3	1	3	0.0069	0.0067	0.0243
35	2	2	1	3	2	1	0.0089	0.0104	0.0384
36	2	2	1	3	3	2	0.0150	0.0133	0.0498

8.5.3 *Computation for the Optimality Function (Hole Quality Attribute Index (HQAI)–S_j) & Degree of Utility (U_j)*

As the problem is related to the hole quality attribute selection, therefore the hole quality attribute index (HQAI) is calculated using Eq. (8.5). After calculating the weighting normalized matrix, the next and final step is to compute the optimality function (S_j) and the degree of utility (U_j) using Eq. (8.6). The investigational test possessing the uppermost score of the HQAI (S_j) will be selected as the best available optimum alternative. The computed results have revealed that the 9th experimental run gives the highest value of the calculated hole quality attribute index (Table 8.6).

8.6 Method 2: Implementation Steps of Topsis Method for the Considered USM Case Study

The considered case study for realizing the capability of selected MCDM approaches is related with the experimental investigation conducted with ultrasonic machining method using Taguchi's designed experiments. The output response data has been undertaken from the experimental work, which has been reflected in Table 8.3. The following are the implementing steps for practicing the TOPSIS method potentially. These are as follows:

8.6.1 *Normalized Matrix*

As the case study is having three different attributes of non-beneficial type, therefore, the experimental raw data has been normalized as per the formulation discussed in Eq. (8.7). The normalized response data is illustrated in Table 8.7 below.

8.6.2 *Weighted Normalized Matrix*

The considered case study is consisting of three different hole quality measures namely hole oversize, out of roundness and conicity. The equal importance weightage has been provided to all the three attributes, i.e. 0.33 for each attribute. Then using Eq. (8.8), the weighted normalized matrix is attained as presented below in Table 8.8.

Table 8.6 Calculated values of HQAI (S_j) and degree of utility (U_j)

Experimental runs	HQAI (S_j)	U_j
1	**0.0084**	0.147
2	0.0119	0.208
3	0.0238	0.416
4	0.0119	0.208
5	0.0346	0.604
6	0.0400	0.699
7	0.0205	0.358
8	0.0266	0.465
9	**0.0572**	1.000
10	0.0227	0.396
11	0.0301	0.526
12	0.0536	0.936
13	0.0186	0.325
14	0.0234	0.408
15	0.0307	0.536
16	0.0146	0.256
17	0.0165	0.289
18	0.0357	0.624
19	0.0122	0.214
20	0.0184	0.321
21	0.0541	0.946
22	0.0183	0.319
23	0.0241	0.421
24	0.0390	0.682
25	0.0119	0.209
26	0.0133	0.232
27	0.0315	0.550
28	0.0212	0.371
29	0.0379	0.662
30	0.0481	0.841
31	0.0159	0.278
32	0.0286	0.501
33	0.0314	0.549
34	0.0243	0.425
35	0.0384	0.670
36	0.0498	0.870

Table 8.7 Normalized matrix for response data

	Selected parameter levels						Normalized hole quality measures		
Exp. runs	A	B	C	D	E	F	HOS	OOR	Conicity
1	1	1	1	1	1	1	0.2791	0.4404	0.2413
2	1	1	1	1	2	2	0.1620	0.3002	0.2202
3	1	1	1	1	3	3	0.1052	0.2114	0.0741
4	1	2	2	1	1	1	0.2214	0.3591	0.1483
5	1	2	2	1	2	2	0.0935	0.1336	0.0440
6	1	2	2	1	3	3	0.0599	0.1385	0.0447
7	2	1	2	1	1	1	0.1382	0.0549	0.2627
8	2	1	2	1	2	2	0.1007	0.0615	0.1114
9	2	1	2	1	3	3	0.0308	0.0470	0.0645
10	2	2	1	1	1	1	0.2857	0.0387	0.1762
11	2	2	1	1	2	2	0.1752	0.0334	0.1096
12	2	2	1	1	3	3	0.1373	0.0149	0.0918
13	1	1	1	2	1	2	0.1249	0.1253	0.1383
14	1	1	1	2	2	3	0.0926	0.1736	0.0916
15	1	1	1	2	3	1	0.0979	0.0536	0.0848
16	1	2	2	2	1	2	0.2029	0.4967	0.1012
17	1	2	2	2	2	3	0.1917	0.0971	0.1526
18	1	2	2	2	3	1	0.0593	0.1266	0.0594
19	2	1	2	2	1	2	0.1595	0.2848	0.2120
20	2	1	2	2	2	3	0.1250	0.0932	0.1899
21	2	1	2	2	3	1	0.0270	0.1723	0.0606
22	2	2	1	2	1	2	0.2244	0.0932	0.1100
23	2	2	1	2	2	3	0.1301	0.0721	0.0989
24	2	2	1	2	3	1	0.0897	0.0422	0.0586
25	1	1	1	3	1	3	0.2902	0.0826	0.4622
26	1	1	1	3	2	1	0.2932	0.0809	0.2812
27	1	1	1	3	3	2	0.0662	0.0576	0.1243
28	1	2	2	3	1	3	0.2305	0.0492	0.1515
29	1	2	2	3	2	1	0.2197	0.0202	0.1425
30	1	2	2	3	3	2	0.0949	0.0303	0.0449
31	2	1	2	3	1	3	0.2403	0.0620	0.2989
32	2	1	2	3	2	1	0.1960	0.0268	0.2833
33	2	1	2	3	3	2	0.1094	0.0409	0.0977
34	2	2	1	3	1	3	0.1414	0.0826	0.0819
35	2	2	1	3	2	1	0.1109	0.0527	0.0461
36	2	2	1	3	3	2	0.0652	0.0413	0.0410

Table 8.8 Weighted normalized matrix for response data

	Selected parameter levels						Weighted normalized hole quality measures		
Exp. runs	A	B	C	D	E	F	HOS	OOR	Conicity
1	1	1	1	1	1	1	0.0929	0.1467	0.0804
2	1	1	1	1	2	2	0.0539	0.1000	0.0733
3	1	1	1	1	3	3	0.0350	0.0704	0.0247
4	1	2	2	1	1	1	0.0737	0.1196	0.0494
5	1	2	2	1	2	2	0.0311	0.0445	0.0147
6	1	2	2	1	3	3	0.0200	0.0461	0.0149
7	2	1	2	1	1	1	0.0460	0.0183	0.0875
8	2	1	2	1	2	2	0.0335	0.0205	0.0371
9	2	1	2	1	3	3	0.0102	0.0157	0.0215
10	2	2	1	1	1	1	0.0951	0.0129	0.0587
11	2	2	1	1	2	2	0.0583	0.0111	0.0365
12	2	2	1	1	3	3	0.0457	0.0050	0.0306
13	1	1	1	2	1	2	0.0416	0.0417	0.0461
14	1	1	1	2	2	3	0.0308	0.0578	0.0305
15	1	1	1	2	3	1	0.0326	0.0179	0.0282
16	1	2	2	2	1	2	0.0676	0.1654	0.0337
17	1	2	2	2	2	3	0.0638	0.0323	0.0508
18	1	2	2	2	3	1	0.0197	0.0422	0.0198
19	2	1	2	2	1	2	0.0531	0.0949	0.0706
20	2	1	2	2	2	3	0.0416	0.0310	0.0632
21	2	1	2	2	3	1	0.0090	0.0574	0.0202
22	2	2	1	2	1	2	0.0747	0.0310	0.0366
23	2	2	1	2	2	3	0.0433	0.0240	0.0329
24	2	2	1	2	3	1	0.0299	0.0141	0.0195
25	1	1	1	3	1	3	0.0966	0.0275	0.1539
26	1	1	1	3	2	1	0.0976	0.0269	0.0937
27	1	1	1	3	3	2	0.0220	0.0192	0.0414
28	1	2	2	3	1	3	0.0768	0.0164	0.0504
29	1	2	2	3	2	1	0.0732	0.0067	0.0475
30	1	2	2	3	3	2	0.0316	0.0101	0.0149
31	2	1	2	3	1	3	0.0800	0.0206	0.0995
32	2	1	2	3	2	1	0.0653	0.0089	0.0943
33	2	1	2	3	3	2	0.0364	0.0136	0.0325
34	2	2	1	3	1	3	0.0471	0.0275	0.0273
35	2	2	1	3	2	1	0.0369	0.0176	0.0154
36	2	2	1	3	3	2	0.0217	0.0138	0.0137

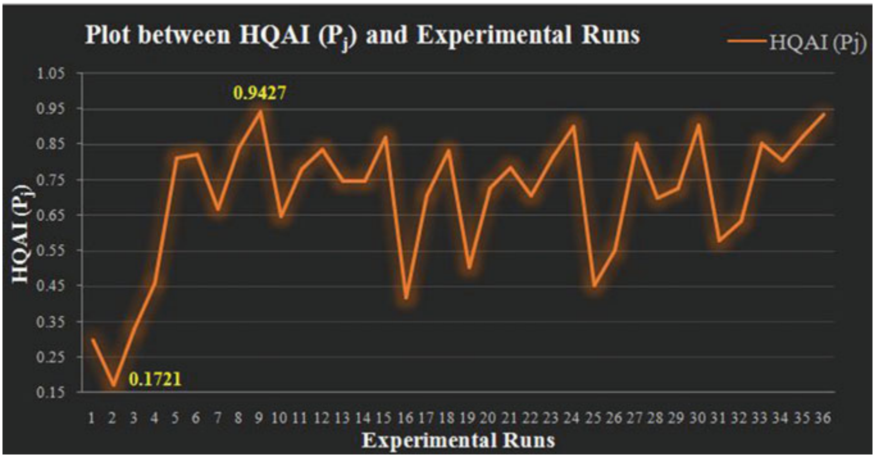

Fig. 8.3 Representation of computed P_j values versus experimental runs

8.6.3 Computation for the Particular Alternative to the Ideal Solution (Hole Quality Attribute Index (HQAI)-P_j)

After calculating the weighting normalized matrix, the subsequent stile is to compute the perfect and negative-perfect result using Eqs. (8.9), and (8.10). After this, the parting of every substitute from the ideal one has been calculated using Eqs. (8.11), and (8.12). The trial test having the uppermost score of the HQAI (P_j) will be selected as the best available optimum alternative. As the problem is related to the hole quality attribute selection, the hole quality attribute index (HQAI-P_j) is calculated using Eq. (8.13). The computed results have revealed that the 9th experimental run gives the highest value of the calculated hole quality attribute index (P_j) (Table 8.9 and Fig. 8.3).

8.7 Conclusions

In this present work, the selection of the optimum hole quality conditions in real-life manufacturing environment problems through multiple criteria decision-making (MCDM) approaches has been attempted. The case study has been selected from the experimental work conducted in USM of composite material (WC-Co). Two different MCDM approaches called as the ARAS technique, and the TOPSIS method have been discussed and implemented. On the basis of the present research study, major inferences are as follows:

1. A multiple criteria decision-making based methodologies are proposed and validated for the selection of best possible parametric alternative condition available

Table 8.9 Calculated values of HQAI (P_j) for the case study

Experimental runs	HQAI (P_j)
1	0.2997
2	**0.1721**
3	0.3314
4	0.4609
5	0.8123
6	0.8238
7	0.6696
8	0.8408
9	**0.9427**
10	0.6485
11	0.7834
12	0.8379
13	0.7468
14	0.7479
15	0.8700
16	0.4188
17	0.7056
18	0.8350
19	0.5059
20	0.7259
21	0.7856
22	0.7076
23	0.8160
24	0.9009
25	0.4524
26	0.5544
27	0.8553
28	0.7009
29	0.7265
30	0.9040
31	0.5804
32	0.6340
33	0.8556
34	0.8073
35	0.8734
36	0.9344

for the hole quality attributes in USM of composites. The adaptable ethos of these methods makes them more appropriate for plentiful solicitations in offering the optimum solutions to the practical industrial environment issues.

2. Current work deals with the innumerable characteristics, which outlines the hole quality aspects of tungsten carbide based composite in ultrasonic machining are identified. For both the explored MCDM methods, i.e. ARAS, and TOPSIS, the computed results have revealed that the 9th experimental run gives the highest value of the calculated hole quality attribute index (HQAI). This particular machine test is containing of the variable mixture as cobalt content—24%, work thickness—3 mm, tool profile—hollow, material of tool—stainless steel, abrasive grit size (mesh size)—500, and power rating—80%.
3. In addition to this, experiment runs 1st, and 2nd have been suggested as the worst solution providing alternatives as per the methodology of ARAS, and the TOPSIS approach, respectively.
4. The suggested multiple criteria decision-making (MCDM) approaches can be utilized for any real-life industrial environment issue associated to the selection and optimization of numerous, interrelated attributes of attention, under the inspiration of numerous situations of inputs.

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Chapter 9
Reliability Analysis of CNG Dispensing Unit by Lambda-Tau Approach

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Abstract CNG is considered a low maintenance cost and environment friendly fuel. Its use as an alternative fuel has surged in cities having CNG stations. Due to limited number of CNG stations, there is a substantial gap between demand and supply of CNG fuel. CNG dispensing unit is an important system of CNG station. Extended operation of dispensing unit is required for delineating this gap. For this, availability and reliability of CNG dispensing unit should be high. The present study reviews and exemplifies the fuzzy reliability analysis approach for behavioural analysis of CNG dispensing unit. The reliability block diagram and fuzzy Lambda-Tau approach have been used for evaluating reliability parameters. Fuzzy methodology has been used for representing failure rate and repair time. In present research work a comparative study of conventional fuzzy theory and vague theory has been expounded. The crisp reliability input and output data have been fuzzified using extension principle and alpha-cut approach. The fuzzy output has been defuzzified for assessing the system behaviour. The results of the study were communicated to system analyst and maintenance engineer.

Keywords CNG · Reliability · Fuzzy methodology · Lambda-Tau approach · Triangular fuzzy number · Vague theory · Alpha cut

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List of Abbreviations

FMEA	Failure mode and effect analysis
RPN	Risk Priority Number
FRPN	Fuzzy Risk Priority Number
GRA	Grey Relational Analysis
FIS	Fuzzy Inference System
CNG	Compressed Natural Gas
PM	Particulate Matter
ISO	International Standards Organization
IS	Indian Standard
NASA	National Aeronautics and Space Administration

9.1 Introduction

India is the world's third largest consumer of petrol and diesel with a consumption of 240 lakh barrel per year after US and China. India has grown into big market of consumer and commercial vehicles. The sales of passenger and commercial vehicles are showing an increase 2.8% (about 4 million units) over previous year. Due to this, India has replaced Germany as fourth largest automotive market in world. Study shows that by the year 2040, India will be the largest consumer of petrol and diesel. The burning of these fuels results in large gas emissions which causes environmental pollution. Increasing fuel prices and strict emission norms have necessitated for use of fuels that have low running cost, low Carbon dioxide (CO_2), Nitrogen oxide (NOx), Sulphur dioxide (SO_2) and particulate matter (PM) emission respectively. Compressed natural gas (CNG) is a popular fuel having clean burning properties and has low emissions of the above-mentioned gases and PM. It is distributed from the storage tanks in CNG dispensing station. The ISO: 16923:2016, specifies the design, construction, operation, maintenance and inspection stations for fueling CNG to vehicles. The hazards at dispensing station are high and it can be attributed to two reasons.

1. Complex arrangement of subcomponents.
2. Long operating duration of dispensing station.
3. The inherent properties of CNG.

A CNG dispensing unit is a complex system having various configurations (series and parallel) of subcomponents like metering skids, compressor, priority panel, dispenser and cascade unit. High reliability and availability are required for operating CNG dispensing units for longer durations. Being, lighter than air, there is always possibility of leakage through faulty sub-systems of dispensing station. As CNG is inflammable its leakage can lead to fire and explosion hazard at dispensing unit. This can affect components of system, process, monitory functions, personals and people.

Therefore, proper maintenance planning of CNG dispensing station is essential. For this, proper knowledge of system behaviour is required for effective maintenance planning. The present study exemplifies reliability analysis of CNG dispensing unit in National Capital region of India. The paper is structured as Literature Review, that discusses various research methods used for reliability analysis; Research Methodology, that proposes the flowchart of the research work; Illustrative Case Study, that discusses application of approach to case study, Result and Discussion, that discusses the analysis of the case study and Conclusion, that gives overall view and managerial implication of study.

9.2 Literature Review

Reliability is defined as the probability of performance of system for required function, for a time period when used under stated operating condition. Reliability, availability and maintenance engineering are the important concepts for the real industrial systems and to deal with their performance. In the industrial system, it is required to consider uncertainty and unreliability as the major criteria for maintenance planning. The unavailability of a system can be reduced or minimized by eliminating the various type of uncertainties associated with the operating system. This can be done by integrating fuzzy methodology with reliability analysis of system. The next sections discus about the tools used for reliability analysis and application of fuzzy methodology.

The reliability tools of FTA and PN use it and the latter being considered better tool, as cut sets and paths sets can be easily calculated. Most of the methods used for reliability analysis use probabilistic models that require huge information. Fuzzy methodology is capable of handling such imprecise and vague data in logical manner.

9.3 Reliability Tools

The reliability analysis is a powerful tool for the risk analysis, availability studies and design of systems. A number of tools are used for description of subcomponent, their relationship and configuration with the system, e.g. Reliability Block Diagrams (RBD), Failure Mode and Effect Analysis (FMEA), Fault Tree Analysis (FTA) and Petri Nets (PN) [1, 7, 8, 10, 18, 22]. The series–parallel combinations of various subcomponents in a complex industrial system are represented by using OR/AND symbols. This section discusses various tools used for reliability analysis. The discussion is restricted to the use of FTA, RBD and FMEA.

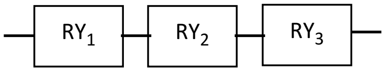


Fig. 9.1 Series combination RBD

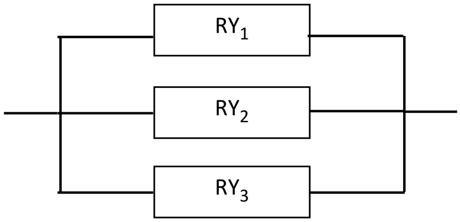


Fig. 9.2 Parallel combination RBD

9.3.1 Reliability Block Diagram

Reliability block diagram is a method for calculation of system reliability and availability for complex and large system. It is the visual illustration of the components or subcomponents and its reliability. To draw RBD for any system, knowledge of functions, relations of each component is required. RBD technique uses series and parallel configuration of systems which are depicted as blocks. It uses blocks which are connected either in series or parallel to define the logical communication of failure in a system. A series connection implies that all components in the connection must be fully operational (Fig. 9.1). Whereas when the connection is parallel it implies that all the components in the connection may not be operational or in standby (Fig. 9.2). For series combination the reliability is calculated as shown below in Eq. 9.1.

$$RY_{Series} = RY_1 * RY_2 \ldots * RY_N \tag{9.1}$$

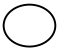
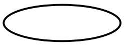
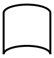
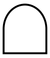
For parallel combination the reliability is calculated as shown below in Eq. 9.2.

$$RY_{Parallel} = 1 - \{(1 - R_1) * (1 - R_2) * \ldots * (1 - R_N)\} \tag{9.2}$$

9.3.2 Fault Tree Analysis and Petri Nets

Fault Tree Analysis (FTA) is a logical diagram in which the probability for the final event is evaluated with the noted probability of failure in the components of the system. It is widely used in aviation industry, chemical industry, manufacturing plants, nuclear sciences, neurosciences, banking, etc. It was developed in 1960 for the reliability assessment in aerospace industry. It clearly elucidates through graphics the interrelationship of failure among the different components/parts/fault that helps in analysing the specific fault step by step. FTA uses simple illustrations which makes it easier and simple in understanding. This analysis enables the interpreter to be able to understand the flow in which the system works and to identify the system links

Table 9.1 Fault tree symbols and description

S. No	Description	Symbol
1	Top Event: The complete breakdown of a system due to a fault in part/sub-component. It is illustrated by a rectangle	
2	Basic Event: This is the lowest level of an event where the failure is recorded and causing the system to fail. This level depicts the point of maximum resolution. It is illustrated by a circle	
3	Intermediate Event: This event whose failure is the effect of a failure in the lowest level of the system causing the top event to fail. It is illustrated by an oval	
4	AND Gate: This shows the relationship between components/parts that may lead to failure. It is illustrated by the above symbol	
5	OR Gate: This shows a standby relationship between the components/parts that may lead to failure. It is illustrated by the above symbol	

prone to failure and to take appropriate maintenance steps. Fault Tree Analysis (FTA) differs from cause and effect diagram as it does not illustrate all the possible causes for the breakdown in the system or its effect. It is a tailor-made illustration which depicts the top failure event and the events which lead to the failure of the top event. This analysis considers only the realistic fault. FTA is not a quantitative model but a qualitative model which can be assessed quantitatively. The fault tree symbols and description has been shown in Table 9.1.

This technique has been used extensively by the research community in reliability analysis in diverse fields, e.g., tunnel boring machine, process industry (petrochemical), healthcare, power delivery system, solar array fault, water treatment plant [3, 6, 14, 16, 25, 27].

9.3.3 FMEA

This technique was proposed by US Military for assessment of weapon system reliability in the year 1949. Further this technique was used by NASA for risk assessment of space program (Apollo Mission) in the year 1960. This technique is extensively used for risk analysis in aviation, automotive, manufacturing, medical, power plants (nuclear, thermal, hydraulics, wind energy, solar energy, etc.), paper plant and food process industries respectively. It is a systematic and knowledge-based approach [2], which is used to assess possible causes of failure, its frequency, severity on system and detection probability (for systems and sub-systems), so that effective and timely maintenance planning leads to avoidance of failure and improve availability of system. The product of these variables is called risk priority number (RPN), used for risk analysis and prioritization. Though, to remove uncertainty and vague judgement, fuzzy methodology has been used by many researchers in different area of application [5, 17, 28].

9.3.4 Fuzzy Methodology

Most of the methods used for reliability analysis use probabilistic models that require huge information. Fuzzy methodology is capable of handling such imprecise and vague data in logical manner [23]. Fuzzy methodology finds its application in safety and risk analysis [15], human reliability [12], software reliability [26] and in many more areas. This section discusses various techniques of incorporating fuzzy methodology in reliability analysis.

9.3.5 Fuzzification

Fuzzification is the process of converting crisp scores into fuzzy number. Due to technological advancements, systems are becoming compact and complex. The reliability analysis for complex system requires large amount of data. The probabilities of occurrence of failure are rare, thus the data for analysis suffers from uncertainty and vagueness. Fuzzy methodology is used to remove this limitation from analysis. FTA, Petri nets and RBD are used for modelling of system and fuzzy methodology is used to remove uncertainty. Knezevic and Odoom [9] developed an integrated framework of PN and LT (lambda-tau) approach for assessing reliability parameter at different sets for reliability analysis of real-world operating system. The alpha-cut approach was used to define interval of confidence. The reliability data was reported on a confidence interval basis together with crisp value. This approach was further used by researchers for reliability analysis of complex behaviour of non-redundant robot [13], pulping system [21], press unit in paper mill [11], paper mill [4], butter oil processing plant [20], water treatment plant in coal fired thermal power plant [19]. The Lambda-Tau approach is used to analyse complex systems through fault tree and reliability body diagram. This methodology requires the identification of basic events, which should not be repeated events and lead to the common top event. In many cases Boolean substitution reduction techniques are used for analysis. By using the AND and OR Gates (Table 9.2) relation between events of the fault tree, a

Table 9.2 AND-OR gate relationship

Gate	λ_{AND}	τ_{AND}	λ_{OR}	τ_{OR}
Conventional expression (*n-Inputs*)	$\prod_{i}^{n} \lambda_i [\sum_{j=1}^{n} \prod_{i=1, i \neq j}^{n} \tau_i]$	$\frac{\prod_{j=1}^{n} \tau_i}{\sum_{i=1}^{n} [\prod_{j=1, i \neq j}^{n} \tau_j]}$	$\sum_{i=1}^{n} \lambda_i$	$\frac{\sum_{i=1}^{n} \lambda_i \tau_i}{\sum_{i=1}^{n} \lambda_i}$
Equation number	(3)	(4)	(5)	(6)

Table 9.3 Fault tree symbols and description

Parameters	Equation	Equation number
Mean time to repair	$MTTR_s = \frac{1}{\beta_s} = \tau_s$	(7)
Mean time to failure	$MTTF_s = \frac{1}{\lambda_s}$	(8)
Mean time between failure	$MTBF_s = MTTF_s + MTTR_s$	(9)
Availability	$A_s(t) = \frac{\beta_s}{\lambda_s+\beta_s} + \frac{\lambda_s}{\lambda_s+\beta_s} e^{-(\lambda_s+\beta_s)t}$	(10)
Unavailability	$Q_S(t) = \frac{\lambda_S}{\lambda_S+\beta_S}\left[1 - e^{-(\lambda_S+\beta_S)t}\right]$	(11)
Reliability	$R_s(t) = e^{-\lambda_s t}$	(12)
Expected number of failures	$W_s(0, t) = \frac{\alpha_s \beta_s}{\alpha_s+\beta_s} t + \frac{\alpha_s^2}{(\alpha_s+\beta_s)^2}\left[1 - e^{-(\alpha_s+\beta_s)t}\right]$	(13)
Maintainability	$M_S(t) = 1 - e^{\left(\frac{-t}{MTTR}\right)}$	(14)

relationship for repair and failure rates for system is derived. The relations are shown in from Eqs. 9.3–9.14 and Tables 9.2 and 9.3.

where τ_s = repair time and λ_s = failure rate

The extension principle developed by Zadeh [30] and later modified by Yager [29] is used to extend mathematical laws of crisp numbers to fuzzy number. Every fuzzy set is associated with crisp set also called α- cuts. The α- cuts consists of element of a fuzzy set at least to the degree of α. Figure 9.3 shows the fuzzy triangular number with $\check{Y}$ with α- cuts.

The α cut of a fuzzy set $\check{Y} = (y_1 y_2 y_3)$ is denoted by Y^α (Eq. 9.15), such that:

$$Y^\alpha = \left\{x \in X | \mu_{\check{Y}}(x) \geq \alpha\right\} \tag{9.15}$$

The interval of confidence as defined by α- cuts is shown by Eq. 9.16

$$Y^\alpha = [\{(y_2 - y_1)(\alpha) + y_1\}, \{-(y_3 - y_2)(\alpha) + y_3\}] \tag{9.16}$$

where α ranges from $1 \geq x \geq 0$.

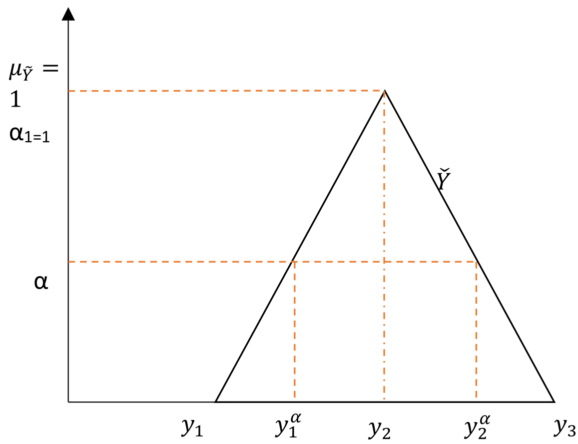


Fig. 9.3 Fuzzy triangular number $\check{Y}$ with α- cuts

Similarly, α- cuts can be defined for vague set. A vague set can be defined as (Eq. 9.17)

$$\tilde{P} = \left\{x, \mu_{\tilde{P}}(x), 1 - v_{\tilde{P}}(x) | x \in X\right\} \tag{9.17}$$

For universal set X represented by $\mu_{\tilde{P}}(x)$ and $1 - v_{\tilde{P}}(x)$ describing truth and false membership for $\mu_{\tilde{P}}, \mu_{\tilde{P}}|X \rightarrow [01]$ and $v_{\tilde{P}}, v_{\tilde{P}}|X \rightarrow [01]$ respectively, subjecting to condition (Eq. 9.18) the values of term $\mu_{\tilde{P}}(x)$ and $v_{\tilde{P}}(x)$ represents the degree of truth and false membership of x satisfying the condition,

$$\mu_{\tilde{P}} + v_{\tilde{P}} \leq 1 \forall x \in X \tag{9.18}$$

The degree of hesitation is given by Eq. 9.19

$$1 - \mu_{\tilde{P}} - v_{\tilde{P}} \tag{9.19}$$

for $x \in X$.

A vague set $\tilde{P} = [(y_1, y_2, y_3)\mu, v]$, can be defined as triangular vague set (Fig. 9.4) (Eqs. 9.20 and 9.21)

$$\mu_{\tilde{P}}(x) = \left\{ \begin{array}{c} \mu\left(\frac{x - y_1}{y_2 - y_1}\right), y_1 \leq x \leq y_2 \\ \mu, x = y_2 \\ \mu\left(\frac{y_3 - x}{y_3 - y_2}\right), y_2 \leq x \leq y_3 \\ 0, \text{otherwise} \end{array} \right\} \tag{9.20}$$

and

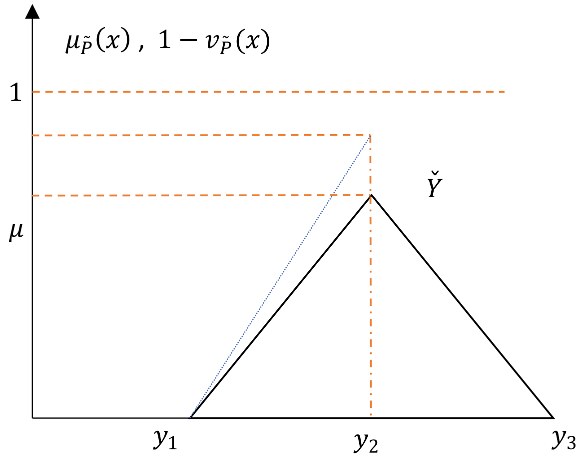


Fig. 9.4 Fuzzy triangular vague set

$$1 - v_{\tilde{P}}(x) = \left\{ \begin{array}{c} v\left(\frac{x-y_1}{y_2-y_1}\right), y_1 \leq x \leq y_2 \\ \mu, x = y_2 \\ v\left(\frac{y_3-x}{y_3-y_2}\right), y_2 \leq x \leq y_3 \\ 0, \text{otherwise} \end{array} \right\} \tag{9.21}$$

The interval of confidence as defined by α- cuts for triangular vague set is shown by Eqs. 9.22 and 9.23.

$$P_{\mu}^{\alpha} = [\{(p_2 - p_1)(\alpha/\mu) + p_1\}, \{-(p_3 - p_2)(\alpha/\mu) + p_3\}] \tag{9.22}$$

where $\alpha \in [0\mu]$

$$P_{v}^{\alpha} = [\{(p_2 - p_1)(\alpha/v) + p_1\}, \{-(p_3 - p_2)(\alpha/v) + p_3\}] \tag{9.23}$$

where $\alpha \in [0v]$.

The assumption is reliability analysis using Lambda-Tau approach has been given by Garg [4]. The defuzzification is done using centroid method, as its computation is simple and easy to understand [24].

$$\tilde{X} = \frac{\int_{x_1}^{x_2} x\mu_{\check{T}}(x)dx}{\int_{x_2}^{x_2} \mu_{\check{T}}(x)dx} \tag{9.24}$$

9.4 Research Methodology

The proposed methodology is shown in Fig. 9.5.

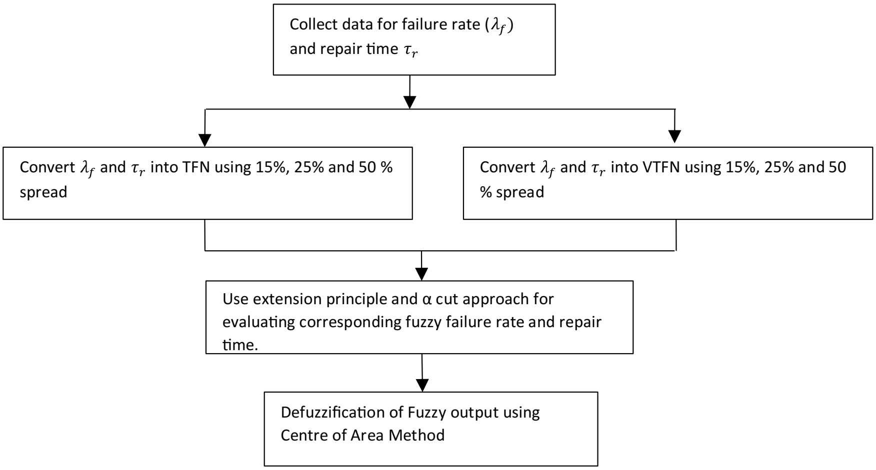


Fig. 9.5 Research methodology

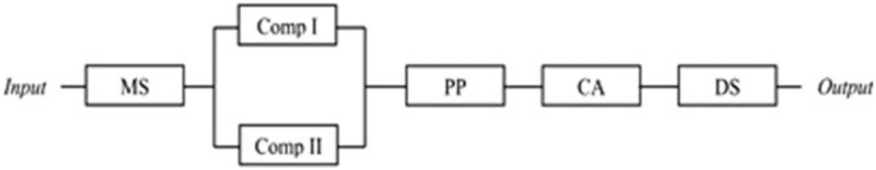


Fig. 9.6 RBD of CNG dispensing unit

9.4.1 Illustrative Case Study

This study was carried out at CNG dispensing station in, Delhi NCR (India), which has 264 outlets with 893 dispensing unit. The CNG station has been divided into different sub-systems. These are as follows: (i) Metering Skid (ii) Compressor (iii) Priority Panel (iv) Cascade (v) Dispenser. For continuous supply of CNG gas, it is important that all sub-sub-systems of CNG station work for long durations without breakdown. It is only possible if components or machine have high quality and reliability. CNG station is an integration of complex mechanical systems. If any of the components or system in the CNG station fails due to failure of any of its sub-systems or sub-sub-system than it will lead to shut down of whole of the station. Therefore, it is very crucial for maintenance engineer to identify the risk level of each sub-sub-system, prioritize it and remove critical cause of failure. The RBD of CNG dispensing unit is shown in Fig. 9.6.
where MS = Metering Skid, Comp I and II: Compressor, PP: Priority Panel, CA: Cascade, DS: Dispenser Unit.

Using reliability block diagram and Eqs. 9.3–9.6

Table 9.4 15%, 25% and 50% spread for fuzzy triangular set

System table	LH FR	Failure rate	RH FR	LH RR	Repair rate	RH RR
15% spread	0.007305311	0.008594484	0.009883657	8.480822712	9.977438485	11.47405426
25% spread	0.006445863	0.008594484	0.010743105	7.483078864	9.977438485	12.47179811
50% spread	0.004297242	0.008594484	0.012891726	4.988719243	9.977438485	14.96615773

Table 9.5 15%, 25% and 50% spread for fuzzy vague set (truth membership)

System table	LH FR	Failure rate	RH FR	LH RR	Repair rate	RH RR
15% spread	0.007305308	0.008594484	0.009883652	8.48082271	9.977438485	11.47405425775
25% spread	0.006445862946	0.008594484	0.01074310491	7.89880547	9.977438485	12.0560715027083
50% spread	0.005013448958	0.008594484	0.012175518898	5.820172450	9.977438485	14.134704520

Table 9.6 15%, 25% and 50% spread for fuzzy vague set (false membership)

System table	LH FR	Failure rate	RH FR	LH RR	Repair rate	RH RR
15% spread	0.007305308	0.008594484	0.009883652	8.48082271	9.977438485	11.47405425775
25% spread	0.006445862946	0.008594484	0.01074310491	7.79487382	9.977438485	12.16000315
50% spread	0.004834397	0.008594484	0.01235457	5.61230915	9.977438485	14.34256782

$$\lambda_S = \lambda_1 + \lambda_2\lambda_3(\tau_2 + \tau_3) + \lambda_4 + \lambda_5 + \lambda_6$$

where λ_S is failure rate of whole system and $\lambda_1, \ldots, \lambda_6$ are failure rates and τ_2, τ_3 are repair time of individual component.

$$\tau_S = \frac{\lambda_1\tau_1 + \lambda_2\lambda_3\tau_2\tau_3 + \lambda_4\tau_4 + \lambda_5\tau_5 + \lambda_6\tau_6}{\lambda_S}$$

where τ_S is repair time of system.

The equivalent failure rate (λ_e) and repair time (τ_e) respectively has been calculated using Eqs. 9.3–9.6.

$\lambda_e = 0.008594484$; $\tau_e = 9.977438485$.

This crisp score has been transformed into TFN using extension principle coupled with alpha-cut values $\alpha_i = 0, 0.1, 0.2\ldots1$ and $\mu, v = 0.6, 0.2$.

Using Eqs. 9.7–9.16 and 9.24 different reliability parameters are calculated and their corresponding defuzzied values for 15%, 25% and 50% spread of fuzzy triangular set are calculated. Similarly, for fuzzy vague set using Eqs. 9.7–9.16 and 9.17–9.21 various reliability parameters have been calculated for 15%, 25% and 50% spread respectively for mission time 100 h. The results are tabulated in Tables 9.4, 9.5 and 9.6 for fuzzy triangular set and fuzzy vague set (both for truth and false membership function). The variations of different reliability parameters are shown from Figs. 9.6, 9.7, 9.8 and 9.9.

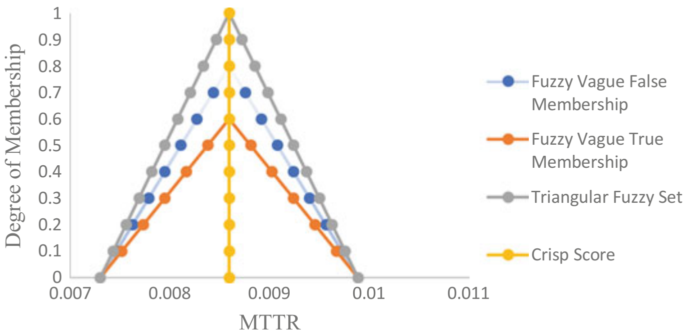


Fig. 9.7 MTTR variations for fuzzy vague and triangular set

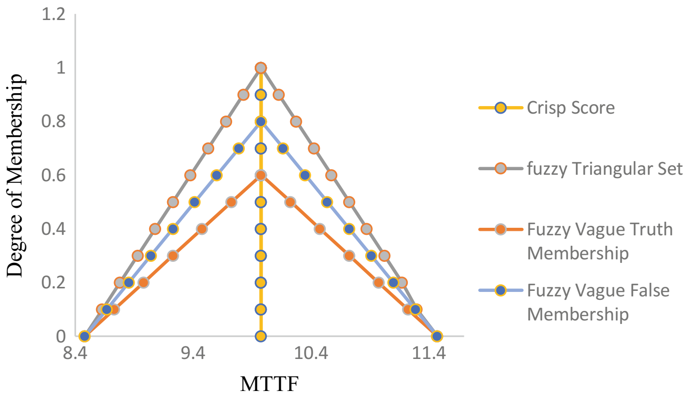


Fig. 9.8 MTTF variations for fuzzy vague and triangular set

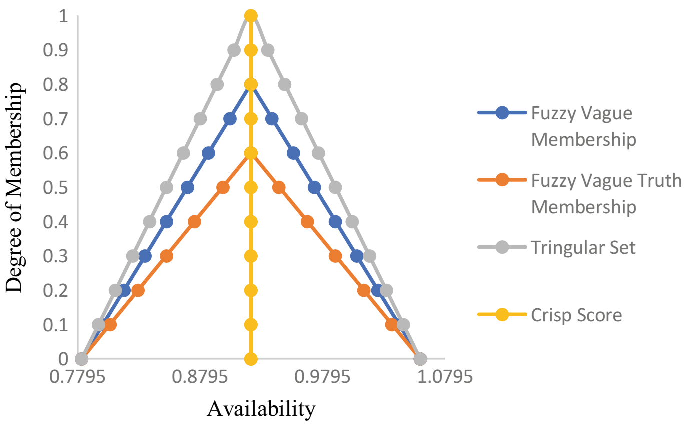


Fig. 9.9 Availability variations for fuzzy vague and triangular set

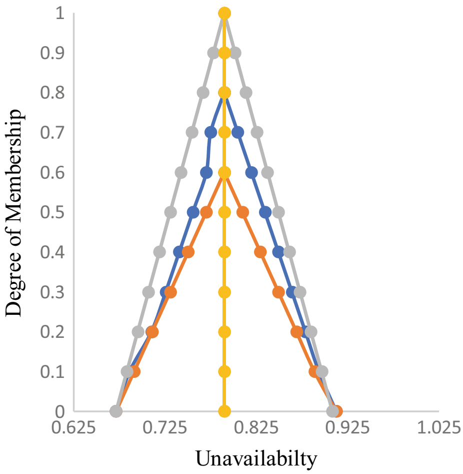


Fig. 9.10 Unavailability variations for fuzzy vague and triangular set

9.5 Result & Discussion

The interval of confidence for fuzzy vague set (truth and false membership function respectively) and triangular set are shown in reliability Tables 9.4, 9.5 and 9.6 respectively. Also, variations in reliability parameter are shown from Figs. 9.6, 9.7, 9.8 and 9.9. There are inferences to be drawn from this analysis.

(i) From Tables 9.4, 9.5 and 9.6, it obvious that reliability of CNG dispensing system lies in the range of [0.35988623, 0.4869049]. Therefore, the degree of acceptance, rejection and hesitation that reliability of CNG dispensing unit is 0.42339550, will be 1,0 and 0 respectively.

(ii) If degree of acceptance is ‘z’ for the statement that reliability of CNG dispensing unit lies in [0.35988623, 0.4869049] and is not equal to 0.42339550, then degree of rejection is 1- ‘z’ and degree of hesitation is 0.

(iii) Similar inference can be drawn from for other parameters.

(iv) The variations of different parameters using fuzzy triangular and vague set has been shown in Figs. 9.6, 9.7, 9.8 and 9.9. It is clear from all the figures that crisp values of the all parameters are constant w.r.t, all membership function values.

(v) For Fig. 9.10 the membership curves are parabolic in nature and not linear.

(vi) For fuzzy triangular set, the variations of parameters are shown for only degree of acceptance. There is no analysis using degree of hesitation in it.

(vii) From Tables 9.4, 9.5 and 9.6, it is clear that defuzzied values of reliability parameters are changing with the increase in spread, whereas the crisp values are constant in nature. The defuzzied values for MTTR, Availability, Maintainability, Unavailability, expected number of failure and Reliability first increase and then decrease as the spread changes. The defuzzied value of MTBF first decrease and then increase with change in spread. On other hand, defuzzied values of MTTF increase with change in spread. This also asserts that while planning for maintenance activities rather than using crisp values, defuzzied values of reliability parameters should be used. These defuzzied values give real insights of the behaviour of the system. For example, maintenance activities can be planned on the basis of defuzzied MTTF. The maintenance activity can be scheduled on or after defuzzied MTTF for respective spreads of ± 15 and 25% spread respectively or before crisp MTTF. The selection of spread will depend on system knowledge, operating conditions and available data.

9.6 Conclusion

This case study presents the use of Lambda-Tau approach for reliability analysis of CNG dispensing unit. The case presented may help system analyst and maintenance engineer to understand the system behaviour modelled using different parameters. The formation of fuzzy number from the crisp reliability data, use of extension principle coupled with alpha cuts will help in removing vagueness, imprecision in reliability studies. The use of vague theory can assist in better analysis of system behaviour and reliability analysis. The concepts of degree of acceptance, rejection and hesitation are viable in real-life situations where decision may be done using combination of acceptance and hesitation. The vague set theory also separates the degree of truth and false membership and level of confidence of experts lies in [0 1]. This further removes the grey area which may be left after analysis. The fuzzy reliability analysis has important managerial implication. The maintenance activities can be based on any of the defuzzied reliability parameter as system behaviour can be predicted. The ability to model highly complex real-world operating system, mitigation of uncertainty from analysis and availability of crisp, fuzzified and defuzzied reliability parameters are one of the many benefits of this approach.

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Chapter 10
Assessment of Health Risks Among Tractor Operators Due to Whole-Body Vibration

Kuljit Singh, Jagjit Singh Randhawa and Parveen Kalra

Abstract Exposure of human operator to whole-body vibration generated from tractors has been associated with low back pain (LBP) and degeneration of intervertebral disc. Researchers related the ischial tuberosities with the theory of evenly distributed pressure and found that pressure at the ischials decreased when the seat is more comfortable. This paper concentrates on the assessment of prevalence of MSDs and related ill effects among tractor operators and non-tractor operators during driving. The study was carried out on 80 active operators, out of which 40 (50%) were tractor operators and 40 (50%) were nontractor operators. All the participants were aged between 20 and 50 years old and taken from the region of Punjab, India. The results revealed that tractor operators reported more health-related problems (LBP, neck pain and shoulder pain, etc.) in comparison to non-tractor operators. Work-related musculoskeletal symptoms,i.e. LBP in 70% of operator, neck pain in 60% of operator and shoulder pain in 43% of operator were greatest among tractor operators. It can be concluded that tractor operators are more prone to MSDs occurred due to WBV. Thus, providing a cushion on the seat during operation may cause operation more comfortable and the operator may experience less prevalence of LBP, neck pain and shoulder pain. Further, this paper concentrates on the assessment of ride comfort and related ill effect among tractor operators, those who use cushion and not use cushion on the seat. The second phase of study was done on 40 tractor operators, out of which 25 (62.5%) tractor operators use cushion on tractor seat and 15 tractor operators (37.5%) did not use cushion on the seat. Most of the tractor operators stated that cushion on the seat is more supportive and also give them more comfort. The result also indicated that the tractor operators, who used cushion on the seat, reported less health-related problems (LBP, neck pain and shoulder pain, etc.). Work-related

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musculoskeletal symptoms were greatest, i.e. LBP (87%), neck pain (87%) and upper back pain (33%) among those tractor operators who did not use cushion on the seat during driving. It was found that cushions made of any fabric material are better than cushionless driving seat. Thus, it can be concluded that tractor operators who used cushion on the seat during driving were more comfortable and experience less prevalence of LBP, neck pain and upper back pain.

Nomenclature

WBV Whole-Body Vibration
LBP Low Back Pain
MSD Musculoskeletal Disorder

10.1 Introduction

Human operator of mobile machines or other vehicles, operating on rough and uneven surfaces, has been exposed to whole-body vibration (WBV), which are transmitted through seat or floor of the vehicle (www.hse.gov.uk). In medium- and large-scale manufacturing industries, for the flow of inventories from warehouses to production facilities, material handling equipment such as forklift play a major role. Similarly, agriculture machinery such as tractors and other equipment are used. This agriculture machinery generates a lot of vibrations because of improper structural and/or engine design of the vehicle and bad road/surface conditions. Hence, the operators of agricultural machinery are exposed to extreme vibration and are more prone to the occurence of MSDs.

The characteristics of vibration and duration of exposure are parameters, on which the response to a vibration exposure is primarily dependent. Many researchers have been attracted to this field and number of studies have been carried out in the past to evaluate the effects of whole-body vibration. These studies concluded that possible effects of whole-body vibrations can be divided into three categories: Interference with comfort, Interference with activities and Interference with health [5].

Further, vibration intensity frequency which can be low, medium or high, lead to increase or decrease in the human comfort level and health-related issues. Risks to health and safety of human operator are majorly dependent on the exposure to high levels of whole-body vibration and this exposure can cause or aggravate back injuries to operators of heavy machinery and tractors [2, 8, 13]. When the magnitude of vibration is high and the posture of operature is awkward, the situation results in excessive risk of injury and disorder [7].

Exposure of tractor operator to whole-body vibration generated from tractors has been associated with low back pain and degeneration of intervertebral disc [11, 12]. It is therefore essential to assess the effect of whole-body vibration on operator health. As per ISO 2641-1:1997 standard, three postures namely standing, sitting and recumbent can be used to study the effect of vibration on the human health.

10.2 Background and Review

Many researchers have been attracted to the field of whole-body vibration and carried out various researches in this field which affects human health. In various studies, to measure the level of exposure of human being to whole-body vibration, vibration under controlled and standardised conditions have been considered. These conditions have been used to assess the behaviour of the vehicle–seat–operator system. In most of the studies, an international standard (ISO 2631/1, 1985, 1997) or a national standard (BS6841, 1987) have been taken as basis. For the study on tractor, specific standards, both for laboratory measurements (ISO 5008, 1979) and for measurements on normalised track (ISO 5007, 1990) have been set up [6, 9, 10]. Boshuizen et al. [1] concluded that operators of mobile machinery, transportation vehicles, heavy vehicles, agriculture machinery and helicopters are predominantly exposed to high levels of whole-body vibration, which are unsafe to the human operator. Futatsuka [4] compared health risks occurred due to exposure to whole-body vibration, among farmers operating agriculture machines in the farms with farmers who are non-operator, using questionnaire. Koley et al. [8] investigated the effects of WBV on male tractor operators using Oswestry pain questionnaire and assess the severity of low back pain. Cvetanovic and Zlatkovic [3] investigated the level to which the human operator is exposed to whole-body vibration and found that tractor operators are exposed to high level of vibration, which leads to health-related problems. For the measurement of the risk assessment of whole-body vibration, various national and international standards have been drafted. Certain frequencies of vibration have negative effects upon different parts of the body and vibration influence the human body in many different ways. Hence, it is important to assess the effects of wholebody vibration on human health and to mitigate the level of vibrations, generated from machinery/vehicles, certain methods must be developed.

10.3 Assessment of Health Risks Among Tractor Operators

10.3.1 Assessment Survey

The first phase of the study was done on 80 active operators, out of which 50% (40 participants) were non-tractor driver and 50% (40 participants) were tractor driver that may be exposed to whole-body vibration. All the participants were aged between 20 and 50 years old (M = 35.5, SD = 2.6) and all the operators were taken from Punjab region. The survey questionnaire was composed of structured questions on medical history such as ache, pain and discomfort which may have experienced by tractor or non-tractor operators in the last 12 months. Occupational history such as cushion used or not used on the tractor seat during driving was also assessed.

For medical and occupational history assessment, the Self Reporting Assessment Questionnaire was used, which consisted of 22 dichotomous (yes/no) questions, 15 of which addressed physical symptoms and 6 addressed the occupational history. Each positive answer is equivalent to one point.

In the second phase of the study, the assessment of ride comfort and related ill effect among tractor operators, those who use cushion and not use cushion on the seat was carried out. The study was done on 40 tractor operators. The same Self Reporting Assessment Questionnaire was used as mentioned above.

10.3.2 Survey Objective

The aim of this study was to assess and compare the health risks that may occur due to whole-body vibration among the non-tractor operators and tractor operators.

The main objective of the study was to design/develop a detailed questionnaire by the identification of critical factors contributing to whole-body vibration. Further, to study the importance of using a cushion in view of whole-body vibration

10.4 Results and Discussion

10.4.1 Prevalence of MSDs in Non-tractor Operator

The data collected through a questionnaire of non-tractor operators (Table 10.1 and Fig. 10.1) showed that 13 operators (33.0%) experienced LBP. 13 operators (33%) and 4 operators (10%) reported neck pain and shoulder pain, respectively, during the last 12 months. For these persons, more than five episodes of LBP were experienced, each typically lasting between a few minutes and 2 days. In the health surveillance study of non-tractor driver, there were questions asking during one-on-one interaction, whether low back and neck shoulder affect their normal activities and cause any job away day (i.e. absenteeism). No operator claimed that their normal activities are affected due to these and none missed a job day.

Table 10.1 Prevalence of pain, aching or discomfort in non-tractor operators

	Discomfort								
	Wrists/hands	Elbows	Shoulder	Neck	Upper back	Lower back	Hips/thighs	Knee	Ankle
Non-tractor operators (Nos.)	5	3	4	13	3	13	2	5	4
Non-tractor operators (%)	13	8	10	33	8	33	5	13	10

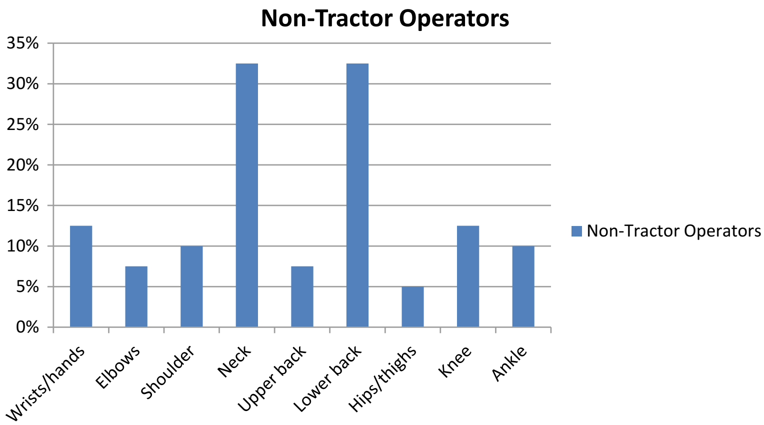

Fig. 10.1 Percentage prevalence of pain, aching or discomfort in non-tractor operators

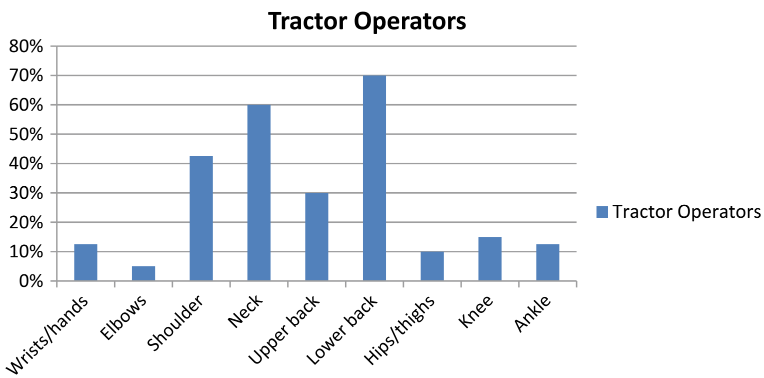

Fig. 10.2 Percentage prevalence of pain, aching or discomfort in tractor operators

10.4.2 Prevalence of MSDs in Tractor Operator

The data of tractor operators (Table 10.2 and Fig. 10.2) revealed that 28 operators (70.0%) out of 40 operators experienced LBP. 24 operators (60%) and 17 operators (43%) reported neck pain and shoulder pain, respectively, during the last 12 months. Most of them have experienced more than ten episodes of LBP, each typically lasting between a few minutes to 2 days. Furthermore, the questionnaire data indicated that back pain had little effect on their ability to work and on the ability to take part in recreational/social activities. Operators also claimed that when the severity of low back pain and neck pain is more, then the operators were consulted doctor for health examination and getting proper treatment.

Table 10.2 Prevalence of pain, aching or discomfort in tractor operators

	Discomfort								
	Wrists/hands	Elbows	Shoulder	Neck	Upper back	Lower back	Hips/thighs	Knee	Ankle
Tractor operators (Nos.)	5	2	17	24	12	28	4	6	5
Tractor operators (%)	13	5	43	60	30	70	10	15	13

10.4.3 Comparison for Prevalence of Pain, Aching or Discomfort in Non-tractor Operators and Tractor Operators

The results of the survey are shown in Table 10.3 and found that there is a difference in prevalence of pain, aching or discomfort among non-tractor operators and tractor operators. The prevalence of lower back pain is in 33% of non-tractor operator which is much lower as compared to 70% of tractor operator. Similarly, prevalence of neck pain is in 33% of non-tractor operator as compared to 60% of tractor operator. Hence, tractor operators are at higher risk of being disabled at a younger age than the reference group. In general, the prevalence of discomfort is higher among the tractor operators that leads health-related problems.

10.4.4 Statistical Analysis

The responses of pre-assessment questionnaire were analyzed using the Statistical Package for the Social Sciences (SPSS) software. Two independent sample tests was used to analyze the significant difference (if any) among the non-tractor operators and tractor operators with respect to the prevalence of pain, aching or discomfort on various parts of the human body. All results were considered significant at $p < 0.05$ level.

The Ranks Table 10.4 provides information regarding the output of the actual Mann–Whitney U test. It shows mean rank and sum of ranks for the two groups tested (i.e. non-tractor operators and tractor operators). Table 10.4 indicates tractor operator group can be considered as having the higher prevalence of pain or discomfort. The group with the highest mean rank had the highest prevalence of pain. The tractor operators were experienced more prevalence of pain or discomfort (mean rank = 47, mean rank = 46, mean rank = 45 and mean rank = 48) than non-tractor operators (mean rank = 34, mean rank = 35, mean rank = 36 and mean rank = 33) for shoulder, neck, upper back and lower back, respectively (Figs. 10.3 and 10.4).

Test statistics Table 10.5 shows the actual significance value of the test. Specifically, the Test statistics table provides the test statistic, U statistic, as well as the asymptotic significance (2-tailed) p-value. The result shows that there is a significant effect of operator groups with respect to prevalence of pain and discomfort. From this data, it can be concluded that prevalence of pain in shoulder (U = 540, p = 0.001), neck (U = 580, p = 0.014), upper back (U = 620, p = 0.010) and lower back (U = 500, p = 0.001) among the tractor operators was statistically significantly higher than the non-tractor operator group.

Table 10.3 Comparison for prevalence of pain, aching or discomfort among non-tractor operators and tractor operators

	Discomfort								
	Wrists/hands	Elbows	Shoulder	Neck	Upper back	Lower back	Hips/thighs	Knee	Ankle
Non-tractor operators (%)	13	8	10	33	8	33	5	13	10
Tractor operators (%)	13	5	43	60	30	70	10	15	13

Table 10.4 Ranks table (Mann–Whitney test)

	Operators	N	Mean rank	Sum of ranks
Wrist	1	40	40.50	1620.00
	2	40	40.50	1620.00
	Total	80		
Elbow	1	40	41.00	1640.00
	2	40	40.00	1600.00
	Total	80		
Shoulder	1	40	34.00	1360.00
	2	40	47.00	1880.00
	Total	80		
Neck	1	40	35.00	1400.00
	2	40	46.00	1840.00
	Total	80		
Upper back	1	40	36.00	1440.00
	2	40	45.00	1800.00
	Total	80		
Lower back	1	40	33.00	1320.00
	2	40	48.00	1920.00
	Total	80		
Hips	1	40	39.50	1580.00
	2	40	41.50	1660.00
	Total	80		
Knee	1	40	40.00	1600.00
	2	40	41.00	1640.00
	Total	80		
Ankle	1	40	40.00	1600.00
	2	40	41.00	1640.00
	Total	80		

10.4.5 Comparison for Prevalence of Pain, Aching or Discomfort Among Tractor Operators Who Used Cushion and not Used Cushion on Tractor Seat

From the survey, it was also observed that, out of 40 tractor operators, 25 (62.5%) operators used cushion material on the tractor seat, regularly or occasionally while driving.

The purpose is to decrease vibration intensity of driving seat, to increase comfort and to increase fatigue period of driver. Many tractor operators stated that cushion

Table 10.5 Test statistics table (Mann–Whitney test)

	Wrist	Elbow	Shoulder	Neck	Upper back	Lower back	Hips	Knee	Ankle
Mann–Whitney U	800.0	780.0	540.0	580.0	620.0	500.0	760.0	780.0	780.0
Wilcoxon W	1620.0	1600.0	1360.0	1400.0	1440.0	1320.0	1580.0	1600.0	1600.0
Z	0.000	−0.459	−3.283	−2.451	−2.562	−3.334	−0.844	−0.323	−0.352
Asymp. Sig. (two-tailed)	1.000	0.646	0.001	0.014	0.010	0.001	0.399	0.747	0.725

Grouping variable: operators

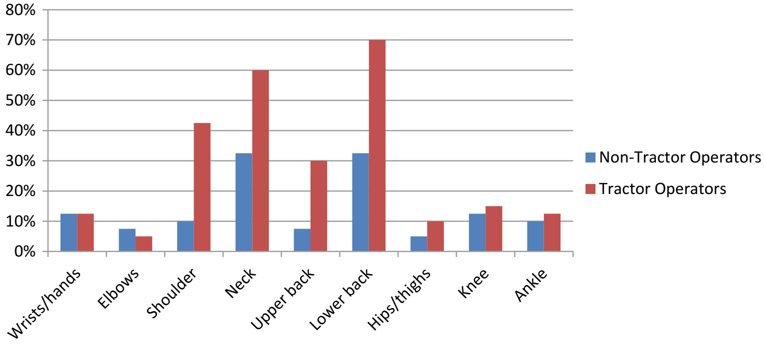

Fig. 10.3 Percentage prevalence of pain, aching or discomfort among non-tractor operators and tractor operators

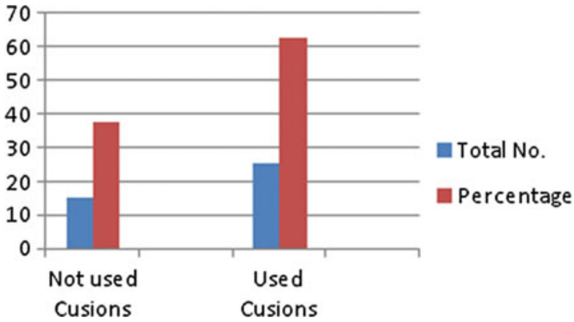

Fig. 10.4 Percentage of operators who used cushion and not used cushion

Table 10.6 Comparison of operators who used cushion and not used cushion on tractor seat

	Total no. of operators	
	Not used cushion on seat	Used cushion on seat
Total no.	15	25
Percentage	37.5	62.5

has more support and gave them more comfort than without cushion in terms of jolts and jerks (Table 10.6).

A comparison was done in order to compare the tractor operators, those used cushion and not used cushion. The results are shown in Fig. 10.5. It indicates that the cushioned seat is better than the without cushion seat. The result indicated that the tractor operators, who used cushion material below the seat, reported less health-related problems (back pain, neck pain and shoulder pain, etc.). Work-related musculoskeletal symptoms were greatest in the low back (87%), neck (87%), shoulders (40%) and upper back (33%) among the tractor operators (without cushions). On the other side, 60% of tractor operators (with cushion) reported back pain and 44%

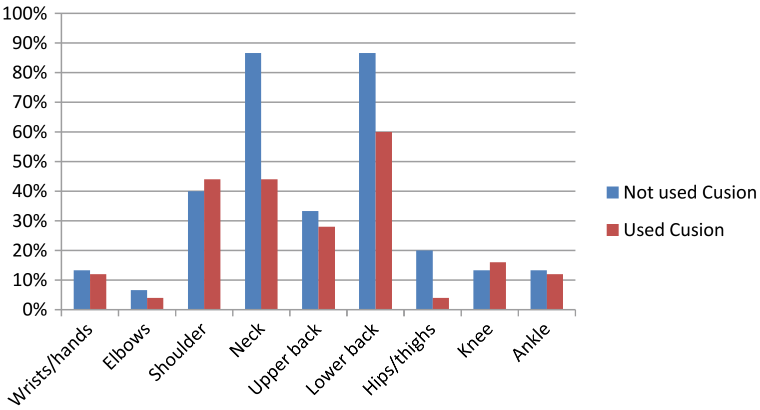

Fig. 10.5 Comparison in prevalence of pain, aching or discomfort among tractor operators who used cushion and not used cushion

operators reported neck pain. As shown in Tables 10.7 and Fig. 10.5, it can be concluded that tractor operators who use cushioning pads below the seat during driving were more comfortable and experienced less prevalence of lower back pain, neck pain and upper back pain.

Cushion may display more evenly distributed pressure. This means that cushions would better distribute the pressures between the cushion–driver interfaces. Of course, a more evenly distributed pressure contour at the seated person could result in more comfort and less fatigue, which results less in health-related problems. Although further assessment and testing is needed to quantify this benefit. It was seen, that any elastic, soft material used on the driving seat (Fig. 10.5) contributes to enhance the comfort level.

10.5 Conclusions

In summary, it is revealed that more musculoskeletal symptoms (specifically relating to the low back, neck and shoulder pain) were observed among the tractor operators than the non-tractor operators. WBV exposure equal to or greater than the ISO limit can adversely affect the health and well-being of the worker. Tractor operators may be exposed to whole-body vibration so it is important to carry out the research on exposure to whole-body vibration on tractor operators.

Table 10.7 Comparison in prevalence of pain, aching or discomfort among tractor operators who used cushion and not used cushion

Track operators	Discomfort								
	Wrists/hands	Elbows	Shoulder	Neck	Upper back	Lower back	Hips/thighs	Knee	Ankle
Not use cushion (%)	13	7	40	87	33	87	20	13	13
Use cushion (%)	12	4	44	44	28	60	4	16	12

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Chapter 11
Modelling, Simulation and Optimization of Product Flow in a Multi-products Manufacturing Unit: A Case Study

Janpriy Sharma and Arvind Jayant

Abstract Simulation is a vital tool for validation of methods and architectures in the complex manufacturing environment before there application on shop floor for the production process. Manufacturing simulation, digital engineering tools and procedures have a positive impact on the manufacturing industry. Simulation models have been extensively used in manufacturing to enhance the design, planning and productivity of the processes. In manufacturing environment, crucial material movement, is controlled by various dynamic factors. Situations becomes cumbersome for assembling plants which deal with multi-product, owing to the dominance and interconnectedness of dynamic factors. Analysing of these factors in real-life business environment is very complex in nature and required the use of modelling and simulation tools. This chapter glimpses modelling and simulation application, in a multi-product automobile gear manufacturing plant, aimed for development of an efficient production system that expresses ability for assurance of timely product deliveries at minimal cost. For three distinct type of gear production lines, simulation-based models were developed using Arena® Simulation Software. The proposed simulation model is capable enough to increase the resource's utilization rate and production rate of gear manufacturing process by identifying the bottlenecks in the manufacturing system. The models developed are capable enough to be synchronized with the company's other products and hence aids in highly precise production planning and scheduling exercises within the company.

Nomenclature

SCM	Supply Chain Management
SC	Supply Chain
WIP	Work in Process

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EOL End of Life
AGV Automated Guided Vehicle
ISO International Standard Organization
FIFO First-in, First-Out

11.1 Introduction

Dynamics associated with various manufacturing systems is under consistent consideration of researchers from several decades [1]. The process of familiarization with the manufacturing systems dynamics posseses a serious challenge, as it encloses exploration of the network of interacting manufacturing systems and its associated dynamics which makes it even more challenging. Numerous studies have documented manufacturing as a healthy source leading to competitive advantage, succeeding with the development of benchmarked manufacturing strategies, in thrust area of operations management. The traditional approach focused manufacturing strategies on the internal operations within manufacturing firms particularly concerned with the physical transformation of materials.

More recently, collaboration of the existing manufacturing systems with supply chain systems has shifted centre of focus on this new trend, working in the achievement of sustainability in a variety of manufacturing systems [2]. Supply chain (SC) which are discussed precisely within the scope of this article, referred it to a set of networked organizations working together in direction of source, reproduce and distribution of products and services at customer end [3].

SCM triggers by placing an order of raw materials and/or semi-finished parts at suppliers, which are further processed by manufacturing plant or product assembly line to the production of finished products [4]. Generated production levels are shipped to distributors, next to retailers, and finally to end users—the customers. Supply chain participants belong to different countries or regions, with markable differences in levels of technology and security. In fact, many supply chain management systems are possessed to be global in nature.

Simulation has broadened its applicability in areas of manufacturing, inventory management, supply chain, healthcare, transportation [5]. In the context of manufacturing systems simulation, the results are real estimate of original working conditions and can be achieved in a predictable manner [2].

In this study, the Gear Job shop manufacturing process at XYZ Limited plant is modelled and simulated. This study provides a verified and validated model to address the problem related to low productivity and ineffective resource utilization, to achieve this, first existing model of gear manufacturing unit was developed and simulated using Arena 15.1 simulation package. Second, based on the existing model results flaws in the existing system were verified. After the analysis of the existing model, the final model was proposed and tested. Certainty associated with results was defined statistically, using a confidence level of 95% and required number of simulation runs were calculated within this confidence level. At last, sensitivity analysis was undertaken to analyse key parameter resource utilization, WIP, fork truck utilization, product flow time effect.

11.2 Modelling and Simulation in Manufacturing Environment

Simulation models can glimpse the real-time phenomenon's because lesser bounding assumptions are required [6]. Therefore, simulation portraits dynamic nature of material flow by realistic replication within a factory rather than assurance of static analysis, which is hindrance in establishing a good system [7]. Simulation takes leading edge by not disturbing ongoing processes within factory premises, but it provides a tool that is flexible and less costly than experimentation and physical prototyping. Simulation-based experimentation finishes in minutes, which requires a long span of actual experimentation. Identification of problems along with well-defined objectives, logic associated with it and variables (Global and Local Variable) act as foundation, from where paradigm of modelling and simulation actually starts [8, 9].

The run length of simulation runs depends upon the purpose of the simulation. Mostly, a consensus about system are made on the basis of simulation run length of 1 month, 300 days, in lieu with conditions at ending point. Although, some modelling errors whether, mathematical, logical and operational are checked for the thorough length of simulation run [10].

Simulation represents only how the system under consideration is going to perform under set various random input conditions and its resulting outputs, it should not be considered as optimization technique [11].

Ruiz et al. [12] studied application of Simulation process in manufacturing field used SimShop as simulation tool which includes the tasks like sequenced as modelling phase followed by its simulation run phase and collection of key parameters. Simulation result validated that architecture of agent used for simulation are compatible with an intelligent manufacturing meta-model proposed and its working synchronizing with needs of new manufacturing environmental and empowering high level of flexibility for development of complex models and experiments.

Jayant et al. [13–16] studied reverse logistic network and sustainable supply chain systems of exhausted inverter batteries collection in North India, the aim was to model and simulate the reverse logistic network for collecting end-of-life products within XYZ industry. The tool used for modelling and simulation was Arena software (15.1) by Rockwell animation studio to find solution to problem areas identified and to improve reverse logistic operation.

Nyemba and Mbohwa [17] explored various dynamics impacting the material movement within manufacturing environment, complexity in assembling them, because of tangled interconnectedness levels between various factors. A case study of a timber processing and furniture manufacturing industry is presented, which has a batch production tool which is used for this problem for modelling and simulation was done by Arena software.

Awasthi and Chauhan [5] proposed a layout of manufacturing systems which have automated guiding systems with four machines, 2 AGV, single loading/unloading area and one parking station for AGV recharging facilities. For the given layout, simulation was performed for parts scheduling and routing by Arena Software. The result produced gave the best scheduling policy for parts sequencing, part dispatched by AGVs and part processing at machines.

Depending upon the results generated by simulation, attempt of additional runs on the experiments can be achieved by changing factors such as starting conditions, variables, parameters, decision rules and run length of simulation [18].

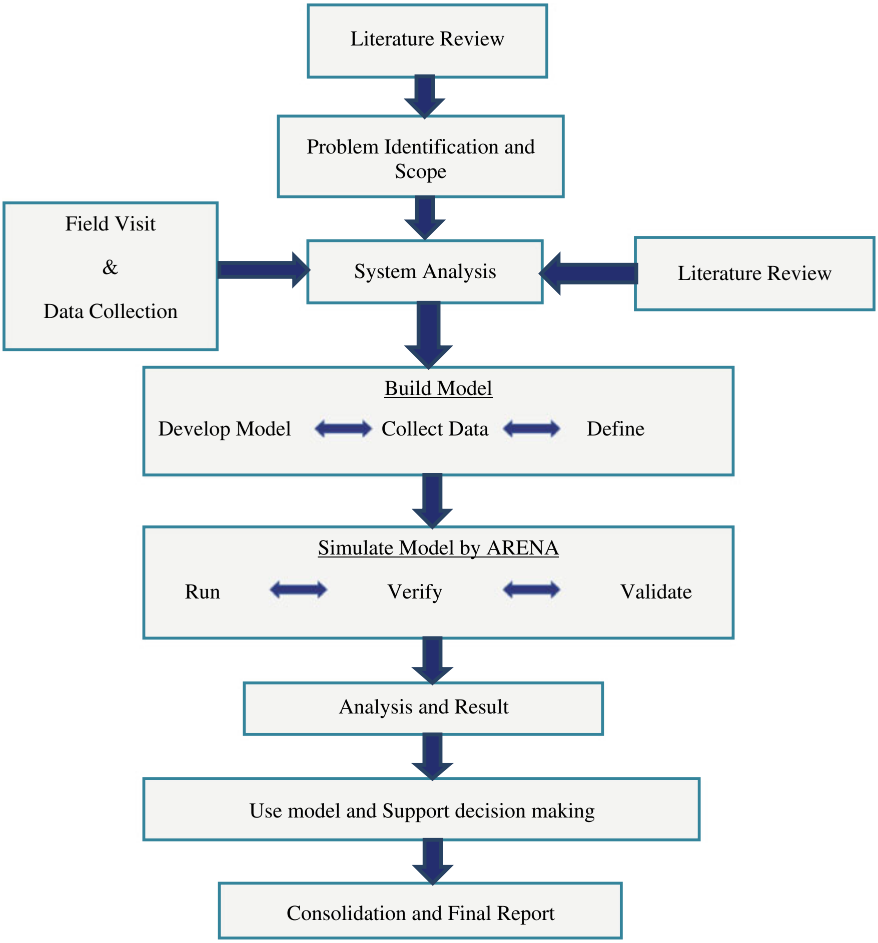
11.3 Outcome of Literature Review

- Modelling and simulation of gear job shop manufacturing have been accessed at limited level.
- Visualization and analysis of supply chain network of job shop production systems are required in more detail.
- Internal transport utilization has still not been explored fully in manufacturing systems.

11.4 Objectives of Research

- Study and analysis of pertaining issues of low productivity and ineffective resource utilization in the case of gear manufacturing industry.
- Existing gear manufacturing setup modelling and simulation by Arena 15.1 simulation package and its result analysis.
- To design and develop a new simulation model, keeping in view realistic and predictable constraints, proposed model and its simulation results are based on Arena 15.1 simulation package.
- Study and analysis of key parameters having relevance with strengthening of production supply chain network of the case company with enhanced productivity.
- Validation of results generated at confidence level of 95% acknowledging number of desired simulation run.

11.5 Methodology



11.6 Case Study of Gear Manufacturing Company

XYZ Pvt. Ltd. is the leading brand name of North India in automobile gear manufacturing established in October 2000, and the quality product has brought laurels and trust of many national and international automobile manufacturers. World-renowned brands of automotive sector such as "Caterpillar", "Cummins", "Hero Moto Cop", "Tata Motors" are their privileged customers. XYZ Pvt. Ltd. manufactures three types of gear Spur Gear, Helical Gear, Worm Gear. The company whose study is presented in this article is having International accreditation of ISO/Ts 16949, ISO 14000, having annual turnover of 325.9 million rupees with strength of 200 employees working

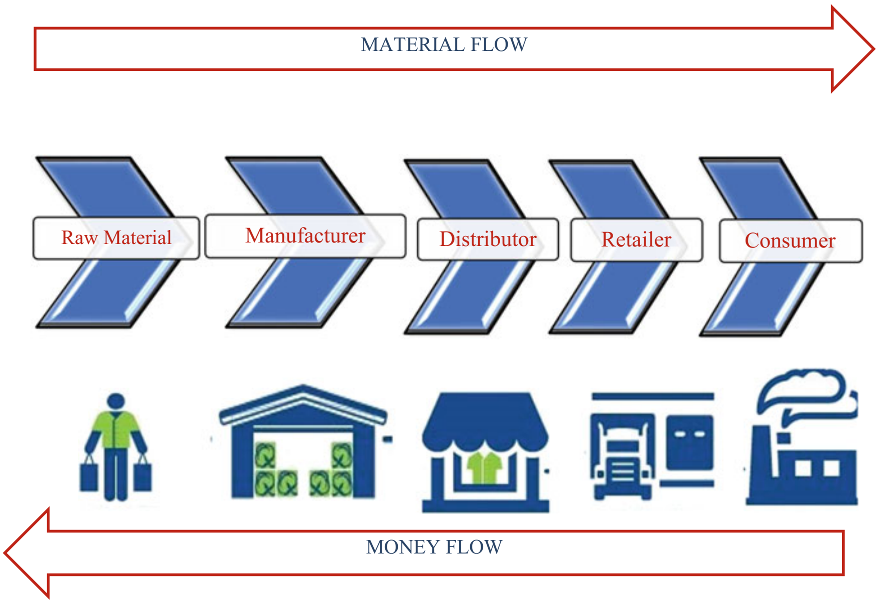


Fig. 11.1 Supply chain network

Fig. 11.2 Products manufactured at XYZ Pvt. Ltd.

in 3 daily shifts of 8 h each. This gear manufacturing firm is spread in total area of 8000 m^2 out of which still 3500 m^2 is covered area. High variation in demand at customer end and keeping in view agility of supply chain in this network, company is having general purpose machines like lathe, milling, drilling, polishing (shaving and honing) and dedicated paint shop. The company follows job shop production schedule in which each manufacturing cell is being handled by a trained technician (Figs. 11.1, 11.2 and 11.3).

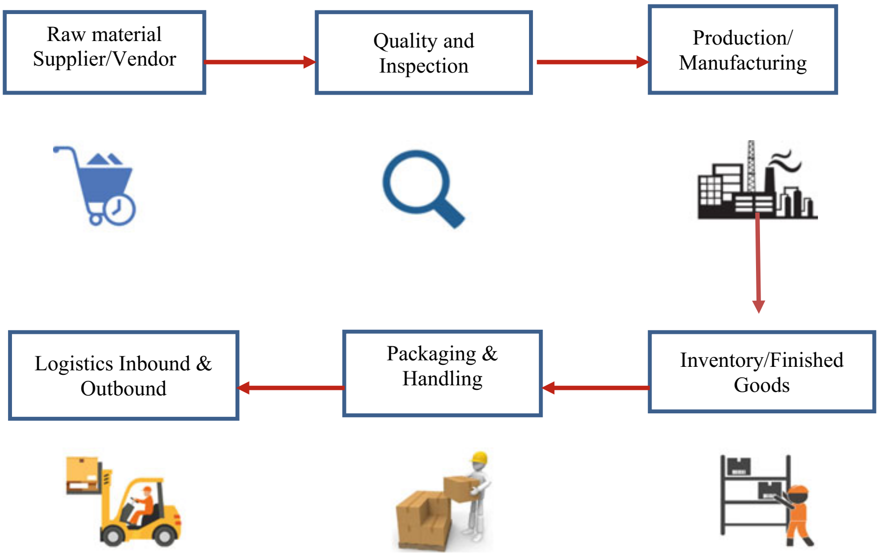


Fig. 11.3 Supply chain of XYZ Ltd.

11.6.1 Production Scenario at XYZ Ltd.

XYZ Pvt. Ltd. manufacturers automotive gears of three types namely Spur Gear (G1), Helical Gear (G2), Worm Gear (G3). Geographical layout of proposed company comprises of location as following:

- Arrival Dock
- Milling workstation with four milling machines
- Drilling workstation with three drilling machines
- Paint shop with single spray both
- Polishing workstation
- Shop exit

Generally, the firm produces 50% of gear G1, 30% of gear G2, 20% of gear G3. Processing of gears based upon type to be manufactured starts with the arrival of raw material at receiving station (Arrival Dock), where distinct operation specified for each gear type are done, after completion of operation finished product takes shop exit. Operation sequence of for the product under consideration is ordered as milling processing, drilling operation, painting, polishing of gears. Table 11.1 depicts the operation sequence for each gear type along with processing time at each stage of operation. Figure 11.4 glimpses geographical layout of XYZ Pvt. Ltd. also routing sequence for each product category. For transfer of product within inter workstation zone, two fork trucks are deployed running at speed of 100 feet/minute. On job completion at any workstation, the processed gear is placed within an output buffer, request for transportation is made by means of fork truck, and the gear waits until fork

Table 11.1 Operation plan gears (by type)

Type of gear	Sequence of operations	Time to process (minutes)
G1	Milling operations	35
	Drilling operations	20
	Painting operations	55
	Polishing operations	15
G2	Milling operations	25
	Painting operations	35
	Polishing operations	15
G3	Drilling operations	18
	Painting operations	35
	Polishing operations	15

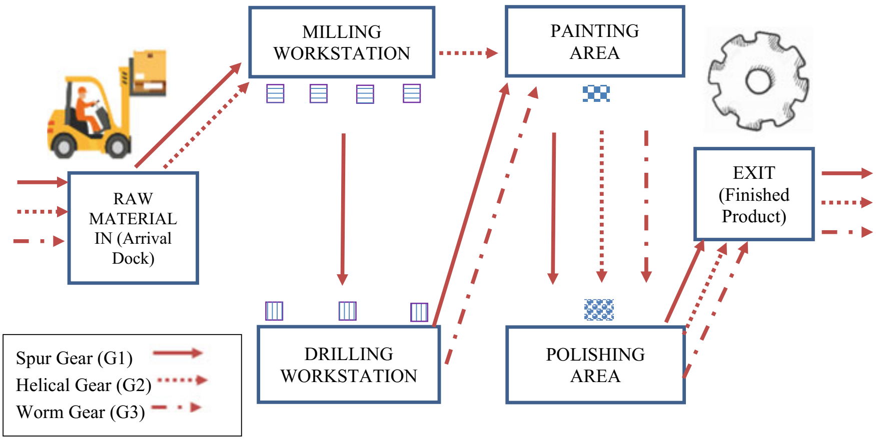


Fig. 11.4 Layout of job shop at XYZ Pvt. Ltd. and operation sequence by gear type

truck arrival. After transportation of gear to the next shop location, it is dropped in a FIFO input buffer. Finally, on completion of last process of polishing, the finished gear makes its way via shop exit and leaves for customer use.

11.7 Simulation Modelling of Gear Job Shop Manufacturing at XYZ Ltd.

Simulation package Arena belongs to Rockwell Automation Studio, which allows such versatile designing, used within this study. Section 11.7.1.2 shows the modelling steps as well as simulation model logics used in while the development of models by ARENA 15.1. Simulation begins by "Create Jobs" where gears to be manufactured

Table 11.2 Distances among job shop locations

From station location	Destination	Distance covered (in feet)
Arrival dock	Milling workstation	100
	Drilling workstation	100
Milling workstation	Drilling workstation	300
	Paint area	400
	Polishing area	150
Paint shop	Polishing area	300
	Arrival dock	250
Drilling workstation	Paint area	150
	Polishing area	400
Polishing area	Arrival dock	250
	Shop exit	200
Shop exit	Arrival dock	550
	Drilling workstation	500
	Milling workstation	300
	Paint area	400
	Polishing area	200

enter the manufacturing system in the given lot size and after that as per the company requirements, the job type (G1, G2, G3) is assigned. After that as per Table 11.1, the operation plan is executed for the time limits defined for each job type assigned earlier. To facilitate the necessary movement of in process/processed gears for distances as per Table 11.2, fork trucks are utilized and also being model in simulation envelope. At last counter tally, records for total number out, processing time and resource utilization and flow time for each type of job. Finally, the job makes "Shop Exit", making all engaged resources free and quits the system of simulation under consideration.

11.7.1 Simulation Model Development

System represents manufacturing of gears starting with raw material and ending as a finished product. Gear entities are recreated by '*Create*' module, depicted here as Create Jobs. Entities (Gears) per arrival indicates that jobs are approaching with a batch size of 5 in once, and between two consecutive arrivals follows uniform distribution between 100 and 108 min. Every distinct arrival of gear is referred to as distinct entity. After the arrival of raw material enters '*Assign*' module depicted "Assign Job Type & Sequence". By discrete distribution sampling type of gear in lieu with production policy is assigned and saves code corresponding to it (1, 2 or 3) by

'*Type*' attribute. Sequence to be followed for production of each gear type is defined by 'S*equence*' module from the '*Advanced Transfer*'. Three sequences (G1, G2, G3) are defined here, one for each gear. Sequence name and series of steps associated with it in order of processing are specified within the scope of '*Sequence*'. For follow up of steps, '*Steps*' dialogue spreadsheet is opened. Each step entry is specifying the station name and its associated value.

Location of job shops ismodelled as by '*Station*' Module. Accordingly, each gear to be produced succeeds towards '*Station*' module, to depict situation equivalent to physical arrival of entity, following this gear entities is proceeding towards job shop floor as per predefined operations categorization. To end ongoing gear entity flow, it passes through '*Request*' module from *Advanced Transfer Module.* '*Transporter*' summarizes demand for a *Fork Truck* transporter. Selection rule for transporter is nearest distance to arrival dock. As fast entity receives truck for pick up of product, it knocks '*Transport*' module, depicted as "*Shop Floor*", having all details of Entity starting and destination type. As for three types of different products, group of *Station* module called '*Set*' is used, each being part of modelling, in direction of milling to polishing. Architecture of all set is the same through modelling (except for names). Here detailed description how process occurs at milling group is shown, it is then addressed for '*Free*' *module*, depicted as "*Free Fork Truck at Mill*", transporter will wait at *Station* module until requested. Then product enters '*Process* module called 'Milling' where resources allocated for this process, i.e. Milling Machine follows *Seize Delay Release* rule and processing is done for the time specified in *Sequence* Module. To model four milling machines capacity of four is indicated in *Resource* module.

After concluding the milling operations, product entity gates towards *Request* module, depicted as "*Request Truck at Milling*", where entity request for transportation to next operation, may be chances persist of wait in queue here, referred as "*Request Truck at Milling*". *Queue.* With truck arrival, both gear and transporter enter the '*Transport*' module referred as "*Transport from Milling*". Lastly, transporting fork truck is unfettered by '*Free*' module, called "*Free Truck at Exit*", and the statistics for finished entity is done by '*Statistic*' modules for time persistent and flow time (tally statistic) and then way towards from at a *Dispose* module.

Randomness associated with various distinct simulation inputs enables simulation run to develop a statistical estimate of the performance measure, keeping measure aloof. So that, the developed estimates are statistically precise (small variance) and free from any type of biasness, the following parameters are specified.

- Replication length of each simulation run = 30 days (1 month).
- Count of independent simulation Runs = 60.
- Work hours for which simulation done = 8 h per day.

Key parameters under consideration having compliance with problem identified are

- Work in process
- Resources utilization

- Fork truck utilization
- Number seized by resources
- Product flow time
- Number In/Out.

11.7.1.1 Assumptions

1. Plant produces 50% of gear G1, 30% of gear G2, 20% of gear G3.
2. Gear entities inter arrival time follow uniform distribution (100, 108) minutes in the batch of 8.
3. For transportation of gear between two destinations, twofork trucks are deployed
4. On job completion at a location, output buffer is used for storage, request for transportation of product to fork truck is allowed and the gear waits for fork truck to arrive.
5. When gears are transported to next location, it is placed in first-in, first-out (FIFO) input buffer.
6. All processes follow a predefined routing and sequence of operations performed on gear being manufactured.

11.7.1.2 Modelling Logic

See Fig. 11.5.

11.7.1.3 Model Development and Simulation of Gear Job Shop Manufacturing by ARENA

Arena Simulation package by Rockwell Inc., enables its users to develop model and simulate it for various modular designs. This section shows the structure as well as modelling and simulation logic being used in this study. Simulation starts with "Create Jobs" where gears to be manufactured enter the manufacturing system in the given lot size and after that as per the company requirement the job type (G1, G2, G3) is assigned. After that as per Table 11.2, the operation plan is executed for the time limits defined for each job type assigned earlier. To facilitate the necessary movement of in process/processed gears for distances as per Table 11.2 fork trucks are utilized and being model in simulation envelope. At last counter tally, records for total number out, processing time and resource utilization and flow time for each type of job. Finally, the job makes "Shop Exit", making all engaged resources free and quits the system of simulation under consideration.

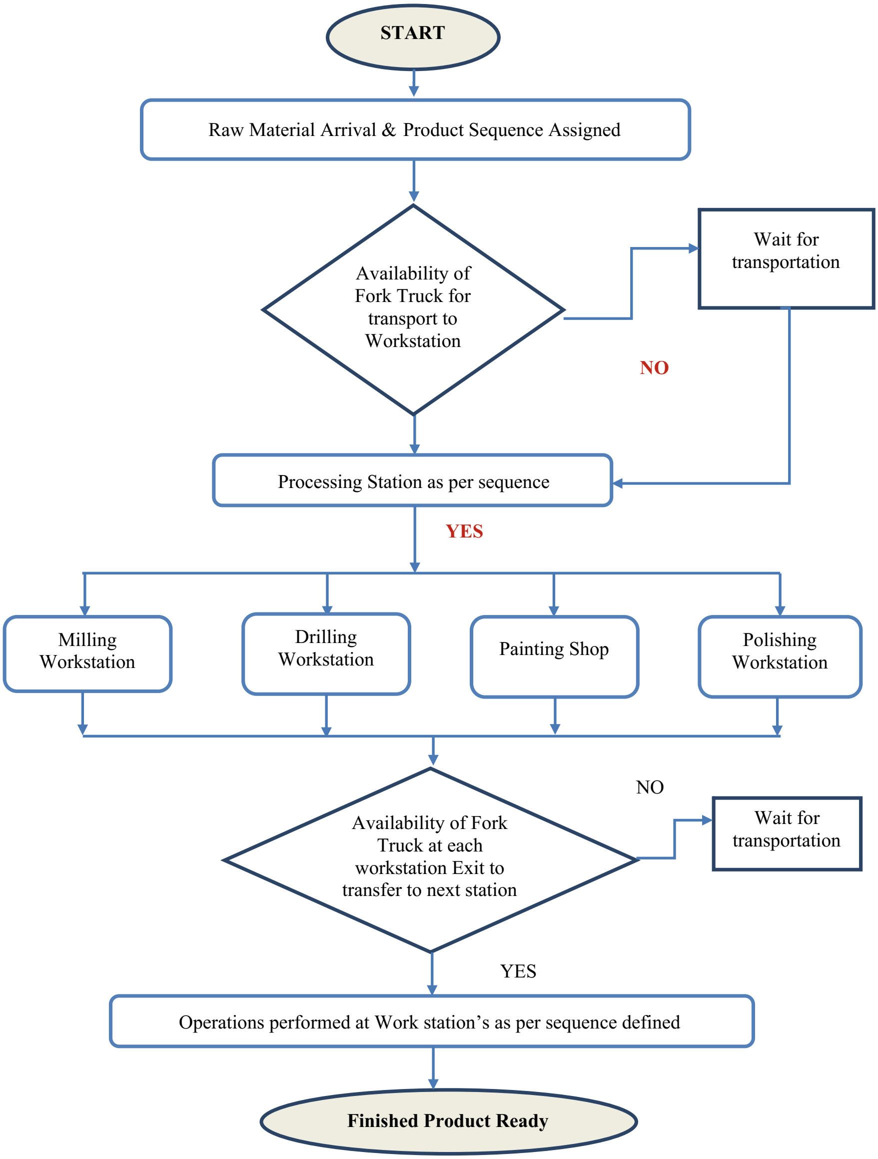


Fig. 11.5 Logic diagram

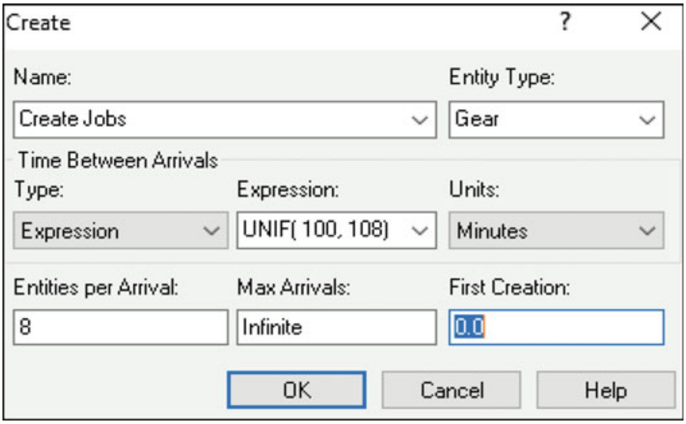


Fig. 11.6 Arena window portraying, *Create* module *Create Jobs*

Table 11.3 Distribution used in modelling

Name	Distribution	Expression
Job inter arrival time	Uniform	UNIF (100,108)

Table 11.4 Scheduled utilization of resources at gear manufacturing job shop

Resources	Scheduled resource utilization (average) for 60 replications		
	Existing model	Proposed model	Improvement (%)
Drilling machine	0.2012	0.2534	25.94
Milling machine	0.5903	0.7423	25.74
Polish gear	0.2492	0.3121	25.24
Spray both	0.3298	0.4850	47.05

Table 11.5 Time-persistent usage of types of gear manufactured

Flow time	Entity usage in hours for 60 replications		
	Existing model	Proposed model	Improvement (%)
Gear G1 flow time	2.7320	3.8533	41.04
Gear G2 flow time	2.3754	3.6996	55.74
Gear G3 flow time	2.1784	2.5861	18.72

Arrival of Gear Entity

Arrival of gear entities in form of raw material is undertaken by *Create* module, under *Create Jobs*, (In Reference to Fig. 11.6). The *entities per arrival* field designates the batch size of gear entity, i.e. 8 here and the time between arrivals shows that inter arrival time are uniformly distributed between 100 and 108 min. After arrival, each entity proceeds as single unit (Tables 11.3, 11.4, 11.5, 11.6, 11.7, 11.8 and 11.9).

Table 11.6 Number in and number out for gear manufacturing job shop

Number in/out	Number of gear in/out for 60 replications		
	Existing model	Proposed model	Improvement (%)
Number in	289	364	26
Number out	286	359	25.52

Table 11.7 Work in process of entities at gear job shop manufacturing

Entity	Work in process of entities for 60 replications		
	Existing model	Proposed model	Improvement (%)
Gear	3	5	66.67

Table 11.8 Fork truck utilization at gear job shop manufacturing

Fork truck utilization	Work in process of entities for 60 replications		
	Existing model	Proposed model	Improvement (%)
Fork truck	0.3381	0.4204	24.34

Table 11.9 Total number seized by resources for gear job shop manufacturing

Resources	Total number seized by resources (average) for 60 replications		
	Existing model	Proposed model	Improvement (%)
Drilling machine	603	759	25.87
Milling machine	1154	1451	25.73
Polish gear	287	359	25.08
Spray both	230	577	47.05

After making entry of entities, to execute some work on it, it ways towards *Assign* module called *Assign Job Type and Sequence*, (Fig. 11.7), using discrete distribution sampling type of gear to be produced is assigned by saving code (1, 2, or 3) in *Type* attribute and *ArrTime* attribute is assigned to govern simulation clock, *Tnow* manages and calculates flow time of each product. At last, the attribute *Entity. Sequence* is assigned *Type* attribute value. This attribute is necessary for follow-up of correct operation sequence by product type.

Operation sequence for threetypes of gear are defined well in *Sequence* module belonging to *Advanced Transfer* panel, (Refer Fig. 11.8). Three sequences are defined here for each gear type to be produced.

Each sequence comprises of sequence name and steps associated with it listed in the processing routing. In Fig. 11.8, five steps of gear G1 are shown and for each step, processing time is assigned.

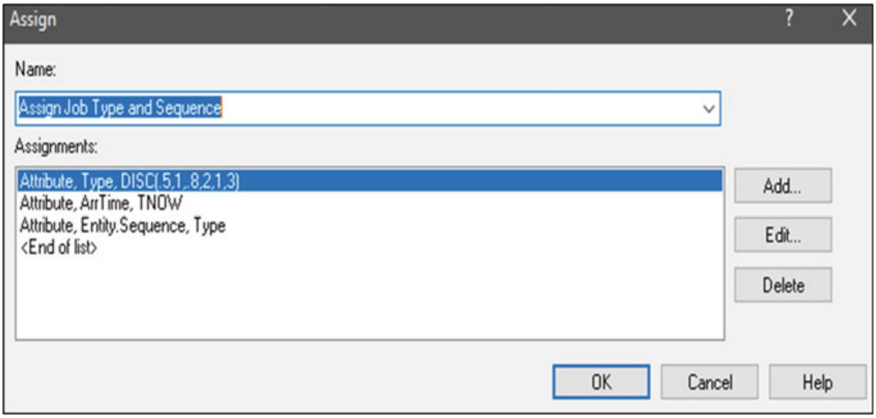


Fig. 11.7 ARENA window portraying *Assign* Module, *Assign Job Type and Sequence*

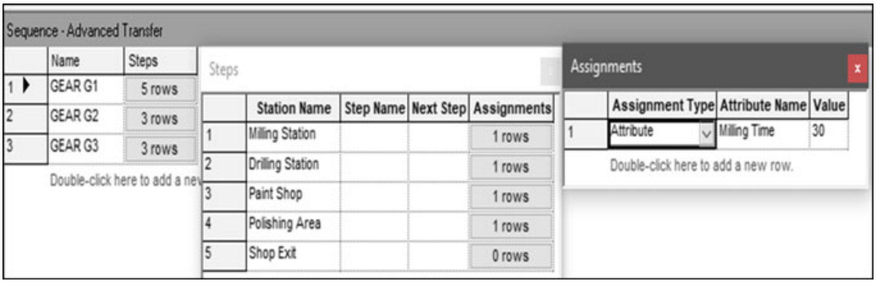


Fig. 11.8 ARENA window portraying *Sequence* module, *Assignments* for each type of gear

Transportation of Gear

Locations within job shop are modelled by *Station* module. Accordingly, every entity proceed to *Station* module, *Arrive_Dock,* to depict similarity with physical arrival at some station (Fig. 11.9). This point ways entities to job shop floor.

Entity flow towards *Request* module named *Request a Truck,* (Refer to Fig. 11.10), field indicating *Transporter Name* refers to request for *fork truck.* In *selection rule* field, selection is based upon request nearest to arrival dock. *Truck_ID* attribute stores information of transporters available, available for transportation purpose. This attribute will govern to free a particular truck for next pick up. As soon as entity seizes a truck, it gates to *Transport* module, *Transport to Shop floor* (Refer to Fig. 11.11). Gear/Transporter destination is mentioned by *Entity destination type* by *Sequence* option, representing that operation sequences are determined by sequence number of entity.

Fig. 11.9 ARENA window portraying *Station* module, *Arrive_Dock*

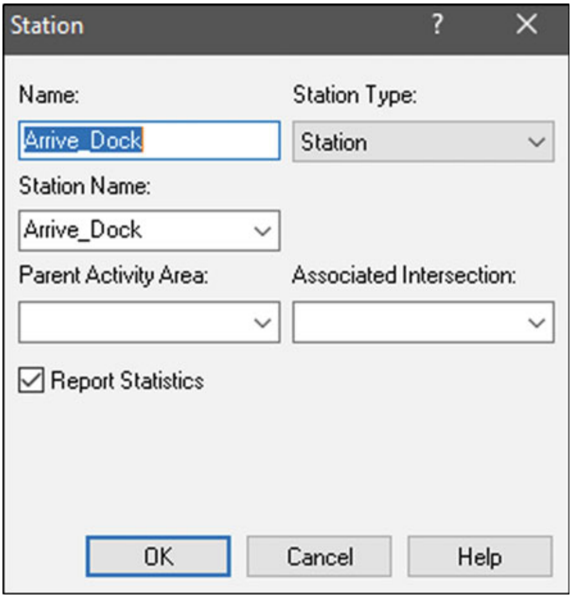
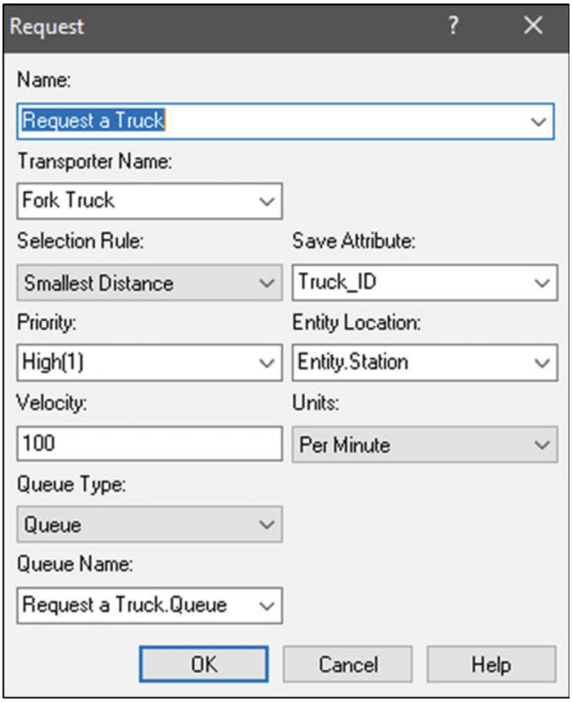


Fig. 11.10 ARENA window portraying *Request* module, *Request a truck*



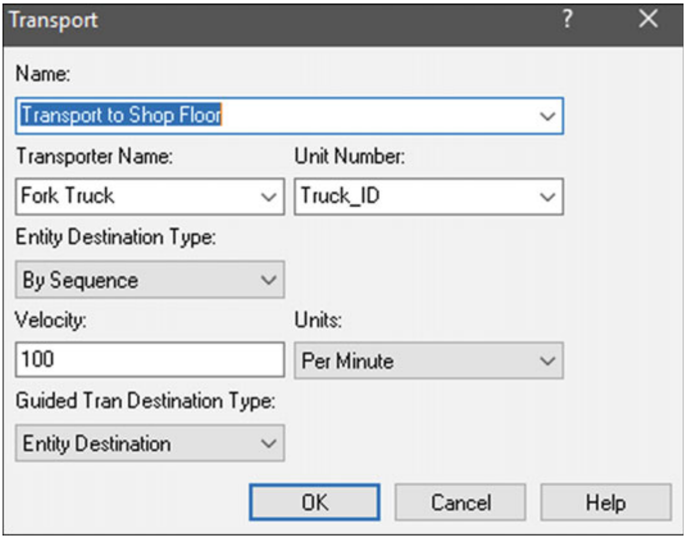


Fig. 11.11 ARENA window portraying *Transport* module, under *Transport to Shop floor*

Processing of Gears

When a gear as per defined routine enters for processing at milling station, it enters the *Station*, module called *Milling Station* (Fig. 11.12). After that it succeeds towards *Free* module, *Free Truck at Mill*, where *Transporter Name* and *Unit Number* fields indicate that truck after usage is to be freed for other entities pick up, using the *Truck_ID* attribute of the freeing gear entity (Fig. 11.13).

After vacating vehicle from load transporter stays at its last destination *Station* till a fresh need of pick up of entity is made, while the gear entity flow towards next module. Here gears make a move towards *Process* module, *Milling*. Milling machine is seized here for operation completion and its associated processing time are governed by attribute *Milling Time* specified in *Sequence* module (Refer to Fig. 11.14).

On accomplishment of milling operation, entity succeeds to *Request* module, *Request Truck at Milling,* here, request for transportation to other station is made, equally as first request from the *Arrival Dock* to job shop floor (Fig. 11.15).

As per predefined routing sequence entities proceeds. After completing all sequences of necessary operations entity moves to *Station* module*, Shop Exit* (Fig. 11.16) which ends each operation.

Next, the truck used in transportation is vacated in *Free* module, *Free Truck at Exit,* (Fig. 11.17) finished gear records statistics mentioned in earlier attributes and then it makes plant exit at a *Dispose* module.

Flow times of entities are tallied by *ArrTime* attribute of each finished gear entity as in *Record* module, called *Tally flow time* (Refer to Fig. 11.18). These tally times are matched by each of gear type, using the mechanism of tally set. *Tally set Name* field depicts those tallies which are to be entered in *Set Index* field (Refer to Fig. 11.19).

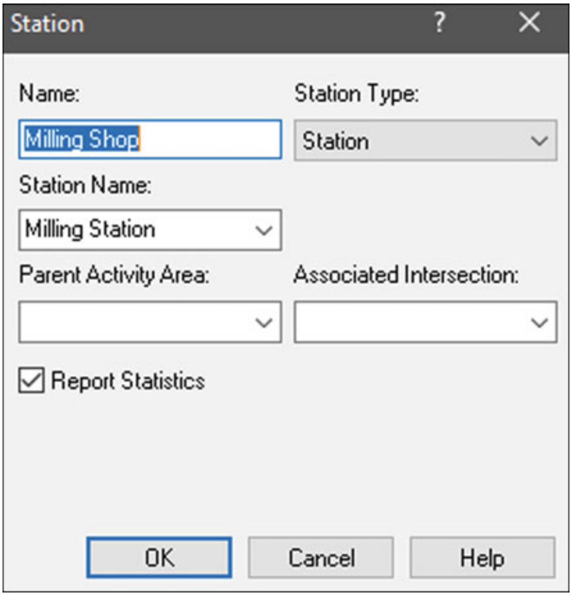


Fig. 11.12 ARENA window portraying *Station* Module, *Milling Shop*

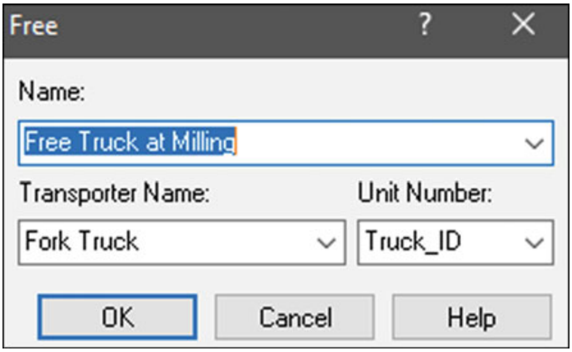


Fig. 11.13 ARENA window portraying *Free* module, *Free Truck at Milling*

The Flow times which is used here come under *Set* module of *Basic Process* template (Refer to Fig. 11.22).

A *distance set* field for specifying the name of a *Distance* module allowing the user to specify distances between pairs of *Station* modules, a *Velocity* and *Units* field that specify the transporter speed and *Initial Position* status is within *Transporter* module (Refer to Fig. 11.20).

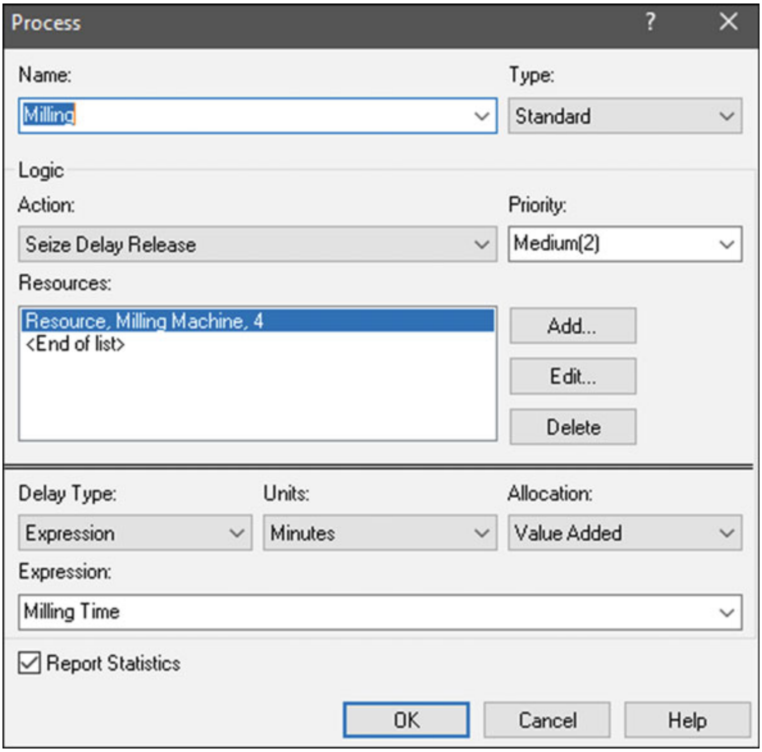


Fig. 11.14 ARENA window portraying *Process* module, *Milling*

Figure 11.21 Displays the dialog spreadsheet of the *Distance* module and the corresponding *Stations* dialog spreadsheet.

Finally, fork utilization is calculated (*a Time-Persistent Statics)* and statistics of flow time (*Tally Statics)* ae mentioned in *Statistic* spreadsheet, (Refer to Fig. 11.22). Variable *nt(transporter_name)*assigned for calculation of utilization based statistics *nt(Fork Truck).*

Overall Arena model composing of all operations performed at gear job shop manufacturing is shown in Fig. 11.23.

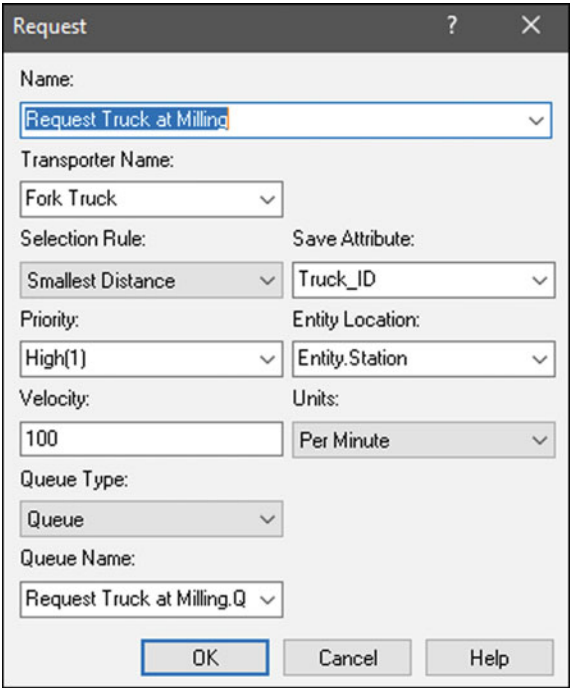


Fig. 11.15 ARENA window portraying Request module, *Request Truck at Milling*

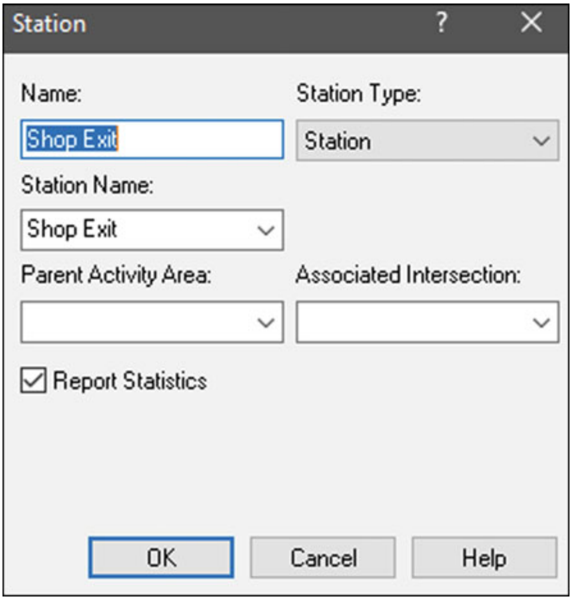


Fig. 11.16 ARENA window portraying *Station* module, *Shop Exit*

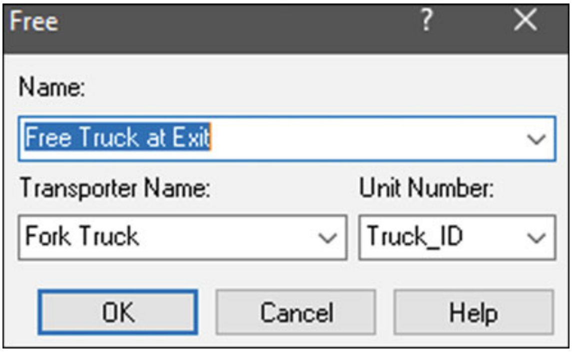


Fig. 11.17 ARENA window portraying *Free* module, *Free Truck at Exit*

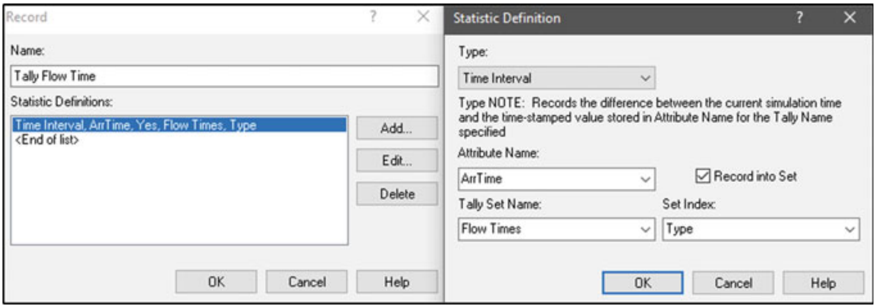


Fig. 11.18 ARENA window portraying *Record* module *Tally flow time*

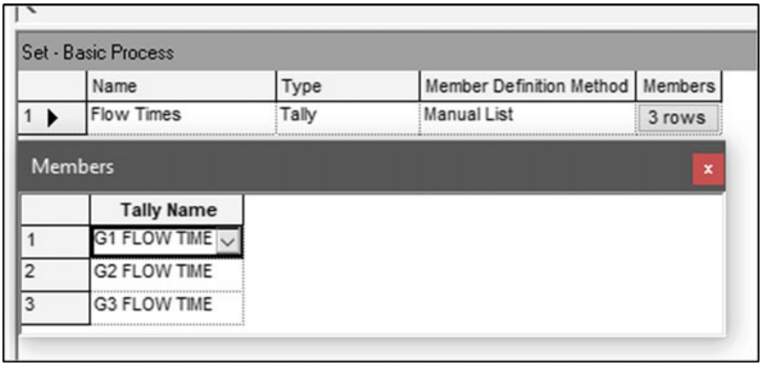
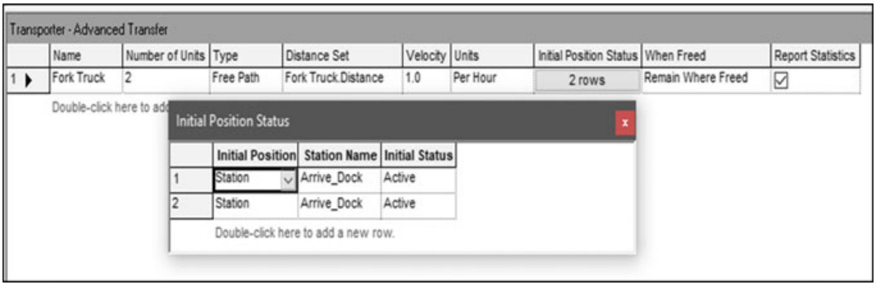


Fig. 11.19 ARENA window portraying *Set* module *Flow times*



Transporter - Advanced Transfer

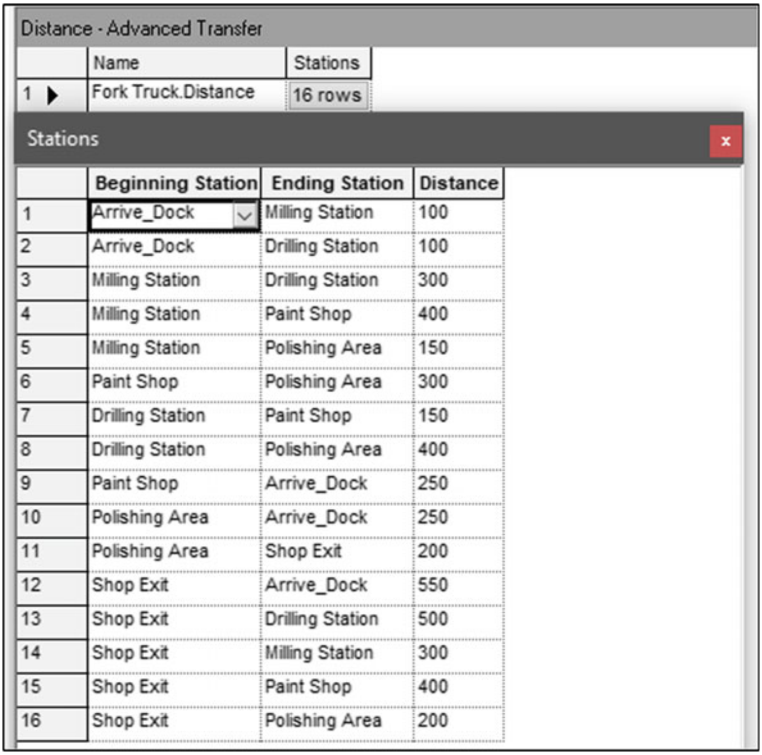
	Name	Number of Units	Type	Distance Set	Velocity	Units	Initial Position Status	When Freed	Report Statistics
1	Fork Truck	2	Free Path	Fork Truck.Distance	1.0	Per Hour	2 rows	Remain Where Freed	☑

Initial Position Status

	Initial Position	Station Name	Initial Status
1	Station	Arrive_Dock	Active
2	Station	Arrive_Dock	Active

Double-click here to add a new row.

Fig. 11.20 ARENA window portraying, *Transporter* module and *Initial position status*



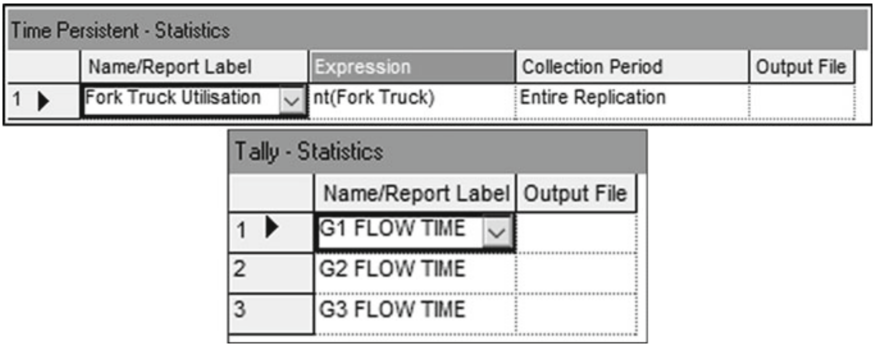
Distance - Advanced Transfer

	Name	Stations
1	Fork Truck.Distance	16 rows

Stations

	Beginning Station	Ending Station	Distance
1	Arrive_Dock	Milling Station	100
2	Arrive_Dock	Drilling Station	100
3	Milling Station	Drilling Station	300
4	Milling Station	Paint Shop	400
5	Milling Station	Polishing Area	150
6	Paint Shop	Polishing Area	300
7	Drilling Station	Paint Shop	150
8	Drilling Station	Polishing Area	400
9	Paint Shop	Arrive_Dock	250
10	Polishing Area	Arrive_Dock	250
11	Polishing Area	Shop Exit	200
12	Shop Exit	Arrive_Dock	550
13	Shop Exit	Drilling Station	500
14	Shop Exit	Milling Station	300
15	Shop Exit	Paint Shop	400
16	Shop Exit	Polishing Area	200

Fig. 11.21 ARENA window portraying *Distance* module and *Stations* dialog spreadsheet



Time Persistent - Statistics

	Name/Report Label	Expression	Collection Period	Output File
1	Fork Truck Utilisation	nt(Fork Truck)	Entire Replication	

Tally - Statistics

	Name/Report Label	Output File
1	G1 FLOW TIME	
2	G2 FLOW TIME	
3	G3 FLOW TIME	

Fig. 11.22 ARENA window depicting *Statistics* module for collection of *Fork truck utilization* and *Flow time tallies*

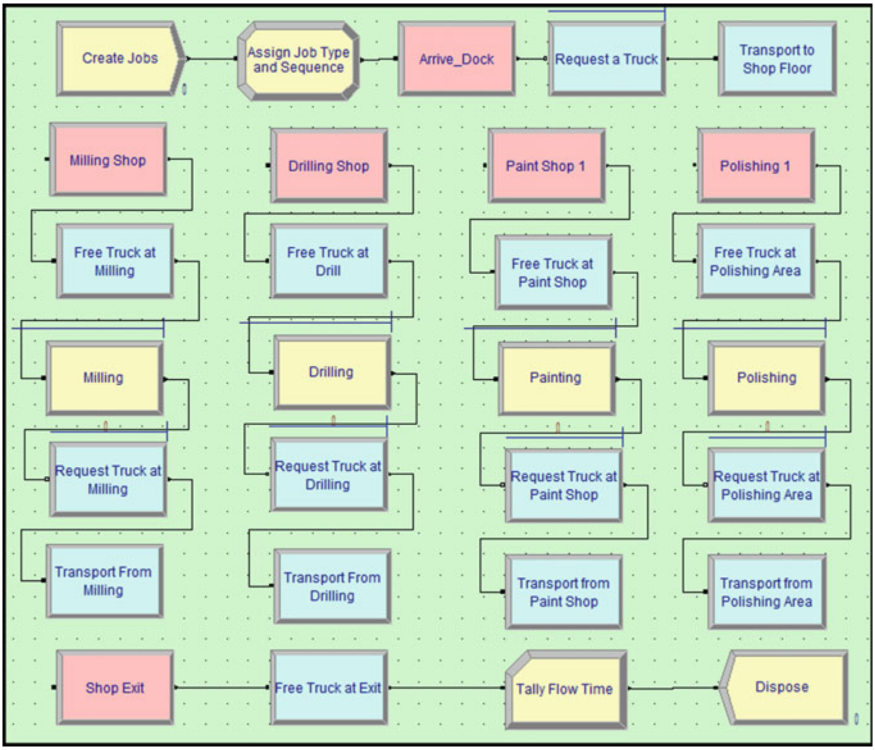


Fig. 11.23 Arena model of gear job shop manufacturing

11.7.2 Verification and Validation

Verification is done at operationality end of model [19, 20]. It is done to ensure that

- Programming errors within modelling.
- Scope of the model is not affected by any errors, oversights or bugs.

In gear manufacturing process, the verification of model is a spontaneous process for number of replications it makes. Here acceptable level of error is assumed to be less than 5%.

To make assurance that modelled data portraits the best actual working and to enhance ts relevance a confidence interval analysis was executed. At confidence interval of 95%, and the necessary number of replications of simulation was calculated by the following [21]:

$$n = \frac{(z_{\alpha/2})^2\,\sigma^2}{d^2}$$

where $n =$ replications required, d refers to sensitivity level, $\sigma =$ standard deviation, z refers to critical value from the standard normal table at the assumed confidence level. For our model to achieve 95% confidence level, 60 replications are required.

Figure 11.24 [2] shows the ARENA input analyser module generated curve fitting of distribution chosen for Job inter arrival time, square error value, mean standard deviation, corresponding p-value for Chi-Square test and Kolmogorov–Smirnov test.

- Distribution used here shows square error value 0.000206 which is less than 5%.

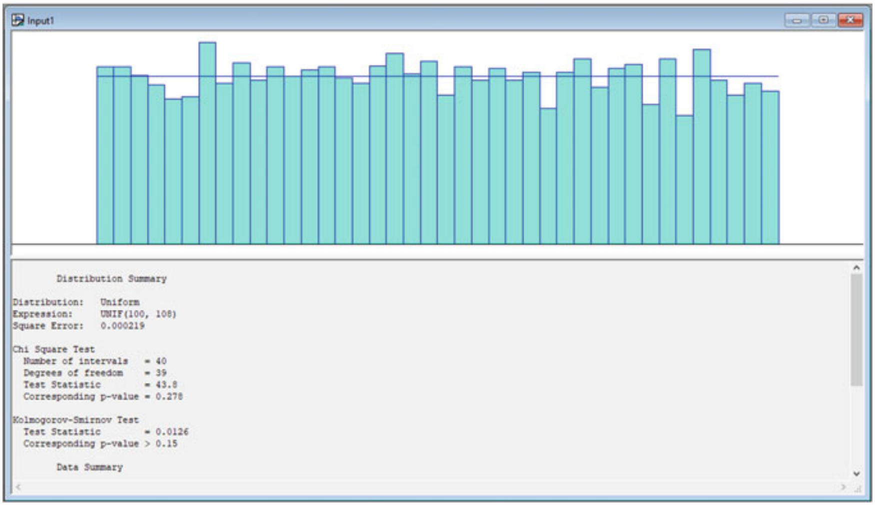


Fig. 11.24 Job inter arrival time distribution analysis

- Corresponding p-value > 0.15 for the Chi-Square test and for Kolmogorov–Smirnov p-value > 0.25 which proves the goodness of fit.
- Standard deviation for the distribution used is 2.32.

Hence, above all parameters and diagram of distribution verify and validate its correctness at 95% confidence level.

11.8 Results and Discussion

Generated results after successful completion of modelling and simulation of production flow lines in the existing setup by which bottlenecks associated with various workstations were revealed among them main are: improper resource utilization, reduced capacity of seizing entities, poor entity flow time, reduced work in process. From simulation results of the existing setup and discussions with company technical executives, the main bottleneck was single spray booth availability which was having a processing time of 55 min. As all processes time were optimized for their best performance, so keeping in view working hours' constraint, strict labour laws implementation, routine maintenance activities and company spawning customer network for future endeavours. Idea of new spray booth was recommended because of sufficient land availability in company premises and firm's interest in increasing production level at any cost, to generate more capital and client's satisfaction. On increasing spray booth to 2 NOS if breakdown occurs at one booth production may not stop and can be bypassed, which was not in the existing provision of company setup and it can be boon for firm, for high volume order accomplishment.

Recommendation of proposed model was validated by simulation of proposed model and its qualitative results showed improvements in term of key parameters as discussed above. Table showing the comparison between existing and proposed model mathematical figures are shown below to further prove suggestion and its actual implementation benefit to XYZ Pvt. Ltd. All the results are generated at 95% confidence level by Arena 15.1 version. Computer used for generating results is having configuration of Intel i7 Core Processor having 8 GB RAM compatible with Window 10 Pro Edition (Figs. 11.25, 11.26, 11.27, 11.28 and 11.29).

11.9 Conclusion and Future Scope

The presented work provides a solution to the problem of low productivity and ineffective resource utilization of XYZ Pvt. Ltd. gear manufacturing unit. First, the existing gear production unit and working of plant were analysed and existing setup bottlenecks were identified in the process. Second, simulation-based model was developed using Arena 15.1 simulation package and generated results were tested for their familiarity with gear job shop manufacturing mentioned in the case study. Based

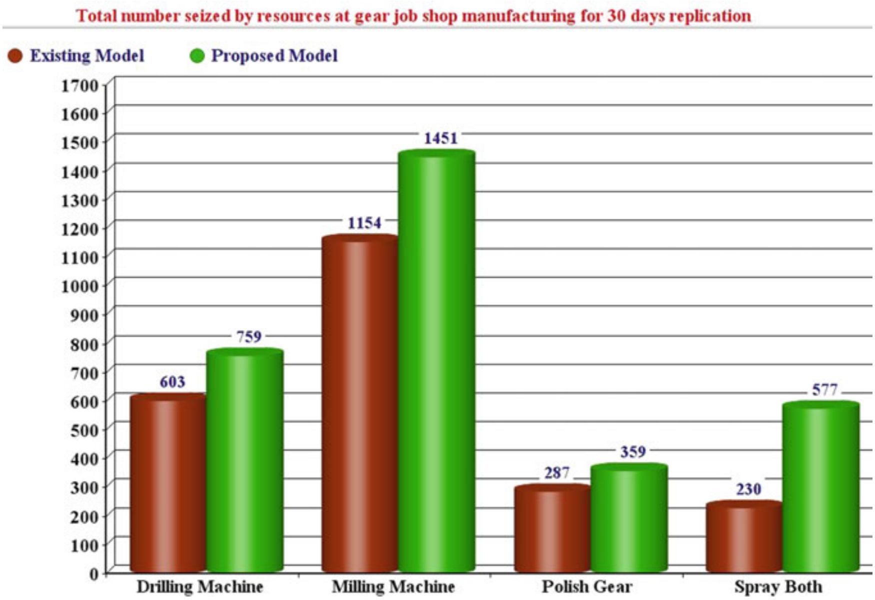


Fig. 11.25 Comparison between total number seized by resources for existing and proposed model for 30 days replication

Fig. 11.26 Comparison between Number in and number out for existing and proposed model for 30 days replication

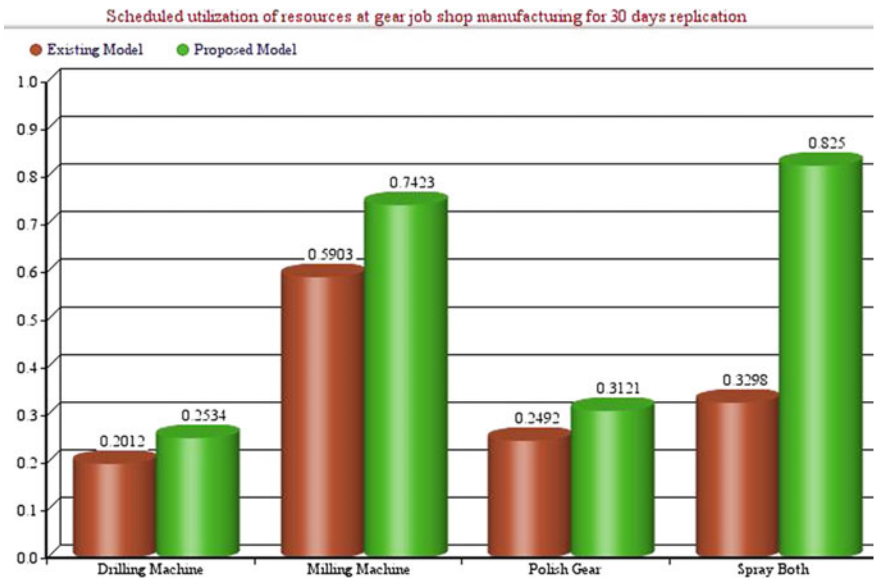


Fig. 11.27 Comparison between scheduled resource utilization for existing and proposed model for 30 days replication

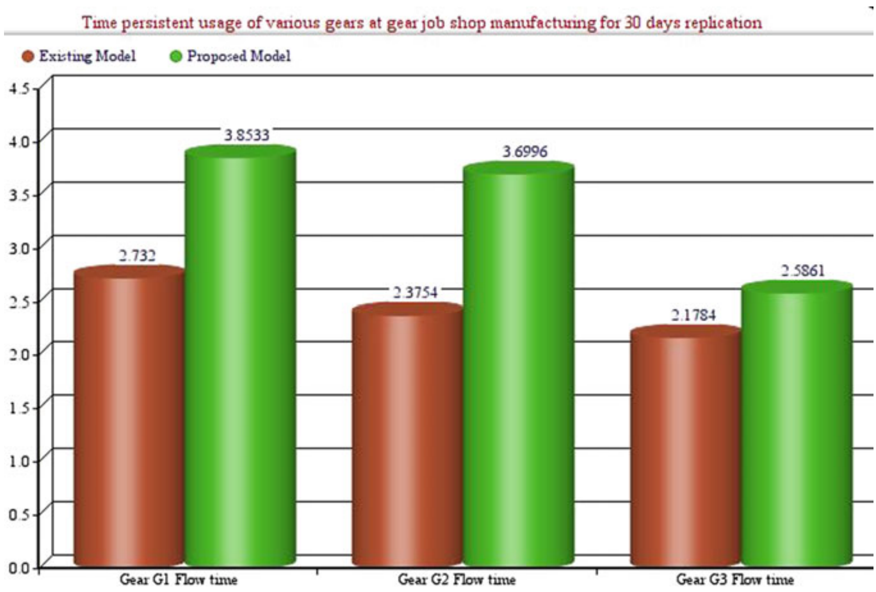


Fig. 11.28 Comparison between time-persistent usage of various gears for existing and proposed model for 30 days replication

Fig. 11.29 Comparison between resource fork truck utilization among existing and proposed model for 30 days replication

on existing setup bottleneck, a model was proposed and key parameters proving the solution to company problem were identified and comparison of the existing and proposed model was done. All the values used in the comparison were generated by Simulation in Arena 15.1 at 95% confidence level and validated. The following conclusions have been made in present work

- Using Arena 15.1 as modelling and simulation tool developed model calculates scheduled resource utilization, time-persistent usage of types of gear manufactured in plant, Number In/Out, work in process, fork truck utilization, total number seized by resources.
- Simulation run used to propose results are validated at confidence level of 95% i.e. 60 replication lengths for 30 days run length.
- Parameter Scheduled resource utilization showed improvement for all resources installed at manufacturing unit, utilization of drilling machine improved by 25.94%, milling machine by 25.74%, polishing by 25.24% and spray booth by 47.05%.
- Parameter time-persistent flow times of gear G1, G2, G3 showed improvement of 41.04% for G1, 55.74% for G2, 18.72% for G3, respectively.
- Parameter Number In/Out showed improvement of 26% for total number in and 25.52% for total number out, respectively.
- Parameter work in process of gear entities showed improvement of 66.67%.
- Parameter fork truck utilization showed improvement of 24.34%.

- Parameter total number seized by resources at plant showed improvement, drilling machine seizing capacity increased by 25.87%, milling machine seizing capacity improved by 25.73%, polish gear seizing capacity improved by 25.08% and spray booth seizing capacity improved by 47.08%.

Simulation-based analysis revealed that the company can get leading edge by increasing its product throughput by going through the phase of improvements proposed and thus satisfying customer demand in more efficient way and ultimately scaling to sustainable operations, flexibility in supply chain network and company growth. Simulation models shown are flexible enough to handle any changes with needs of company. Thus, enabling company to analyse and validate new products prior to launching them. Simulation approach not lonely benefits by improving production level and resource utilization but also virtual analysis of new system and plans, without any disruption to ongoing processes.

Supply chain is dynamic process, it must be modified to tailor itself with emerging challenges faced by the company along with exploration of newer approaches and innovations serving the needs of advanced technology and market. Presented work can be expedited in the direction as below:

- Same work can be validated by using other simulation software's like FlexSim, SimShop, Petrinet, Awesim, Simullink, Promodel.
- Presented work scope can be broadened to improve the cost associated with transportation, Resources Running cost.
- Diversification of simulation experiments and its associated runs by utilizing channel of simulation-based optimization techniques such as meta-models or variance analysis technique can be applied.

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Chapter 12
Benchmarking the Interactions Among Drivers in Supply Chain Collaboration

Rajiv Kumar Garg, Anish Sachdeva and Harjit Singh

Abstract Manufacturing companies are under the stress to give best quality products at minimum cost within the minimum delivery time, in spite of unpredictable economic conditions. Due to global competition like improved customer satisfaction and minimum cost, the organizations are thinking for innovative methods for creating competitive advantage. One such way is the collaboration among all the members of supply chain. To understand supply chain collaboration, we have to know the driving forces of collaboration within the supply chain. In this study, from the relevant literature and the advices of an expert team composed of technical and managerial of the manufacturing firms and academicians, 20 collaborative drivers have been diagnosed. An ISM-based model has been formed to study the understanding of the collaborative drivers in adopting supply chain collaboration within a manufacturing organization. We propose the ISM model, and an MICMAC investigation is done. Its practical significance is to make use of the decision-makers' knowledge to give a fundamental understanding of a complicated situation, followed by a course of action for problem-solving.

Keywords Supply chain collaboration · Benchmarking · Drivers · ISM · MICMAC

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12.1 Introduction

Manufacturing firms are under the stress to give efficient products at less cost within the reliable minimum delivery time, even during unfavorable economic environment. Due to globalization like improved customer service and cost reduction, firms are looking for innovative ways for creating competitive advantage, and one such way is supply chain collaboration (SCC) [1]. Globalization and competitive pressures have increased demands on firms to fulfill the customer needs all over the globe on time [2]. Supply chain management (SCM) literature shows a growing interest in SCC [3, 4]. It has the requirement for more relationships among supply chain (SC) members [5]. The collaboration between supply chain members has become a common practice in many modern supply chains [6]. SCC is the relation among supply chain members developed over a period of time to gain higher quality, lower cost, and greater product innovation, enhance market value, and reduce risks [7].

Organizations having practice collaboration in their supply chain gain more benefits as compared with the firms which perform individually. The major benefits of the collaboration are in the form of efficiency and effectiveness, it reduces overall supply chain cost comparing with, non-collaborative supply chain firms. Due to the large benefits of SCC, a very large number of organizations are going to apply collaborative strategies to enhance the performance of their supply chain [8]. Therefore, the study related to the collaborative supply chain is one of the emerging topics in this global environment [9]. Collaboration is explained as two or more firms sharing the responsibility of exchanging management, planning, execution, and performance measurement information, and acts as the driving force behind SCM [10]. A large no of the literature showed that collaboration within the supply chain has a significant impact on cost saving, decision-making, and problem-solving [11, 12].

SCM is an important area of research for researchers and practitioners from a large number of disciplines. SCM has been treated as the most famous operations strategy for developing organizational competitiveness in the twenty-first century [13]. SCM has been starting from past seven decades, starts with the name traffic, and then it becomes order management, and further came to warehousing departments. Then it would come under the name of the physical distribution. Then inventory management which further allowed by customer service then added a new term integrated logistics, and further production planning and procurement, then it became SCM; this is further embedded into the value chain, which ultimately accounts for the values related to demand and supply [14]. Collaborative activities are the all related multiple functions of the supply chain. Different members of SC cannot compete individually, so a continuous dynamic system of collaborative drivers is required, through which all members become part of a unified system and come close and collaborate with other members of the SC to achieve a common goal, and sign all necessary documentation for collaborative activities so do according to the sign agreements and work to get the required supply chain performance. These are the various crucial drivers in literature, which made SCC more successful, these factors accelerate the organizations to implement collaboration in SC [15]. Due to lack of understanding the drivers into the way to collaboration in SC, and it results in collaboration failure in the supply chain [16].

On the basis of the available literature, relevant to this study, and the suggestions of an expert team, 20 collaborative drivers have been diagnosed [17]. Drivers are the multidimensional factors, which acts as driving forces to achieve supply chain collaboration. Analyzing the interactions among the identified drivers, and implementing the interpretive structural modeling (ISM) methodology, this work pursues to establish the following contributions:

- First, an ISM-based hierarchical model is built. The model provides the understanding of the collaborative drivers in adopting SCC in manufacturing organizations. Based on the understanding, decision-makers can prepare the company to implement SCC.
- Second, an impact matrix cross-reference multiplication tested to a classification (MICMAC) analysis is implemented. The analysis shows that there is no autonomous collaborative driver. It indicates that all the identified collaborative drivers have an important role in the implementation of SCC.

Thus, the ISM-based model and MICMAC analysis may be treated as significant additions from this research work. The structure of the paper is designed as follows. Section 12.2 describes the review of the existing relevant literature. Section 12.3 describes the problem description. Section 12.4 describes the methodology. Section 12.5 describes the application of the proposed methodology. Section 12.6 describes MICMAC analysis. Section 12.7 describes the results and discussion. Section 12.8 describes the managerial implications, and the conclusion is given in Sect. 12.9.

12.2 Literature Survey

Since the 1980s, SCM is the area of interest; all of the academicians and practitioners are equally interested in this field [18]. SCM is the new area of interest by comparing with another area in the field of management studies [19, 20]. Due to global competition, product life cycle has reduced, which builds stress on supply chain partners that are tolerated by adding innovative strategies which increase the scale of economy and customer satisfaction [21]. "Collaboration is the working of two or more than two companies collectively to run supply chain operations and having a better result as compare to when these firms work individually" [22]. By collaborating there is a better result for uncertainties in demand and supply [23]. Collaboration within the supply chain is the major topic of research for the last decade [24]. Collaboration in the supply chain is the requirement to construct a more responsive and efficient chain to provide values to the customer [16].

SCM has been a considerable component of competitive strategy to increase organizational productivity and profitability [25]. In spite of SCM has large literature, the concept of collaboration come in 1990, but some companies have been using collaborative practice in different ways for several decades [26]. Since the last three decades, academics and practitioners have interested in various types of collaborative practices in the supply chain [27]. There are a very large number of benefits of collaboration but the right observation regarding the meaning of collaboration and how to start and at where is the present situation is still challenging for supply chain partners [28–30]. These are the various crucial factors which made SCC more successful, these factors accelerate the firms to implement collaboration initiatives [15]. Collaborative relationships between supply chain members make benefits like inventory reduction, on-time delivery service, and lesser product development cycles [31]. Due to not properly understanding the drivers into the way to collaboration in SC, the collaboration would not be as required and therefore uncertainty in the organization's performance is increased and it leads to collaboration failure in supply chain [16, 32, 33].

Collaboration is a set of practices that are exercised collectively by the collaborating partners to improve innovation and to raise supply chain performance, and the collaborative drivers are the visualization of internal and external focused functional areas for an organization [9, 34, 35]. Effective implementation of SCC requires some forms of planning and preparation in advance, this means the organization's ability to execute various collaborative drivers effectively and efficiently [36]. It is a necessity that which are the various collaborative drivers that reflect collaboration, and how to visualize these driving forces in an organization to gain benefits from collaboration [34]. To execute the collaboration in the long term requires various types of skills and technology. Thus, preparation in the form of skills, technology, and identifying suitable partner which could result in better execution capability and in-depth relationship requires attention in the collaborative literature.

12.3 Problem Descriptions

From the literature about SCC, the study of collaborative drivers in the SC is still under research. No study discussed interactions among these collaborative drivers. Therefore, more research on collaborative drivers is required to understand and implementing collaboration in the supply chain. After a literature survey and discussion with the expert team, 20 collaborative drivers to understand and implementing SCC have been identified. After a literature survey and discussion with the expert team, 20 collaborative drivers to understand and implement SCC have been identified. These collaborative drivers are shown in tabular form in the following text. The identified collaborative drivers are shown in Table 12.1.

Table 12.1 The identified collaborative drivers

	Collaborative drivers	Definition	Authors
1	Competition	All the members of SC like customer, retailer, wholesaler, distributor, manufacturer, and supplier are stakeholders	[28, 37–43]
2	Commitment	Commitment is the important driver to make long-term relationship among SC partners. It is the willingness of SC members to work together to achieve a common goal. Commitment is an important ingredient for SCC	[31, 35, 40, 44–50]
3	Adaptations	Adaptation is the process of adopting or the addition of the concept of collaboration in SC and follows the procedure of collaborative strategies in the chain. Adoption is helpful to reduce the hindrances in the way to collaboration	[44, 47, 51, 52]
4	Technology	Technology is used to share information within the chain and monitor the chain. It enhances the visibility of chain by providing better collaboration among the SC partners. It also increases flexibility in the chain. Examples are MIS, ERP, DSS, TPS, etc.	[37–39, 52, 53, 55]
5	Trust	Trust is one of the key drivers of SCC. Collaboration is made on a base of trust. It acts as a binding force among SC partners. The importance of trust is increasing day by day in literature. It reduces conflicts and increases collaboration under uncertain conditions	[28, 31, 44–50, 53, 56–58]
6	Management policies	Management policies are the decision at management level due to the right implication of collaboration in SC. These are the agreements, common goal outline, and received benefits. It also includes reward and risk sharing policies	[50, 57, 59, 60]
7	Collaborative communication	Collaborative communication is the message transmission process within SC partners in the form of direction, mode, frequency, and influence strategy. It clearly shares goals among the members of all SC and leads to effective realization of defined objective under provided resources, pressure, and time	[5, 47, 61–63]

(continued)

Table 12.1 (continued)

	Collaborative drivers	Definition	Authors
8	Business strategy	Business strategy is the important driver behind an organization's eagerness to collaborate with other members of SC partners. It has common practices, efficient information sharing, techniques, and win-win situation for all members of SC	[37, 38, 55, 59, 60]
9	Joint long-term relations	Joint long-term relations are the development of a roadmap that has to be in order to achieve a defined objective. Collaboration between the firms and departments may be increased by using joint long-term relations within the SC. This is one of the important elements that eliminate conflicts between partners of the supply chain, and also measure the contribution of partners and encourage desirable behavior between partners and establish the collaborative relationship between SC partners	[47, 49, 65]
10	Collaborative agreement	Collaborative agreement is the first step to start collaboration; it is the detailed legal document within all SC members. It is an essential document to manage all the discrepancies within SC members. It is the system which consists of series of rules, through which rights and responsibilities are formed and agreed by all SC members	[40, 56, 60]
11	Better information sharing	Information sharing is the exchange of proprietary information among SC partners by using media such as Internet, mail, telephone, and fax. The shared information must be relevant, complete, accurate, and confidential in a timely manner within all SC	[22, 28, 31, 41, 43, 45, 46, 48, 49, 52, 56, 57, 60–62]
12	Cooperation	Cooperation within SC is required for effective SCC. It is the alignment of work objectives and available resources to achieve the SCC. Cooperation is required in all collaborative activities	[22, 28, 40, 47, 66]

(continued)

Table 12.1 (continued)

	Collaborative drivers	Definition	Authors
13	Appropriate performance measure	The performance metric must be devised and implemented as required by the nature of organization. The main role of the performance measure is to guide the SC partners to enhance the overall performance	[22, 31, 43, 57, 59]
14	Globalization	Globalization is the process, by which organizations experience international pressure. It is the collaboration among people, organizations, and governments of all nations. It has effects on all area of in societies around the globe. It is one of the important drivers of SCC	[22, 28, 31, 38–41, 52, 54, 55, 58]
15	Incentive alignment	Incentive alignment is the process of sharing risks, costs, and benefits within SC partners	[22, 33, 46, 50, 59]
16	Joint decision-making	The organizations having practice collaboration worked together and did joint decision-making to achieve organizational goals. This also leads to trust and commitment which is required for long-term successful collaboration relationships	[22, 46, 50, 55, 59, 65]
17	Innovative SC process	Innovative supply chain process indicates to the degree to which SC members plan efficient processes that increase customer satisfaction and help to enhance SCC	[22, 31, 37, 49, 67]
18	Resource sharing	Resource sharing is the process of sharing and investing in capabilities and assets within SC partners. Resources may be technology, facility, manufacturing equipment, and physical resources. It also helps to achieve successful SCC	[31, 45, 49, 56]
19	Knowledge sharing	By sharing knowledge, the members of SC responded to the competitive environment in a better way and worked together to achieve collaboration in SC	[22, 28, 31, 48, 53, 64]
20	Organizational culture	Organizational culture is the value that is useful to explain the functioning of the organization, and also gives behavioral norms. It enhances the opportunities to make better competitive advantages. It provides the environment which is necessary to all collaborative activities that executed to be in the expected way	[41, 45, 50, 58]

12.4 ISM Methodology

ISM methodology is mainly designed as a group learning process, but can also be used individually [67]. ISM methodology converts unclear models of systems into well-defined models, which is useful for many purposes. ISM methodology is used for a systematic and logical thinking approach; this gives order and direction for various complicated relationships among the variables [68]. ISM methodology asks for grouping expert opinion by grouping various methods like nominal technique, brainstorming, and affinity diagramming in making contextual relationships among the variables [69]. The ISM methodology has been proposed for modeling the barriers to implement green supply chain management in the Indian automobile industry [70]. The ISM methodology has been used in the Indian cement industry to model the variables of energy conservation by using direct and indirect interrelationships [71]. The ISM methodology was used to modeling the future objective variables of waste management [72]. The ISM model was developed for supplier selection in manufacturing company having the build-to-order type supply chain environment [67]. The ISM methodology was used for modeling the variables affecting in the green supply chain management [73].

The main drawback of ISM methodology is that of the unfairness of the expert who is deciding the variables, which will affect the final model [67]. ISM methodology does not give any weightage to the variables. In this study, we identify interactions of the collaborative activities in implementing an SCC in the manufacturing sector.

The procedure for ISM methodology [67] is as follows:

(a) The identified collaborative drivers are listed.
(b) Develop a contextual relationship for each collaborative driver with respect to other drivers.
(c) To show the pair-wise relationships between collaborative drivers, develop structural self-interaction matrix (SSIM), which is based on Step 2.
(d) Develop and check transitivity of reachability matrix, which is based on SSIM. This matrix is confirmed for transitivity. Transitivity means if a variable “X” is related to “Y” and “Y” is related to “Z”, then “X” must be related with “Z”.
(e) Differentiate the reachability matrix into different hierarchical levels.
(f) Draw directed graph from the relationships in reachability matrix and delete transitive links.
(g) Develop ISM model by replacing collaborative driver’s nodes with statements.
(h) Check conceptual inconsistency of the model and do modifications if necessary.

The flowchart for the ISM-based methodology is shown in Fig. 12.1.

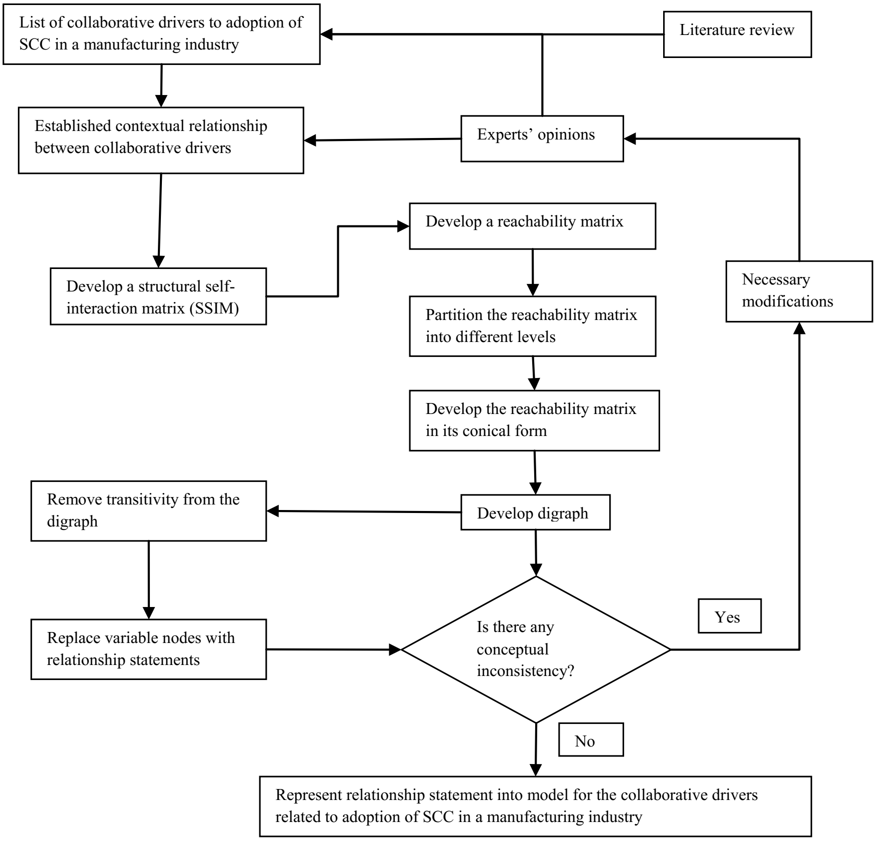

Fig. 12.1 Flowchart for the ISM-based methodology

12.5 Application of the ISM-Based Methodology for Collaborative Drivers to the Implementation of SCC

In this section, the above-discussed methodology of ISM is used to model the various collaborative drivers which are helpful for implementation the collaboration in SC. Twenty collaborative drivers have been selected after discussion with the expert team and backed by the existing available literature. The selected collaborative drivers are shown in Table 12.1. After the analysis of interactions among the collaborative drivers, an ISM-based model is developed following the procedure discussed in Sect. 12.4.

12.5.1 Overview of the Manufacturing Sector

Adding accounts in the global competitive environment is a tough job; firms increase their efforts for retaining the existing customers and, at the same time, remain competitive in the current market, and it is feasible only by increasing the customers' satisfaction. Due to globalization, the reduction in the product life cycle builds pressure on whole supply chains, which is handled by adding competitive strategies that enhance directly and indirectly scale of economy and customer satisfaction [43].

The manufacturing industry is a fundamental part of the economy [74]. Supply chain growth is reasonable in developed economies and increasing in emerging economies [75]. In this study, the manufacturing industry is considered to model the various collaborative drivers for the SCC implementation. This work will helpful for SCM of the industry to analyze the interactions among the collaborative drivers while implementing SCC in the industry. First, the process of implementation of SCC in the manufacturing sector has been discussed with the expert team. Twenty drivers have been identified after several times discussion with the expert team and supported by the existing available literature. The considered collaborative drivers, as discussed above, are tabulated in Table 12.1. After the process of interactions among the drivers, an ISM-based model is proposed following the procedure is given in Sect. 12.4.

12.5.2 Structural Self-interaction Matrix (SSIM)

Based upon the contextual relationships between collaborative drivers, the relation between those two collaborative drivers i and j, and direction between these two are discussed. The four alphabets as a symbol have been used to relate directionally one driver with another (i and j) [76]:

V–driver i leads to driver j.
A–driver j leads to driver i.
X–drivers i and j help each other.
O–drivers i and j are not related.

In this study, first driver leads to sixteenth driver so we use symbol "V" in the (1, 16) cell; sixth driver leads to the third driver so we use symbol "A" in the (3, 6) cell; first and tenth drivers help each other so we use symbol "X" in the (1, 10) cell; first and fourth drivers have no relation so we use symbol "O" in the (1, 4) cell; and so on. The relationships are made for the remaining collaborative drivers in Table 12.2.

Table 12.2 SSIM for the collaborative drivers

Sr. no.	Collaborative drivers	Factor no.																			
		20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1
1	Competition	O	A	A	O	V	O	V	A	O	O	X	A	O	V	A	A	O	V	A	X
2	Commitment	O	O	A	V	V	V	O	O	V	A	O	O	X	V	O	V	A	O	X	
3	Adaptations	V	V	O	O	A	A	O	V	V	V	O	V	X	V	A	A	A	X		
4	Technology	V	V	O	O	V	A	O	X	V	V	O	O	A	V	A	V	X			
5	Trust	O	A	A	O	V	A	A	V	V	X	X	V	X	V	A	X				
6	Management policies	V	O	V	V	V	V	O	V	V	A	V	O	V	V	X					
7	Collaborative communication	O	O	X	V	X	A	O	V	O	X	X	X	A	X						
8	Business strategy	V	O	A	O	V	O	O	O	A	A	V	V	X							
9	Joint long-term relations	O	A	A	O	A	A	O	A	O	A	O	X								
10	Collaborative agreement	X	O	A	O	V	V	A	O	A	O	X									
11	Better information sharing	V	V	V	V	V	V	V	V	V	X										
12	Cooperation	O	V	A	A	O	A	V	O	X											
13	Appropriate performance measure	O	O	X	A	A	A	A	X												
14	Globalization	O	O	O	V	V	O	X													
15	Incentive alignment	O	O	A	O	V	X														
16	Joint decision-making	V	O	V	V	X															
17	Innovative SC process	O	A	A	X																
18	Resource sharing	V	A	X																	
19	Knowledge sharing	V	X																		
20	Organizational culture	X																			

12.5.3 Reachability Matrix

SSIM matrix is converted into a binary matrix, by substituting the sign "0" or "1" in place of O, X, A, V by the rule of substitution given below [76]:

- In the SSIM matrix, if (i, j) value is V, then in reachability matrix (i, j) value replace to "1" and (j, i) value replace to "0"; this means V (1, 3) in the matrix, "1" for (1, 3) cell and "0" for (3, 1) cell.
- If (i, j) cell value is A in SSIM matrix, then (i, j) cell value for reachability matrix is "0" and (j, i) cell value is "1"; this means A(1,2) in the matrix, "0" for (1,2) cell and "1" for (2,1) cell for reachability matrix.
- If (i, j) cell value in SSIM matrix is X, then (i, j) cell value for reachability matrix is "1" and (j, i) cell value is also "1"; this means X (1, 10) in the SSIM matrix, "1" is for (1, 10) cell and "1" for (10, 1) cell in the reachability matrix.
- If (i, j) cell value in SSIM matrix is O, (i, j) cell value for reachability matrix is "0" and (j, i) cell value is also "0"; this means O (1,4) in the SSIM matrix, "0" is in (1,4) cell and "0" in (4,1) cell in the reachability matrix.

Following this rule, the initial reachability matrix for collaborative drivers is formed as shown in Table 12.3.

The final reachability matrix for the collaborative drivers is formed by incorporating the transitivity rule as discussed in Sect. 12.4. The final reachability matrix for collaborative drivers is reached as shown in Table 12.4.

12.5.4 Level Partitions

The antecedent set and reachability for each collaborative driver are calculated from final reachability matrix. The reachability set for a driver is the driver itself and other, which it influences. The antecedent set for a driver is the driver itself and other drivers, which might influence it. After finding both sets, the intersections between these sets are derived from the drivers. Antecedent set, reachability, and intersection sets are derived for all collaborative drivers. Drivers having same intersection set and reachability set are assigned top level in the ISM hierarchy [67] and say Level 1. This is the end of iteration 1 as shown in Table 12.5. The Level 1 is discarded from the other remaining drivers, and iteration 2 is done with the same procedure above. Continue this iterative procedure until the levels of each driver are found out. It is understood that the collaborative drivers "joint long-term relations", "appropriate performance measure", "innovative SC process", and "resource sharing" are at Level 1. The collaborative drivers "commitment", "trust", "collaborative communication", "business strategy", "cooperation", "joint decision-making", "knowledge sharing", and "organizational culture" are at Level 2. The collaborative drivers "competition", "adaptations", "technology", "collaborative agreement", "better information sharing", "globalization", and "incentive alignment" are at Level 3. The collaborative driver "management policies" is at Level 4.

Table 12.3 Reachability matrix for the collaborative drivers

Sr. no.	Collaborative drivers	Driver no.																			
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
1	Competition	1	0	1	0	0	0	1	0	0	1	0	0	0	1	0	1	0	0	0	0
2	Commitment	1	1	0	0	1	0	1	1	0	0	0	1	0	0	1	1	1	0	0	0
3	Adaptations	0	0	1	0	0	0	1	1	1	0	1	1	1	0	0	0	0	0	1	1
4	Technology	0	1	1	1	1	0	1	0	0	0	1	1	1	0	0	1	0	0	1	1
5	Trust	1	0	4	0	4	0	4	4	4	4	4	4	4	0	0	4	0	0	0	0
6	Management policies	1	0	1	1	1	1	1	1	0	1	0	1	1	0	1	1	1	1	0	1
7	Collaborative communication	0	0	0	0	0	0	1	0	1	1	1	0	1	0	0	1	1	1	0	0
8	Business strategy	0	1	1	1	1	0	1	1	1	1	0	0	0	0	0	1	0	0	0	1
9	Joint long-term relations	1	0	0	0	0	0	1	0	1	0	0	0	0	0	0	0	0	0	0	0
10	Collaborative agreement	1	0	0	0	1	0	1	0	0	1	0	0	0	0	1	1	0	0	0	1
11	Better information sharing	0	1	0	0	1	1	1	1	1	0	1	1	1	1	1	1	1	1	1	1
12	Cooperation	0	0	0	0	0	0	0	1	0	1	0	1	0	1	0	0	0	0	1	0
13	Appropriate performance measure	1	0	0	1	0	0	0	0	1	0	0	0	1	0	0	0	0	1	0	0
14	Globalization	0	0	0	0	1	0	0	0	0	1	0	0	1	1	0	1	1	0	0	0
15	Incentive alignment	0	0	1	1	1	0	1	0	1	1	0	1	1	0	1	1	0	0	0	0
16	Joint decision-making	0	0	1	0	0	0	1	0	1	0	0	0	1	0	0	1	1	1	0	1
17	Innovative SC process	0	0	0	0	0	0	0	0	0	0	0	1	1	0	0	0	1	0	0	0
18	Resource sharing	1	1	0	0	1	0	1	1	1	1	0	1	1	0	1	0	1	1	0	1
19	Knowledge sharing	1	0	0	0	1	0	0	0	1	0	0	0	0	0	0	0	1	1	1	1
20	Organizational culture	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	1

Table 12.4 Final reachability matrix for the collaborative a drivers

Sr no.	Collaborative drivers	Driver no.																			
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
1	Competition	1	0	1	0	1	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1
2	Commitment	1	1	1	1	1	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1
3	Adaptations	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
4	Technology	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
5	Trust	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
6	Management policies	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
7	Collaborative communication	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
8	Business strategy	1	1	1	1	1	0	1	1	1	1	1	1	1	0	1	1	1	1	1	1
9	Joint long-term relations	1	0	1	0	0	0	1	0	1	1	1	0	1	1	0	1	1	1	0	0
10	Collaborative agreement	1	0	1	1	1	0	1	1	1	1	1	1	1	1	1	1	1	1	0	1
11	Better information sharing	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
12	Cooperation	1	1	1	1	1	0	1	1	1	1	0	1	1	1	1	1	1	1	1	1
13	Appropriate performance measure	1	1	1	1	1	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1
14	Globalization	1	0	1	1	1	0	1	1	1	1	1	1	1	1	1	1	1	1	0	1
15	Incentive alignment	1	1	1	1	1	0	1	1	1	1	1	1	1	0	1	1	1	1	1	1
16	Joint decision-making	1	1	1	1	1	0	1	1	1	1	1	1	1	0	1	1	1	1	1	1
17	Innovative SC process	1	0	0	1	0	0	0	1	1	1	0	1	1	1	0	0	1	1	1	0
18	Resource sharing	1	1	1	0	1	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1
19	Knowledge sharing	1	1	1	0	1	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1
20	Organizational culture	0	1	0	0	1	1	1	1	1	0	1	1	1	1	1	1	1	1	1	1

Table 12.5 Partition matrix for the collaborative drivers

Sr. no.	Collaborative drivers	Reachability set	Antecedent set	Intersection set	Level
1	Competition	3,4,6,11	3,4,6,11	3,4,6,11	III
2	Commitment	2,3,4,5,7,8,11,12,15,16,19,20	2,3,4,5,6,7,8,11,12,15,16,19,20	2,3,4,5,7,8,11,12,15,16,19,20	II
3	Adaptations	3,4,6,11	3,4,6,11	3,4,6,11	III
4	Technology	3,4,6,11	3,4,6,11	3,4,6,11	III
5	Trust	2,3,4,5,6,7,8,11,12,15,16,19,20	2,3,4,5,6,7,8,11,12,15,16,19,20	2,3,4,5,6,7,8,11,12,15,16,19,20	II
6	Management policies	3,4,6,11	3,4,6,11	3,4,6,11	IV
7	Collaborative communication	2,3,4,5,6,7,8,11,12,15,16,19,20	2,3,4,5,6,7,8,11,12,15,16,19,20	2,3,4,5,6,7,8,11,12,15,16,19,20	II
8	Business strategy	2,3,4,5,7,8,11,12,15,16,19,20	2,3,4,5,6,7,8,11,12,15,16,19,20	2,3,4,5,7,8,11,12,15,16,19,20	II
9	Joint long-term relations	1,3,7,9,10,11,13,14,16,17,18	1,2,3,4,5,6,7,8,9,10,11,12,13,14,15,16,17,18,19,20	1,3,7,9,10,11,13,14,16,17,18	I
10	Collaborative agreement	3,11	3,4,6,11	3,11	III
11	Better information sharing	3,4,6,11	3,4,6,11	3,4,6,11	III
12	Cooperation	2,3,4,5,7,8,12,15,16,19,20	2,3,4,5,6,7,8,11,12,15,16,19,20	2,3,4,5,7,8,12,15,16,19,20	II
13	Appropriate performance measure	1,2,3,4,5,7,8,9,10,11,12,13,14,15,16,17,18,19,20	1,2,3,4,5,6,7,8,9,10,11,12,13,14,15,16,17,18,19,20	1,2,3,4,5,7,8,9,10,11,12,13,14,15,16,17,18,19,20	I
14	Globalization	3,4,11	3,4,6,11	3,4,11	III
15	Incentive alignment	3,4,11	3,4,6,11	3,4,11	III
16	Joint decision-making	2,3,4,5,7,8,11,12,15,16,19,20	2,3,4,5,6,7,8,11,12,15,16,19,20	2,3,4,5,7,8,11,12,15,16,19,20	II
17	Innovative SC process	1,4,8,9,10,12,13,14,17,18,19	1,2,3,4,5,6,7,8,9,10,11,12,13,14,15,16,17,18,19,20	1,4,8,9,10,12,13,14,17,18,19	I
18	Resource sharing	1,2,3,5,7,8,9,10,11,12,13,14,15,16,17,18,19,20	1,2,3,4,5,6,7,8,9,10,11,12,13,14,15,16,17,18,19,20	1,2,3,5,7,8,9,10,11,12,13,14,15,16,17,18,19,20	I
19	Knowledge sharing	2,3,5,7,8,11,12,15,16,19,20	2,3,4,5,6,7,8,11,12,15,16,19,20	2,3,5,7,8,11,12,15,16,19,20	II
20	Organizational culture	2,5,6,7,8,11,12,15,16,19,20	2,3,4,5,6,7,8,11,12,15,16,19,20	2,5,6,7,8,11,12,15,16,19,20	II

Table 12.6 Levels partitions for all collaborative drivers

Sr. no.	Level number	Collaborative drivers
1	First	• Joint long-term relations • Appropriate performance measure • Innovative SC process • Resource sharing
2	Second	• Commitment • Trust • Collaborative communication • Business strategy • Cooperation • Joint decision-making • Knowledge sharing • Organizational culture
3	Third	• Competition • Adaptations • Technology • Collaborative agreement • Better information sharing • Globalization • Incentive alignment
4	Fourth	• Management policies

12.5.5 ISM-Based Model

From the level partitions (Table 12.6), the ISM model is built as shown in Fig. 12.2. It is observed from the ISM-based model that the collaborative driver "management policies" at Level 4 is a very significant driver in adopting SCC in the manufacturing industry as it becomes the base of the ISM-based hierarchy (Table 12.6).

12.6 MICMAC Analysis

With the help of the developed ISM-based model, an MICMAC analysis is done which is based on the driving and dependence power of the identified drivers under study. The driving power and dependence power are calculated from final reachability matrix, the numbers sum of all "1's" in the corresponding row and column of that collaborative drivers is the driving and dependence power. Driving power means a driver influencing other drivers, and dependence power means a driver influenced by other drivers. The powers of all collaborative drivers are shown in Table 12.7.

The collaborative drivers can be partitioned into four quadrants, according to their driving and dependence power, and their respective drivers are shown in Table 12.8.

Table 12.7 Power-based ranks of collaborative drivers

Sr. no.	Collaborative drivers	Driving power	Driving-based rank	Dependence power	Dependence-based rank
1	Competition	17	IV	19	II
2	Commitment	19	II	15	V
3	Adaptations	20	I	18	III
4	Technology	20	I	15	V
5	Trust	20	I	18	III
6	Management policies	20	I	07	VI
7	Collaborative communication	20	I	19	II
8	Business strategy	18	III	19	II
9	Joint long-term relations	11	VI	20	I
10	Collaborative agreement	17	IV	19	II
11	Better information sharing	20	I	18	III
12	Cooperation	18	III	19	II
13	Appropriate performance measure	19	II	20	I
14	Globalization	17	IV	17	IV
15	Incentive alignment	18	III	18	III
16	Joint decision-making	18	III	19	II
17	Innovative SC process	11	VI	20	I
18	Resource sharing	18	III	20	I
19	Knowledge sharing	18	III	17	IV
20	Organizational culture	16	V	18	III

Table 12.8 Grouping of collaborative drivers according to their driving power and dependence

Quadrant no.	Name of elements	Driving power	Dependence power	Collaborative drivers
I	Autonomous	Weak	Weak	
II	Dependent	Weak	Strong	
III	Linkage	Strong	Strong	Technology, commitment, knowledge sharing, globalization, adaptations, trust, better information sharing, incentive alignment, organizational culture, collaborative communication, business strategy, cooperation, joint decision-making, competition, collaborative agreement, appropriate performance measure, resource sharing, joint long-term relations, and innovative SC process
IV	Driver or independent	Strong	Weak	Management policies

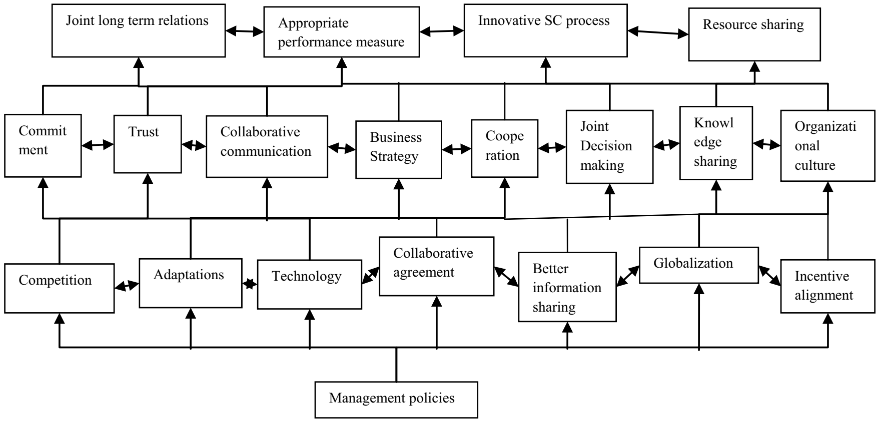

Fig. 12.2 ISM-based model of collaborative drivers

In this study, there is no autonomous and dependent driver. Linkage collaborative drivers having high driving and high dependence power, but are unstable in nature, because any action on these activities will affect the others and also feedback on themselves. Using MICMAC analysis, a driving power and dependence power diagram for collaborative drivers is plotted in Fig. 12.3.

12.7 Results and Discussion

The aim of this work is to review and to analyze the interactions among the collaborative drivers for the implementation of SCC in the manufacturing sector. An ISM-based model has been formed to study the understanding of the collaborative drivers in adopting SCC in the manufacturing industry. We propose the ISM model, and an MICMAC investigation is done. The ISM model gives a hierarchy of behaviors about collaborative drivers for the implementation of SCC. The supply chain decision-makers can get an understanding of these collaborative drivers and observe their interdependencies and relative importance. The insights from the ISM-based model is that the collaborative drivers "joint long-term relations", "appropriate performance measure", "innovative SC process", and "resource sharing" are at Level 1 and position at top of the ISM-based model. These drivers have strong dependence power and weak driving power. The rest of the collaborative drivers are categorized on other levels as follows:

Level 2. Collaborative drivers "commitment", "trust", "collaborative communication", "business strategy", "cooperation", "joint decision-making", "knowledge sharing", and "organizational culture" are found.

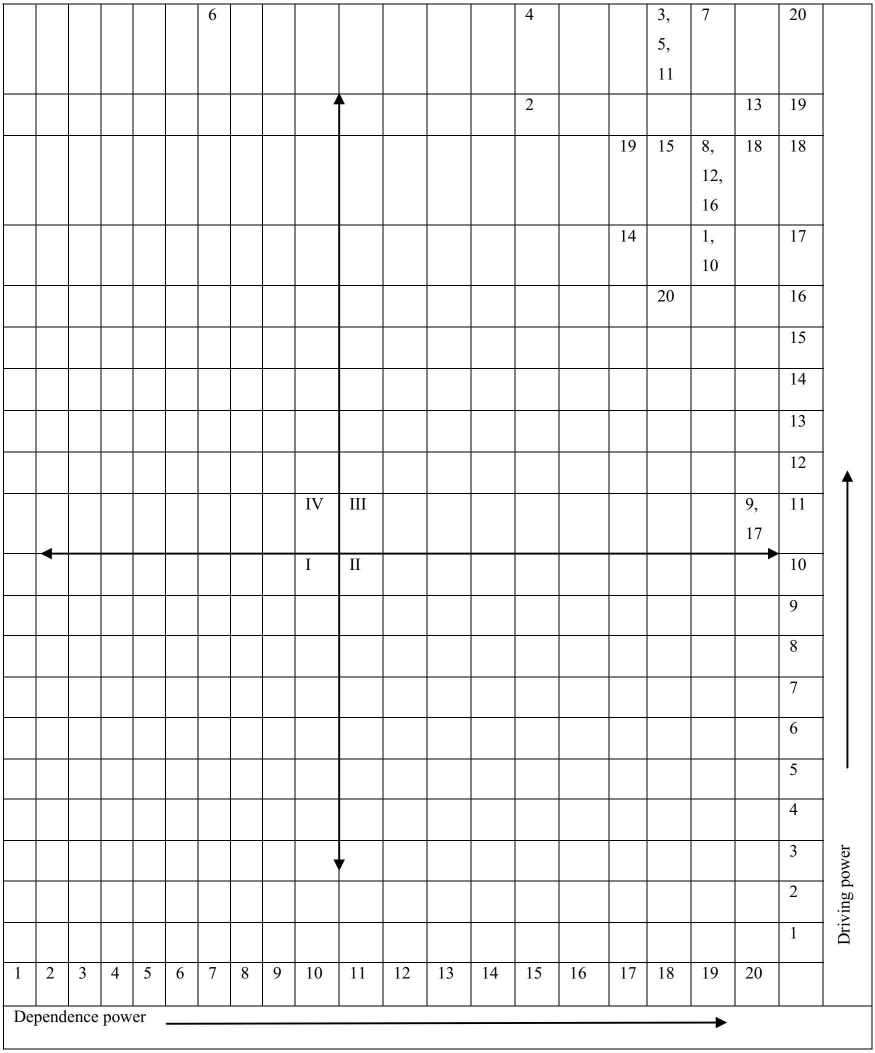

Fig. 12.3 MICMAC analysis of the collaborative drivers

Level 3. Collaborative drivers such as “competition”, “adaptations”, “technology”, “collaborative agreement”, “better information sharing”, “globalization”, and “incentive alignment” are found.

Level 4. Collaborative activity “management policies” is found.

Finally, Level 4 forms the base of the ISM-based model and can be recognized as a significant collaborative driver in adopting SCC. This driver has highest driving power and lowest dependence power. This implies that “management policies” plays an important role and work as the major driver in the implementation of SCC in the manufacturing industry.

By operating MICMAC analysis, the dependence-driver diagram is sketched which gives knowledge about the relative significance and the interdependencies among the collaborative drivers. From Fig. 12.3, it is found that in this work, there is no autonomous collaborative driver. It is understood all the collaborative drivers examined in this work will impact the implementation of SCC. Among the 20 drivers examined in this study, no driver is falling in the dependent quadrant in the dependence-driver diagram, and it is acknowledged that these drivers will depend on other collaborative drivers. The drivers like technology, commitment, knowledge sharing, globalization, adaptations, trust, better information sharing, incentive alignment, organizational culture, collaborative communication, business strategy, cooperation, joint decision-making, competition, collaborative agreement, appropriate performance measure, resource sharing, joint long-term relations, and innovative SC process fall under the linkage quadrant; they are unstable and possess high driving power and high dependence power. The remaining driver "management policies" falls under the driver or independent quadrant; they possess high driving power and low dependence power. Hence, the proposed ISM model and MICMAC analysis will be helpful to supply chain decision-makers to enhance the decision-making process. The study will contribute a clear picture of the importance of the various collaborative drivers.

12.8 Managerial Implications

ISM methodology is a technique that facilitates managers to establish a map of the complicated relationships between various elements in a decision-making process. The theoretical significance of this methodology is that it can clarify a complicated system into a hierarchical model having multiple levels. Its practical significance is to make use of the decision-makers' knowledge to give a fundamental understanding of a complicated situation, followed by a course of action for problem-solving.

The ISM-based model formed in this work will give an insight to SCM decision-makers about the collaborative drivers for the implementation of an SCC. Using this model, the supply chain decision-makers can prioritize the collaborative drivers, take steps to maintain them, and reap the full benefits of SCC. The MICMAC analysis shows that there are no autonomous drivers in the process of implementing SCC. The autonomous drivers are weak dependence and weak driving power, and hence, these drivers do not have much leverage on the system. The absence of autonomous drivers shows that all the considered collaborative drivers are important in the study. The ISM model and MICMAC analysis are the particular contributions of this study.

12.9 Conclusion

It is the necessity of every supply chain to remain competitive, for surviving in this globally competitive environment. This is possible only if all the members of supply chain collaborate with each other. Collaboration in the supply chain has become an emerging part of the supply chain management. Based on the available literature and a consultation with the expert team, 20 collaborative drivers to the implementation of SCC in the manufacturing industry have been identified. The interaction between the collaborative drivers is analyzed and modeled by using ISM-based methodology.

The insights from the ISM-based model are that the collaborative drivers “joint long-term relations”, “appropriate performance measure”, “innovative SC process”, and “resource sharing” are at Level 1 and position at top of the ISM-based model. These drivers have strong dependence power and weak driving power. Similarly, the remaining drivers are found on different levels, and finally, the “management policies” forms the base of the ISM-based model; this driver must be given important consideration by the decision-makers in SC. Thus, the awareness about these collaborative drivers will help the firm to understand and implement SCC. The MICMAC analysis is carried out on the collaborative drivers using the dependence and driving power. The absence of autonomous drivers proves that the considered collaborative drivers have an important role in implementing SCC in the manufacturing sector. Thus, ISM model and MICMAC analysis are considered as important contributions to the literature.

In this work, a relationship model among the collaborative drivers has been formulated using ISM-based methodology. The model is developed on the basis of the interactions among drivers as identified by the expert team having technical and managerial experts in the manufacturing sector and academicians. The limitation of this study is that the model does not give weightage to the drivers, so the proposed model needs to be validated using structural equation modeling, which is the scope for future work. Hence, the proposed model for the manufacturing sector implementing SCC may be built.

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Chapter 13
Significance of Electronic Waste Management for Sustainable Industrial Production

Rishabh Kumar Saran and Shashikant Yadav

Abstract We review the type of toxic substances that exist in e-waste, their impact on environment, health of human beings, and management approaches that are being used to manage e-waste in some developed countries. Several tools like Material Life Cycle Assessment (LCA), Extended Producer Responsibility (EPR), Multi-Criteria Analysis (MCA), and Flow Analysis (MFA) are being used for the management of e-waste in developed countries. Multiple tools working together coherently are required to resolve the e-waste problem.

Keywords E-waste management · Life cycle assessment · Multi-criteria analysis

13.1 Introduction

With the advent of technology, many smart electronic devices are being introduced to the world at a very fast pace, causing the elimination of old and present devices. Factors like advancement in the technology, attractive consumer designs, compatibility, and marketing strategies are responsible for the short lifetime of many electronic goods. A recent study has shown that, in the United States, over 130 million electronic devices are discarded annually which becomes e-waste and the number continues to increase [11, 12]. It mainly includes televisions, computers, and monitors. In China, around 1.1 million tons of e-waste, with a contribution from local electronics manufacturing as well as from imports from developed countries, is generated every year [8, 18].

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Due to financial constraints and longer life of electronic devices, e-waste management is not the main concern for many developing countries. However, import of discarded e-waste from developed countries is a major source of waste in these countries. Due to limited policies and laws and lack of safeguards on the safe disposal of these imported electronic goods, the developing countries have started facing the serious threat to the environment and human health [3, 31, 32, 40]. Some studies have shown that halogenated organic compounds like Polychlorinated Biphenyls (PCBs) and Polybrominated Diphenyl Ethers (PBDEs) and many toxic metals get released from e-waste, which can cause serious harm to the health of human beings and the environment [12, 34, 35]. Countries like China, India, Cambodia, Pakistan, Indonesia, Thailand, and some African countries like Nigeria are the major importers of e-waste from developed countries and are facing problems related to e-waste [5, 6, 8, 19, 20, 33].

Some of these countries are now challenging the problems associated with e-waste and taking strong actions to deaden the e-waste with the advent of management tools and strict laws. Developing countries, including India, China along with few other countries have lately made amendments in their laws to deal with the growing problem of disposal and management of imported e-waste [3, 32, 40]. Additionally, some electronic equipment manufacturers are coming up with plans of safe disposal of e-waste employing modern technologies in both developing and developed countries [8, 11, 12, 23].

13.2 E-Waste Toxicity to Human Beings

Strict and serious actions should be taken on e-waste since the toxic chemicals present in it are causing a big threat to human health and environment. Use of e-waste disposal methods like landfill and incineration are already affecting human health. A case study from China, India, and Ghana has shown that this toxicity from e-waste is affecting human health in both chronic and acute conditions [12, 28]. Also, workers who are involved in the primary phase of recycling e-waste are having a direct impact of toxic materials on their health. Additionally, many natural resources get contaminated by this recycling phase causing toxic substances to enter the food chain and hence transmitting to humans [33].

In the light of findings of some more case studies, exposure of human beings to POPs and toxic heavy metals released from e-waste has an adverse impact on the health of the local inhabitants where the waste is disposed and the people working there. Women and children are worst affected by these toxins [5, 19, 40].

There is already an international environmental treaty that aims to eliminate or prevent the production and use of POPs, viz., Stockholm Convention. However, there have been substantial delays with the enactment of these laws in some countries like the USA, which is one of the largest producers of e-waste in the world [12, 24, 35].

13.3 Impacts of E-Waste on Environment

Though the occurrence of toxic materials in e-waste is known from last 20 years, there are still insufficient laws and legislation of waste management, leading to an enormous growth of e-waste. This rapid growth in a short period of time eventually led to unsuitable e-waste management in both developing and developed countries, causing immense harm to the environment [35].

The impact of e-waste management by disposal to landfills and by recycling has already shown hazardous effects on the environment, which is summarized below.

Recycling

The manual process of recycling e-waste around the world leads to contamination of natural resources like soil, water, and air and causing poisoning to local inhabitants. The major toxic metals that are released from this recycling process include Cr, As, Hg, Ni, Cd, and Pb; organic contaminants include BFRs, PAHs, PBDs, PCBs, etc., which cause contamination of environmental resources [15, 22, 27]. Cities like Gauteng in South Africa, Karachi in Pakistan, Guiyu and Taizhou in China, Accra in Ghana, and New Delhi in India are reported to be extremely polluted due to large-scale e-waste recycling process [3, 28, 31, 32].

Materials eliminated from e-waste recycling process like PCDD/Fs, PAHs, PCBs, and PBDEs are mainly responsible for causing soil pollution in China along with Zn, Cd, Hg, Cu, Cr, Pb, and As in India adding Ag, Bi, In, Sn, and Zn in the list [12, 24, 35].

In China, the concentration of lead in water bodies downstream the e-waste recycling industry was found to be eight times more than the acceptable limits in drinking water. The water has been reported to be contaminated with higher dissolved concentrations of metal salts than the outside [12]. This implies that recycling process in Guiyu results in highly contaminated water quality around this area [34]. As per the studies, the metals such as Ni, Pb, Cd, Se, Ti, Be, Cr, Cu, F, Al, As, Mn, Ni, Zn, Ag, Cd, Co, Mn, Mo, Ca, V, Sr, Fe, Hg, Cr, Li, Mg, Cu, Fe, Sb, and Zn other than Pb are reported to be the most responsible for causing adverse effects of e-waste on water bodies [10, 34, 37, 38].

Results from China shows that Contamination of air takes place due to bromine and chlorine-containing organic compounds around e-waste recycling sites. Also, the concentration of metals like Cr, Cu, and Zn was reported to be several times higher than that of the other countries in Asia [28, 29]. On the other side, in India, metals like Co, In, Mn, Cu, Pb, Tl Sn Cr, Bi, and Sb were found in higher concentrations around recycling sites, as compared to the other referenced sites [1, 16].

Though the information about the nature of toxic substances that are released from e-wastes and their existence in the environment is inadequate, the available studies show that noticeable quantity of released toxic substances is occupying the environment. The presence of these organic and inorganic contaminants is hazardous to the environment as well as to the human health and expected to last for many years [2, 17, 36].

Landfill disposal
Though the newly constructed landfills can isolate the e-waste that has been produced across the globe, researchers have proved that the presence of chemicals and pollutants found in e-waste dumped in the landfill can migrate to soil and groundwater and can still contaminate the soil and environment [10].

A test called Toxicity Characteristic Leaching Procedure (TCLP) has been carried out to measure the potential toxicity of leachates. This test simulates leaching of toxic substances from e-waste disposed of in the landfill in worst case scenario. It determines the physical and chemical properties of solid waste that makes it toxic and hazardous waste. It has been found that, if the device contains any specific element higher than the specified toxicity limits, they are considered to be TC hazardous waste, like electronic devices [12, 14, 28].

Using this test, it was discovered by researchers that a high amount of lead can leach from cathode ray tubes and printed circuit boards of the TVs. Another independent study also found that Pb is the main element that leaches out of printed wire board, along with some other elements. Studies on leachability of PBDEs showed that incineration before landfill decreased the amount of PBDEs released in the environment [3, 19, 33].

13.4 Strategies to Manage E-Waste

Considering the hazardous and intense effects of e-waste on human health and environment in developed as well as developing countries, several tools are being used to manage the e-waste.

These tools are summarized below.

***Life Cycle Assessment* (*LCA*)**
The main purpose of LCA is not only to minimize e-waste problem but also to outline electronic devices in terms of eco-design. Eco-design, i.e., environmental friendly design of products such as printers, desktop computers, washing machines, and toys, can be developed with the help of LCA. It is also a valuable tool to gather information about climate change, ecotoxicity, ozone layer, carcinogens, land use, eutrophication and acidification, and for the enhancement of the environmental performance of goods.

Considering the main application of LCA, i.e., e-waste management, different countries have different approaches of using LCA and the research that has been conducted using LCA in these countries have suggested that recycling is the best approach to manage e-waste than landfilling or incineration [6, 8, 9, 15, 31, 33, 35]. For example, in Switzerland, the case study of six end-of-life scenarios on mobile phones proved that if the materials are recycled, the impact of e-waste is almost two times lesser on the environment. Even Germany agreed to Switzerland with their study. Whereas a study in UK found that landfilling without material recovery is as good as recycling [12].

In Asian countries like South Korea, they use LCA for analyzing the influence of e-waste management, considering both environmental as well as economic factors. Their studies on personal computers disclosed that most effective and environment-friendly way of e-waste management is recycling. However, as per some researches, the environment does get affected where there is a hazardous impact of recycling on the environment [16, 26, 35].

***Material Flow Analysis* (*MFA*)**
MFA is harnessed to study the steps involved in recycling of e-waste at recycling sites or disposal areas. For e-waste management, MFA acts as a decision support tool and can be used to develop proper management protocols.

In Japan, researchers have found that the amount of e-waste recycled has been decreased whereas the amount of reuse and exports amplified considerably. There are multiple methods to analyze the possible amount of e-waste in the region like, market supply method, which provides time for estimation, data for manufacture, and sales in the specific region. Survey method used for MFA found that there are high chances that e-waste production will increase in developing countries like Nigeria, China, Chile, and India. Considering the rapid economic growth and limited data availability, the combination of MFA with economic assessment will be a valuable tool for e-waste management [20, 24, 26, 39].

***Multi-criteria Analysis* (*MCA*)**
Considering quantitative and qualitative problems of problems, MCA is mainly designed for decision making which considers tactical resolutions and resolving multifaceted problems [21]. MCA is being used to address environmental issues like e-waste management to develop alternate e-waste management approaches. Scientists used a six-step method to analyze the "trade-off" between the economic profits and environmental welfares of the EoL of coffee makers process [4, 7, 30].

Researchers in Spain used MCA for the selection of a suitable location for recycling of e-waste, which mainly involved quantitative and economic criteria for choosing locations.

So, in short, though MCA is not extensively employed for e-waste management, it is generally employed for hazardous and solid waste management, and it is one of the useful tools that can be employed in amalgamation with other tools those are being employed for E-waste management [6, 23].

***Extended Producer Responsibility* (*EPR*)**
EPR deals with e-waste management at national level, which includes many advanced nations like Japan, Switzerland, European Union, and some states of US and Canada. The main aim of EPR is to credit the accountability to manufacturers, to take back products after they have used by customers, which is based on polluter-pays principles [11, 12, 16].

Since e-waste is a priority waste, many countries are focusing on treatment and recycling of taking back products. Holland takes back products like big sized household appliances and IT related products and recycles them at a rate of up to 45–75% of weight [18]. UK, Germany, and Switzerland take back the electronic appliances and recycle and recover those products up to 50–80% of weight [27, 35]. Also, Japan, US, and Canada take back used household appliances and recycle them at the rate of 50–80%. On the other hand, in India, due to illegal import of e-waste and vast black market of electronic devices, EPR policies are not that strongly developed. In addition to India, Thailand is also non-OECD country and is still striving to develop EPR policy. Since the government fund is fixed and rigid, EPR has become a costly arrangement for e-waste management. Thailand has employed a product fee system that emphases on buyback of products, which encourages end users to pass material to the recycling sector [12, 16].

13.5 The Characteristic Features of Tools for E-Waste Management

Since the e-waste management is a huge problem, it is necessary to produce eco-designed devices, proper collection of e-waste, recovery, and recycling e-waste using benign techniques, its disposal, and mainly to promote the responsiveness of huge effect of e-waste on the environment and human health. Though many developed countries are actively working on this, it is still difficult to persuade local communities to contrivance such strategies [11, 13, 20].

Among the various tools available for e-waste management, MCA, EPR, LCA, and MFA are being popularly used in many developed countries. LCA mainly focuses on calculation of the economic and environmental aspect associated with EoL of e-waste and the effect of material consumption. It also used to conduct the analysis of product development and eco-design. Because of its better decision taking on e-waste disposal, many countries like Germany, India, Japan, Korea, Columbia, Switzerland, United Kingdom, Taiwan, and Thailand are using it [22, 25].

Countries like China, India, and Nigeria that have large e-waste recycling use MFA to keep the record of where this e-waste is being exported and processed [32]. Considering environmental benefits and economic profits, MCA is employed for choice making and generally not employed for e-waste management. EPR completely concentrates on the program that offers the accountability to manufacturers to take back goods and accomplish the next treatment routes. It is presently used by many countries like Japan, Germany, Thailand, India, United Kingdom, Switzerland, The Netherlands, and some states of the United States and Canada. To summarize, every individual technique has a unique class when employed for e-waste management. Thus, a combination of all these gives the ideal model for e-waste management.

13.6 Conclusion

E-waste is a serious threat to both local and global scales that has appeared in not only developed countries but also in developing countries and around the world. Due to the advance of technology and abolition, e-waste is being produced in massive amount, which contains nothing but toxic chemicals that pollute the environment and has a negative impact on human health. Many tools including MCA, MFA, EPR, and LCA are being used for e-waste management. A single tool may be insufficient and imperfect, but the combination of these tools can help to accomplish triumph in e-waste management.

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