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Anish Sachdeva · Pradeep Kumar ·
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Operations Management and Systems Engineering

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Lecture Notes on Multidisciplinary Industrial Engineering

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Chapter 1
Process and Instrument for Visual Inspection of Mechanical Components for Imperfections Evaluation in Land Removal Equipment

Alex Tenicota, Stalin Nuela, Cristian Redroban, Ángel Larrea, and Luis Contreras

Abstract The lack of a process and an instrument to serve as a tool to control the technical condition and maintenance of land removal equipment in material handling is an acute social and industrial problem. Hence, the definition of these tools is an essential factor of safe operation in the mining, oil, and construction industry, as major sources for the development of a country. Therefore, the results of this investigation are presented based on the objectives pursued by the design, validation, and analysis of the reliability of a process and instrument for visual inspection of mechanical components for land removal equipment, which constitutes an adequate and efficient tool for inspectors, operators, and maintenance team in need to evaluate tolerable imperfections and defects. To validate the results obtained, the Delphi method was applied and the agreement between experts was assessed using Kendall's coefficient. Moreover, the factorial analysis for principal components was carried out to assess construct validity. Thus, it is concluded that the tool represents a source of technical information that supports the decision-making considering operation and maintenance parameters evidenced in the inspection critical routes.

Keywords Process and instrument for visual inspection · Land removing equipment · Mechanical components · Operation and maintenance · Imperfections evaluation

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1.1 Introduction

The handling of materials assisted by land removal equipment should include the following: Scrapers, loaders, trackers or wheel tractors, backhoes, bulldozers, agricultural, and industrial tractors, and similar equipment, designed for heavy-duty jobs [15]. The various industries of oil, energy, construction, and mining, require equipment and technology necessary to perform heavy work and land or materials removal. However, according to the analysis of specialized work in technological development [11, 13], shows the shortage of regulation and control of operation parameters for land removal equipment, even though the productive matrix has undergone changes that represent an increase in productivity, and thus the need to optimize the mining, oil and energy exports, as evidenced by Ecuador.

According to the contributions that describe the Ecuadorian productive context [5, 7, 16], they mention that the industrial activity that uses heavy-duty machinery and land removal equipment has been generally regulated in the operational, health and occupational safety files of the Ministry of Labour and Employment, Ministry of Public Work and Transport and the Ecuadorian Institute of Standardization (INEN), through ministerial agreements, regulations, and rules that are based on parameters or minimum requirements to be fulfilled. However, specialized studies in land removal machinery as known internationally according to [5, 6, 10] recognize that the guarantee of correct management and conservation of the machinery operation needs the control and monitoring of the operation parameters of each component or system that causes economic problems or accidents resulting from failures or breakdowns, which could be overcome through maintenance actions.

According to the information from the scientific contributions of maintenance management, the visual technical inspection is a preventive maintenance activity developed in the operation of critical equipment, [19, 20, 22]. Even more, the specialized contributions in standardization of engineering processes such as [8, 9], consider visual inspection as a method of non-destructive testing or technical tool for monitoring condition and control of discontinuities and imperfections in operating parameters. "Discontinuities and tolerable imperfections may be considered as important defects to determine the rejection or repair of an object" [12].

The public and private companies belonging to the industrial sector, comply with international standards set out mainly by the Society of Automotive Engineers SAE, American Society of Mechanical Engineers ASME, American Society of material testing ASTM, and international standards organization ISO, which regulate the context of the production system of transportation processes under quality guidelines. For the sustainable operation of the land removal equipment as part of a productive system, regardless of the industrial sector, there is a need to regulate the vehicular fleet due to frequent failures in systems and components, which according to [2, 3] are caused by an unregulated working environment resulting in over-exertion, poor installations, lack of lubrication and contamination of lubricating oil. Despite this fact, several contractors who offer the service of land transportation using land removal equipment, in the great majority of Ecuadorian productive systems, have not evidenced the fulfilment of visual technical inspections based on the study of the operation parameters considering conformity or inconformity criteria of the working conditions demanded by international institutions.

It is therefore appropriate to identify discontinuities or imperfections, considering the operation and maintenance conditions of the mechanical components through a well-grounded, valid, and reliable visual inspection process. This research leads to the definition of strategies that promote technological, academic, and decision-making development, supporting the production and quality service of the public and private industrial sector, to regulate the operation of land removal equipment. The implementation of the process and the proper use of the visual inspection instrument as a condition monitoring strategy would be the most viable alternative, the same that at least should respond to the following questions: what are the imperfections to consider as a defect or tolerable for inspection?, what are the critical routes that evidence greater inspection results in mechanical components of the land removal equipment? and in which components are evidenced major problems of dissatisfaction recorded in inspection processes of land removal equipment?, as long as it agrees with the established high level of confidence and public acceptance.

The aim of the research is to show the results of the definition, validation, and analysis of the reliability of the process and instrument for visual technical inspection of mechanical components for the removal equipment to evaluate imperfections. For meeting the target, it is necessary to carry out tests, to compile and analyze criteria of professionals that take part in the operation and maintenance of land removal equipment in diverse industrial sectors. It is necessary for the instrument to consider the operating parameters according to standardized and field-experienced criteria, so they possess characteristics of measurement and assessment in the development of visual inspections. Therefore, the incidence of the defects can be identified, thus trying to determine the improvement actions to avoid possible breakdowns or accidents, with the optimization of essential activities of corrective, preventive, and improving maintenance (scheduled or unscheduled) [4, 21].

1.2 Methods and Materials

It constitutes an application research, transversal and non-experimental, formed in three stages: (a) Design of the process and instrument, (b) evaluation of its reliability and validity of content and, (c) analysis of the construct validity. The stages were described after the conceptual revision of the constructs as follows:

(a) Design of the process and instrument

The bibliographic review and the analysis of the information were necessary to specify and summarize the characteristics that define the normal working conditions to be considered for the structure of the process and instrument design. The basis of the approach for the design of both the process and the instrument was dimensioned by the functional, environmental, and documented data from inspections, of which 32 subdimensions were reviewed, which lead to the formulation, presentation and writing of 40 initial items that constitute the instrument. The formulation of the instrument documentary for the visual technical inspection of land removal equipment was defined to collect data from sources evidenced in the field according to the detail of sensitive or critical mechanical components. For the study, the regions with the highest humidity conditions were considered, such as the Amazon and the coast of Ecuador that utilize land removal equipment the most. The cases of mining, polyducts, constructions that require the process of land removal were considered for the study.

The evidence to be collected in the inspection process consists of the description of the functionality levels for the land removal equipment obtained from the status review of the mechanical components found in the inspection routes. In the inspection, routes are grouped the mechanical components to be monitored, according to standardized catalogues, called Caterpillar checklist, due to the mentioned company is the main manufacturer of land removal equipment. The critical inspection routes selected for the present study were located from different visual points including the view from the round, top view on the equipment itself, in the engine compartment, and inside the operator's cabin.

For the detail of critical components, catalogues of the main manufacturers distributed in the medium were taken into account, in addition to technical documents of international regulation specialized in machinery inspection topics, like the standard of railway and mobile cranes; ASME B30.5: 2014, standard of articulated cranes; ASME B30.22: 2016, safety standard for low and high lift trucks; ASME B56.1: 2010, so for each system the work capacity, safety measures and the levels of defects or faults that may occur were described.

For the selection of the logic of inspections, the results developed in scrapers, loaders, tractors, and excavators used for the assembly of petroleum derivatives pipelines as in [14], were taken as reference. Figure 1.1 shows the process of inspection for land removal equipment and details each of the stages.

Step 1. In the general data collection, the person in charge of the inspection gathers the information of the extension of the route, concentration points, responsible for operation and maintenance of each machinery, place and time in which the work is carried out and highlights the use of reference standards to explain the objectives and scope.

Step 2. In the contractor data survey or so-called company providing machinery services for land removal, the person in charge of the inspection reviews evidence that certify the fulfilment of technical norms and regulations of transit according to demand the productive process and contractual responsibilities are established.

Step 3. In the collection of the technical data of the equipment, the person in charge of the inspection gathers information that contemplates technical characteristics of the vehicle (Fig. 1.2) such as model, year of manufacture, mileage, load capacity, tonnage, type of transmission, and traction mode.

Step 4. In the inspection of the systems, the operating and service conditions are registered and evaluated, in five inspection routes observed from lower view

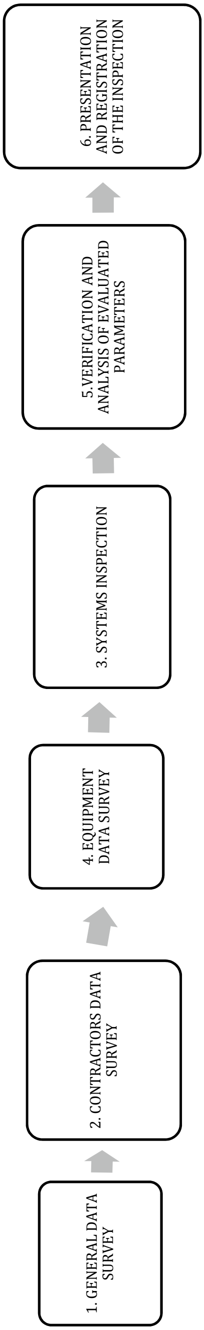

Fig. 1.1 Stages of the visual inspection process for land removal equipment

Fig. 1.2 Technical characteristics of the vehicle

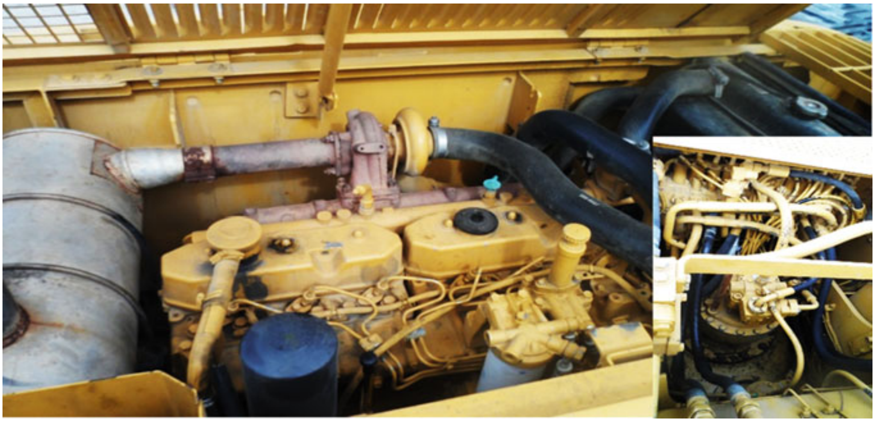

Fig. 1.3 Mechanical components to be inspected in the engine compartment route

without stepping onto the equipment, top view on the equipment itself, in the engine compartment (Fig. 1.3), and inside the operator's cabin (Fig. 1.4). The inspection reflects results according to the criteria of conformity and nonconformity, in the case of existing defects such as leak, crack, wear, cut, corrosion, or significant deformations that limit the operation of essential systems, such as hydraulic system, mechanical transmission system, electrical system, controls and signage, and lifting system. On the other hand, tolerable imperfections are considered as cases of dirt, missing minor mechanical elements, and low levels of fluids.

Step 5. In the verification and verification of evaluated parameters, the inspector and personnel responsible for the operation of the land removal equipment consolidate the results in the inspection and detail the assessments, in summary, showing the conformity or nonconformity according to technical discussions in agreement with regulations.

Fig. 1.4 Components to be inspected in the engine compartment route

Step 6. In the presentation and registration of the inspection, "the consolidated results are presented in reports to the industry supervision area in this case to certified companies that meet state requirements such as the case of the Ecuadorian Accreditation Service" [1].

(a) Reliability assessment and content validity of the instrument.

In order to understand the content validity, the Delphi method was applied with the purpose of defining the convergences, discrepancies, and consensus, on the viability of the documentary instrument and the proposed inspection procedure. Initially, a first-round survey consultation was conducted via email, to a significant sample of 35 professionals, selected with a margin of error of 5 and a 95% confidence level of a total of 38 technicians immersed in the inspection who work or who were part of certification companies in the country. The participation of the interviewees was used to define the level of knowledge about the operational context of the equipment for land removal within the mining, oil, and construction industry that requires the process of land removal. The determination of the coefficient of expertise k, categorized the people with more experience, relevance, and training.

To select the experts through the second round of questions, criteria of knowledge and argumentation (K_c, K_a) were considered, of which 60% were engineers who currently belong to the main certifying companies in the country, and the remaining 40% are engineers who previously participated in technical inspections of the operation for land removal equipment. The second round of questions to the selected experts was carried out in two stages so that in the first stage, the group of main parameters for the inspections were obtained and in the second stage, two additional parameters were incorporated according to the observation expressed by the participants. These questions referred to the selection and qualification of the level of incidence in the acceptance "conformity", rejection "nonconformity" or observation of parameters to be measured by mechanical components of the land removal equipment, taking into account the incidence they have to cause defects or failures

To support the reliability of the instrument, the Cronbach's Alpha was calculated, and to establish the agreement between the criteria of the experts, the analysis was carried out through the Kendall coefficient W when dealing with ordinal data. According to the work specialized in non-metric statistics [17] 1995, the Kendall coefficient is used when you want to know the degree of association between k sets of ranks, so it is especially useful when the experts are asked to assign ranges to the items, for example, from 1 to 4. The coefficient is 0 and the maximum 1, which is based on the sum of the ranges obtained from the different experts, it represents the minimum value assumed by the coefficient as 0 and the maximum as 1. "In the case that the coefficient is 1 shows perfect agreement among the evaluators, if it is 0 shows that the agreement is not greater than that expected at random, and if the value of the coefficient is negative the level of agreement is lower than expected at random" [18].

(b) Construct validation of the proposed instrument

The factorial analysis was performed by main mechanical components to evaluate the construct validity of the instrument and the logic of the inspection process. It was necessary to identify the existence of a correlation between the variables of the instrument by means of the Bartlett sphericity test, with which the factorial analysis was proven to be useful. As a reference, it was considered adequate for the values reached of $\alpha < 0.05$, and the Kaiser–Meyer–Olkin (KMO) sample adequacy measure, which indicated the intercorrelation of variables as a feasible value, for figures greater than 0.7. Next, the main results are presented:

Results of the reliability analysis and validation of the instrument's content
The results of the first survey to the 38 professionals with experience in inspection show that 35 experts determine the totality of high and medium knowledge of the inspection process according to the critical routes proposed. The coefficient of competence of 82.3% (28 experts) is justified by experts with 5 or more years of experience in the inspection of land removal equipment according to similar work carried out and only 17.5% (7 experts) obtained an average level, justified between 1 and 5 years of experience and different arguments in the logic of the inspection process.

Regarding the second round, the knowledge coefficient (K_c) of 12 and 15 expert cases was around 0.9 and 0.8, respectively, as well as 2 and 6 cases between 0.6 and 0.7. With these results, it was decided to use the study for all the experts.

Of the 35 experts surveyed according to the individual criterion, a standardized Alpha coefficient of 0.7721 was obtained in accordance with the items mentioned in the instrument in which different levels of incidence are evidenced for the assessment of imperfections in mechanical components. Thus, reflecting acceptable reliability of the same. The symmetry of the items shown in Table 1.1 is adequate, as shown

Table 1.1 Results of the first phase reliability analysis of the designed instrument

Items (Critical routes of inspection)	Level of incidence for the assessment of imperfections detected in mechanical components of land removal equipment						Individual variance/total variance	Individual variance/total variance	Individual Alpha
	Very high	High	Medium	Low	No incidence	Surveyed			
From the ground	16	14	3	2	0	35	0.28644	0.71356	0.73455
On the machine	12	12	5	6	0	35	0.23709	0.76291	0.78535
In the engine compartment	11	19	3	2	0	35	0.26622	0.73378	0.75536
Inside the cabin	12	7	7	9	0	35	0.21025	0.78975	0.81298
Sum of variances				8.6255					
Criteria				Reliability coefficient (absence)				0 a 0.59	
				Reliability coefficient (acceptable)				0.59 a 0.99	
				Reliability coefficient (ideal)				1	
Reliability coefficient CRONBACH				0.7721					

Table 1.2 Results of the instrument application to the experts in the second round

Stages of the technology for management	Category 1 very high	Category 2 high	Category 3 medium	Category 4 low
From the ground	0.5294	0.9412	0.9706	1000
On the machine	0.7941	0.8529	0.9706	1000
In the engine compartment	0.5588	0.9412	1	0.3467
Inside the cabin	0.5294	0.8823	0.9118	1000

by the values of variance, so we can say that bias due to the lack of independence of the data is not supported empirically.

Knowing that the results of the first round of surveys to the experts is not enough, the second round shows proportional values of relative frequencies of each critical inspection route analyzed, which reflects the opinion of experts according to each determined category, see results in Table 1.2

The category of high level of incidence to assess the defects in mechanical components is composed of 4 items of the critical routes valued with scores greater than 0.50. The category of very high incidence level to assess the defects in mechanical components reflected higher cases for critical routes grouped on the machine, in the engine compartment, and inside the operator's cabin with higher frequencies over 0.8 which reflects the percentage ratio of the number of mechanical components of the mentioned route. In the category of high incidence all the stages were kept between the frequencies of 0.91 and 1.00, and for the medium incidence reached the frequency of 1.00 shown a greater number of mechanical components that are part of the inspection in these routes, however, the route in the engine compartment is the only one that showed a lower value in the fourth category, demonstrating that most mechanical components show an incidence in the assessment of the imperfection.

The results show that most of the experts categorize the inspection routes understudy, in very high and high incidence of cases that evidence nonconformity criteria or defects in mechanical components documented in inspections of the land removal equipment. This means the degree of adequacy of the mentioned instrument, therefore, the instrument is suitable to be applied. Once the construction of the instrument was finished, the concordance analysis by means of the Kendall Coefficient of Concordance was performed and its results show that the items of the instrument measured the same construct in consideration of the basic principles of Sufficiency, Clarity, Consistency, and Relevance. The results shown in graph 1 differentiate each category according to each concordance coefficient which coincided higher than 0.75 in all cases, so that statistically ($p < 0.05$) are significant. The results of the Kendall coefficient show that there was a high level of agreement among the experts as to what was measured in the instrument, therefore validating the instrument.

Table 1.3 Results of the factorial analysis of main components

Variables	KMO	*P* value	Factors**		
			1	2	3
– From the ground	0.835	0.000*	0.858		
– On the machine			0.825		
– In the engine compartment			0.769		
– Inside the operator's cabin				0.734	
– Less critical mechanical components from all inspection routes					0.672

Note * $p < 0.05$, ** C

Results of the construct validation of the proposed instrument (Factorial analysis by main components)

The application of the multivariate technique to evaluate the construct validity called the Bartlett test was statistically significant ($p = 0.000$), moreover, in the sample adequacy measure of KMO, 0.835 was obtained. The results of the multivariate technique are described in Table 1.3, where the correlated instrument variables plus a fifth variable that combines shared characteristics are identified. The technique of analyzing the main mechanical components that compose each inspection route was applied, were chosen some of the elements such: Axles—Final controls, differentials, brakes, hydraulic lines, hydraulic oil tank, bucket, rod bucket cylinder, retainers, windscreen wipers, windscreen washer, bar, frame, body, tires, pivot or swivel, hoses, and radiators (Figs. 1.5, 1.6, 1.7 and 1.8).

The main components were selected due to their higher volume of documented cases or evidence of imperfections evaluations such as defects around 81.8% of the total variance, and in the Varimax rotation, better representation and classification of coefficients are shown. The results of each represented and classified component show an easy interpretation, reduction of the items, and the group of three factors explained by this method, which give an approximate (81%) of the total variance.

- Factor 1: Intrinsic aspects to valuations of rejection or nonconformity imperfections. This factor relates the assessment results of crack (*see example in* Fig. 1.9), wear, corrosion or leaking defects, that show a high probability of occurrence in the mechanical components of the inspection routes from the ground of the equipment, on the machine, and inside the engine compartment of the earth removal equipment.
- Factor 2: Extrinsic aspects to valuations of rejection or nonconformity imperfections. This factor relates the assessment results of crack, wear, cut, or deformation defects that show a high probability of occurrence in the mechanical components of the inspection routes within the operator's cabin
- Factor 3: Aspects of valuation of tolerable imperfections. This factor is related to the results of the classification of cases of dirt, missing mechanical elements, low

Fig. 1.5 Hydraulic lines

Fig. 1.6 Bucket

Fig. 1.7 Tires or undercarriage

Fig. 1.8 Hydraulic oil tank

Fig. 1.9 Cracked tire

levels of fluids occurred, or the ones that manifest high probability of occurrence in the mechanical components of all routes

The results of the validation and reliability analysis show that the instrument allows to obtain objective, reliable and valid information on the evaluation of imperfections manifested as defects or tolerable within a process of visual inspection considering the parameters of operation and maintenance of components mechanics for land removal equipment describing their technical condition.

Regarding the results obtained during the inspection, they show conformity and nonconformity assessments according to the type of imperfection found, however; It should be understood that such assessments could be common in various types of road equipment, but in different operational contexts could vary depending on the workload, the city, the conditions of the roads and the type of maintenance that is carried out. The findings match with what was shown in the visual inspection work on the Cuenca—Pascuales pipeline [14], which constitutes in the technical condition determination of the road equipment from contractor companies.

The research contributes with the increase of the useful life of the mechanical components in each system by means of the identification of the imperfections evidenced by each of the experts interviewed, which confirmed cases of leakage, crack, wear, cutting, corrosion, and deformations, as determinants for the assessment of nonconformity or defect, and in the same way with tolerable imperfections. Moreover, the investigation showed the detail of the cases of nonconformity valuations of the main equipment for land removal, such as Excavators, Loaders, Bobcat, Bulldozer, which were displayed to each expert interviewed according to their experience in inspection and generated databases.

The main limitations of the study are summarized in the absence of the level analysis of agreement among the inspectors, therefore the results should be carefully reviewed before generalizing or extrapolating to another context not yet explored, and the sample size should have been increased for the multivariate analysis for future research.

Finally, it is recommended to carry out studies with more inspections that are part of diverse operation and maintenance conditions accordingly identified, and to gather several inspectors for each case, so that the observed variables could be affected in different ways.

1.3 Conclusions

The process and visual inspection instrument of mechanical components allow obtaining an objective, valid and reliable assessment of the imperfections which may be tolerable, and rejection of nonconformity.

The way in which the data was collected allowed us to study the level of incidence for the assessment of imperfections detected in mechanical components of land removal equipment. Thus, the instrument under the designed procedure provides a large amount of information that supports the decision-making, based on the operation and maintenance parameters that constitute the technical state of the equipment, which are shown in the critical inspection routes.

The result in the medium term is the identification of priorities for the development of maintenance activities of mechanical components classified by critical sectors that affect vehicle performance. The technical instruments that support the quality of the inspection processes contribute as a first-hand alternative to guarantee the functionality of the equipment and road safety.

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Chapter 2
Development of Computer-Aided System to Generate Tool Path for Single Point Incremental Forming Process Using MATLAB

Dhanna Ram, Vikas Sisodia, Mudit Sand, and Shailendra Kumar

Abstract In the present paper, the work involved in generating tool paths for different part geometries using Single-point Incremental Forming (SPIF) process is discussed. The part geometries are cone, pyramid, cone with varying wall angle (with circular generatrix), pyramid with varying wall angle (with circular generatrix), hybrid shape (combination of cone and pyramid), hybrid shape with varying wall angle (with circular generatrix), parabolic and hemispherical. For this various SPIF process parameters were considered while developing MATLAB GUI based code. It takes SPIF parameters as inputs (geometric and forming parameters) for generating the required tool path. For the said geometries two tool path types are considered, i.e., incremental/profile and spiral/helical tool path. Tool path thus generated is first simulated using GWizardE (CNC program simulation software) and then validated using SPIF process setup. The said program can be used for tool path planning and generation for multistage Incremental Sheet Forming (ISF) process also. The present work is undertaken with the aim to reduce computational effort required for generating tool paths and to save time and cost for experimentation and research work in the domain of SPIF process.

Keywords Incremental sheet forming (ISF) · Wall angle · Step size · MATLAB · Graphical user interface (GUI) · Computer-aided design (CAD) · Computerized numerical control (CNC)

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Nomenclature

D	Top diameter of cone
d	Tool/punch dimeter
h	Forming height/depth
ISF	Incremental sheet forming
p	Step size or pitch
r	Tool/punch radius
SPIF	Single point incremental forming
∅	Wall angle or forming angle
CAM	Computer-aided manufacturing

2.1 Introduction

Single Point Incremental Forming (SPIF) is an advanced sheet metal forming process for the production of sheet metal prototypes and parts. It does not require a dedicated punch and dies system for forming of sheet as compared to other conventional sheet metal processes [1]. It can be easily carried out on three-axis CNC conventional milling machine. Desired target geometry is first modelled with the help of CAD software and then using Computer-Aided Manufacturing (CAM) software, tool path is generated in terms of G-code and M-code (i.e. CNC programming). A schematic layout of SPIF process is shown in Fig. 2.1. Researchers have applied SPIF process in many areas starting from medical and biomedical areas with the manufacturing of human prosthesis and skull cavity to some of the very complex industrial parts used in high-end aeronautical and automobile applications [2]. It is evolving an advanced sheet metal process that can be used for manufacturing of sheet metal prototypes with less setup and tooling cost [3, 4]. Tool path is generated using costly CAM software packages like Mastercam, Catia, etc. Cost of such software packages is significant. These CAM packages are not specially designed for the forming processes like SPIF process. The objective of present work is to develop a low cost and easy to use program which can generate tool path for selected part geometries.

Worldwide researchers have applied their efforts to develop a strategy to generate tool path in the domain of SPIF process. For example, Skjoedt et al. [5] applied efforts to develop a dedicated program that uses the coordinates of profile milling CNC code and converts them into a helical tool path with continuous feed in all the three axial directions. It is reported that the proposed helical program works satisfactorily only for pyramid and conical shape but for muffler, coordinates were divided into two sections in order to produce the required part. However, this work does not replace the requirement of CAM software package for generating the CNC codes. Malhotra et al. [6] proposed a strategy to generate spiral toolpath program for single point incremental forming. It is reported that better and accurate tool path was obtained in proposed methodology along with the reduced forming time as compared

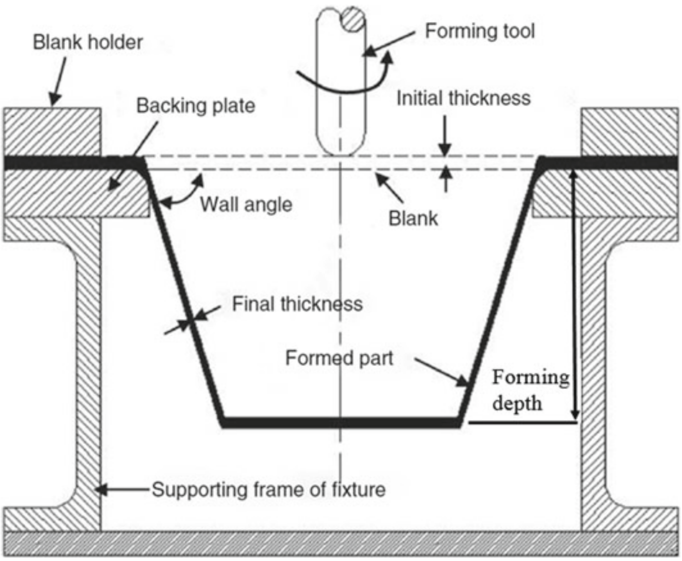


Fig. 2.1 Schematic representation of single point incremental forming [3]

with commercial CAM toolpath. This methodology can handle symmetric as well as asymmetric shapes and was a step toward automation of toolpath generation for incremental sheet forming process.

Lu et al. [7] developed feature specific tool path planning and generation algorithm for ISF process. It was pointed out that the tool path was generated according to specified critical edges with reduced forming time. Zhu et al. [8] proposed a spiral tool path generation method with constant scallop height based on the triangular mesh model. It was concluded that the proposed method was capable of generating a spiral tool path with constant scallop height according to the given tool radius. From the literature review, it is observed that very less efforts have been applied to develop a dedicated system for tool path planning and generation for SPIF process. The commercially available CAM packages are costly as well as it requires significant efforts and time in learning and operating them. Therefore, there is a need for developing such a system that can generate a tool path for various selected geometries. The proposed MATLAB based code can effectively generate tool path (both spiral, i.e., helical and profile) for several different experimental geometries (conical frustum, rectangular pyramid, hybrid, parabola, hemispherical, conical frustum with varying wall angle, pyramid with varying wall angle). Also, it takes SPIF process parameters (geometric parameters as well as forming parameters) as input for generating tool paths. The present work can also be used for multistage incremental sheet forming.

2.2 Steps Involved in Tool Path Generation

The complete tool path generation using the proposed system is done in three simple steps. It involves loading of program into editor window of MATLAB software. Thereafter run command is given. A graphical user interface pops up on the screen in which selection of tool path type (profile or spiral) and shape (cone, pyramid, etc.) can be done as per research work's requirement then click on proceed. After clicking on proceed another GUI pops on to the screen in which input of forming parameters like feed (in mm/min), spindle speed (in rpm) cutter diameter (in mm) and dimensions of selected shape along with the wall angle to be formed and step size needs to be given.

After supplying these necessary inputs which control the process click on generate. The required CNC program is generated in command window of MATLAB. From here the tool path can be copied and fed in the controller of CNC machine. The complete step by step procedure for tool path generation is shown in Fig. 2.2. The said procedure for tool path planning and generation is easy to use and does not require any special learning.

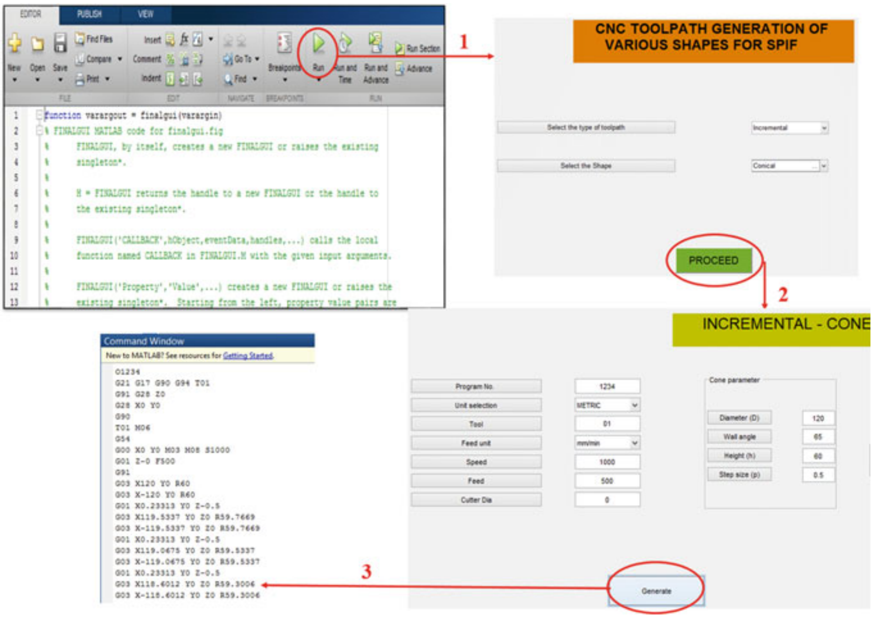


Fig. 2.2 Step by step procedure for tool path generation

2.3 Incremental or Profile Tool Path

For such type of tool path, the tool moves in one plane (say *x*–*y* plane) till it comes back to its initial point in single loop. Thereafter it moves in vertically downward direction. The vertically downward motion is defined by step size. In the second loop, after reaching to next plane tool continues its motion similar to that of an earlier loop. This process continues till the complete geometry is deformed. The profile tool path is as shown in Fig. 2.3.

In order to generate a profile tool path for conical geometry following geometrical parameters and forming parameters are taken as input. They are also represented in Fig. 2.4.

1. Top diameter of cone (D)
2. Forming depth (h)
3. Tool diameter (d)
4. Wall angle (ϕ)
5. Step size (p).

For such geometries generally, tool contact point does not change and amount of radius compensation to be provided remains the same throughout the geometry.

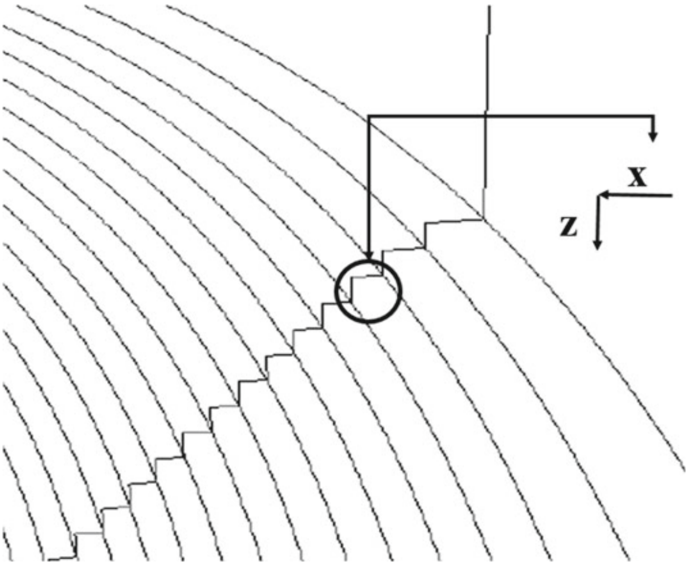
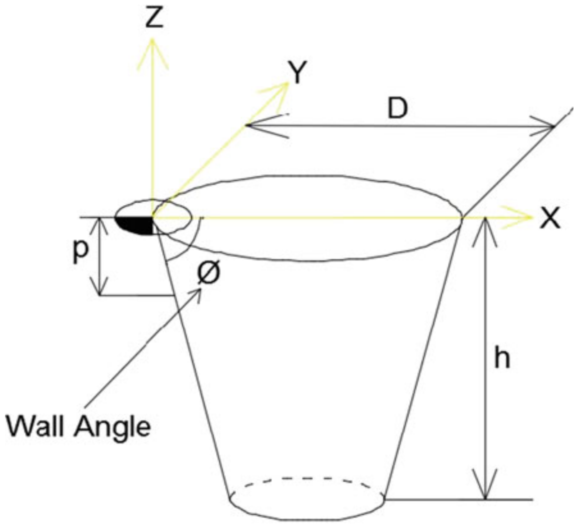


Fig. 2.3 Structure of profile tool path [5]

Fig. 2.4 Conical frustum



Hemispherical ended tool is used in SPIF process, so tool radius compensation is given by

$$r_1 = r \times \sin \varnothing \tag{2.1}$$

where r is tool radius and ϕ is wall angle. It can be set zero as per requirement. First tool comes at $x = r_1$, $y = 0$ and $z = r \times (1 - \cos \varnothing)$ from machine zero. After this, incremental mode is applied. As one complete circular movement is made in two halves, so from here tool makes counter-clockwise circular interpolation with radius $\frac{D-2\times r_1}{2}$, another counter-clockwise circular interpolation with radius $\frac{D-2\times r_1}{2}$ this is the end of first loop. Now tool moves in x-direction by amount $p \times \cot \varnothing$ and as well as in z-direction by amount p, where p is step size. As one complete circular movement is made in two halves, so from here tool makes counter-clockwise circular interpolation with radius $\frac{D-2\times r_1-2\times b\times p \cot \varnothing}{2}$, another counter-clockwise circular interpolation with radius $\frac{D-2\times r_1-2\times b\times p \cot \varnothing}{2}$, where b is step number and it ranges from $1 \le b \le \text{nos}$. Number of steps (nos) is given by the relation

$$\text{nos} = \frac{h - r \times (1 - \cos \varnothing)}{p} \tag{2.2}$$

To repeat the above cycle until the complete desired forming depth is achieved, while loop is used in MATLAB, a sample of which is given Appendix 1. Tool path simulation of the generated program is performed using GWizardE (a CNC program simulation software package). The result of the simulation is as shown in Fig. 2.5. From Fig. 2.5 various views of constant wall angle conical frustum can be seen.

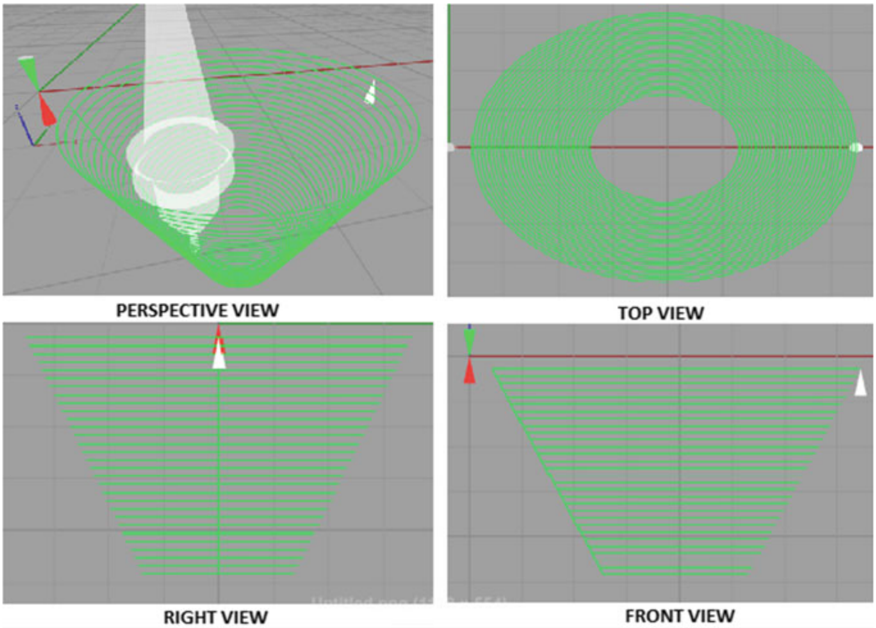


Fig. 2.5 Tool path simulation of conical frustum

Further validation of this generated tool path using MATLAB is performed on the SPIF setup as shown in Fig. 2.6.

The formed component is shown in Fig. 2.7. The validation of the generated tool path is performed using 1 mm thick AA1050 aluminum alloy sheet. Therefore,

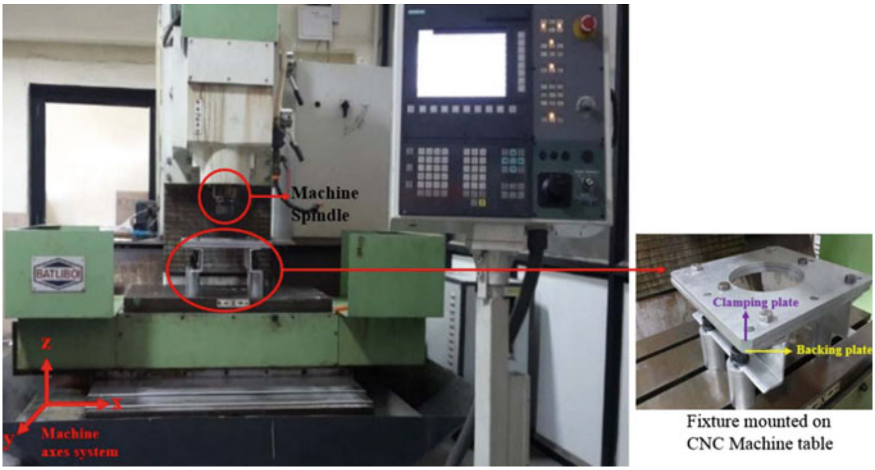


Fig. 2.6 SPIF process setup for validation of generated tool path [1]

Fig. 2.7 Validation of constant wall angle conical frustum

the proposed method of tool path planning and generation successfully gives the required CNC program for different shapes used for research work. In a similar manner profile or incremental tool path for a rectangular pyramid, hybrid shape (combination of cone and pyramid), parabolic, hemispherical, Conical frustum with varying wall angle (circular generatrix) shape can be generated (Figs. 2.8 and 2.9).

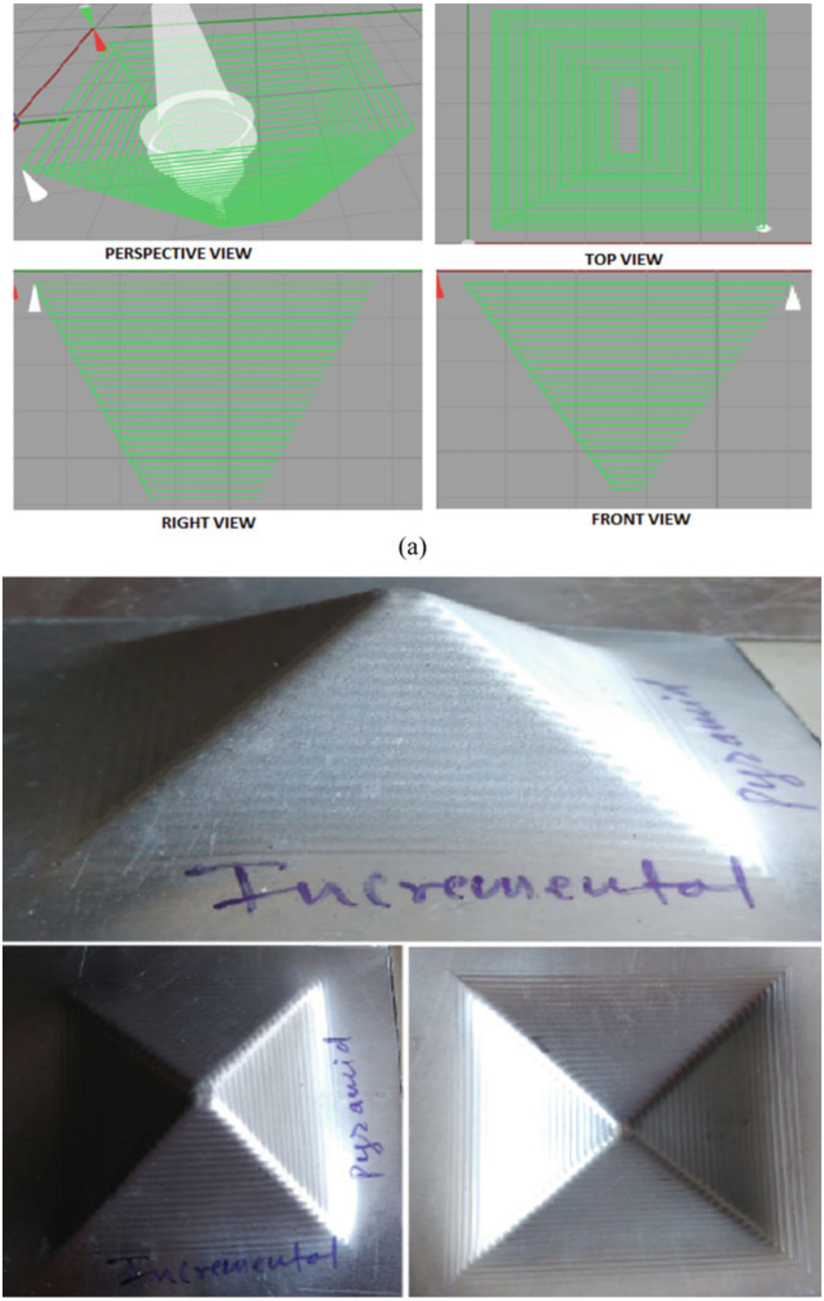


Fig. 2.8 **a** Tool path simulation of pyramid. **b** Validation of pyramid on SPIF process setup

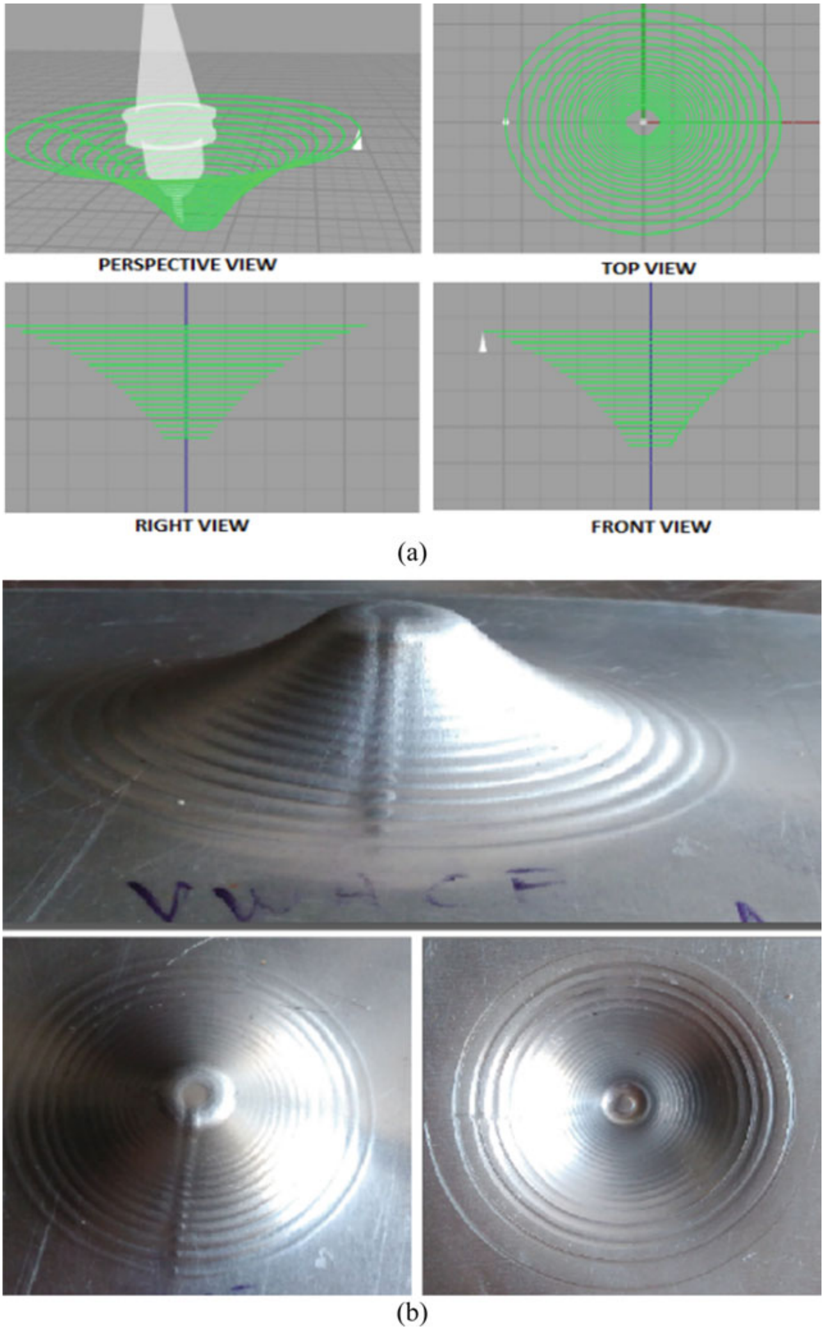


Fig. 2.9 **a** Tool path simulation of varying wall angle cone. **b** Validation of varying wall angle cone on SPIF process setup

2.4 Spiral or Helical Tool Path

Profile tool path is capable of producing any complex geometry. But one of the major demerits of profile tool is that it causes scarring on the surface of the part [5]. This is undesirable on parts that are aesthetically important. However, it can be minimized by diverting it to some converging surface or along the edges of the shape. One other way is to deform the sheet metal with the help of spiral tool path. In the spiral tool path tool continuously move along the *x*–*y* plane and simultaneously the feed is given in *z*-axis. This eliminates the scarring problem. This way spiral tool path gives better surface properties as compared to profile tool path (Fig. 2.10).

In order to generate spiral tool path for conical geometry, geometrical parameters and forming parameters such as diameter of cone (D), forming depth (h), tool diameter (d), wall angle (ϕ), step size (p) are taken as input. They are also depicted in Fig. 2.4. In spiral tool path, tool moves along the periphery while maintaining a gradual helix along the vertically downward direction (depth or *z*-direction). The distance from one particular point in a loop to the corresponding point on the consecutive loop is constant and is termed as step size. For such geometries, generally, tool contact point does not change and amount of radius compensation to be provided remains same throughout the geometry. Generally, the hemispherical ended tool is used in SPIF process, so tool radius compensation is given by Eq. (2.1).

In spiral tool path radius varies continuously throughout the geometry. Radius varies according to the following expression.

$$R = A + (B \times \theta) \tag{2.3}$$

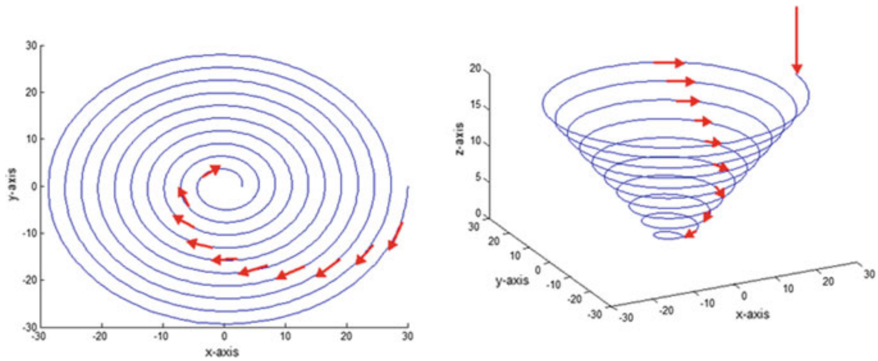


Fig. 2.10 Spiral tool path [9]

where A and B are constants and θ is angle made by circular arc with central axis of the cone.

Now by applying boundary conditions

(i) At $\theta = 0$.
R is also given by $R = \left[\frac{D}{2}\right] - r_1$ so, Equating both the terms of R

$$\left[\frac{D}{2}\right] - r_1 = A + (B \times 0)$$

We have $A = \left[\frac{D}{2}\right] - r_1$.

(ii) At $\theta = 2\pi$.

$$R = \left[\frac{D}{2}\right] - r_1 - p \times \cot \varnothing$$

Equating $\left[\frac{D}{2}\right] - r_1 - p \times \cot \varnothing = \left[\frac{D}{2}\right] - r_1 + B \times 2\pi$.
We have as $B = -\frac{p \times \cot \varnothing}{2\pi}$ and by putting the values of A and B in Eq. (2.3)

$$R = \left[\frac{D}{2}\right] - r_1 - \frac{p \times \cot \varnothing}{2\pi} \times \theta \tag{2.4}$$

In the present work generation of spiral tool path for conical geometry one loop is divided into eight parts, so θ in each interval is 45° as shown in Fig. 2.11. First tool returns to $x = r_1$ $x = r_1, y = 0$ and $z = r \times (1 - \cos \varnothing)$ from machine zero. After this incremental mode is selected. Since one complete circular loop is made in eight parts, so from here tool makes counter-clockwise circular interpolations with radiuses r_1, r_2, r_3, r_4, r_5, r_6, r_7 and r_8 (as shown in Fig. 2.11) with simultaneously motion in

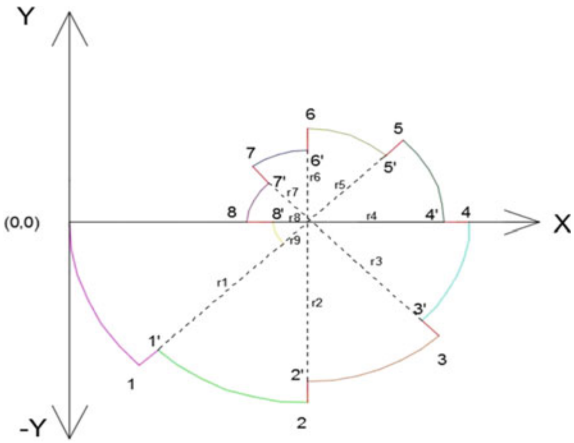


Fig. 2.11 Movement of the tool in one loop in spiral tool path

z-direction (vertically downwards). This completes one first loop. In next or subsequent loop r_1 becomes r_9. To repeat the above loop until the desired forming depth is achieved, while loop is used in MATLAB software, which is given in Appendix 2. In similar manner spiral tool path planning and generation can be done for pyramid, cone with varying wall angle (with circular generatrix), pyramid with varying wall angle (with circular generatrix), hybrid shape (combination of cone and pyramid), hybrid shape with varying wall angle (with circular generatrix), parabolic and hemispherical geometries. First simulation of the generated CNC program is performed using GWizardE (a CNC simulation software package) and thereafter its validation is done on SPIF process setup (as depicted in Fig. 2.6). The spiral tool path simulation along with its validation of conical geometry is depicted in Fig. 2.12.

2.5 Conclusion

In the present work, efforts have been applied to generate CNC program for two tool path types using MATLAB. The generated tool path is simulated in CNC simulation software package and validated using SPIF process setup. For simplicity and ease of use, a GUI has been prepared to select the tool path type and thereafter selection of geometry parameters and forming parameters. The work eliminates the need of purchasing the costly CAM software package (for example Mastercam, Catia, etc.) as far as an experiment related to research work is concerned. Hence time required for learning and operating such software is also eliminated. The present work can be further extended for other part geometries depending upon the requirement. This work can also be used for multistage incremental forming. Since it takes geometrical and forming parameters as input, so with such input one has better control over the process and its characteristics. However, the present work does not eliminate the requirement of CAM software completely. For producing complex industrial sheet metal parts CAM software package is required. If any industrial part resembles the shape discussed in the present work then the proposed MATLAB code can be applied.

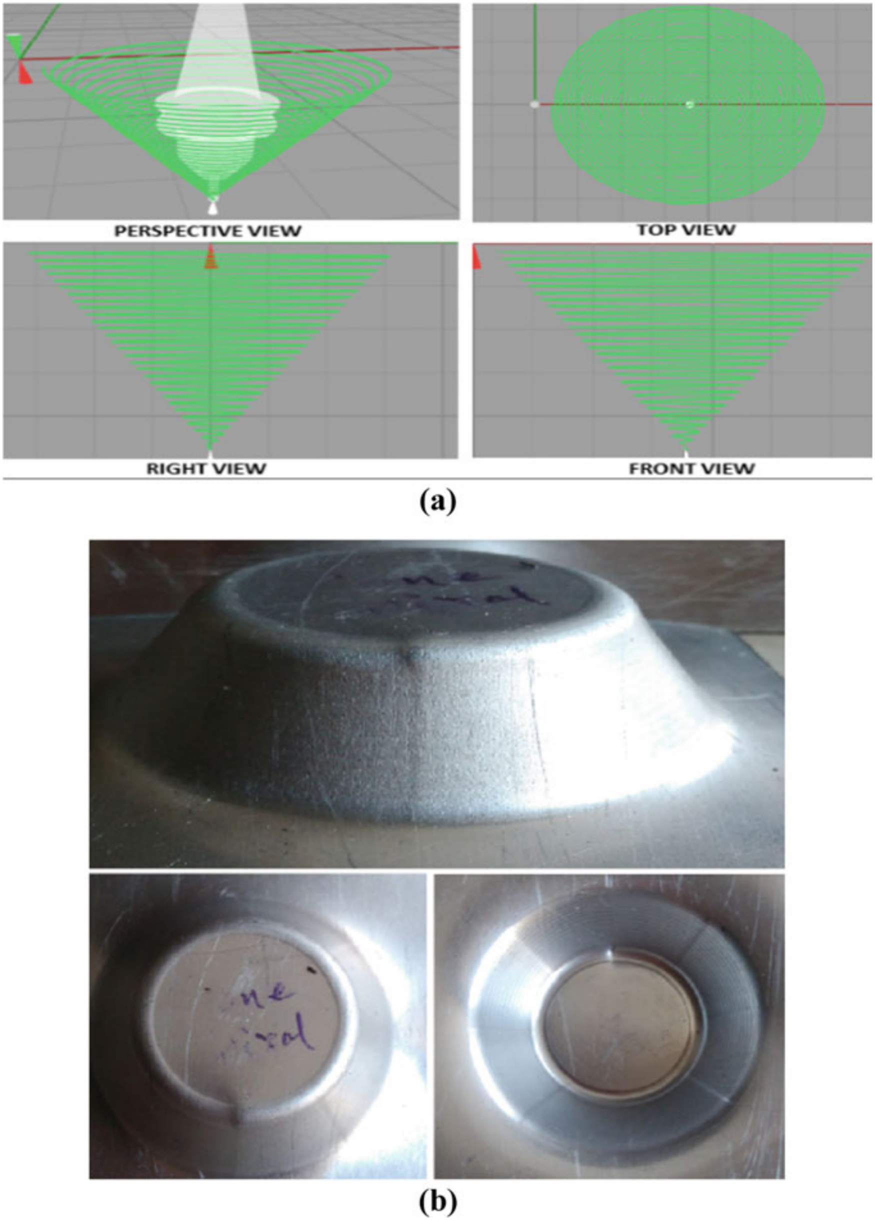


Fig. 2.12 **a** Spiral tool path simulation of conical geometry. **b** Validation of spiral tool path for conical geometry

Appendix 1: Sample Code for Incremental/Profile Tool Path

```
----
----
Φr=pi*(Φ)/180; %Angle should be in radian for calculation in Matlab
cr2=(d/2)*sin(Φr);
cr3=(d/2)*(1-cos(Φr));
k1=D-2*cr2 ;
b=0; % step no. as loop variable
k2=k1-2*(b+1)*p*cot(Φr);
k3=k1/2;
k4=k2/2;
k5=p*cot(Φr);
No. of steps = h-cr3/p;
G00 Xcr2 Y0 Z-cr3;
G91;
G03 Xk1 Y0 Rk3;
G03 X-k1 Y0 Rk3;
while b < No. of steps
      k5=p*cot(Φr);
      k2=k1-2*(b+1)*p*cot(Φr);
      k4=k2/2;
      G01 Xk5 Y0 Z-p;
      G03 Xk2 Y0 Z0 Rk4;
      G03 X-k2 Y0 Z0 Rk4;
      b=b+1;
end
----
----
```

Appendix 2: Sample Code for Spiral Tool Path

```
----

----
R=D/2;
Φr=pi*(Φ)/180;
cr=d*sin(Φr)/2;
cr3=d*(1-cos(Φr)/2;
b=0; %Step no. as loop variable
k4=p/8;
NO. of Steps=(h-cr3)/p;
G00 Xcr Y0 Z-cr3
G91
while b < NO. of Steps
      R=R-cr;
      r2=R-k4*cot(Φr);
      r3=r2-k4*cot(Φr);
      r4=r3-k4*cot(Φr);
      r5=r4-k4*cot(Φr);
      r6=r5-k4*cot(Φr);
      r7=r6-k4*cot(Φr);
      r8=r7-k4*cot(Φr);
      r9=r8-k4*cot(Φr);

      x1=R-R*(.7071);
      x2=r2*(.7071);
      x3=r3*(.7071);
      x4=r4-r4*(.7071);
      x5=r5*(.7071)-r5;
      x6=-r6*(.7071);
      x7=-r7*(.7071);
      x8=r8*(.7071)-r8;

      x11=(R-r2)*(.7071);
      x22=0;
      x33=(r4-r3)*(.7071);
      x44=(r5-r4);
      x55=(r6-r5)*(.7071);
      x66=0;
      x77=(r7-r8)*(.7071);
      x88=r8-r9;
```

```
      y1=-R*(.7071);
      y2=-r2+r2*(.7071);
      y3=-r3*(.7071)+r3;
      y4=r4*(.7071);
      y5=r5*(.7071);
      y6=r6-r6*(.7071);
      y7=r7*(.7071)-r7;
      y8=-r8*(.7071);

      y11=(R-r2)*(.7071);
      y22=(r2-r3);
      y33=(r3-r4)*(.7071);
      y44=0;
      y55=(r6-r5)*(.7071);
      y66=(r7-r6);
      y77=(r8-r7)*(.7071);
      y88=0;
       G03 Xx1 Yy1 Z-k4 RR
       G01 Xx11 Yy11 Z0
       G03 Xx2 Yy2 Z-k4 Rr2
       G01 Xx22 Yy22 Z0
       G03 Xx3 Yy3 Z-k4 Rr3
       G01 Xx33 Yy33 Z0
       G03 Xx4 Yy4 Z-k4 Rr4
       G01 Xx44 Yy44 Z0
       G03 Xx5 Yy5 Z-k4 Rr5
       G01 Xx55 Yy55 Z0
       G03 Xx6 Yy6 Z-k4 Rr6
       G01 Xx66 Yy66 Z0
       G03 Xx7 Yy7 Z-k4 Rr7
       G01 Xx77 Yy77 Z0
       G03 Xx8 Yy8 Z-k4 Rr8
       G01 Xx88 Yy88 Z0
       R=r9+cr; %Radius after completion of one cycle
       b=b+1; %b=step-no.
end
----
----
```

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Chapter 3
A Novel Method for Spindle Radial Error Measurement using Laser Pointer and Digital Camera

Sanil Pande and S. Denis Ashok

Abstract This paper presents a machine vision system that utilizes a laser pointer mounted in the chuck and a camera that records the projected laser spot. An image processing methodology is developed to detect the laser spot while operating a lathe at different speeds. The centroid of the spot is calculated using image moments to obtain its coordinates, and shape matching using Hu moments is performed to validate the detection. A mathematical analysis of the coordinates using curve fitting to a Fourier series is implemented in order to obtain the synchronous and asynchronous spindle radial errors. The synchronous error is found to follow a periodic pattern, and the errors are found to increase with respect to operating speed. The harmonic components of spindle radial error are thus measured and presented.

Keywords Machine vision · Image processing · Spindle error measurement · Fourier transform

3.1 Introduction

A spindle refers to the rotating part installed in the headstock of a lathe. Spindle error can be attributed to internal causes in the machine such as misaligned bearings, out-of-round bearings, structural vibrations and general wear and tear over time. ANSI/ASME Axes of Rotation: Methods for Specifying and Testing provides the standards for measurement, specifications and testing of the synchronous and asynchronous errors in rotating machine tools [1]. A mathematical model approach to separate the centering error and synchronous components of spindle radial errors is presented in [2]. In [3], a machine vision system using circular Hough transform to detect the center of a cylindrical workpiece is implemented to measure the form error of the master cylinder and the components of spindle radial error. The detection of a laser spot based on the hue and value corresponding to the brightest spot in an image has been implemented in [4]. Methods to detect the laser spot include

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Lecture Notes on Multidisciplinary Industrial Engineering,
https://doi.org/10.1007/978-981-15-6017-0_3

thresholding and background subtraction, and subsequent coordinate mapping of the obtained coordinates [5]. In [6], the use of modified circular Hough transforms in which gradients are not assumed to converge at a single point for detecting laser spots in images is proposed. In [7], laser spots were detected using background subtraction and noise removal, and laser spot tracking was performed by implementing an improved Kalman filtering algorithm. In this work, image processing using masking, closing and noise removal is implemented, and Fourier series curve fitting is used to segregate synchronous and asynchronous spindle errors.

3.2 Methodology

3.2.1 Experimental Setup

The proposed machine vision system consists of a camera, a laser pointer and a surface on which the laser spot is projected, as shown in Fig. 3.1. The camera utilized is inbuilt in the OnePlus 5T smartphone and it captures video at a resolution of 1920 $\times$ 1080 pixels at a rate of 30.04 frames per second. The laser pointer uses a laser diode to emit light of wavelength 630–680 nm. It is a class IIA laser with a power output less than 1 mW. The projected spot follows a Gaussian profile. A matte black surface is chosen to project the laser spot on since it limits the reflectivity of the laser beam resulting in a coherent laser spot for image processing. The distance between the laser emitter and the perpendicular surface is measured to be 16.7 cm using a regular scale. The distance between the camera and the surface is 16.6 cm. The resultant angle between the focal axis of the camera and the spindle axis is 6.3°.

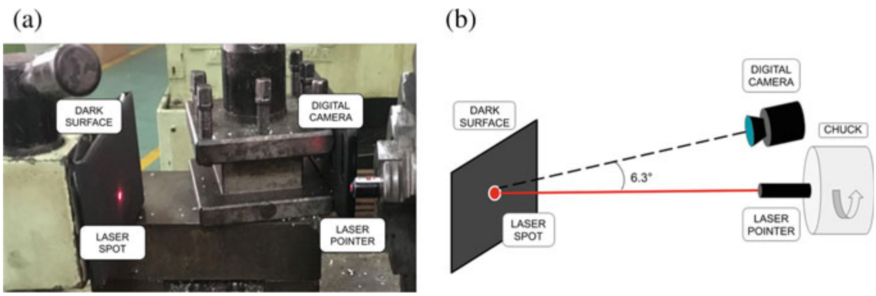

Fig. 3.1 **a** Laser pointer and projected spot, **b** camera setup schematic

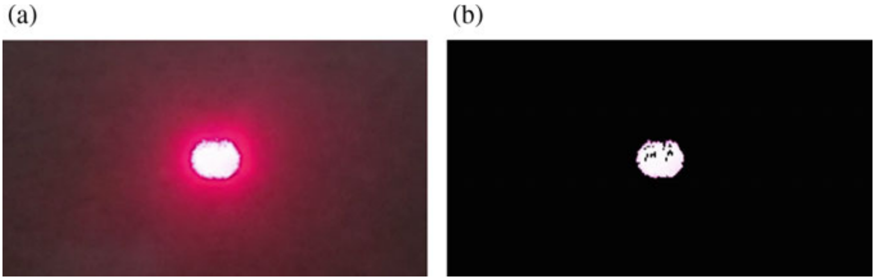

Fig. 3.2 **a** Cropped region of interest, **b** masked image

3.2.2 Conversion of Pixels to Real World Measurements

Images of slip gauges were captured at a distance equal to 16.5 cm, equivalent to the original setup. An image of a slip gauge of length 100 mm and breadth 35 mm was taken, and the pixel coordinates of the corners were obtained. The perimeter of the rectangle thus formed was found to be equal to 3271.22 pixels, corresponding to a perimeter of 270 mm of the slip gauge. The conversion factor was thus found to be 0.08254 mm/pixel or 82.54 μm/pixel.

3.2.3 Color Thresholding and Binarization

The image processing is performed using the Python programming language with its open-source computer vision library, OpenCV. The frames in the video are cropped to a region of interest of 960 × 540 pixels which encompasses the range of motion of the laser spot. A masking operation is performed on each frame to extract red pixels. The masking values are between [0, 0, 250] and [160, 255, 255] in the hue–saturation–value color space. Upon thresholding, a binarized image is obtained which has a pixel value of 1 corresponding to the red pixels in the original image, resulting in a clear demarcation of the laser spot from its background as shown in Fig. 3.2.

3.2.4 Closing Morphological Operation

The laser spot has some concavity due do a defect in the emitting diode as shown in Fig. 3.3a. To compensate for this, a closing morphological operation with a kernel size of 25 × 25 pixels is applied. The closing operation is performed by dilation and then erosion of an image, as described in Eqs. (3.1) and (3.2), where *x*' and *y*' are half of the kernel size, i.e., 12 pixels.

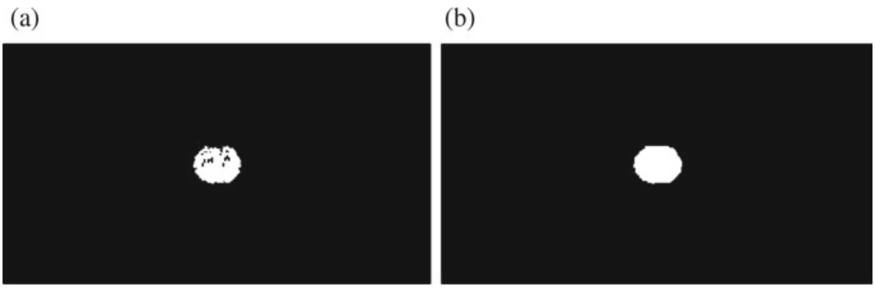

Fig. 3.3 **a** Binarized image, **b** closing operation

$$f_{\text{dilation}}(x, y) = \max_{(x', y') \neq 0} \text{img}\big(x + x', y + y'\big) \tag{3.1}$$

$$f_{erosion}(x, y) = min_{(x', y') \neq 0} img\big(x + x', y + y'\big) \tag{3.2}$$

The result is a convex laser spot with a consistent shape as shown in Fig. 3.3b.

3.2.5 Noise Removal with Gaussian Blur

In order to remove noise and smoothen the edges of the laser spot, the image is correlated with a kernel of size 7 × 7 pixels, the elements of which are an approximation of a Gaussian function in two dimensions given by Eq. (3.3). The denoised image with smoothed edges is shown in Fig. 3.4.

$$G(x, y) = \frac{1}{2\pi\sigma^2} e^{\frac{(x^2 + y^2)}{2\sigma^2}} \tag{3.3}$$

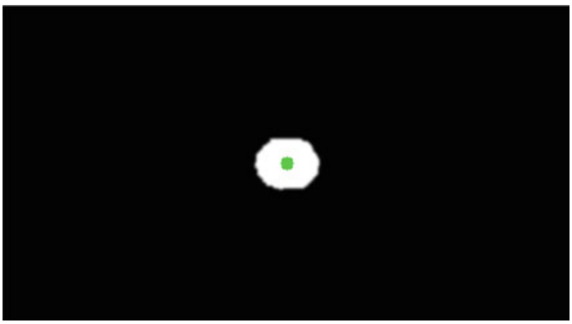

Fig. 3.4 Centroid marked by a green dot

3.2.6 Laser Spot Detection

In order to measure the pixel coordinates of the laser spot, we calculate the centroid of the image which is equivalent to the centroid of the laser spot. The X and Y coordinates of the centroid of an image are calculated using the image moments, as given in Eq. (3.4).

$$\{\bar{x},\ \bar{y}\} = \left\{\frac{M_{10}}{M_{00}}, \frac{M_{01}}{M_{00}}\right\} \tag{3.4}$$

M_{00} denotes the area of the laser spot and M_{10} and M_{01} denote the raw moment of the image in the x and y directions, respectively. The detected centroid is denoted by the green dot as shown in Fig. 3.4.

3.2.7 Fourier Analysis of Coordinates

A Fourier series curve fitting is performed on the collected X and Y coordinates using the sum of least squares method. The general Fourier series equation is used, up to the fifth harmonic. The general form of a Fourier series equation is given by Eq. (3.5).

$$f(t_i) = a_0 + \sum_{h=1}^{H}(a_h \cos(w \times h \times t_i) + b_h \sin(w \times h \times t_i)) \tag{3.5}$$

The curve fitting of the X and Y coordinates of the laser spot with respect to time provides us with the following parametric coefficients shown in Table 3.1.

The dominant frequencies are a_0, a_1 and b_1 in which the centering error can be attributed to. The remaining frequencies from the second harmonic onward contribute to the synchronous error. The residual error is used to determine the asynchronous errors in the lathe.

3.3 Results and Discussions

3.3.1 Laser Spot Detection

The consistency of the shape of the laser spot can be verified by calculating the Hu moments of the image. This gives us seven moments of increasing order for the detected spot in each frame, which depend on the shape of the image and are translation, scale and rotation invariant [8]. The $\log_{10}$ of the calculated moments for

Table 3.1 Fourier series coefficients obtained by least square curve fitting

Parametric coefficients	a0	a1	b1	a2	b2	a3	b3	a4	b4	a5	b5	w
X (45 RPM)	0.0498	−2.503	−0.9678	0.0155	0.0146	−0.0149	0.0170	−0.0003	−0.0038	−0.0020	−0.0130	5.016
Y (45 RPM)	−0.0033	−0.9437	2.567	0.0169	−0.0075	−0.0160	−0.0057	−0.0001	0.0023	−0.0102	0.0018	5.016
X (71 RPM)	−0.0594	−2.461	2.091	0.0080	−0.0252	0.0049	−0.0148	0.0027	−0.0048	0.0036	−0.0035	7.952
Y (71 RPM)	−0.0642	2.188	2.468	−0.0281	−0.0148	0.0194	0.0119	−0.0040	0.0008	0.0040	−0.0046	7.953

Table 3.2 Hu moments calculated for successive frames

Hu moments	Frame 1	Frame 2	Frame 3	Frame 4	Frame 5	Deviation (magnitude) (%)
Moment #1	3.177565	3.177388	3.176317	3.172763	3.176592	0.15
Moment #2	7.469690	7.519065	7.543288	7.466522	7.481772	1.02
Moment #3	11.868214	12.321896	12.204218	12.461534	12.227923	4.86
Moment #4	13.114282	13.231826	12.900100	13.034997	13.139142	2.54
Moment #5	−25.637807	−26.121476	−25.454779	−25.792012	−25.849473	2.59
Moment #6	−16.856538	−16.992348	−16.708980	−16.816648	−16.984048	1.68
Moment #7	26.035402	26.204890	−26.421183	−26.485036	−26.290253	1.71

five consecutive frames is given in Table 3.2. The change of sign across the seventh moment denotes that the shape is a mirror image of the preceding frame, which is consistent with the fact that the laser spot is symmetric and thus the same as its mirror image. The similarity of the moments across frames is indicative of the robustness of the laser spot detection method used, as shown in [9].

3.3.2 *Synchronous Error*

The synchronous errors are obtained from the second to fifth harmonics of the curve-fitted Fourier series as shown in Table 3.1. The polar plots in Fig. 3.5 are observed to follow a similar shape at different speeds, suggesting that the synchronous error is a periodic function of the angular displacement. The offset in the plots is due to the change in the starting position during the experiment, since the relative angular displacement is considered. The amplitude of the synchronous error is found to be 79.5 microns at 45 RPM and 92.7 microns at 71 RPM.

3.3.3 *Asynchronous Error*

The asynchronous error which is caused by random errors in the lathe is obtained through the curve-fitting residuals. It is found to vary randomly, as shown in the

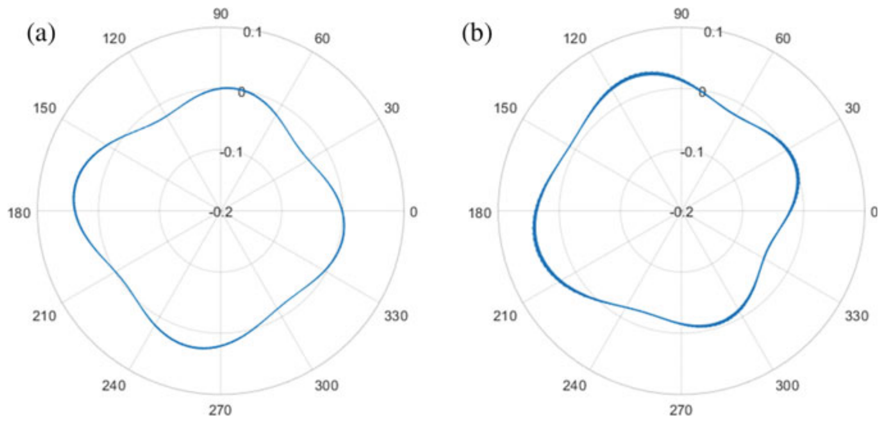

Fig. 3.5 **a** Error (in mm) at 45 RPM, **b** error (in mm) at 71 RPM

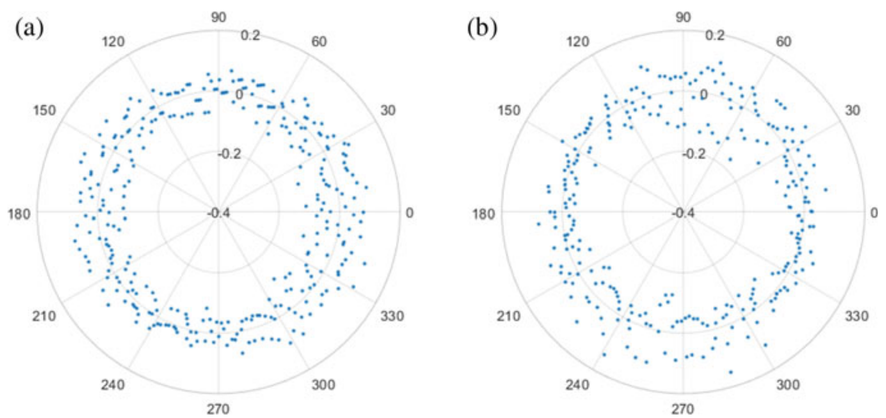

Fig. 3.6 **a** Error (in mm) at 45 RPM, **b** error (in mm) at 71 RPM

polar plot in Fig. 3.6. The amplitude of error is 233.2 microns at 45 RPM and 319.4 microns at 71 RPM.

3.3.4 Combined Spindle Radial Error

The amplitude of both synchronous and asynchronous errors is found to increase with an increase in the operating speed of the lathe. The contribution of the synchronous error is found to be lesser compared to that of the asynchronous error toward the combined error. The error measurements are given in Table 3.3.

Table 3.3 Measurements of synchronous and asynchronous spindle error

Type of error	Synchronous error		Asynchronous error		Combined error	
	45 RPM	71 RPM	45 RPM	71 RPM	45 RPM	71 RPM
Minimum value (μm)	−36.4	−46.3	−121.6	−167.5	−145.2	−182
Maximum value (μm)	43.1	46.4	111.6	151.9	117.6	147.5
Amplitude (μm)	79.5	92.7	233.2	319.4	262.8	329.5

3.4 Conclusions

A general method of detecting laser spots through the use of computer vision is developed. These operations which involve masking, binarization, closing and blurring are observed to be robust in the detection and tracking of the laser spot, as shown by the consistency in the Hu moments through successive frames. The synchronous error is found to vary between 50 and 100 μm, while the asynchronous and combined errors vary between 200 and 350 μm. The synchronous, asynchronous and combined errors are found to increase at higher operating speeds. It is observed that the synchronous error is a periodic function due to the inherent errors in the spindle. The proposed method can be used as a low-cost implementation for the testing of machine tool spindles.

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Chapter 4
Measuring TQM Awareness in Indian Hospitality Industry

Faisal Talib and Zillur Rahman

Abstract Hospitality industry is considered one of the rapidly growing industries of Indian service sector due to its ability to generate huge employment, share in economic development of country, and developing a healthy relationship between the two countries. Hospitality industry needs to maintain and improve its performance continuously by identifying customer needs and fulfilling their requirements to remain at the top among other service industries. Total quality management (TQM) is considered as one of the approaches for this purpose and should be treated as a way of life for all the service industries. But how can TQM become a "a way of life" in the industry if the managers and practitioners are not aware of it? For this purpose, the present study addresses managers' awareness and familiarity of TQM program in the Indian hospitality industry. The data were collected using a self-administered questionnaire to 112 hospitality industries in India. A total of 34 useable survey questionnaires were considered for the final analysis. The result recommended that the Indian hospitality industry is well aware of TQM principles and practices and they in large adopt programs that improve quality performance and customer satisfaction. It was also observed that there is a need to train employees in advanced quality improvement techniques and in inducing quality culture within the industry. Some latest TQM models or frameworks as proposed by the TQM experts and academicians may also be adopted by the managers and practitioners of the industry to get maximum benefits.

Keywords TQM · TQM awareness · Hospitality · Industries · Quality improvement tools · India

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4.1 Introduction

Over the last decade, Indian service especially hotels and tourism industries (hospitality industry) and government have shown a keen interest in total quality management (TQM). It was Planning Commission [31] and Quality Council of India [34] reports on standards, accreditation, and quality control and assurance, which focused on quality managers and government attention on TQM. However, earlier researches on quality and related areas have provided little evidence on the awareness level of TQM in the Indian hospitality industry. Only a few research studies have been undertaken in Indian context that too at a low or fragmented level. Although a significant number of manufacturing, small and medium enterprises (SMEs), corporate and public industries have inculcated a form of TQM in their trade [13, 16, 27, 36, 52] and have derived demonstrable benefits from the application of such approaches, still there is a need for much more study on TQM particularly on the weakest area like an assessment of TQM awareness and its measurement in the field of business performance as few people are actually exploring this issue in the Indian service sector. Industries like hospitality, wishing to implement TQM therefore, face difficulties as they are under tremendous pressure to perform and sustain in the global market and gain competitive advantage.

Hence, there is a need for the Indian hospitality industry to know about the TQM awareness and related issues to cope-up with other emerging sectors. Further, TQM literature suggests that only a few studies have been done in the hospitality sector that too on different issues other than the assessment of TQM awareness and restricted to developed countries only. It is therefore predicted that researchers in this area have largely remained silent and indifferent to the assessment of TQM awareness in the hospitality industry. Accordingly, there is a need to study such an issue to bridge this gap in the available literature on the hospitality industry.

In light of the above, the objective of this study was framed to fill the void in the literature by investigating the awareness of TQM in Indian hospitality companies using a survey-based approach. Such an analysis will help researchers understand the development and progress of TQM in the hospitality industry to date and will help to draw attention to some gaps to be fulfilled by the future researchers in the area.

The study is organized as follows. After review of literature on TQM, the research methodology is described. The explanation of results and discussion section follows. The conclusions drawn from the study followed by some implications to managers and future research scope closes the study.

4.2 Literature on TQM

The literature on TQM is quite exhaustive, encompassing an overabundance of research works on development of TQM models [5, 10, 18, 30, 42, 43, 47], case studies [3, 9, 22, 28]; critical practices of TQM [38, 42, 44], relationship between TQM and quality performance [4, 20, 21, 32, 33, 37, 40, 43], development of qualitative studies on TQM [29, 39, 45, 48, 49], and quality tools and techniques [25, 49, 51], and many more.

Several research studies have also been conducted using different quality award models like Malcolm Baldrige National Quality Award (MBNQA), Deming Quality Award and European Foundation Quality Award (EFQA) frameworks to examine the impact of TQM on organization performance [5, 24, 30, 51].

All the above studies have used different approaches to study TQM in different organizations. However, some studies on TQM in hospitality which needs to be discussed in this paper are presented in the following section.

4.2.1 TQM in Hospitality Industry

Bouranta et al. [8] identified the TQM critical factors and their effect on organization performance in the hotel industry of Greece and found that strategic quality planning, top management, employee knowledge, and education, employee quality management and customer focus are the factors responsible for quality improvement while Amin et al. [1] studied the structural relationships between TQM, employee satisfaction, and hotel performance. The findings of the study were: seven determinants of TQM showed positive relationships with employee satisfaction and hotel performance, and leadership role and customer focus have critical roles in improving employee satisfaction and hotel performance.

Sila and Ebrahimpour [41] analyzed and capered TQM practices in three luxury hotels while Claver-Cortés et al. [11] examined how TQM is associated with managerial factors such as training, information, and communication technologies and information system (ICT/IS) and environmental management. A literature review conducted by Keating and Harrington [23] on the implementation of the quality program in the hotel industry observed that top-management commitment and the provision of training and value promotion throughout the organization were important dimensions for the growth of Irish hotel industry. They further observed that quality management (QM) in this industry is lacking in involvement, communication, and teamwork dimensions.

Eraqi [15] evaluated the customer’s views related to tourism quality in Egypt using TourServQual model and measured tourism business performance. A recent study by Daghfous and Baskhi [14] assessed and explored the extent of UAE hotels using IT (information technology) system to improve back-end operations and customer services with special focus on TQM, customer relation management (CRM), and supply chain management (SCM) through a questionnaire survey methodology. They proposed a conceptual model for a better understanding of the strategic challenges faced by IT/IS managers in this industry. Similarly, a study by Holjevac [19] emphasized business ethics as a dimension of TQM in Croatian tourism sector. Further, during the current literature review, no study was found on TQM in context within

Table 4.1 Population and sample size for hospitality industry

Industry	Population (N)	Sample size based on GDP contribution (n)	Return responses	Valid responses	Rejected responses	Percentage response
Hospitality	350	112	39	34	5	30.3

Indian hospitality industry context. This suggests a lack of research gap in the knowledge about TQM in Indian hospitality industry and therefore, the current study was undertaken.

4.3 Research Methodology

A survey methodology based on a questionnaire was carried out to accomplish the objective of this study in the select Indian hospitality industry (including hotels and tourism). Next section describes sample and data collection procedures used together with instrument development and target respondents administration approach.

4.3.1 Sample and Data Collection

A database i^3 (i-cube, Information Infrastructure for Institutions), Centre for Monitoring Indian Economy Private Limited, India (i^3, CMIE, 2010) was used to identify the names of select Indian hospitality companies. The information provided by the database is: company name, address of the company, contact person, and e-mail ID. The target population of this study is 350 companies obtained from the database (Table 4.1). A minimum sample size based on GDP contribution of hospitality industry from the total contribution of GDP in the Indian service sector was used in this study. Using this methodology, minimum sample size of 112 was obtained (Table 4.1) and used for further study. A simple random sample approach was utilized to draw a sample from the calculated size.

4.3.2 Research Instrument Development and Administration

A self-administered structured instrument was designed in this research based on the works of Antony et al. [2], Bhat and Rajashekhar [7], and Rad [35]. The instrument was modified by consulting with academicians and quality experts and was initially validated through a pilot survey before it was actually used for primary data collection. The instrument developed was divided into two sections. The first section comprises the demographic information of the respondents including profession, gender, years of experience as well as the general background of the company and the second section collects information regarding the awareness of TQM in Indian hospitality companies. Eight statements were constructed that seek the opinion about awareness of TQM and various facets concerning TQM in the company. The instrument used a 5-point Likert scale, with 1 = very little, 3 = moderate, and 5 = very much, depending on the type of question.

The target respondents for this study were top and middle-level administrators/managers who have sufficient level of experience and qualification and therefore, they will be aware of the TQM program. A total of 112 questionnaires were e-mailed to different hospitality companies. After several follow-ups and personal contacts, a total of 39 companies responded which were selected for this study, however, only 34 useable survey instruments were included for the data analysis as five instruments were unusable, yielding a response rate of 30.3% (Table 4.1).

4.4 Results and Discussion

4.4.1 Profile of Respondents

The first section of the instrument developed for this study seeks the demographic data of the respondents. As shown in Table 4.2, the profile of the survey respondents comprised 16 tourism (47.1%) and 18 hotels (52.9%) companies out of which 20.6% were government and 79.4% were private owned companies. The breakdown of gender of the respondents was 30 (88.2%) male and 4 (11.8%) female. It suggests that the majority of the Indian hospitality companies are male-dominated companies in their quality department. Regarding the year of experience, there were only five respondents (14.7%) who have less than five years of experience, and the remaining 29 respondents (85.3%) were having more than five years of experience. Reflecting that majority of respondents' job tenure at their current organization was more than five years at the time of survey and hence, low job turnover problem was not observed. It was also found that almost all the responding companies were quality certified meaning that the group of companies is either implementing or is in the process of getting TQM implemented in some way. Finally, the responses received from different departments/sections are as follows: 4 from quality (11.8%), 6 from product and services (17.6%), 5 from customer relation (14.7%), 11 from marketing (32.4%), 5 from information management services (14.7%), and 3 from others (8.8%).

Table 4.2 Characteristics of respondents

Characteristics	Number of respondents	Percentage of respondents
Company type		
Star hotel	18	52.9
Tourism	16	47.1
Total	$n = 34$	100
Ownership		
Government	7	20.6
Private	27	79.4
Total	$n = 34$	100
Number of employees		
50 or less	6	17.6
Exceeding 50 or more	28	82.4
Total	$n = 34$	100
Respondent position		
CEO/Director/Managing Director/CEO/General Manager	4	11.8
Project Manager/Senior Manager	6	17.6
Quality Engineer/Service Manager/Human Resource Manager	10	29.4
Manager/Technical Manager/Operations Manager	8	23.5
Others (Like Consultant; Customer Relation Officer; Assistant Manager)	6	17.6
Total	$n = 34$	100
Years of experience		
5 years or less	5	14.7
5 years plus	29	85.3
Total	$n = 34$	100
Gender		
Male	30	88.2
Female	4	11.8
Total	$n = 34$	100
Department		
Information Management Services	5	14.7
Product and Services	6	17.6

(continued)

Table 4.2 (continued)

Characteristics	Number of respondents	Percentage of respondents
Quality	4	11.8
Customer Relation	5	14.7
Marketing	11	32.4
Others	3	8.8
Total	$n = 34$	100

4.4.2 Assessing the Awareness of TQM in Indian Hospitality Industry

In order to assess the awareness of TQM in the Indian hospitality industry, various statistical tools and techniques were adopted like graphical representation of data, mean and standard deviation, and Pearson's correlation analysis using SPSS 16.0 software [12]. Figures 4.1, 4.2, 4.3, 4.4, 4.5, 4.6, 4.7, and 4.8 shows the results of all eight statements individually based on percentage of responses on five-point scale as well as Fig. 4.9 depicts the compiled result of TQM level awareness statements on the mean scale. As can be seen from Figs. 4.1, 4.2, 4.3, 4.4, 4.5, 4.6, and 4.7, the responses received in most of the TQM awareness statements the perceived levels of awareness is quite high (between 3 and 5 on five-point scale) while responses received in case of statement 8 (Fig. 4.8) shows lowest level of awareness. Similarly, it can be seen from Fig. 4.9 that all the eight statements except TQM awareness statement 8 (mean score of 3.41) are loaded above moderate mean values, i.e., more than 3.5 scores. This could be also observed from Table 4.3 which shows descriptive statistical analysis by computing mean scores and standard deviations of all the statements related to awareness of TQM program. Again from Table 4.3, the perceived level of

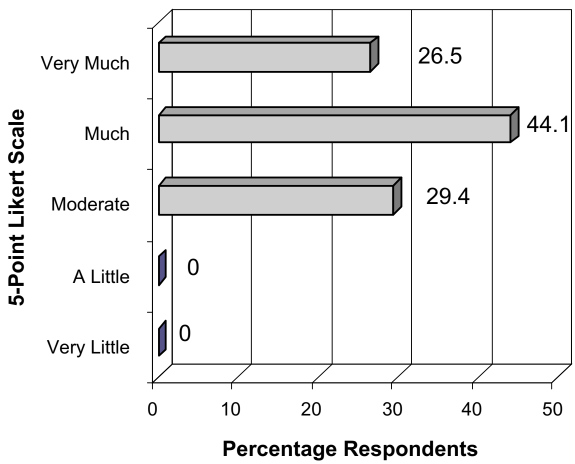


Fig. 4.1 *Statement 1*—TQM concepts and practices familiarity

Fig. 4.2 *Statement 2*—TQM acts as guiding philosophy in the company

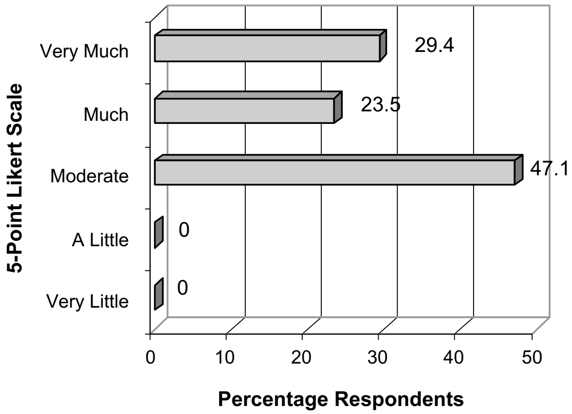


Fig. 4.3 *Statement 3*—Training of employees on TQM concepts and practices by the company

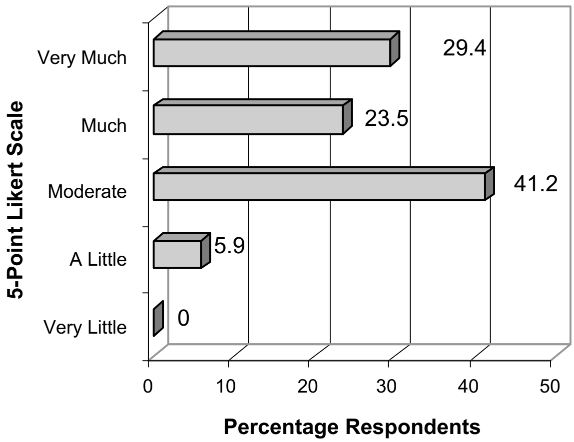
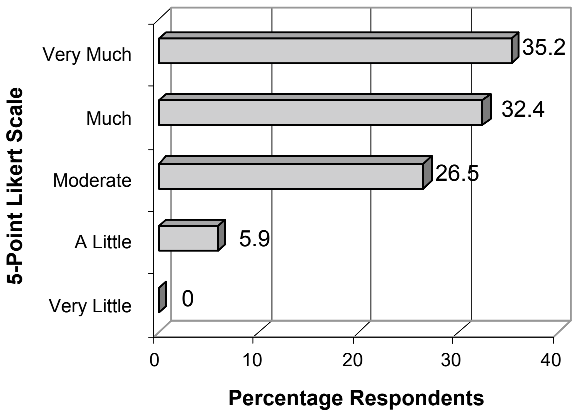


Fig. 4.4 *Statement 4*—Guaranteeing high quality of products and services through TQM



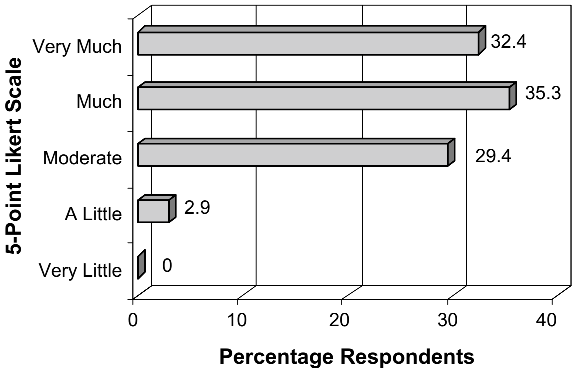


Fig. 4.5 *Statement 5*—Company practices TQM program across all the departments

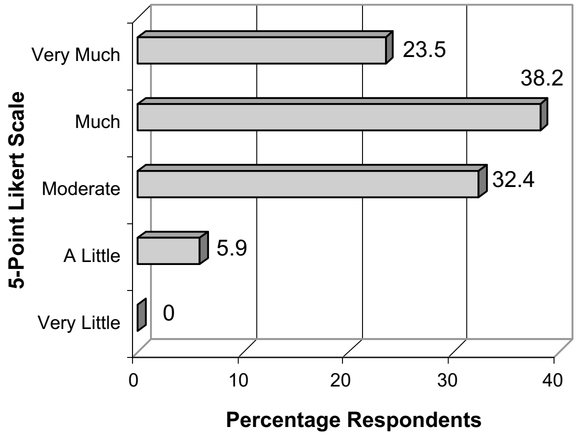


Fig. 4.6 *Statement 6*—TQM in your company is successful

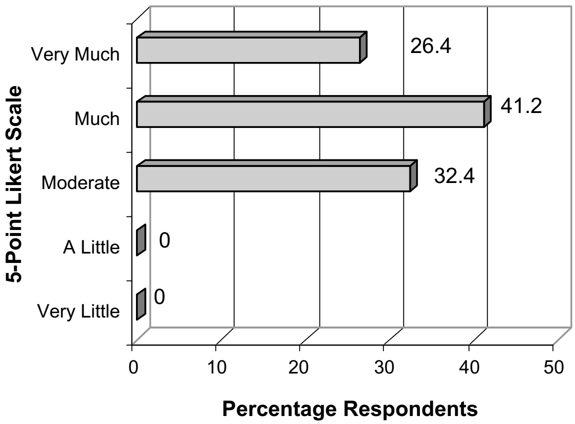


Fig. 4.7 *Statement 7*—Company is well versed with continuous quality improvement and innovation program

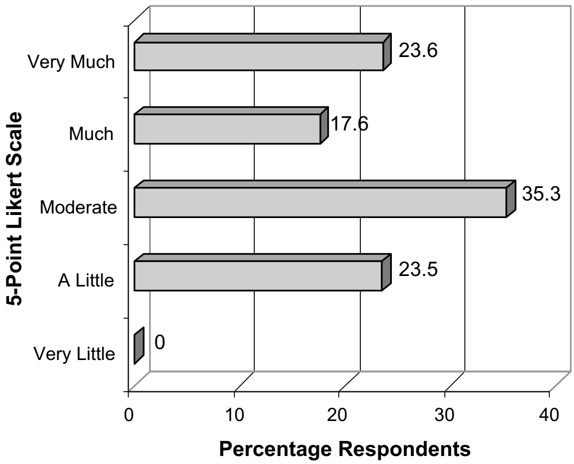


Fig. 4.8 *Statement 8*—Usage of any TQM model (like MBNQA, PDCA, EQAM, etc.) in the company

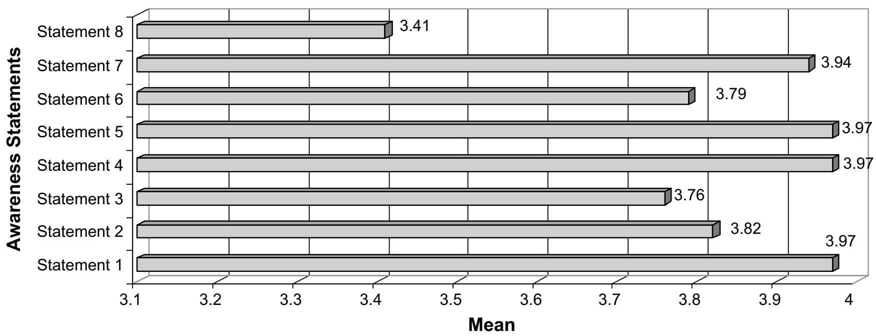


Fig. 4.9 TQM awareness in Indian hospitality industry

TQM awareness varies between the mean scores of 3.41 and 3.97, and the standard deviations range from 0.758 to 1.104. This implies that the perception levels of awareness and knowledge of TQM program in Indian hospitality companies are quite high. The mean responses obtained were in-between 'moderate' and 'very much'. The higher values of standard deviation also indicate the dispersion in a widely spread distribution implying that the awareness of TQM and its measuring statements are an approximation to a normal distribution [46].

From Fig. 4.9 and Table 4.3 it can be seen that the mean scores of TQM awareness statement 1, 4, 5, and 7 range between 3.94 and 3.97 while for statements 2, 3, and 6 between 3.76 and 3.82. This implies that equal importance had been given to all the statements instead of emphasizing individual TQM awareness statements. Hence, it may be arrived at a judgment that TQM had been observed as a strategic approach.

Table 4.3 Mean, standard deviation, and correlation coefficients

Statement	Mean	Standard deviation	TQM aware-ness	1	2	3	4	5	6	7	8
Statement-1	3.97	0.758	0.794^{**} 0.000	1.000							
Statement-2	3.82	0.869	0.791^{**} 0.000	0.727^{**} 0.000	1.000						
Statement-3	3.76	0.955	0.821^{**} 0.000	0.576^{**} 0.000	0.532^{**} 0.000	1.000					
Statement-4	3.97	0.937	0.804^{**} 0.000	0.681^{**} 0.000	0.663^{**} 0.000	0.635^{**} 0.000	1.000				
Statement-5	3.97	0.870	0.866^{**} 0.000	0.642^{**} 0.000	0.674^{**} 0.000	0.684^{**} 0.000	0.705^{**} 0.000	1.000			
Statement-6	3.79	0.880	0.785^{**} 0.000	0.626^{**} 0.000	0.585^{**} 0.000	0.553^{**} 0.000	0.470^{**} 0.000	0.665^{**} 0.000	1.000		
Statement-7	3.94	0.776	0.709^{**} 0.000	0.563^{**} 0.000	0.362^{*} 0.035	0.635^{**} 0.000	0.498^{**} 0.000	0.536^{**} 0.000	0.692^{**} 0.000	1.000	
Statement-8	3.41	1.104	0.537^{**} 0.001	0.160 0.367	0.298 0.086	0.382^{*} 0.026	0.276 0.115	0.392^{*} 0.022	0.277 0.113	0.206 0.243	1.000

Note **Significant at 0.01 level (two-tailed), *Significant at 0.05 level (two-tailed)

Besides this, the lowest mean score comes from the statement ‘Usage of any TQM model in the company’ (3.41) having received an only a moderate score. This suggests that TQM managers and quality practitioners should focus on improving the current quality management (QM) model and emphasize the usage of advanced quality tools and techniques. They should encourage the organizations to adopt new and recently developed TQM models which are validated and accepted by the quality researchers to enhance the business performance.

Finally, Pearson’s correlation analysis was performed on all the eight TQM awareness assessing statements for two purposes. The first was to check the presence of multicollinearity. Secondly, it was performed to understand the relationships between variables. Two-tailed ($p < 0.01$ and $p < 0.05$) bivariate correlation technique which computes Pearson’s correlation coefficient was performed using SPSS program. The correlation coefficient values are in the range from -1 to $+1$. A value of zero or nearly zero indicates no relationship between the variables. Additionally, a value of more than 0.60 is treated as closely correlated, a value ranging between 0.30 and 0.60 shows moderate correlation, and a value smaller than 0.30 is observed as poorly correlated [26]. From Table 4.3 (Pearson’s correlation matrix), the highest coefficient of correlation is 0.866, which is below the cut-off of 0.90 for the multicollinearity problem implying that the data in this study is free from collinearity and multicollinearity problems [17].

From Table 4.3, it is observed that the correlation coefficients presented in the form of matrix are quite high for all the eight statements under study. A total of 36 correlations were obtained, maximum of which is greater than 0.35 accept for the TQM awareness statement ‘8’ which showed weak or low correlation coefficients between almost all the awareness statements. This result further strengthens the above findings.

4.5 Conclusions

The paper successfully accomplishes the objective of this study and presents the survey findings of managers awareness of TQM principles and practices in the Indian hospitality industry. The study was conducted by assessing the opinion of the top- and middle-level administrators who are directly responsible for providing quality services and have knowledge of TQM program implementation in the company. From the empirical analysis as indicated in the results and discussion section, it is concluded that the Indian hospitality industry is well aware of TQM program. The only unfavorable outcome was in the adoption of any validated TQM model proposed by eminent researchers and quality experts.

Overall, the empirical findings of the present study reflect that the respondents are aware of TQM program and familiar with its principles and practices. It is practiced throughout the hospitality industry. It was observed that the majority of hospitality companies accept that TQM is a guiding philosophy in their company which plays an important role in the company’s progress. Further, it was revealed that most of the companies are in the process or have trained their employees in TQM concepts and practices. It was also found that the top-management and employees understand that TQM is a way of guaranteeing high-quality products and services, which could help in achieving customer satisfaction and improving position in the marketplace. Furthermore, it was also found that the Indian hospitality industry is quite familiar with the continuous quality improvement and innovation program which is a positive indication of a progressive industry.

Moreover, this paper has pointed out some areas where there is a need for further improvements like a need for training to the employees in advance quality tools and techniques, change of culture from traditional to quality culture, implementation of new and improved TQM models or frameworks in the company. This will improve the company's performance and achieving better results. Nevertheless, this paper suggests that there is strong evidence of managers' awareness TQM program and familiarity of its principles and practices like the development of quality products and services, continuous training, and quality improvement and innovation program. Further, the adoption of TQM model in the hospitality industry and employees training in advanced quality improvement techniques are the need of the hour.

4.5.1 Managerial Implications

The findings of the present study provide some insights to quality managers and practitioners regarding the awareness of TQM program and its familiarity in the Indian hospitality companies which could improve their business performance. Some of the potential managerial implications of the hospitality companies are:

- The findings of this study provide a practical understanding of current TQM status in the Indian hospitality industry. It would provide the policymakers and practitioners to think about those areas where there is a need to improve for better performance.
- The findings suggest that TQM program should be implemented holistically rather than on a piecemeal basis to get the maximum advantage.
- The findings suggest quality managers should remain up-dated from time to time by reviewing their current TQM program/model so that they may be able to compete in the global market.
- This study also gives enough functional experience to the managers in their present roles and suggests training in new and emerging quality improvement tools as well as the development of quality culture within the industry.

4.5.2 Future Research

Some of the scopes for future researchers are as follows:

- In the present research, top- and middle-level administrators were the dominant respondents. It is suggested that different positions of the employees within the company may be allowed to give the responses so that a wider perspective on the TQM philosophy within industry may exist.
- The sample size of this study may not be large enough and increased to have more accurate results and conclusions.
- This study was conducted in one country only. Future research may include other South Asian countries (especially the neighbor countries like Pakistan, Sri Lanka, Bangladesh, etc.) to make the study more universally applicable in the region and generalizable. Further, the study may be undertaken to understand their TQM awareness and then comparing with the Indian findings.
- The relationship between the TQM awareness and company performance as well as the prioritization of various facets of TQM program may be studied and incorporated using AHP and ANP approaches.

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Chapter 5
Sustainable Supplier Selection and Order Allocation Considering Discount Schemes and Disruptions in Supply Chain

Akash Sontake, Naveen Jain, and A. R. Singh

Abstract Supplier evaluation and selection on economic, social, and environmental dimensions are crucial for sustaining the pressure of a competitive global supply chain. In this work, a mixed-integer linear programming for supplier selection and order allocation in a single period, multi-supplier, multi-item environment with a prime consideration to the selection of transportation alternatives while delivering items is developed. To capture the real-world situation, the proposed model incorporates no discount and all quantity discount situations considering the bad quality and late delivery disruptions in the supply chain. To reflect a wide variety of operational conditions, two scenarios with two cases have been developed to demonstrate the effect of disruptions and discounts over demand and procurement cost. A real-life case of the automotive sector in central India is studied to validate the proposed model. Also, sensitivity analysis has been performed to understand the trade-offs between different sustainability criteria and the total cost of purchase.

Keywords Sustainable supplier selection · Order allocation · Discount schemes · Disruptions · Sustainability

5.1 Introduction

Formulation and implementation of sound and robust strategies for production planning and management activities for inventory management is important for the industry to exist in the tough competitive global market. Specifically, the selection of a set of right suppliers is a vital decision for the industry to make, as suppliers being upstream supply chain partners help the industry to gain competitive advantage. Therefore, supplier evaluation and selection have become a strategic decision for the managers [11]. Often the supplier selection problem is considered as a Multi-Criteria

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Decision-Making (MCDM) problem in which both qualitative and quantitative evaluation criteria are considered for the formulation of a set of potential suppliers for making the final selections [22]. Carrying out the final selection of suppliers needs addressing of two crucial aspects (i) establishment of the degree of importance of selection criteria and (ii) evaluation of suppliers performance with regard to the selection criteria [38].

In recent years, integration order allocation model with supplier selection decision model has been extensively addressed by the researchers. Researchers have proposed various order allocation models with the objective of determining the optimal order quantity of items to be allocated to each supplier to meet the production plan considering the laid constraints [12, 41]. Earlier supply chain decisions of Supplier Selection and Order Allocation (SS&OA) considered only economic criteria. However, in the last two decades, there has been exponential growth in sustainability awareness among the various stakeholders of the industry. Customers, employees, government agencies, nonprofit organizations are very much vigilant about the sustainable actions and goals of the industry. The advent of sustainable development concept imposes new rules and regulations in the supply chain, forcing decision-makers to consider three pillars of sustainability or Triple Bottom Line (TBL) [5], i.e., environmental, economic, and social criteria in decision-making. According to the Brundtland report, "Sustainable development is to meet the needs of the present without compromising the need of future generation" [50]. In recent years, Sustainable Supply Chain Management (SSCM), where the inclusion of social and environmental dimensions along with the economic sustainability dimension is considered by decision-makers, has attracted the attention of persons from both industry and academia [6, 8]. Inclusion of sustainability objectives in the industry's supply chain helps in achieving two-fold advantages. Firstly taking sustainability initiatives helps the industry to stay competitive in the global market and helps in timely fulfill of market demands. Secondly, sustainable and green methods help industry's to build an image in the market and thus achieves higher sales [17]. Further, taking up sustainability activities in the supply chain helps industries to comply with the stringent government laws and improve their sustainability performance level [51]. Suppliers play a major role in facilitating the industries in meeting the sustainability objectives [30]. Working with the suppliers who take into account sustainability practices while manufacturing helps the company to enhance sustainability rank among their supply chain competitors. Thus, Sustainable Supplier Selection (SSS) is the evaluation and selection of suppliers on the basis of their performance relative to TBL [23]. However, the economic competition in the market is becoming severe each day. Therefore, selection of suppliers needs to be addressed not only on sustainability criteria but also to be investigated on the type of discount scheme offered by the supplier [24, 41]. In a real-world the situation, industry allocates orders for the same items to multiple suppliers so as to survive in a competitive market as various uncertainties exist which might cause the firm to lose its existing customers and has to see more time for the product to reach market. Further, suppliers offer various discount schemes when the order quantity is large in order to increase their chances of selection and also encourage the buyer to buy more. On the other hand or the industry the order quantity increases but the unit price of the item offered by the supplier decreases.

Most of the researchers have addressed the supplier selection and order allocation problem considering only the economic and environmental dimensions of sustainability [9, 25, 26]. With the growing awareness about social issues more recently, social dimension has also been considered with economic and environmental aspects of sustainability in researches pertexting to sustainable supplier selection and order allocation [1, 32, 42]. Further, most researchers have considered only single item while addressing order allocation problem. Researches considering social, environmental, and economic criteria for supplier selection and considering multi-item with quantity discounts and disruptions are very scarce. Further, consideration of different modes of transportation to reduce greenhouse gas emissions to lower the environmental impact is very less addressed.

Accordingly, for the above-mentioned problem, in this work SSS&OA problem of the strategic decision-maker in a single period, multi-item, multi-supplier environment considering quantity discount and disruptions in shipment such as bad quality and late deliveries has been considered. Further, multiple transportation modes problem is considered by the decision-maker to deliver allocated orders because the threat of climate change has been increasingly discussed at an international level, with greenhouse gas emissions from fossil energy sources being at the forefront of governmental concerns [40]. Transportation activities while delivering allocated order to companies' accounts a major portion in GHGs emission. Selection of proper transportation modes, improving vehicle fill and determining the number of trucks for delivery are crucial decisions to improve environmental sustainability.

The proposed SSS&OA model comprises of three phases: in the first stage, sustainability criteria and sub-criteria in economic, social, and environmental dimensions are established based on companies' competitive strategy, expert's opinions, government regulations and available literature and sustainable supplier evaluation and selection are performed. Further, Analytic Hierarchy Process (AHP) method is applied for assigning weights to criteria and sub-criteria for each sustainability dimensions and supplier's sustainability performance on these criteria is evaluated by applying Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS) and based on performance ranks are awarded to the suppliers. In the second stage, a mathematical model is developed to minimize total Purchasing cost, Ordering cost, Transportation cost, considering disruptions of defective items cost, late delivery cost and GHG emission penalty along with maximizing score of the supplier on basis of sustainability dimensions. In the third stage Order delivery (OD) by the suppliers is addressed by considering a truck routing problem to minimize transportation cost, GHGs emissions, and improving truck fill. A case study in automobile company producing car accessories situated in central India is applied to accumulate model parameters and to demonstrate the applicability of the proposed model.

The rest of this paper is organized as follows. Section 5.2 provides a brief literature review of related work. Section 5.3 provides details of the mathematical model. Sections 5.4 and 5.5 covers the AHP and TOPSIS MCDM techniques used in the study. Section 5.6 presents the application of the model in the case company and finally, Sect. 5.7 gives concluding remarks of the paper.

5.2 Literature Review

In this section, a literature review related to SSS&OA, Discount schemes, disruptions, and Transportation problems is given and finally, research gaps and proposed research contributions are presented.

5.2.1 *Sustainable Supplier Selection*

In recent years, a major shift is experienced by supply chain decision-maker with the advent of sustainability in the present world. Thus, the inclusion of environmental and social criteria is considered in research along with economic criteria [2, 6, 17, 15, 16, 25, 29]. Supplier selection is a multi-criteria decision-making process. So, managers always try to opt for the best approach to select and evaluate their suppliers in order to optimize their companies' benefits and to achieve higher sustainability ranks among its supply chain counterparts. In literature researchers have considered various MCDM approaches: AHP [6], TOPSIS [38], BWM [6], DEMATEL [17, 48], etc.

5.2.2 *Order Allocation*

In the traditional supply chain, only economic criteria were prevalent for supplier selection and evaluation. Hadian et al. [18] proposed a supplier selection and order allocation problem in which a Multi-Objective Linear Programing (MOLP) is converted to single-objective problem using Weighing method to develop a mathematical model for allocating orders to suppliers. The multiple objectives in their problem include Cost minimization, Maximizing Purchasing value, minimizing the number of defective and late delivered items. Tsai [52] stated that determining the suppliers and splitting orders between them has become a major challenge for buying firms. Keeping in mind the statement, SS&OA problem of MOMIP model considering imperfect shipment is presented by the author which is solved by the weighing method which is traditional, popular, and easy to implement. Basnet and Leung [3] presented a Multi-supplier, Multi-item, Multi-period inventory lot-sizing scenario aimed to minimize Procurement cost which includes purchasing cost, holding cost and ordering cost with constraints of capacity and demand. Songhori et al. [49] proposed a supplier and transportation alternatives selection problem. Data development analysis model is utilized to determine the relative efficiency of suppliers and transportation alternatives. In order allocation phase, Multi-objective mixed integer programming is considered with objectives of cost minimization and overall efficiency maximization. Razmi and Rafiei [44] proposed a Hybrid Analytic Network Process-mixed integer mathematical model in purchasing planning to select suppliers and allocate orders to them. Wang et al. [54] considered a *n*-capacity supplier inventory system with Suppliers having different lead times and purchase prices in linear integer programming model of SS&OA to select the best suppliers and to determine reorder level order splitting among suppliers. Meena and Sarmah [33] studied the problem of SS&OA under risk of supplier failure due to disruption events with objectives of minimizing expected total cost which includes purchasing cost, supplier management cost, and expected loss cost. Ruiz-Torres and Mahmoodi [45] presented a mathematical model that optimizes the allocation of demand across a set of selected suppliers with objectives of minimizing expected total cost which includes purchasing cost, supplier management cost, and expected loss cost. Fazlollahtabar and Mahdavi [7] proposed an integrated approach of AHP, TOPSIS, and multi-objective nonlinear programming to consider various factors in choosing the suppliers and splitting orders among selected suppliers to maximizing total purchasing value and minimizing the budget, total penalty due to tardiness and defect rate. Sawik [47] proposed a problem which deals with optimal supplier selection and order allocation in the presence of supply chain disruption risks. Table 5.1 presents a brief review of the SSS and OA literature.

5.2.3 *Quantity Discounts*

Quantity discount offerings in procurement play a major role in providing benefits to both the suppliers and buyers. Some discounts increases annual demand from customers, while others may only increase the order size [37]. Tsai [52] stated Price discount encourages buyers to make large purchases, and are a common and effective way for a supplier to promote their product. Thus, researchers have included quantity discounts in model formulation. Recently, Cheraghalipour and Farsad [6] proposed a multi-objective model for SS&OA where they utilized both all quantity and Incremental discount schemes for model formulation. Gupta et al. [16] employed a weighted possibilistic programming approach for sustainable vendor selection and order allocation in a fuzzy environment considering All quantity discount schemes to attract buyers. All quantity discount in multi-period green supplier selection problem is proposed by Hamdan and Cheaitou [19] where suppliers availability varies in each period. Jain et al. [21] utilized a chaotic bee colony approach for SS&OA problem considering all quantity and incremental discount. The author has reported that all quantity discount scheme is more preferable than an incremental discount scheme. However, in an overview for quantity discount by Munson and Jackson [37], the author has reported that all quantity discount represents by far the most popular form of quantity discount and is applied best in the purchase made at a single point of time or single period purchasing model. Further, the authors stated that incremental

Table 5.1 Literature review on SS&OA

Authors	Solution approach	Mathematical model	Economic	Environ mental	Social	OA	Item[a]
Basnet and Leung [3]	Enumerative search algorithm	✓	✓			✓	MI
Ruiz-Torres and Mahmoodi [45]	EXCEL solver	✓	✓			✓	SI
Razmi and Maghool [43]	MINLP, ANP	✓	✓			✓	SI
Wang et al. [54]	Genetic algorithm	✓	✓			✓	SI
Fazlollahtabar and Mahdavi [7]	AHP, TOPSIS, MINLP	✓	✓			✓	MI
Lee et al. [28]	ANP	✓	✓	✓			MI
Govindan et al. [14]	Fuzzy TOPSIS, MOLP	✓	✓	✓		✓	SI
Orji and Wei [39]	System dynamic simulation	✓	✓	✓	✓	✓	MI
Gupta et al. [16]	Fuzzy, Probabilistic programming	✓	✓	✓	✓	✓	MI
Tsai [52]	Weighing method	✓	✓			✓	MI
Nourmohamadi Shalke et al. [38]	RMCGP, TOPSIS	✓	✓	✓	✓	✓	MI
Cheraghalipour and Farsad [6]	RMCGP, BWM	✓	✓	✓	✓	✓	MI
Mohammed et al. [36]	Fuzzy AHP, MOP	✓	✓	✓	✓	✓	SI
Mirzaee et al. [34]	Fuzzy goal programming	✓	✓			✓	MI
Vahidi et al. [53]	Hybrid SWOT QFD	✓	✓	✓	✓	✓	MI
Hamdan and Cheaitou [19]	Branch and cut algorithm	✓	✓	✓		✓	MI
Govindan et al. [13]	MOP	✓	✓	✓	✓	✓	SI

(continued)

Table 5.1 (continued)

Authors	Solution approach	Mathematical model	Economic	Environ mental	Social	OA	Item[a]
Ghadimi et al. [10]	A multi-system agent approach	✓	✓	✓	✓	✓	SI
Lo et al. [29]	FMOLP	✓	✓	✓		✓	MI
Babbar and Amin [2]	Fuzzy QFD	✓	✓	✓		✓	MI
Lee and Chien [27]	Stochastic programming	✓	✓			✓	MI

[a]*MI* multi-item; *SI* single item

Table 5.2 Literature review on discounts and disruptions

Authors	Discount			Disruptions
	All quantity	Incremental	Volume	
Basnet and Leung [3]			✓	✓
Ruiz-Torres and Mahmoodi [45]	✓			✓
Shalke et al. [38]	✓	✓		
Cheraghalipour and Farsad [6]	✓	✓		✓
Lee and Chien [27]	✓			
Gören [17]				✓
Hamdan and Cheaitou [19]	✓			
Meena and Sarmah [33]	✓			✓
Gupta et al. [16]	✓			
Moghaddam [35]				✓

discount works well when the order covers a period of time or when a multi-period model is considered. Table 5.2 addresses some literature on quantity discounts and disruptions.

5.2.4 Disruptions

Suppliers while supplying allocated orders to buyers, sometimes are subjected to disruption which in any form, late delivery, bad quality due to lack in inspection, lost sales, equipment failure, workers strike disturb's supply chain working. This motivates researchers to consider disruptions while developing models. Tsai [52] extended the traditional EOQ model including disruption in shipment, defective items, and late delivery, and formulated an NLP model of SS&OA in multi-item, multi-supplier environments. Similarly, Hadian et al. [18] presented a multi-objective supplier selection and order allocation model that tries to optimize the single buyer and multiple-supplier problem by minimizing the total purchasing cost, the total number of late delivered items and the total number of defective items. However, neither of these two papers imposed penalty over suppliers for such disruptions. The concept of lost sales in which suppliers are not able to meet buyers' demand is introduced in SS&OA model presented by Gören [17]. Thus, in order to make suppliers more resilient and to smoothen up the supply chain's performance considering disruptions and imposing a penalty is much-needed action.

5.2.5 Transportation Alternatives

Growing environmental pollution is a major concern in this era of sustainability where items delivery through transportation modes contributes a major portion by the release of GHG's emissions. To tackle this environmental issue many researches have been done. Bazan et al. [4] informed that GHGs emission from both production and transportation has to be considered in supply chain modeling which allow decision-makers to approach supply chain designing problem with the perspective of sustainable development. Gang, et al. [9] provided a review on OA problem with transportation alternatives, in which authors have concluded that only the buyer decides both order allocation and transportation alternatives. In contrast, he stated that in practice only the price and ordered quantity decisions are taken by the buyer while transportation alternative decisions are taken by Suppliers. Magiera [31] proposed a model to plan deliveries of food products by considering SS and transportation alternatives problems. Bazan et al. [4] in their research concluded that truck capacity, unfilled spaces, have a major impact on GHGs emissions and transportation costs. This has motivated the inclusion of transportation alternative problem with SS&OA in this proposed work.

5.3 Mathematical Model

In this work, a situation is considered where a buyer firm buys its requirements from various available suppliers. A multi-objective mathematical model is developed considering multiple items multiple suppliers' single periods taking into account quantity discount. Each supplier has a limited capacity and is subjected to disruption due to bad quality and late deliveries. The mathematical model is aimed to minimize total Purchasing cost, Ordering cost, Transportation cost, Defective items cost, Late Delivery cost, and GHG emission penalty along with maximizing the score of the supplier on basis of economic, environmental and social dimensions.

5.3.1 Subscripts

i Index of items ($i = 1, 2, \ldots, I$)
j Index of suppliers ($j = 1, 2, \ldots, J$)
k_{ij} Index of discount range from supplier i for item i ($k_{ij} = 1, 2, \ldots, K_{ij}$).

5.3.2 Parameters

C_{ij} Purchase price of item i from supplier j (w/o discount)
$C^{A}_{ijk_{ij}}$ Price of item i for the purchase in discount range k_{ij} of supplier j
D_i Demand of item i in planning horizon
O_j Ordering cost from supplier j
T_j Fixed transportation cost per shipment from supplier j
Cap_{ij} Capacity of supplier j for item i
δ_{ij} Defect rate (in percent) of item i from supplier j
$\delta\mathrm{max}$ Maximum acceptable defect rate of item i
$\bar{d}$ On time delivery that supplier maintains for item i which is measured as percentage of late delivered items
M A sufficiently large number
$\mathrm{LB}_{ijk_{ij}}$ Lower bound of the quantity discount range k_{ij} of supplier j for item i
$\mathrm{UB}_{ijk_{ij}}$ Upper bound of the quantity discount range k_{ij} of supplier j for item i
G Penalty cost per surplus GHG emission (Rs.)
EF^{s} Green house Emission factor(kg/ton-km) by using transportation alternatives
N^{s}_{j} Number of unit supplied by supplier j using transportation alternatives H, M and L per shipment
ϕ_j Distance between supplier j and buyer organization (km)
W_i Weight of item i
DC_i Unit defective cost for item i
DD_i Unit delivery delay cost for item i
d_{ij} =1 if supplier j does not consider any discount for item i
=0 otherwise
d^{A}_{ij} =1 if supplier suggests all quantity discount for item i
=0 otherwise.

5.3.3 Decision Variables

$C'^{A}_{ijk_{ij}}$ =1 if supplier j selects discount range k_{ij} for item i
=0 otherwise
X_{ij} Number of item i bought from supplier j in planning horizon

Y_j =1 if an order is allocated to supplier j
=0 otherwise.

It should be noted that UB_{ij0} and LB_{ij0} are set to zero; $\text{UB}_{ijk_{ij-1}} = \text{LB}_{ijk_{ij}}\ \forall i, j, k_{ij}$; $\text{UB}_{ijk_{ij}} = \infty\ \forall i, j$. To be more precise, each supplier is free to choose between quantity discount and no discount policy, i.e., $d_{ij} + d_{ij}^{A} = 1$, if $d_{ij} = 1$; quantity discount is not considered in a proposed order allocation model.

5.3.4 Objective Functions

$$\begin{aligned}\text{Obj}_1 = {} & (\text{Purchasing cost} + \text{Ordering cost} + \text{Transportation cost} \\ & + \text{Greenhouse emission cost} + \text{Bad quality cost} + \text{Late delivery cost})\end{aligned} \tag{5.1}$$

$$\text{Purchasing cost} = \sum_i \sum_j X_{ij} \times C_{ij} \times d_{ij} + d_{ij}^{A} \sum_i \sum_j \sum_k X_{ijk_{ij}} \times C_{ijk_{ij}}^{A} \times C_{ijk_{ij}}^{\prime A} \tag{5.2}$$

$$\text{Ordering cost} = \sum_j O_j \times Y_j \tag{5.3}$$

$$\text{Transportation cost} = \sum_j N_j^{H} \times \text{TC}_j + \sum_j N_j^{M} \times \text{TC}_j + \sum_j N_j^{L} \times \text{TC}_j \tag{5.4}$$

$$\text{Greenhouse emission cost} = G\left[\sum_i \sum_j \text{EF}^{s} W_i \phi_j N_j^{s} - \text{Limit}\right] \tag{5.5}$$

$$\text{Bad quality cost} = \sum_i \sum_j \delta_{ij} \times X_{ij} \times \text{DC}_{ij} \tag{5.6}$$

$$\text{Late delivery cost} = \sum_i \sum_j \bar{d}_{ij} \times X_{ij} \times \text{DD}_{ij} \tag{5.7}$$

$$\begin{aligned}\text{Obj}_2 = {} & W_{\text{eco}} \sum_i \sum_j X_{ij} \times \text{Eco}_{ij} + W_{\text{env}} \sum_i \sum_j X_{ij} \times \text{Env}_{ij} \\ & + W_{\text{soc}} \sum_i \sum_j X_{ij} \times \text{Soc}_{ij}\end{aligned} \tag{5.8}$$

Subjected to:

$$\sum_i X_{ij} \le \text{Cap}_{ij} \times Y_j\ \forall i, j \tag{5.9}$$

$$\sum_{i} X_{ij} = D_i\left(1 + \delta_{ij}\right) \tag{5.10}$$

$$\delta_{ij} \le \delta\text{max} \tag{5.11}$$

$$\bar{d} \le \bar{d}\text{max} \tag{5.12}$$

$$X_{ij} \le M \times Y_j \tag{5.13}$$

$$\sum_{i}\sum_{j} X_{ij} \le \text{UB}_{ijk_{ij}} + M\left(1 - C'^{A}_{ijk_{ij}} d^{A}_{ij}\right) \forall i, j, k_{ij} \tag{5.14}$$

$$\sum_{i}\sum_{j} X_{ij} \ge \text{LB}_{ijk_{ij}} - M\left(1 - C'^{A}_{ijk_{ij}} d^{A}_{ij}\right) \forall i, j, k_{ij} \tag{5.15}$$

$$\sum_{k_{ij}} C'^{A}_{ijk_{ij}} = 1 \,\forall i, j \tag{5.16}$$

$$\sum N^{S}_{j} = \sum \left[N^{H}_{j} + N^{M}_{j} + N^{L}_{j}\right] \quad S \in H, M, L \tag{5.17}$$

$$\sum_{i}\sum_{j} X_{ij} \le \sum_{j}\sum_{s} N^{s}_{j} \tag{5.18}$$

$$\sum_{i}\sum_{j}\sum_{s} V_i \times N^{s}_{j} \le \sum_{s} V^{s} \tag{5.19}$$

$$\sum_{i}\sum_{j}\sum_{s} M_i \times N^{s}_{j} \le \sum_{s} M^{s} \tag{5.20}$$

$$\begin{aligned} &C'^{A}_{ijk_{ij}}, Y_j \in \{0, 1\} \\ &d^{A}_{ij}, d_{ij} \in \{0, 1\} \,\forall i, j, k_{ij} \\ &N^{H}_{j}, N^{M}_{j}, N^{L}_{j} \ge 0 \end{aligned} \tag{5.21}$$

Equation (5.1) calculates the first objective function and attempts to minimize total cost, which includes purchasing cost, ordering cost, transportation cost, greenhouse emission penalty, late delivery, and bad quality penalty. These costs are presented in Eqs. (5.2)–(5.7) separately. The first part of Eq. (5.2) calculates purchasing cost without discount while second part attempts to minimize purchasing cost with all quantity discounts. Equation (5.3) calculates ordering cost if a supplier is selected. Transportation cost is shown by Eq. (5.4) which is incurred while delivering items to the buyer. Three types of trucks are available with suppliers for items delivery. Equation (5.5) minimizes GHGs emission from transportation activities. If the Government implements regulation on GHGs emission (specifying limit) three conditions occur. The first condition is that, if the limit set by Government is less than the total GHGs emission from supplier j while transporting item i to a buyer than penalty cost G (Rs./ton) is incurred to supplier j for every surplus GHG's emission (ton). For the second condition, if the limit set by the government is more than the total GHG's emission from supplier j while transporting item i to a buyer than the supplier is not penalized, but he can use the remaining carbon emission for emission trading to other firms or suppliers. This model is limited to the first case and for the second case no emission trading is considered, i.e., the total cost due to GHG's emission will set to "0" if the second condition exists. Equation (5.6) and (5.7) attempts to minimize total rejected items and late delivered items. Quality and Late delivery in our case are measured in terms of percentage. The second objective function shown in Eq. (5.8) aims to maximize the weighted sum of total sustainability score of suppliers which includes the economic, environmental and social score. Supplier's scores with respect to criteria are calculated by AHP and TOPSIS. Equation (5.9) assures that the number of items i ordered from supplier j is equal to or less than the supplier's capacity in that time. Equation (5.10) assures that ordered quantity for each item from suppliers should be greater than demand during the planning horizon because defective pieces always remain in purchased quantity. Equations (5.11) and (5.12) puts a limitation on the defect rate of item i from supplier j. Equation (5.13) indicates that if the decision is to purchase item i from supplier j firstly the supplier should be selected. Constraints (5.14)–(5.16) utilize the proper discount range for suppliers who offer incremental discounts. Constraint (5.17) and (5.18) explains that a total number of units transported by using all available vehicles must be equal to the number of units supplied by all available supplier j. Constraint (5.19) and (5.20) are used to show the space and weight limitations on a particular transportation alternative. Constraint (5.21) imposes binary and positive integer constraints.

5.4 AHP

In order to determine the criteria weights, A MCDM technique AHP is employed. The main steps of this technique to obtain the weight of criteria and alternatives (suppliers) are presented below:

Step 1. Develop a pairwise comparison matrix for sub-criteria by giving scores on the basis of relative importance in the scale of 1–9 given by Satty [46], given in Table 5.3.
Step 2. Add elements in each column to find the sum of each column.
Step 3. Divide each element of the pairwise comparison matrix by the sum of each column obtained in step 2.
Step 4. Add each row and find out average to obtain Principle vectors or Eigenvectors which represents weights of sub-criteria.

Table 5.3 Measurement scale [46]

Verbal judgment or preference	Numerical rating
Extremely preferred	9
Very strongly preferred	7
Strongly preferred	5
Moderately preferred	3
Equally preferred	1
Intermediate values between two adjacent judgments (when compromise is needed)	2, 4, 6 and 8

5.5 TOPSIS

TOPSIS is one of the simplest, strongest, and fastest techniques in MCDM which determines the distance of selected alternatives from a positive ideal solution and the negative ideal solution [20]. TOPSIS is based on the concept that the chosen alternative should have the shortest geometric distance from the positive ideal solution and the longest geometric distance from the negative ideal. To obtain the supplier's score TOPSIS is utilized. The steps used in TOPSIS are:

Consider $m \times n$ matrix having m criteria and n alternatives. Let J the set of benefit attribute and J' set of negative attributes.

Step 1. Build the normalized decision matrix which can be described as

$$R_{ij} = \frac{x_{ij}}{\sum x_{ij}^2} \tag{5.22}$$

where R_{ij} is a normalized form of x_{ij}, where x_{ij} is the score of each alternative regarding each criterion.

Step 2. Construct the weighted normalized decision matrix which can be written as

$$V_{ij} = W_j \times R_{ij} \tag{5.23}$$

where W_j is the weight of the criterion.

Step 3. Determine positive ideal solution A^* and negative ideal solution A'

$$A^* = \{V_j^*, \ldots, V_n^*\} \tag{5.24}$$

where $V_j^* = \{\max(V_{ij}) \text{ if } j \in J;\ \min(V_{ij}) \text{ if } j \in J'\}$

$$A' = \{V_j', \ldots, V_n'\} \tag{5.25}$$

where $V_j' = \{\min(V_{ij}) \text{ if } j \in J,\ \max(V_{ij}) \text{ if } j \in J'\}$.

Step 4. Calculate distance measures of each alternative.

The distance from the ideal alternative is:

$$S_i^* = \left[\sum_j (V^* - V_{ij})^2)^{1/2} \right] \quad i = 1, \ldots, m \tag{5.26}$$

Similarly, the distance from the negative ideal alternative is:

$$S_i' = \left[\sum_j (V_j' - V_{ij})^2)^{1/2} \right] \quad i = 1, \ldots, m \tag{5.27}$$

Step 5. Calculate the relative closeness coefficient to an ideal solution C_i^*

$$C_i^* = S_i'/(S_i^* + S_i') \quad 0 < C_i^* < 1 \tag{5.28}$$

A supplier with higher value of relative closeness coefficient has a higher rank among the alternatives.

5.6 Computation Results

5.6.1 Case Study

To demonstrate the applicability of the proposed model, an automobile company situated in central India has been examined. The companies' CEO wants to consider sustainability aspects in its supply network activities in order to achieve higher ranks among its supply chain counterparts. So, the managers and experts concluded to consider the sustainability elements in their supplier evaluation. The company is involved in the production of 4 wheelers and to focus on its core functions, it outsources various accessories from local suppliers which include AC compressor, A/V system, and Navigation units. Buying these raw materials (items) is done from suppliers that considered sustainability requirements in their manufacturing procedures. The model has been used on a network of a supply chain consisting of five suppliers and a single buyer. However, the company wants to select at most three suppliers among the five candidate suppliers. Each supplier can supply multiple items to the buyer and are subjected to disruptions in demand due to the bad quality of manufactured items. Also, items can be purchased once a year. Suppliers are allowed to offer different pricing policies for each item, such as all quantity discounts, or no discount policies. The supplier is available with three types of trucks for items delivery, i.e., Heavy drive truck (Capacity up to 3.5 ton), Medium drive truck (capacity

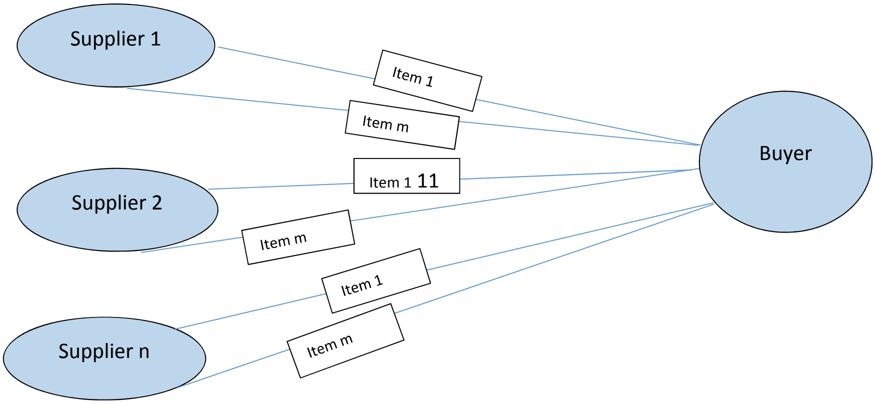

Fig. 5.1 Network configuration

3.5–8 ton), and Low drive truck (capacity > 8 ton). The network configuration is shown in Fig. 5.1.

5.6.2 *Problem Description*

This section describes the data required by the model to set values for the parameters. The supplier selection and order allocation consists of five suppliers who supply three kinds of items and a single buyer. The items are delivered from suppliers to buyers in three kinds of trucks. To study the behavior of the proposed model, data from the buying firm has been collected which is depicted in Tables 5.4, 5.5, 5.6, 5.7, 5.8, 5.9,

Table 5.4 Data related to capacity, purchase cost without discount of items from suppliers, a distance of suppliers and transportation cost from suppliers

Suppliers	AC compressors		A/V system		Navigation units		The distance of suppliers from the buyer	Transportation cost (Rs./km)
	Capacity	Unit cost	Capacity	Unit cost	Capacity	Unit cost		
S1	700	15,000	1700	16,000	900	16,000	150	150
S2	900	14,500	1800	18,000	1100	17,000	50	100
S3	800	17,000	1600	20,000	700	15,000	100	150
S4	1000	15,000	1500	30,000	1200	12,000	50	100
S5	600	19,000	1500	24,000	800	10,000	100	80
Demand for items	1100		2200		1100			

Table 5.5 Expected defect rate of suppliers for different items and penalty

Suppliers	AC compressors	A/V system	Navigation units
S1	0.01	0.02	0.01
S2	0.03	0.02	0.02
S3	0.01	0.01	0.02
S4	0.02	0.02	0.04
S5	0.02	0.02	0.01
δmax	0.05	0.05	0.05
DC_i	2000	3000	2000

Table 5.6 Percentage of late deliveries from each supplier and penalty

Suppliers	AC compressor	A/V system	Navigation units
S1	0.02	0.02	0.01
S2	0.03	0.03	0.02
S3	0.01	0.02	0.02
S4	0.02	0.01	0.04
S5	0.02	0.03	0.01
Max lead time allowed	0.05	0.05	0.05
DD_I	1000	1000	1500

5.10, and 5.11. Table 5.4 depicts the maximum capacity of all types of items, unit purchasing cost of each item from each supplier, and distance of suppliers from the buyer's organization. Expected defect rate of each item from suppliers, maximum allowable defect rate, and penalty associated are given in Table 5.5. Table 5.6 depicts expected late deliveries, allowable late delivery, and associated cost. Discount ranges offered by suppliers for each item are shown in Table 5.7. Table 5.8 gives information related to the weights of items and their dimensions. The capacity of each truck used by suppliers to deliver the items and emission factor of each truck is given in Table 5.9. A maximum number of units that trucks can carry while delivering is depicted in Table 5.10. Each type of truck can deliver multiple items in a single shipment. Table 5.11 depicts the penalty associated with the GHG emission exceeding the permissible limit values.

5.6.3 Solution Procedure

The proposed problem is solved in three phases. In the first, evaluation of suppliers, according to the economic, environmental, and social aspects is studied. For the computation of the criteria's weights along with suppliers' scores, AHP and TOPSIS approach is applied. In the second phase, MS excel solver is utilized to solve the

Table 5.7 Discount range from each supplier

Items	S1		S2		S3		S4		S5	
	Range	Unit price	Range	Unit price	Range	Unit price	Range	Unit price	Range	Unit price
AC compressor	0–200	15,000	0–300	14,500	0–200	17,000	0–300	15,000	0–400	19,000
	200–400	14,000	300–600	14,000	200–400	16,000	300–600	14,500	400–600	18,000
	400–∞	13,000	600–∞	13,000	400–∞	14,500	600–∞	14,000	600–∞	17,000
A/V system	0–300	16,000	0–400	18,000	0–500	20,000	0–300	30,000	0–500	24,000
	300–900	15,500	400–900	17,500	500–1100	19,000	300–800	29,000	500–1500	23,000
	900–∞	15,000	900–∞	17,000	1100–∞	18,500	800–∞	25,000	1500–∞	21,000
Navigation unit	0–200	16,000	0–300	17,000	0–200	15,000	0–300	12,000	0–400	10,000
	200–400	15,500	300–600	16,000	200–400	14,500	300–600	11,500	400–600	9500
	400–∞	15,000	600–∞	15,500	400–∞	14,000	600–∞	11,000	600–∞	9000

Table 5.8 Weight (kg) and dimensions (mm^3) of items

	AC compressor	A/V system	Navigation units
Weight	5	5	3
Dimensions	250 × 250 × 250 mm	457 × 406 × 305 mm	250 × 200 × 130 mm

Table 5.9 Emission factors for trucks and capacity of each truck

Type	Capacity (ton)	Emission factor (kg CO_2/km)
LDV	<3.5	0.3070
DV	3.5–12	0.5928
HDV	>12	0.7375

Table 5.10 Maximum no. of units of each item in each truck

Truck type	AC compressor	A/V system	Navigation unit
LDV	62.9376	17	151.29
MDV	552.512	152.55	1328.15
HDV	2623.26	724.32	6306.15

Table 5.11 Emission penalty data

Emission		Penalty
0	50	100
50	100	200
100	150	300
150	200	400
200	250	500
250	300	600
300	350	700
350	400	800
400	450	900
450	∞	1000

proposed bi-objective model for sustainable supplier selection and order allocation problems. To deliver the allocated order to a buyer, the knapsack problem is utilized which is presented in the third phase.

Table 5.12 Sustainability criteria and sub-criteria

Dimension	Criteria	References
Environmental	Green packaging, emission, and waste disposal, pollution	[16, 38]
Social	Worker safety and health, wages. Child and bonded labor, information disclosure	[6]
Economic	Cost, quality certification, late delivery, performance history	[38]

Table 5.13 Sustainability criteria weights in three dimensions

Economic dimension		Environment dimension		Social dimension	
Criteria	Weight	Criteria	Weight	Criteria	Weight
Cost	0.3109	Pollution	0.5389	Wages	0.4894
Quality	0.4915	Emission and waste disposal	0.2972	Worker safety and health	0.2878
Late delivery	0.1260	Green packaging	0.1637	Child and bonded labor	0.1623
Performance history	0.0714			Information disclosure	0.0603

5.6.3.1 Sustainable Supplier Selection

A team of Decision-Makers (DM) comprising of experts from various departments of the company such as purchasing, production, quality control is formed. All experts are experienced and have significant knowledge of supplier selection process in the organization. Discussion with team members was held and the sustainability criteria for supplier selection were finalized (Table 5.12). Further, steps of AHP are applied and the comparison matrix is established. The CI values were checked and the weights to the sustainability criteria in all three dimensions are established (Table 5.13). Each supplier is assessed for sustainability performance with respect to four economic, three environmental, and five social criteria for every item supplied by them by applying the TOPSIS method. All the steps of TOPSIS, were applied and closeness coefficient of suppliers was established and weighted suppliers score for each item with respect to economic, environmental, and social criteria is established as presented in Tables 5.14 and 5.15, respectively. Based on the values of the final scores, ranks are awarded to the suppliers. The final ranks of suppliers are the following order S1 > S6 > S2 > S3 > S7 > S8 > S4 > S5.

5.6.3.2 Order Allocation

Another round of discussions was held with the DM's and it was decided to examine and test the model in three different scenarios. In the first scenario, optimal order allocation to suppliers is determined without disruption risks like defective items

Table 5.14 Closeness coefficients of suppliers for each item for sustainability criteria

Closeness coefficients									
	Environmental criteria			Social criteria			Economic criteria		
	AC compressor	A/V system	Navigation unit	AC compressor	A/V system	Navigation unit	AC compressor	A/V system	Navigation unit
S1	0.3489	0.3226	0.7065	0.7835	0.7325	0.6513	0.8978	0.8978	0.8978
S2	0.5249	0.4590	0.6816	0.6347	0.7803	0.4616	0.7208	0.7208	0.7208
S4	0.5249	0.4372	0.3620	0.6347	0.6334	0.6194	0.5523	0.5523	0.5523
S5	0.5770	0.4785	0.6648	0.1845	0.1781	0.4311	0.3287	0.3287	0.3287
S6	0.7818	0.7038	0.6743	0.4436	0.3942	0.7863	0.6654	0.6654	0.6654
S7	0.1194	0.8536	0.5139	0.2942	0.8469	0.2149	0.1513	0.1513	0.1513
S8	0.5670	0.1474	0.1516	0.8289	0.4630	0.5122	0.5930	0.5930	0.5930
S9	0.5172	0.3626	0.6724	0.2863	0.4859	0.5789	0.5043	0.5043	0.5043

Table 5.15 Weighted supplier score

	Economic	Environmental	Social	Final scores
S1	0.8978	0.4594	0.7224	0.6932
S2	0.7208	0.5552	0.6255	0.6338
S4	0.5523	0.4414	0.6292	0.5409
S5	0.3287	0.5735	0.2646	0.3889
S6	0.6654	0.7200	0.5413	0.6423
S7	0.1513	0.4957	0.4520	0.3663
S8	0.5930	0.2887	0.6013	0.4943
S9	0.5043	0.5174	0.4504	0.4907

and late delivery. In the second scenario order allocation is optimized by considering disruption risk in the same problem environment. Finally, the results of the said scenarios have been compared. Also, order allocation with discount and without discount is compared in both the scenarios. The third scenario compares the order allocated to suppliers and costs associated when the allowable defect rate by buyer varies.

Scenario 1: Order Allocation—Without Disruptions

In this case, the mathematical model is allowed to determine the allocated quantities to available suppliers without considering the constraints of late delivery and bad quality, i.e., it is assumed that reliability of the quality of items which is supplied by the supplies is 100% in the first scenario. Therefore, it converts the inequality constraints of late delivery and defective rates into equality. The only objective is to optimize the purchasing cost while considering a discount in one case and no discount on another one.

Case 1: No Discount is Offered by the Supplier

In this case, available suppliers do not offer any form of quantity discount schemes to the buyer. It means, supplier having least unit cost has more chances of selection. The results of the order allocated to selected suppliers are shown in Table 5.16. It is seen that order is split among suppliers 1, 2, 3, and 4. The total purchasing cost to the buyer, in this case, is Rs. 63,956,000. The optimal order allocation to suppliers for each item is shown in Table 5.16.

Case 2: All Quantity Discounts is Offered by the Supplier

In this case, it is assumed that all quantity discounts is offered by the suppliers. The unit cost decreases after certain ranges which encourages the buyer to order more quantities with less price. The results of the order allocated to suppliers are shown in Table 5.16. It is seen that order is split among suppliers 1, 2, and 5. The total purchasing cost to the buyer, in this case, is Rs. 60,880,000. Selected suppliers

Table 5.16 Quantity allocation with disruptions

Quantity allocation					
X_{ij}	Without a discount	With discount	X_{ij}	Without a discount	With discount
X11	200	700	X24	0	0
X12	900	400	X25	0	0
X13	0	0	X31	0	300
X14	0	0	X32	0	0
X15	0	0	X33	0	0
X21	1700	1700	X34	300	0
X22	500	500	X35	800	80
X23	0	0			
The total cost to the buyer					
Without a discount INR 63,956,000/-			With discount INR 60,880,000/-		

decrease as more orders are allocated to selected suppliers in higher discount ranges. The total decrease in purchasing cost due to the discount offered is 4.8%.

Scenario 2: Order Allocation—With Disruptions

In this scenario, inequality constraints of late delivery and defective items are introduced while allocating orders to available suppliers. The maximum defect rate and late delivery, the buyer can sustain is 5%. To deal with such uncertainties buyers order more quantities from the suppliers. Two cases are considered for order allocation: (1) Order allocation without quantity discount (2) Order allocation with a quantity discount.

Case 1: No Discount is Offered by Suppliers
In this case, available suppliers do not offer any form of quantity discount schemes to the buyer. It means, supplier having the least unit cost has more chances of selection. Supplier's chances of selection also depend on items quality and delivery time offered by them. The results of the order allocated to selected suppliers are shown in Table 5.17. It is seen that order is split between suppliers 1 and 2 only since they are most eligible to deliver items with allowable defective quality and in the allowable time. The total purchasing cost to the buyer, in this case, is Rs. 72,910,405 which is more than 14% of the purchasing cost in case 1 of Sect. 5.6.3.2.1.

Case 2: When all Quantity Discounts is Offered by the Suppliers
In this case, it is assumed that all quantity discounts are offered by the suppliers. This is the most realistic case where the uncertainties as well as quantity discount scheme offered by the suppliers is considered. The unit cost decreases after certain ranges which encourages the buyer to order more quantities with less price. The results of

Table 5.17 Quantity allocation with disruptions

Quantity allocation					
X_{ij}	Without a discount	With discount	X_{ij}	Without a discount	With discount
X11	244	700	X24	0	0
X12	900	0	X25	0	0
X13	0	422	X31	900	582
X14	0	0	X32	233	0
X15	0	0	X33	0	573
X21	1700	1166	X34	0	0
X22	588	0	X35	0	0
X23		1100			
The total cost to the buyer					
Without a discount INR 72,910,405/-			With discount INR 69,871,462/-		

the order allocated to suppliers are shown in Table 5.17. It is seen that the order is split among supplier 1 and supplier 3. The total purchasing cost to the buyer, in this case, is Rs. 69,871,462. The total decrease in purchasing cost due to the discount offered is 4.16%. Also purchasing cost, in this case, is more than 12.68% of the cost in case 2 of Sect. 5.6.3.2.1.

Order Allocation—A Variation of Purchasing Cost with Allowable Defective Rate

In this scenario mathematical model is allowed to determine the optimal order allocation, purchasing cost, and change in demand when the allowable defective rate by buyer increase from 5 to 7%. Such cases arise when a buyer organization doesn't have strict quality control.

The total items allocated by the buyer to suppliers in each discount ranges are shown in Table 5.18. Almost all the allocated quantities fall in a third discount range which has a minimum unit cost of items. Weak quality control leads to more defective parts in the received orders and thus lower customer satisfaction. When the expected defective rate of 7% is allowed buyer has to order extra 229 units resulting in an increase in purchasing cost from Rs. 69,871,462 to 71,435,659, i.e., 2.23% increase. Similarly ordering cost increases from Rs. 60,000 to Rs. 85,000 which means selected supplier varies with buyer's allowable quality level. To control defects in delivered quantity and hence to satisfy its customers, buying firms should impose a penalty on a number of defective items and late deliveries items which is depicted in Table 5.18. The total defective cost increases from Rs. 230 to Rs. 370 when allowable defect rate changes from 5 to 7%.

Table 5.18 Order allocation variation with allowable defective rate

When the allowable defect rate is 5%						When the allowable defect rate is 7%					
X111	0	X211	0	X311	0	X111	0	X211	0	X311	0
X112	0	X212	0	X312	0	X112	0	X212	0	X312	0
X113	700	X213	1166	X313	582	X113	600	X213	1210	X313	679
X121	0	X221	0	X321	0	X121	4	X221	0	X321	0
X122	0	X222	0	X322	0	X122	0	X222	0	X322	0
X123	0	X223	0	X323	0	X123	0	X223	0	X323	0
X131	0	X231	0	X331	0	X131	0	X231	0	X331	0
X132	0	X232	0	X332	0	X132	0	X232	0	X332	0
X133	422	X233	1100	X333	573	X133	553	X233	1100	X333	487
X141	0	X241	0	X341	0	X141	0	X241	0	X341	0
X142	0	X242	0	X342	0	X142	0	X242	0	X342	0
X143	0	X243	0	X343	0	X143	0	X243	0	X343	0
X151	0	X251	0	X351	0	X151	0	X251	0	X351	0
X152	0	X252	0	X352	0	X152	0	X252	0	X352	0
X153	0	X253	0	X353	0	X153	0	X253	0	X353	0
Costs											
Purchasing cost			INR 69,871,462			Purchasing cost			INR 71,435,659		
Ordering cost			INR 60,000			Ordering cost			INR 85,000		
Defective penalty			INR 230			Defective penalty			INR 370		
Late delivery penalty			INR 115			Late delivery penalty			INR 205		
Increase in demand			143 units			Increase in demand			229 units		

5.6.3.3 Implementation of Knapsack Problem for Planning Items Delivery

Supplier plans the delivery of items after receiving orders from the buyer. In this model, each supplier is available with three types of trucks (HDV, MDV, and LDV). Each truck can carry multiple items in a single shipment. The primary objective in this scenario is to select such truck combination which maximizes the number of items in each truck shipment while minimizing the transportation cost and Greenhouse gas penalty which is shown by Eq. (5.4) which is subjected to constraints shown in Eqs. (5.17)–(5.20). In truck selection, problem two scenarios are considered. In the first scenario, the order has been allocated to suppliers considering no discount. In the second scenario, orders have been allocated considering the quantity discount. In both cases, the allowable defective rate is 5%.

Scenario 1: Items Delivery—Without Discount

In this scenario, the buyer allocates the whole demand to supplier 1 and supplier 2. The results of suitable truck combinations by S1 and S2 are shown in Table 5.19. In solution 1, a number of shipments increase when supplier 1 selects more light drive trucks which results in more distance traveled by the trucks. The trucks release a total of 1234.33 kg of GHGs due to which penalty of Rs. 1,234,325 is incurred by the supplier. In solution 2, when more HDVs and MDVs are used by suppliers for items delivery, GHGs emission reduced to 222.29 kg due to which penalty incurred is Rs. 111,146. Similarly when supplier 2 delivers allocated quantity to the buyer using higher LDVs 339. 03 kg GHGs emitted and the incurred penalty is Rs. 237,321. Emitted GHGS reduces to 59. 84 kg when more HDVs and MDvs are utilized.

Scenario 2: Items Delivery-With Discount

Buyer allocates whole demand to supplier 1 and supplier 3 when a discount is offered by suppliers. The results of suitable truck combinations by S1 and S3 are shown in Table 5.20. GHGS emission and penalty decreases when the supplier uses a number of HDVs and LDVs. For delivering the same number of items to buyer GHGs emission decreases from 1091 to 168.98 kg. GHGS emission and penalty decreases when the supplier 3 uses a number of HDVs and LDVs. For delivering the same number of items to buyer GHGs emission decreases from 94.21 to 57.97 kg while going from solution 1 to solution 3 in Table 5.20.

Effect of a Number of Trucks on GHGs Emission

Truck capacity can play a major role in determining the amount of CO_2 emissions from transport [4]. From Table 5.21 it is clear that as the number of higher capacity trucks increases or lower capacity trucks decreases for delivering the same number of items, transportation cost reduces. Also, GHG emission decreases as more quantities are transported in fewer shipments using more number of HDVs and MDVs (Figs. 5.2 and 5.3).

5.6.3.4 Weight Sensitivity Analysis

To demonstrate the analytical capability of the approach and to analyze trade-offs between criteria, the model is solved by varying weights of sustainability criteria in the range (0, 1) in Eq. (5.8). For example, the first three solutions Sol. 1, 2, and 3 in Table 5.22 considers only one of the criteria, which maximizes economic, environmental, and social scores, respectively. In the rest of the solutions weights are varied in the range (0, 1).

Table 5.19 Truck combinations by supplier 1 and supplier 2

Items delivery in trucks by supplier 1						Items delivery in trucks by supplier 2					
HDV	MDV	LDV	Transportation cost	GHGs emission	Penalty	HDV	MDV	LDV	Transportation cost	GHGs emission	Penalty
1	6	15	503,600	1234.33	1,234,325	0	5	10	224,600	339.03	237,321
2	3	0	450,100	222.29	111,146	2	3	0	195,600	59.84	11,968

Table 5.20 Truck combinations by supplier 1 and supplier 3

Items delivery in trucks by supplier 1						Items delivery in trucks by supplier 3					
HDV	MDV	LDV	Transportation cost (INR)	GHGs emission	Penalty	HDV	MDV	LDV	Transportation cost (INR)	GHGs emission	Penalty
1	3	15	430,700	1091	1,096,101	1	3	6	246,000	94.218	18,843.7
1	4	6	408,200	437.98	394,182	1	4	0	232,500	71.19	14,238.1
1	5	0	394,700	318.98	223,292	2	2	0	228,500	57.97	11,595.9
2	2	0	386,200	168.98	67,594.8						

Table 5.21 Effect of the number of trucks used by supplier 1 on CO_2 emission

CO_2 emission (kg)	Transportation cost	HDV	MDV	LDV
1091	430,700	1	3	15
437.98	408,200	1	4	6
318.98	394,700	1	5	0

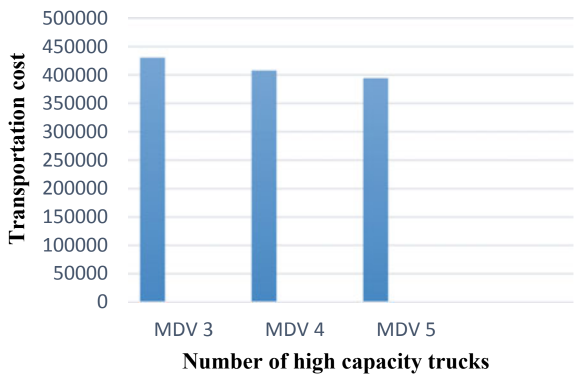

Fig. 5.2 Variation in transportation cost with no. of high capacity trucks

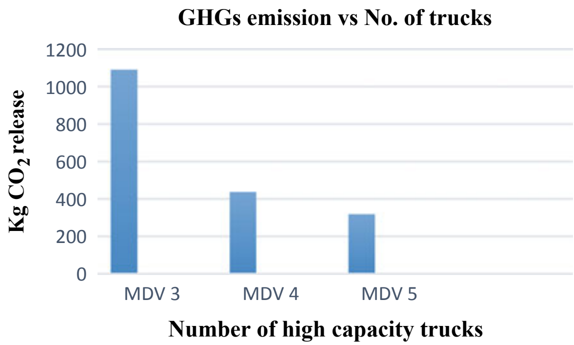

Fig. 5.3 Amount of GHGs release with a change in high capacity truck

In solution 1, supplier 1 and 3 received almost all the orders for all three items, because of the low cost offered by them. Also, for all three items in solution 1, more order is given to supplier 1 due to the lowest defective rate offered by them. In solution 2, supplier 1 did not receive any orders due to poor performance with respect to environmental criteria even though he offered the lowest cost. Supplier 2 and 3 having higher environmental scores and offering low cost are selected for order allocation in solution 2. A social criteria dominating model, as indicated in solution 3, shows that supplier 1 and 3 receives almost all the order for items due to higher performance in social aspects.

Solution 4–12 shows a shift in buyer's perspective from social/environmental dominating supply chain to the economic supply chain. As the buyer assigns more

Table 5.22 Sensitivity analysis

	Solution	1	2	3	4	5	6	7	8	9	10	11	12
Weights	W1	1	0	0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9
	W2	0	1	0	0.45	0.4	0.35	0.3	0.25	0.2	0.15	0.1	0.05
	W3	0	0	1	0.45	0.4	0.35	0.3	0.25	0.2	0.15	0.1	0.05
Score	Eco	3858	0	0	3134	3675	3675	3858	3858	3804	3858	3858	3858
	Env	0	3089	0	2806	2224	2224	2083	2083	2346	2083	2083	2083
	Soc	0	0	3256	2950	3256	3256	3207	3207	2991	3207	3207	3207
Obj 1		68,730,845	72,483,400	72,399,845	74,624,400	72,399,845	72,399,845	68,730,845	68,730,845	68,622,405	68,730,845	68,730,845	68,730,845
Order quantity	X11	700	0	700	0	700	700	700	700	700	700	700	700
	X12	0	900	0	900	0	0	0	0	444	0	0	0
	X13	422	244	422	244	422	422	422	422	0	422	422	422
	X14	0	0	0	0	0	0	0	0	0	0	0	0
	X15	0	0	0	0	0	0	0	0	0	0	0	0
	X21	1700	0	666	0	666	666	1700	1700	1700	1700	1700	1700
	X22	0	1800	0	666	0	0	0	0	588	0	0	0
	X23	566	466	1600	1600	1600	1600	566	566	0	566	566	566
	X24	0	0	0	0	0	0	0	0	0	0	0	0
	X25	0	0	0	0	0	0	0	0	0	0	0	0
	X31	900	0	900	0	900	900	900	900	900	900	900	900
	X32	0	444	0	1100	0	0	0	0	233	0	0	0
	X33	255	700	255	44	255	255	255	255	0	255	255	255
	X34	0	0	0	0	0	0	0	0	0	0	0	0
	X35	0	0	0	0	0	0	0	0	0	0	0	0

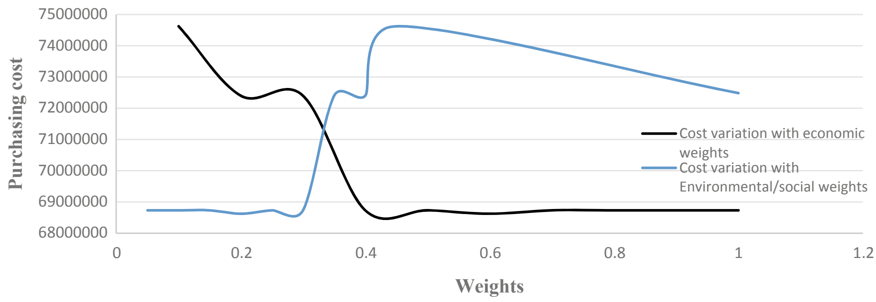

Fig. 5.4 Sensitivity analysis curves

weight to economic criteria, which means giving more preference to cost minimization, procurement cost decreases. In contrast to this, as shown in solution 4–12, when more weight is given to social and environmental criteria, buyer suffers higher procurement cost because, the supplier has to spend more money to manufacture eco-friendly items with minimum waste disposals, avoiding child labors, and providing the worker with occupational safety (Fig. 5.4).

5.7 Conclusion

Identifying the right sustainable suppliers and splitting the orders of multiple items between the selected suppliers has become a major challenge for buying firms. With the advent of sustainability concepts in the recent world, companies are aligning themselves toward the sustainability-driven strategies where they have to consider the three pillars of sustainable development viz. economic, environmental, and social criteria in the decision-making the process. This study presents a multi-objective MIP approach that can assist the DM's in framing SS&OA problems. TOPSIS method, an MCDM approach is used to rank suppliers on the basis of Sustainable performance. The proposed model is more effective in handling real situations since the selection process is multi-objective in nature with multi-items and multi-suppliers. It also incorporates all quantity discount schemes to attract buyers, imposes a penalty on defective parts, late deliveries, and most importantly penalty on greenhouse gases emissions (GHGs). The model also considers the truck allocation problem which helps suppliers to use available trucks efficiently and effectively while delivering items to the buyer. The applicability of the proposed model is justified by a case study of the Indian Automobile industry. Further, the impact of disruptions like defective quality in shipment and late delivery in the procurement process is studied and is compared with the scenarios where disruptions are absent. Joint consideration of disruptions and discount makes the model more complex and realistic which help the DM's to take SS&OA decisions more effectively. The applicability of the proposed model is justified by a case study in the automobile industry in Central

India. Case 1 of scenarios 1 and 2 in the computational results provide the DM's to analyze the effect in demands and purchasing cost due to disruptions which helps the decision-makers to switch suppliers. Sensitivity analysis has been performed in which weights of criteria is varied to select potential suppliers who have optimal performance with respect to sustainability dimensions. Graphical results display that giving 0.3 weight to economic performance and 0.35 to both the environmental and social performance of the supplier provides optimum purchasing strategy for the buyer. The model has been solved using MS Excel solver. Finally, the results from phase three of model, i.e., truck delivery reveal that Greenhouse gases emissions and transportation cost from transportation activities increase when more LDV trucks are used by supplier for items delivery instead of HDvs and MDVs.

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Chapter 6
Vibration Analysis of Railway Wagon Suspension System for Improved Ride Quality using MATLAB Simulink

C. Prithvi, R. Srinidhi, and A. Karthik Hebbar

Abstract In this paper, the dynamic response of the Indian railway wagon suspension system is investigated using MATLAB Simulink under step input condition which simulates the irregularities of the track. In the initial part of the work, a linear dynamic model of the Indian railway wagon suspension system was carried out and later mathematical equations are derived from the model constructed. An equivalent Simulink model in accordance with the equations was constructed in MATLAB Simulink. The system is given a step input to simulate the irregularity of the track and the dynamic response such as displacement, velocity and acceleration of the coach, bogie frame and the wheel were found. From the result, it was observed that for the step input, the major vibrations will occur at the coach and the bogie frame and thus causing discomfort to the passengers. In order to reduce these vibration modifications, it is made to the full suspension model with the use of hydraulic actuator controlled by proportional–integral–derivative (PID) controller. It is then simulated using MATLAB Simulink under the same track condition to study the vibration characteristics. The results of the modified suspension system show greater improvements in comparison with the system without PID controller. The improvization with the modified suspension system is suggested to achieve the travel comfort for the passenger.

Keywords ICF · Simulink · Suspension system · Vibration analysis

6.1 Introduction

Analytical modelling is made to study the dynamic response of the system and to make necessary technical changes to the system for better performance of the

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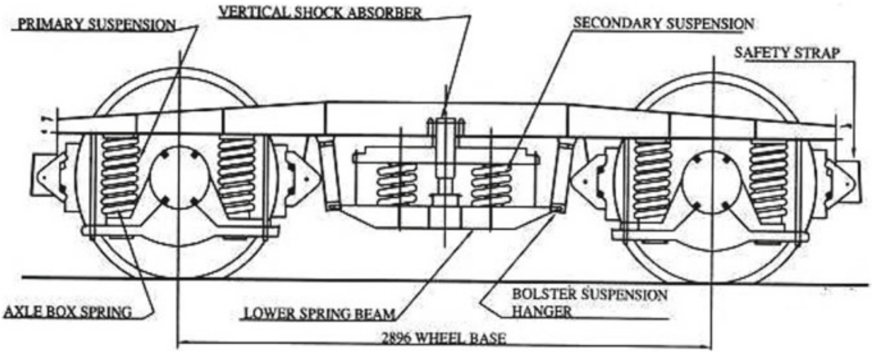


Fig. 6.1 Side view of Indian railway wagon

system. A passenger travelling in Indian railways always experiences some kind of vibration. To minimize these vibrations, the railway wagon has to be redesign or reconstructed with proper technical aspects. In order to bring a technological change to the Indian railway bogie, this project is undertaken. In this project, the vibration characteristics of the Indian railway wagon bogie are studied by analytical modelling the suspension components of the system and the necessary modifications are made to the suspension model to get the better performance of the system. The present work tries to analyse the dynamic performance characteristics of railway suspension model of Indian railway wagon. The Indian railway system bogies are not changed since 1955. The ICF has its own design and structure [1]. To bring a change in its design and structure, extensive modelling and simulation are necessary. The side view diagram and top view diagram of ICF bogie are shown in Figs. 6.1 and 6.2.

The parts of Indian railway wagon system are:

6.1.1 Bogie Frame

The bogie frame railway wagon is manufactured from steel. Bogie frames are sorted into two types, and they are thirteen-ton bogie frame and sixteen-ton bogie frame. All the non-AC coaches are using thirteen-ton bogie frames, and every AC coaches are using sixteen-ton bogie frames. Primary suspension system and secondary suspension system are connected by using brackets with a welding arrangement of bogie frame.

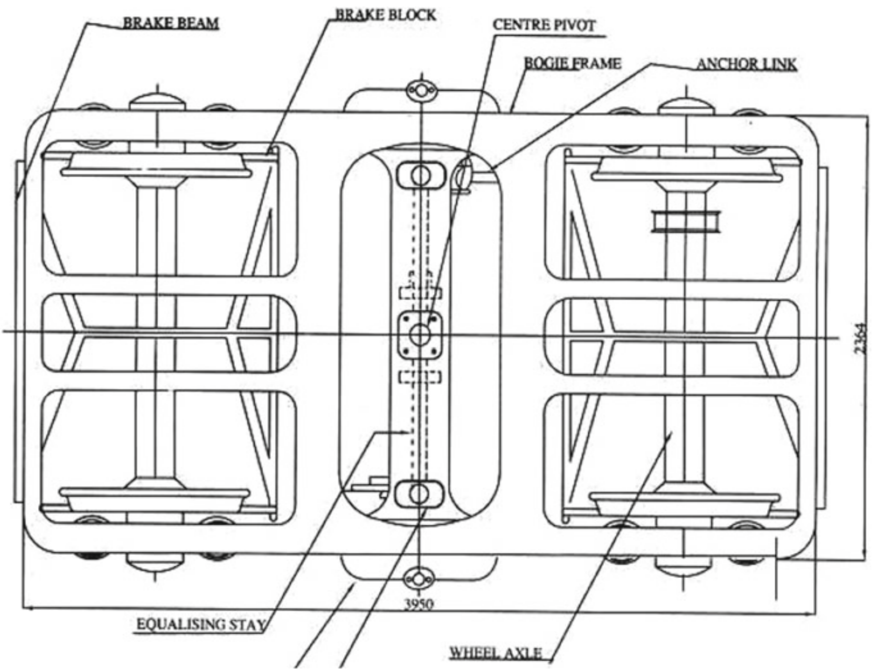


Fig. 6.2 Top view of Indian railway wagon

6.1.2 Bogie Bolster

The central section of the bogie is termed as bogie bolster. It carries the whole weight of a railway coach supported by bogie frame. The centre pivot pin is provided at the mid-section of bogie bolster. Secondary suspension is connected at either bogie face end that connects with bogie bolster. The coach is pivoted to the centre pivot pin that is to the bogie bolster. Centre pivot pin permits the circular motion of the bogie once the rail coach is moving on the arc or curved path. So as to produce the smooth impact for the centre pivot pin, a cylindrical structured member created of metal rubber is placed within the centre pivot.

6.1.3 Secondary Suspension System

Bogie bolster is connected with secondary suspension components using suspension springs and the lower spring beam. The arrangement of bogie bolster cannot have done by the bolting connection or welding connection. Anchor link is used to connect the bogie bolster, and anchor link has hollow rod structure with the housing arrangement. Steel brackets are used to connect the anchor link to the bogie bolster and to the bogie frame. There is hinged arrangement on either side of the anchor link. This allows the movement of bogie bolster during curved line path of the railway [2].

The lower spring beam is used to provide support to the secondary mechanical suspension system. Steel plates are used to manufacture the lower spring beam. The attachment of lower spring beam is on the outer side of the bogie frame using steel made hanger. They are called the Bogie Secondary Suspension Hangers (BSS). The lower spring beam acts as a floating member which is hinged to the bogie frame by the hangers at the top and bottom position. This arrangement allows the vertical or longitudinal movement of the lower spring beam.

The inside part section of the lower spring beam is attached to the bogie bolster by using equalized staying rod. It is manufactured by steel materials like tubes and sheets. It is also fixed on either ends with the lower spring beam and the bogie bolster with by using brackets with the help of welding to the bogie bolster. A pin is used to make the connection between them.

6.1.4 Primary Suspension System

The primary suspension consists of a piston and cylinder arrangement. Wheel axle housing is also provided along with this arrangement. In order to avoid damage, a washer is also used. The sealing ring will act as a piston ring which is placed adjacent to washer. Damper with the oil is used to provide damping effect. The rubber washers are for the arrangement of primary suspension system.

6.1.5 Wheel Set Assembly

The wheel assembly consists of four wheels in two pairs and an axle. The wheels are made by casting and forging process. Roller bearings are used in the Indian railways. The press-fitting arrangement of axle collar with the roller bearing is made. In order to avoid the centre movement of roller, bearing collars are used.

6.2 Full Suspension Model

The model is extended for the full model of Indian railway wagon consisting of four wheels, secondary suspension at both sides and primary suspension at all the wheels [3].

In Fig. 6.3, m_1, m_2 and m_3 represent the masses of coach, bogie frame and the wheel, respectively. The k_1 and c_1 represent the secondary suspension system. The k_2 and c_2 represent the primary suspension system and k_3 represents the stiffness of the wheel.

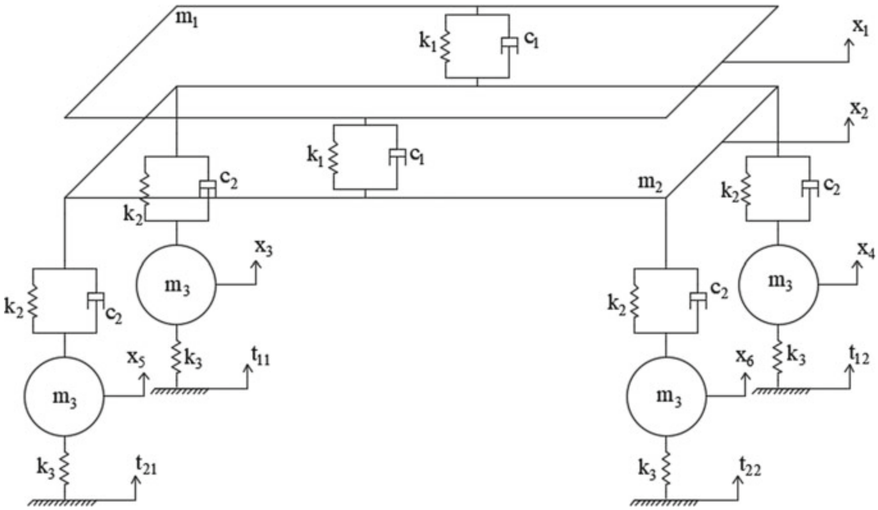


Fig. 6.3 Full linear dynamic suspension model of Indian railway wagon

6.2.1 Equations for the Full Suspension Model

The mathematical equations are developed using Newton's method for the model shown in Fig. 6.3. Newton's second law of motion is applied by considering the free body diagrams of all the masses [4]. The corresponding equations are:

$$m_1\ddot{x}_1 = -2c_1(\dot{x}_1 - \dot{x}_2) - 2k_1(x_1 - x_2) \tag{6.1}$$

$$\begin{aligned} m_2\ddot{x}_2 = & -2c_1(\dot{x}_2 - \dot{x}_1) - 2k_1(x_2 - x_1) - c_2(\dot{x}_2 - \dot{x}_3) \\ & - k_2(x_2 - x_3) - c_2(\dot{x}_2 - \dot{x}_4) - k_2(x_2 - x_4) \\ & - c_2(\dot{x}_2 - \dot{x}_5) - k_2(x_2 - x_5) - c_2(\dot{x}_2 - \dot{x}_6) - k_2(x_2 - x_6) \end{aligned} \tag{6.2}$$

$$m_3\ddot{x}_3 = -c_2(\dot{x}_3 - \dot{x}_2) - k_2(x_3 - x_2) - k_3(x_3 - t_{11}) \tag{6.3}$$

$$m_3\ddot{x}_4 = -c_2(\dot{x}_4 - \dot{x}_2) - k_2(x_4 - x_2) - k_3(x_4 - t_{12}) \tag{6.4}$$

$$m_3\ddot{x}_5 = -c_2(\dot{x}_5 - \dot{x}_2) - k_2(x_5 - x_2) - k_3(x_5 - t_{21}) \tag{6.5}$$

$$m_3\ddot{x}_6 = -c_2(\dot{x}_6 - \dot{x}_2) - k_2(x_6 - x_2) - k_3(x_6 - t_{22}) \tag{6.6}$$

6.3 Simulation Using MATLAB Simulink

To get the dynamic response of the system, it needs to be simulated. The simulation of the suspension model of the Indian railway wagon is done by using MATLAB Simulink [5]. The model is simulated for the fixed parameters of the system [6]. The track "*t*" is simulated for the step input condition [7]. The performance characteristics such as displacement of the coach, bogie frame and the wheel are recorded for the system model.

6.3.1 Simulation of Full Suspension Model

The equivalent Simulink model of the system is created according to Eqs. (6.1)–(6.6) as shown in Fig. 6.4.

The Simulink model consists of six summation blocks representing six equations correspondingly. The displacement, velocity and acceleration can be measured with the scope connected in the circuit. The circuit consists of Integrator and gains which are connected to each other according to the equations.

The model is simulated for the fixed parameters of the system as shown in Table 6.1.

The track input is considered here is step input condition of the track with a time interval of five seconds for each of the wheel. Due to the track disturbance, the maximum displacement is recorded for the coach (m_1) at each of the wheel at regular

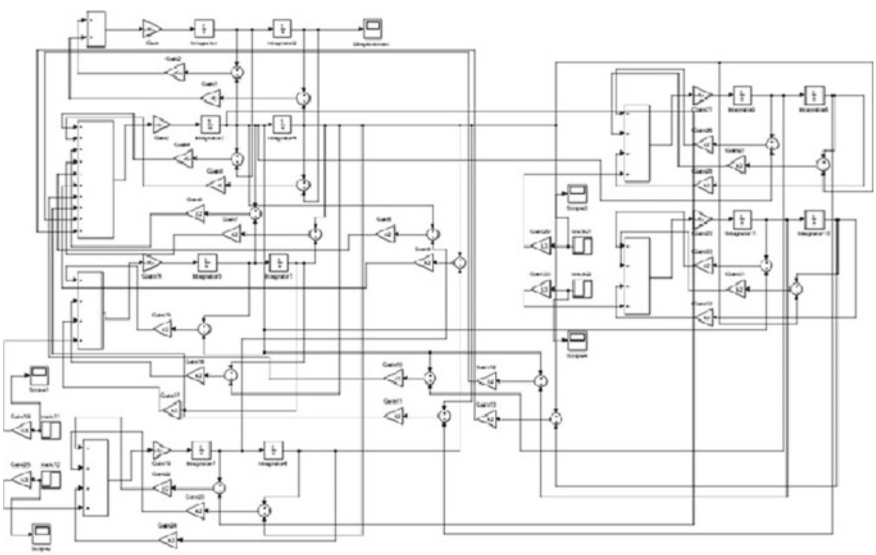


Fig. 6.4 Equivalent Simulink model of full suspension system

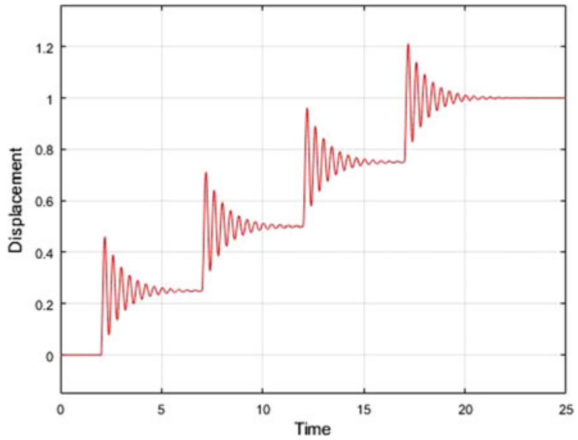


Fig. 6.5 Full model displacements of mass m_1 with respect to time

Table 6.1 Parameters of the system used for full model simulation

Sl. No	Quarter suspension model parameters of Indian railway wagon		
	Parameters	Symbol	Values
1.	Mass of the coach or body	m_1	32,000 (kg)
2.	Mass of the bogie frame	m_2	2615 (kg)
3.	Mass of the wheel	m_3	1500 (kg)
4.	Secondary spring stiffness	k_1	5.8×10^6 (N/m)
5.	Secondary damping coefficient	c_1	60×10^3 (Ns/m)
6.	Primary effective spring stiffness	k_2	7×10^6 (N/m)
7.	Primary effective damping coefficient	c_2	40×10^3 (Ns/m)
8.	Stiffness of the wheel	k_3	35×10^6 (N/m)

time interval of time. The maximum displacement of 0.5 units is measured, and the displacement goes on decreasing with time. The displacement continues again for the next time interval due to the track disturbance at another wheel. Thus, the railway coach undergoes vibration continuously due to the track disturbance (Fig. 6.6).

The displacement results of the bogie frame are comparatively lower than the coach. The maximum displacement of 0.3 units is measured for the bogie frame. The displacement continues again for the next time interval due to the track disturbance at another wheel.

The corresponding velocities of the masses m_1 (coach), m_2 (bogie frame) are recorded and shown in Figs. 6.7 and 6.8, respectively, (Fig. 6.7).

The maximum velocity of 3.8 units is measured for the coach. The velocity goes on decreasing after a step input is passed. The velocity rise is observed again for the next step input at another wheel. Thus, the vibration takes place at each interval

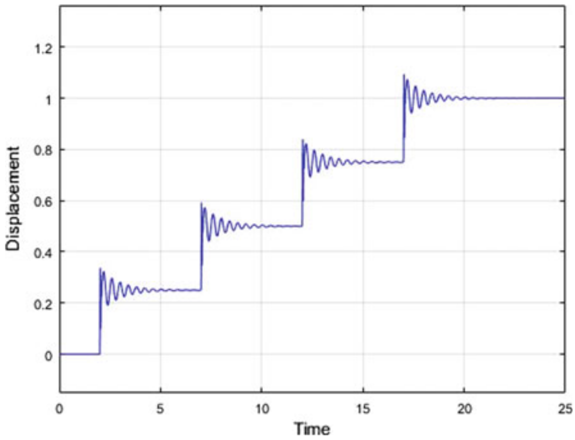


Fig. 6.6 Full model displacements of mass m_2 with respect to time

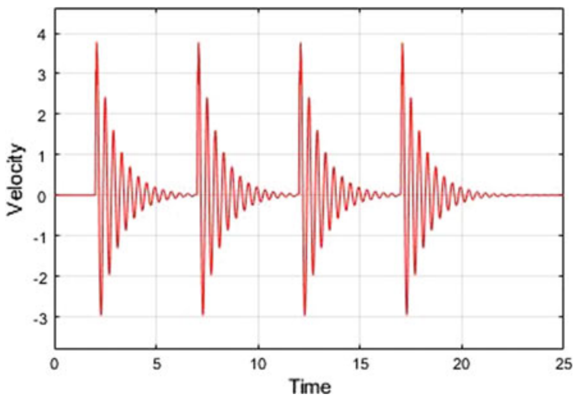


Fig. 6.7 Full model velocity of mass m_1

of step input condition of the track at the different wheels. These effects the ride comfort of the passenger (Fig. 6.8).

The velocity results of the bogie frame are comparatively larger than the coach. The maximum displacement of 22 units is measured for the bogie frame. The velocity continues again for the next time interval due to the track disturbance at another wheel (Fig. 6.9).

The maximum acceleration of 160 units is measured for the coach. The acceleration goes on decreasing after a step input is passed. The velocity rise is observed again for the next step input at another wheel (Fig. 6.10).

The result of full model (coach and bogie frame) shows that the displacement is occurring for every step input condition of the track with the time interval of 5 s. This shows that for the track irregularity presents in a track the system going to vibrate which will affect the passenger ride comfort. The results show that the displacement of the coach (m_1) and bogie (m_2) occurs with a large amplitude for every track disturbance at the four wheels. The maximum velocity is recorded with

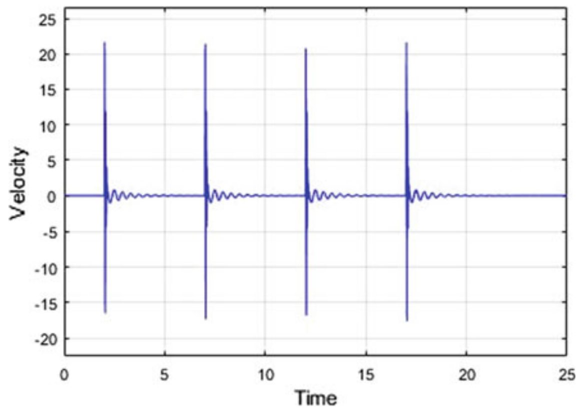


Fig. 6.8 Full model velocity of mass m_2

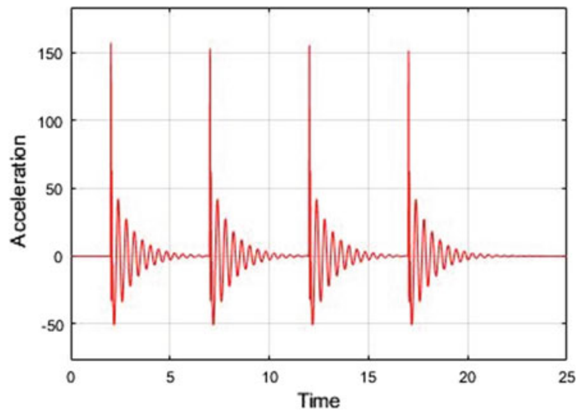


Fig. 6.9 Full model acceleration of mass m_1

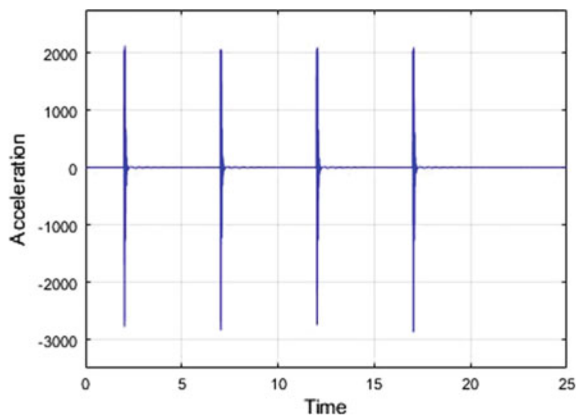


Fig. 6.10 Full model acceleration of mass m_2

a larger settling time for the coach and shorter settling time for the bogie. There is a peak acceleration recorded for the coach and the bogie frame with a larger settling time for the coach and shorter settling time for the bogie. The overall results show that the coach vibrates more when compared to the bogie frame. Hence, it directly affects the person who is travelling in the railway coach.

6.4 Modification

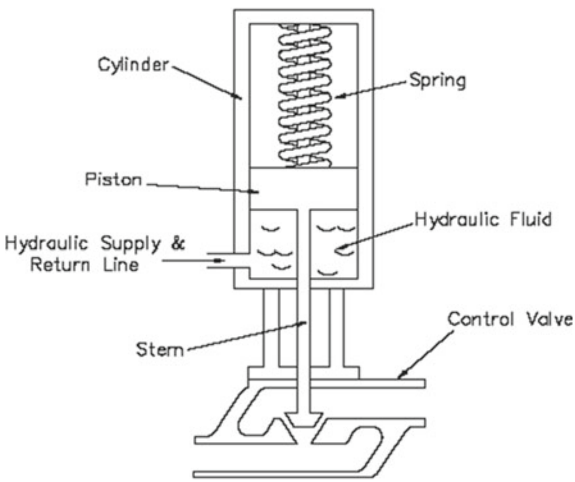
The Vibrations of the bogie has to be minimized for the smooth performance and to achieve the maximum ride comfort for the passenger. Modification to the quarter suspension model of the ICF bogie is made with the application of hydraulic actuator controlled by proportional–integral–derivative (PID) controller in order to minimize the vibration and to achieve the ride comfort for the passenger.

6.4.1 Hydraulic Actuator

A hydraulic actuator consists of a piston and cylinder arrangement that uses hydraulic power for its mechanical movement. The mechanical movement of the piston inside the cylinder can exert a force so that the damping can be achieved. The schematic diagram of hydraulic actuator is shown in Fig. 6.11.

There are two types of hydraulic actuator depending on the movement of piston. They are single acting and double acting cylinder. In single acting, the pressure applied on one side of the piston. In double acting system, the pressure is applied on either side of the piston. The difference in pressure makes the movement from one

Fig. 6.11 Schematic diagram of hydraulic actuator



side to another. By the application of hydraulic actuator, required damping force can be applied in order to suppress the vibrations [8] of the ICF bogie.

6.4.2 Proportional–Integral–Derivative (PID) Controller

Proportional–integral–derivative (PID) controllers are used in the applications of controlling some of the industrial processes. There are three parameters which act as controllers, and these are combined with each other to produce a desired control signal. A feedback controller sends the output signal to the controller. PID controllers are very flexible and perform the control strategy without having much error.

$$u(t) = K_{\mathrm{p}}e(t) + K_i\int_0^t e(t)\mathrm{d}t + K_{\mathrm{d}}\frac{\mathrm{d}e(t)}{\mathrm{d}t} \tag{6.7}$$

6.4.3 P-Controller

P-controller or proportional produces the output which is proportional to error signal $e(t)$. It compares the output signal with the input signal with the help of feedback controller. The error generated is multiplied proportionally with a proportional constant to get the desired output. The controller output is zero for the error value of zero. There exists a steady-state error in the system but the system is always stable. The proportional constant is denoted by K_{p} and as the K_{p} is increased operation speed is also increased.

6.4.4 I-Controller

Due to steady-state error of the p-controller, I-controller is needed to process the variable and the set point. The steady-state error can be eliminated by using I-controller. It integrates the error produced over a period of time until the error value vanishes to zero. It holds the final control value of the control device at which the error becomes zero. The output of the integral control is decreased when there is a negative error is present. The speed of the control system is decreased, and thus, the stability of the system gets affected. By decreasing the value of $K_{\mathrm{i},}$ the speed of the system can be increased.

6.4.5 D-Controller

The error response cannot be predicted by I-controller. D-controller is used to overcome this problem. The output of the D-controller depends on rate of change of error with respect to time. The system response can be increased by the use of D-controller.

By combining all the three controllers, we can achieve the desired control strategy for the system. The desired signal is called as u(t), and the error signal is called as the $e(t)$. These two signals are fed to the PID controller, by the combination of P-controller, I-controller and D-controller the desired output can be obtained.

6.4.6 Ziegler–Nichols Method of Tuning the PID Controller

In order work efficiently, the tuning of the PID controller is important. The PID controller must be tuned in such a way that dynamic response should be controlled to the desired level. There are different types of tuning methods are used to tune the PID controllers. The one of such method is Ziegler–Nichols method. By the use of this method, we can get the optimum values for P-controller, I-controller and D-controller.

Ziegler–Nichols method is a closed-loop method for tuning the PID controller. It is a method of continuous cyclic damping oscillation method. In this, at first the value of P-controller is kept constant for a particular value by keeping I-controller (K_{i}) and D-controller (K_{d}) values to zero. Proportional gain is increased until the system produces the oscillation at a constant amplitude. Gain at which the system produces constant amplitude of oscillation is called ultimate gain (K_{u}) and the time period at which the constant amplitude of oscillations is achieved is called the ultimate time period (T_{u}).

According to Ziegler–Nichols method for the PID controller after getting the ultimate gain (K_{u}) and the ultimate time period (T_{u}), the optimum values of K_{p}, K_{i} and K_{d} are given by,

$$K_{\mathrm{p}} = 0.6K_{\mathrm{u}} \tag{6.8}$$

$$K_{\mathrm{i}} = 1.2K_{\mathrm{u}}/T_u \tag{6.9}$$

$$K_{\mathrm{d}} = 0.6K_u T_u/8 \tag{6.10}$$

The optimum values of K_{p}, K_{i} and K_{d} are obtained using the above-mentioned formulas.

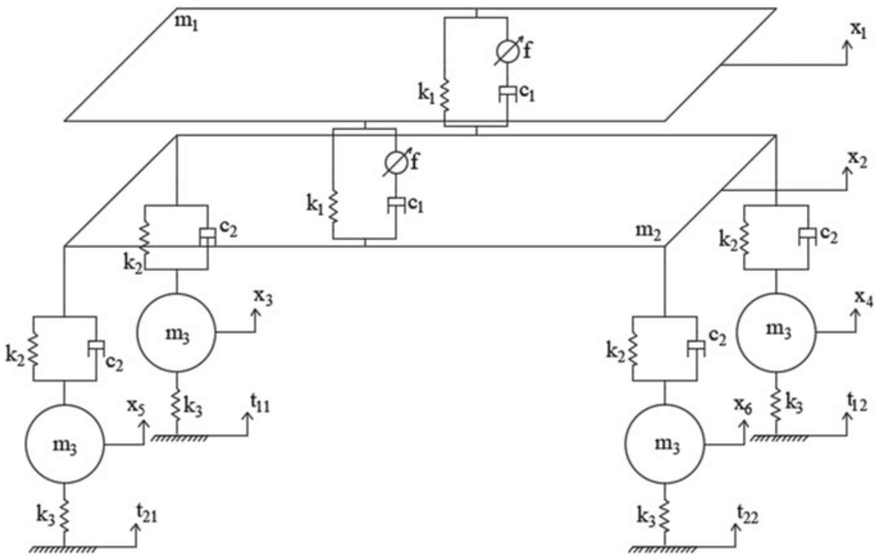


Fig. 6.12 Modified full suspension model of the Indian railway ICF bogie

6.4.7 Modification of Full Suspension Model

The modification is made to the extended model by using the application of hydraulic actuator and PID controller. The hydraulic actuator is connected in series with the damper in the secondary suspension arrangement. Hydraulic actuator is controlled by PID controller which receives the displacement signal from the accelerometer kept over mass m_1 (Fig. 6.12).

6.4.8 Mathematical Equations for the Modified Full Suspension Model

The mathematical equations are developed using Newton's method for the model shown in Fig. 6.13. Newton's second law of motion is applied by considering the free body diagrams of all the masses [4]. The corresponding equations are:

$$m_1\ddot{x}_1 = -2c_1(\dot{x}_1 - f) - 2k_1(x_1 - x_2) \tag{6.11}$$

$$\begin{aligned} m_2\ddot{x}_2 = &-2c_1(\dot{x}_2 - \mathrm{f}) - 2k_1(x_2 - x_1) - c_2(\dot{x}_2 - \dot{x}_3) \\ &- k_2(x_2 - x_3) - c_2(\dot{x}_2 - \dot{x}_4) - k_2(x_2 - x_4) \\ &- c_2(\dot{x}_2 - \dot{x}_5) - k_2(x_2 - x_5) - c_2(\dot{x}_2 - \dot{x}_6) \end{aligned}$$

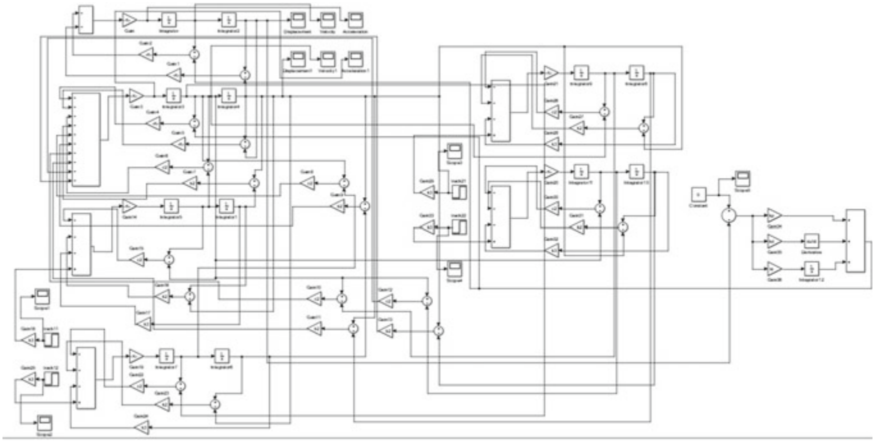


Fig. 6.13 Simulink model of the modified full suspension system

$$- k_2(x_2 - x_6) \tag{6.12}$$

$$m_3\ddot{x}_3 = -c_2(\dot{x}_3 - \dot{x}_2) - k_2(x_3 - x_2) - k_3(x_3 - t_{11}) \tag{6.13}$$

$$m_3\ddot{x}_4 = -c_2(\dot{x}_4 - \dot{x}_2) - k_2(x_4 - x_2) - k_3(x_4 - t_{12}) \tag{6.14}$$

$$m_3\ddot{x}_5 = -c_2(\dot{x}_5 - \dot{x}_2) - k_2(x_5 - x_2) - k_3(x_5 - t_{21}) \tag{6.15}$$

$$m_3\ddot{x}_6 = -c_2(\dot{x}_6 - \dot{x}_2) - k_2(x_6 - x_2) - k_3(x_6 - t_{22}) \tag{6.16}$$

6.4.9 Simulation of Modified Full Suspension Model Using MATLAB Simulink

The Simulink model of the modified full suspension system is made according to the equations. The model is again simulated using MATLAB Simulink for the step input condition of the track t_{11}, t_{12}, t_{21} and t_{22}, taken with a time interval of 5 s at the four wheels, respectively. The Simulink model of the modified suspension system is shown in Fig. 6.14.

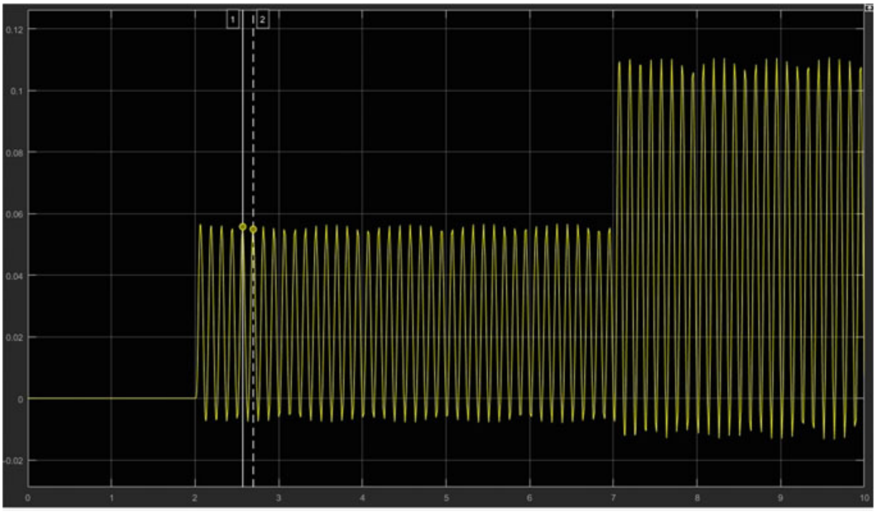


Fig. 6.14 Constant amplitude graph for the value of $K_p = 449$

6.4.10 Ziegler–Nichols Method

According to Ziegler–Nichols method for the PID controller after getting the ultimate gain (K_u) and the ultimate time period (T_u), the optimum values of K_p, K_i and K_d are given by,

$$K_p = 0.6K_u \tag{6.17}$$

$$K_i = 1.2K_u / T_u \tag{6.18}$$

$$K_d = 0.6K_u T_u / 8 \tag{6.19}$$

The optimum values of K_p, K_i and K_d are obtained using the above-mentioned formulas.

The value of K_p for which the constant graph is achieved is called the ultimate gain K_u which is equal to $K_p = K_u = 449$. The corresponding time period is called the ultimate time period T_u and is equal to $T_u = 122.534$ ms. The graph for the value of $K_p = K_u = 449$ is shown in Fig. 6.15.

The ultimate time period T_u is taken from the graph and is shown in Fig. 6.16.

Hence, the optimum values of K_p, K_i and K_d are given by,

$K_p = 269.4$;

$K_i = 4397.4694$;

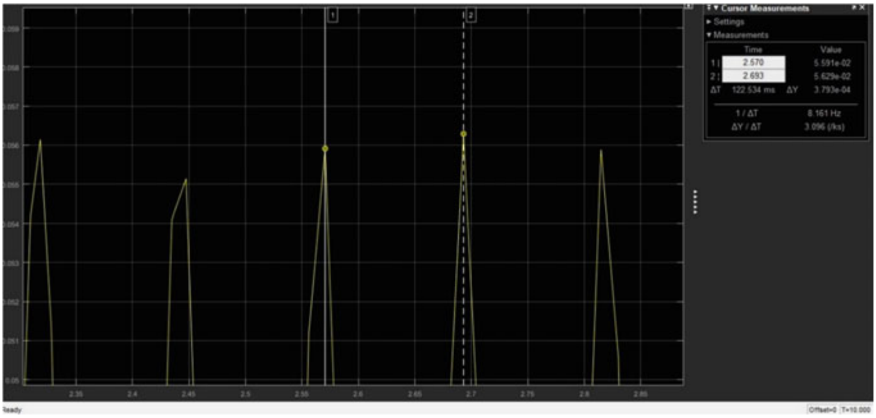
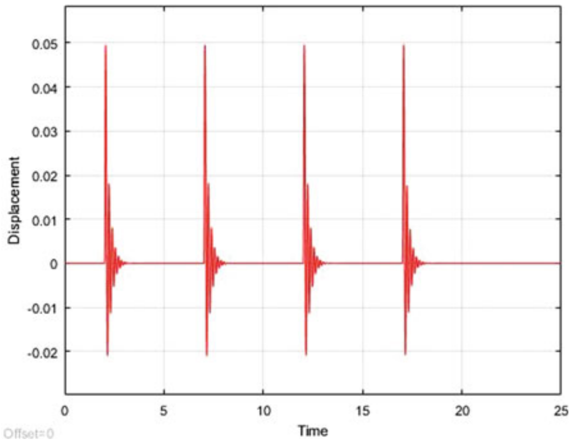


Fig. 6.15 Ultimate time period T_u of modified full suspension model

Fig. 6.16 Modified full model displacement of mass m_1



$K_d = 4.1263;$

6.5 Simulation Results of Modified Full Suspension Model

The performance characteristics such as displacement, velocity and acceleration are recorded for the coach (m_1) and the bogie frame (m_2).

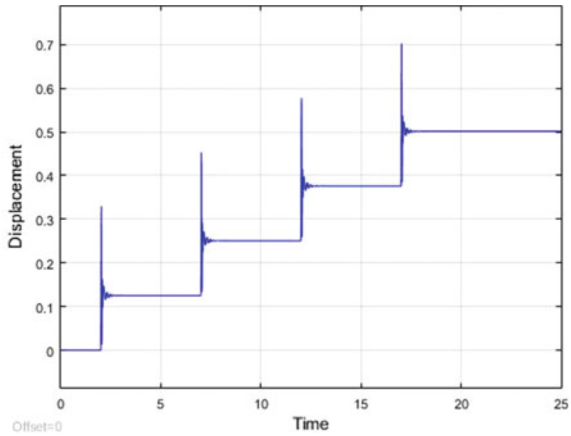


Fig. 6.17 Modified full model displacement of mass m_2

6.5.1 *Displacement*

The displacement of mass m_1 is shown in Fig. 6.17.

6.5.2 *Discussions*

The displacement results of the modified quarter suspension model are reduced by the application of hydraulic actuator controlled by PID controller. There is a much lower amplitude of displacement which is recorded for the coach and the bogie frame with a shorter settling time. There is a much lower peak of velocity, and acceleration is recorded for the modified model with a shorter settling time. Hence by using hydraulic actuator controlled by PID controller, we can minimize the vibrations of the railway wagon and so that the travel comfort for the passenger can be achieved.

6.6 Conclusion

Analytical modelling of railway suspension system of Indian railway wagon is done by considering a linear dynamic system model consisting of mass, spring and damper and having three-degree of freedom system. The model is simulated to get the dynamic response using MATLAB Simulink under step input condition of the track. The result shows that the major vibrations occurring at the wheel are transmitted to the bogie and coach of the railway system with a large settling time. These vibrations of the Indian railway wagon affect the passenger ride comfort. The modification to the Indian railway wagon is made by the application of hydraulic actuator controlled by PID controller and again simulated using MATLAB Simulink under step input condition. The result showed improvements over the original suspension model in suppressing the vibrations. Hence, the use of modified suspension system model is suggested in order to minimize the vibrations and to achieve the ride comfort for the passenger.

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Chapter 7
Analysis of Parking Pricing Strategy using Discrete Event Simulation

Dhananjay A. Jolhe and Ankur Agarwal

Abstract Management of vehicle parking is a crucial part of public transportation in urban areas. In metro cities, the problem of vehicle parking is severe due to space constraint and ever-increasing number of vehicles. The present paper deals with a study on pricing strategies at parking facility of railway station in a tier-2 city. The optimal pricing strategy has been developed considering simulated demand and supply. The study involves the use of discrete event system (DES) simulation technique to analyze and develop optimal parking strategy. A simulation model was developed to generate real-time situation and to perform different types of pricing scenarios in order to get the balance between demand and supply. It is believed that the study would provide useful direction to those working in the field of public parking management.

Keywords Discrete event system simulation · Parking pricing · Demand analysis · Parking scenarios

7.1 Introduction

The Indian auto industry became the fourth largest in the world with sales increasing 9.5% year-on-year to 4.02 million units (excluding two-wheelers) in 2017.[1] At the same time, spaces for parking the vehicles are limited. So definitely there will be a problem of cruising for parking. A study shows that approximately 30% of vehicles are cruising for parking at peak time [1]. Almost each parking facility goes through the stages of under-utilization, normal utilization, and over-utilization at different

[1]Source: India Brand Equity Foundation

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timings of the day. The problem of cruising for parking arises when parking goes through the stage of over-utilization, i.e., demand of parking is more than the spaces available for parking. The duration during which demand is more than supply is called peak time. As such, there is a scope for implementing surge pricing policies for parking facilities, i.e., the price to use the parking facility may be reduced in case of under-utilization and the price may be increased in case of over-utilization. The present study is carried out at a four-wheeler (i.e., car) parking facility at railway station in a tier-2 city located in central India in order to analyze the demand of parking over the different timings of the day and to provide possible solutions to manage this demand as per the spaces available in the parking facility. This paper focuses on the variation in price and its effect on demand of parking. Different scenarios were considered to vary the price and demand for parking. Input variables were drawn from data and four output variables were chosen to make a decision about any scenario. To visualize the effect of different scenarios, simulation experiments were performed in simulation software AnyLogic (v 8.3.3).

The present study is aimed at developing a pricing strategy that would help to increase parking space availability up to the maximum extent at peak time. The study was directed to achieve the following objectives at the parking facility under consideration-

1. To understand and analyze the arrival pattern of cars on each day of the week.
2. To understand and analyze stay pattern of cars on each day of the week.
3. To find out the appropriate pricing strategies for parking in order to balance between demand and supply.

7.2 Brief Literature Review

Many researchers have proposed measures to reduce parking problems. This section provides a review of the works of a few researchers relevant to the present research. Optimal parking price, as defined by Simicevic et al. [2], is the price for which parking demand is at the level of the regular number of parking spaces. Based on the two survey methods, viz. independent survey (counting) and dependent survey (interview), optimal parking price was found out and the study was extended further to explore the possibility of managing parking demand by varying parking pricing. Sen et al. [3] analyzed the parking facility on the basis of accumulation profile and parking demand. The authors observed that peak parking demand may vary from day to day due to a climatic condition, festivals, etc. The authors suggested the existing parking supply should immediately be enhanced to cater the existing parking demand. The authors also found out the forecasted future parking demand which can be effectively used by policymaker for solving parking problems. Chowdhury et al. [4] threw light on useful concepts, such as parking capacity, parking turnover, parking index, parking space inventory and further demonstrated these concepts with a case example of managing parking facility under variable demand scenario. In order to minimize traffic problems, Sharma et al. [5] proposed different parking policies such as centralized parking policy, specific time parking, banned parking on the street, shuttle service encouragement, price-based parking, and periodic parking (short-stay and long-stay). Causes for parking problem and traffic congestion were explored, and suitable measures were proposed.

Simulation approach has been proposed by Harris and Dessouky [6] to analyze parking space availability. The authors used two parameters, viz. average number of cars parked and number of balked cars, to analyze three alternative design layouts for parking with a view of choosing the optimal one. Naser et al. [7] analyzed the different parking lots on the basis of parking statistics such as parking accumulation, parking load, parking turnover, parking duration and findings are made. The authors recommended to build one additional paid parking garage. Herdiansyah et al. [8] measured the performance of parking lot on the basis of parking index. The authors divided the parking index into three categories, namely Good (Index 1), Enough (Index < 1 and > 0.5), and Less (Index < 0.5). The authors also suggested vertical parking lot for the limited horizontal parking area and need of parking attendant for smooth flow of vehicles in the parking lot. Hatanaka et al. [9] discussed the application of discrete event simulation to design hybrid-type parking lot. The authors measured the performance of hybrid-type parking lot in terms of queue length and utilization rate. The authors told that parking lot with shorter parking/unparking time improves the efficiency of the parking lot.

In the available literature, the authors have suggested many solutions to reduce parking problems on the basis of parking pricing and different parking statistics like parking load, parking accumulation, parking utilization, parking turnover, parking duration, etc. But there is no clue that any particular measure will reduce the parking problems in a given situation. To measure the same, experiments are to be performed at a parking facility which is really difficult, risky, and time-consuming process. So, this paper discusses the different pricing scenarios and visualization of its effect on parking facility using discrete event system (DES) simulation software AnyLogic®.

7.3 Problem Identification

Most of the vehicles parking facilities in India are run on "rule of thumb" basis. That is, these facilities rarely use any specific business model developed through research-based strategies. Usually located near market areas or transport stations, these facilities provide limited space for the parking of four-wheelers and two-wheelers for limited period of time. The customers are charged specific amount based on a few standard tariffs. Usually, tariffs are based on usage duration, the most common time duration slots being 3, 12, and 24 h. At a few parking facilities, monthly tariff is also provided for regular users. The parking facility under study follows fixed time-slot-based tariff throughout the day. Being located inside a railway station premises, it is primarily used by the people who visit the station for either drop and pick up of their guests or their own transport. Under fixed tariff pricing for 3 h time slot per vehicle, the user needs to pay a fixed amount of money for the continuous usage of

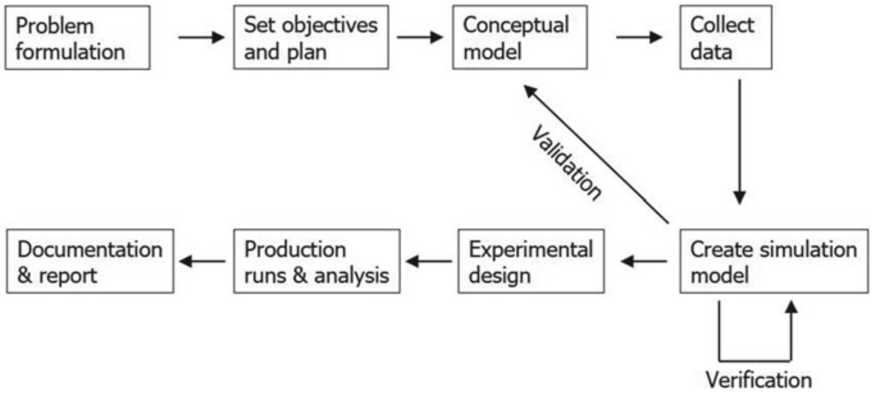

Fig. 7.1 Steps involved in DES simulation

3 h or less, i.e., same parking charges for the usage from 1 to 180 min. The parking charge will double for the next 3 h time slot, i.e., from 181 to 380 min. Obviously, such a tariff system would be economical for the users of long duration parking. However, majority of the parking users park their vehicles for the time less than one hour, and for those, tariff based on 3 h slot would not be economical. The current research presents a simulation-based study to develop appropriate strategy for pricing that would further help to develop sustainable business model. The arrival pattern and the parking duration pattern of the cars at the parking facility were observed, and DES simulation model was developed to mimic real-life behavior of the parking facility. A typical process of building DES simulation model as shown in Fig. 7.1 was adopted. After identifying the problem and objective, the model was conceptualized. Relevant data was collected through records and direct observations which was used to create simulation model. After verification and validation, various pricing options were tested in a simulated environment which helped to identify optimal pricing strategy.

7.4 Model Development

7.4.1 Objective and Assumptions

Any DES simulation model works with well-defined objective(s) and certain set of assumptions. As mentioned earlier, the objective of developing the parking simulation model is to find out the appropriate pricing strategies for parking in order to establish balance between demand and supply. The model was developed with the following assumptions.

(i) The way from the entrance to a specific parking space is unique as well as the way from the parking space to exit.
(ii) A parking staff is always available to provide ticket and receive payment.
(iii) Time for getting a ticket is considered negligible at arrival.
(iv) The time required to reach the parking space is negligible.
(v) The time required to unpark the vehicle and to reach a payment counter is considered negligible.
(vi) No customer will park the vehicle freely.
(vii) Every customer will be treated *equal* for parking, i.e., no priority rule.
(viii) Demand will be reduced by 1% if the price is increased by 5%.

7.4.2 Modeling the Flow of Cars

The layout of parking facility was created using Road Traffic Library in AnyLogic®. As depicted in Fig. 7.2, the layout clearly shows parking spaces (PS) and the direction of movement of cars during the parking process.

The layout shown in Fig. 7.2 itself represents the model which is coupled with the logic represented by flowchart depicted in Fig. 7.3. The flowchart was created using Road Traffic Library and Process Modeling Library blocks in AnyLogic®. Each block in the flowchart is used for a different purpose. Purposes of blocks are briefly described in Table 7.1.

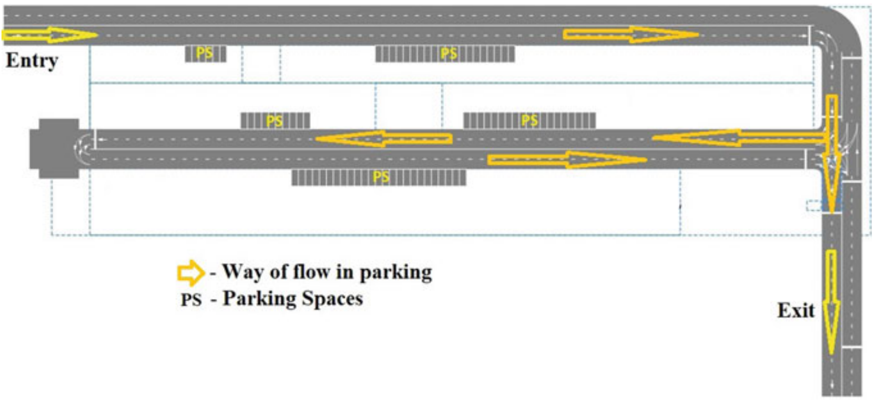

Fig. 7.2 Layout of parking facility showing parking spaces and direction of movement of cars

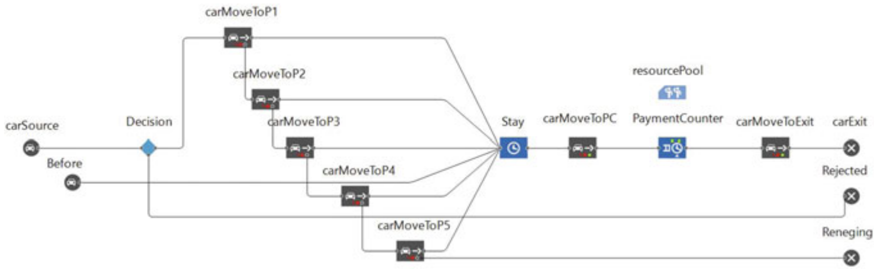

Fig. 7.3 Flowchart depicting the logic for car movement in the parking facility

Table 7.1 Blocks used in the model and their purposes

Block name	Purpose
carSource	Arrival of cars in the parking lot
Before	To show the number of cars already present in the parking lot
Decision	To decide whether the car will enter in parking facility or not
carMoveToPj	Car moving toward parking space. Here, j denotes the group of parking spaces in the parking facility. There are five parking groups, hence, $j = 1$ to 5.
Stay	To stay in parking facility
carMoveToPC	Car moving toward payment counter
Payment counter	Car at payment counter
carMoveToExit	Car moving toward exit
carExit	Car exit
Rejected	Cars will leave due to increase in price
Reneging	Cars will leave due to lack of space
Resource pool	To assign resource at payment counter

7.4.3 Data Collection

Data collection is an important step in a simulation study. Though the railway station under study, 228 trains pass daily with approximately 160,000 passengers embarking and disembarking. The parking facility under consideration is a useful agency to facilitate the city-bound movement of the passengers. Therefore, it is believed that the demand for parking at the parking facility, at a particular time, is primarily driven by a number of passengers alighting and boarding at the railway station at that time. To confirm our belief, the train time table at the railway station was observed and the hourly frequency of trains was sorted out for weekdays. The number of trains passing each hour for 24-h day varies from day to day in a week. The minimum train frequency was observed on Tuesday (97), followed by Thursday (99), Friday (101), Monday, Wednesday, and Sunday (105 each) and maximum on Saturday (107). For any day, hourly train frequency was found to vary from minimum of 0 to maximum

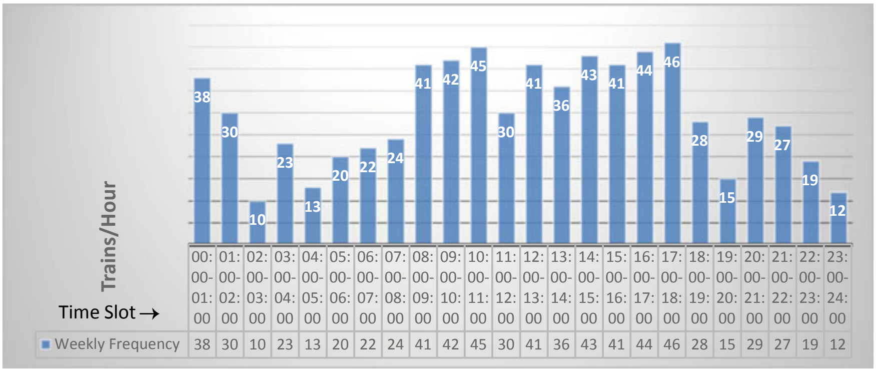

Fig. 7.4 Slotwise weekly train frequencies for the stations

of 9. Almost all the days have shown the highest train frequency for the periods from 8 am to 6 pm and from 12 am to 2 am. The periods from 2 am to 8 am and 6 pm to 12 am reported comparatively lower train frequencies. The total weekly train frequency for each slot of one hour is depicted in Fig. 7.4. It can be concluded that the time periods from 8 am to 6 pm and from 12 am to 2 am represent peak hours while the time periods from 2 am to 8 am and 6 pm to 12 am represent off-peak hours for trains passing through the station.

Along with the train frequencies, data for arrival time and departure time of vehicles in the parking, with their registration number, was collected. Parking duration of the vehicle was found out by subtracting the arrival time from departure time. After data collection, frequencies of car arrivals were observed on an hourly basis. The hourly frequencies of car arrivals, car departures, and the train frequencies were compared for randomly chosen time slots. This comparison is graphically shown in Fig. 7.5. It can be observed that trend of car arrival matches at a few places with that of train frequency. However, the trends of car departure and train frequency are not matching. Thus, from the given sample of data, it is difficult to correlate the car arrival/departure with the train frequency.

The hours having maximum frequencies of car arrivals were chosen for further analysis. For the data on inter-arrival times and parking durations, statistical distributions were fitted using EasyFit (v5.6) software. It was observed that inter-arrival time follows binomial distribution with parameters (0.09272, 6) and parking duration follows geometric distribution with parameter (0.02688) (time in minutes).

7.5 Experimental Runs

The basis of the present study is the law of demand and supply which highlights inversely proportional relationship between price and demand. For running the experiments, it was assumed that the price elasticity of demand is (−0.2). It implies that,

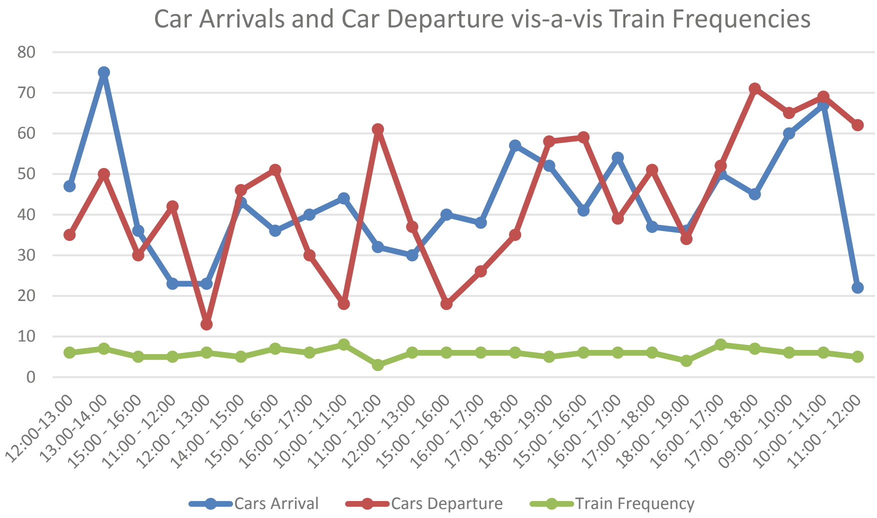

Fig. 7.5 Car arrival and car departure vis-à-vis train frequency

with 5% of the increase in price, the demand for parking will be decreased by 1%. Three parameters, viz. price variation, time duration slot for pricing, and demand factor are discussed below.

a. **Price variation:** Price of parking is an important factor to manage the parking demand as per the law of demand. Price was varied in steps of 5% increment. Price unit is considered in Rupees.
b. **Time duration slot for pricing:** Price in parking is applicable for particular time duration slot, i.e., customers are allowed to park their cars for specific time duration at a particular price. After completing that duration slot, the same charge will be again applicable. Time duration slot is expressed in hour.
c. **Demand factor:** It was assumed that for each 5% increase in price, there will be a decrease in demand by 1%. Value of demand factor will vary from 0 to 1. Here, 1 implies that demand is 100% and 0 implies that there is no demand, i.e., 0%.

7.5.1 Price Calculation Algorithm

An algorithm was written to calculate the charge of parking at the end of vehicle stay. It is shown in Fig. 7.6. Let us consider an example to understand the calculation of parking charge. Suppose price is charged at Rs. 20 per 3 h duration slot for a vehicle. It means that if the vehicle is parked for 0–3 h, Rs. 20 will be charged. If the vehicle is parked for more than 3 h, price will be charged in multiple of Rs. 20 for each 3-h duration slot or part thereof.

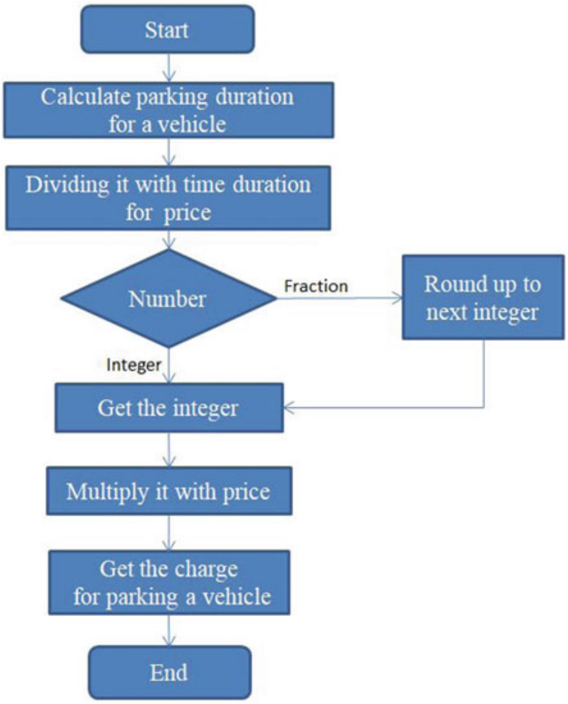

Fig. 7.6 Price calculation algorithm

7.5.2 Alternate Polices

To perform an experiment on an existing model, two policies were made. For policy 1, price elasticity is considered (−0.2). Experimental parameters of policy 1 are shown in Table 7.2.

For policy 2, data analysis presented earlier is taken into account. The purpose of policy 2 is to prefer short time parking users over long time parking users as the former are more frequent. Policy 2 makes use of three types of parking duration slots, viz. up to one hour (short time parking), between one hour and two hours (medium time parking), and more than two hours (long time parking).

It was found after data collection that 70% of the customers were having parking duration up to 1 h, 20% of the customers were having parking duration between 1 h and 2 h, and remaining 10% of the customers were having parking duration more than 2 h. So, policies were designed such that 70% of customers should not be affected. Price of parking was kept constant in policy 2, and it was considered that there will be a 50% decrease in demand while time duration was varied by 1 h for customers falling in different parking duration zone. Experimental parameters of policy 2 are shown in Table 7.3.

Table 7.2 Experimental parameters of policy 1

Policy	Experiment	Parameters		
		Price (Rs.)	Parking slot duration (H)	Demand factor
Existing policy	Experiment 0	20	3	1
Policy 1	Experiment 1	21	3	0.99
	Experiment 2	22	3	0.98
	Experiment 3	23	3	0.97
	Experiment 4	24	3	0.96
	Experiment 5	25	3	0.95
	Experiment 6	26	3	0.94
	Experiment 7	27	3	0.93
	Experiment 8	28	3	0.92
	Experiment 9	29	3	0.91
	Experiment 10	30	3	0.90
	Experiment 11	31	3	0.89

Table 7.3 Experimental parameters of policy 2

Policy	Experiment	Parameters		
		Price (Rs.)	Parking slot duration (H)	Demand factor
Existing policy	Experiment 0	20	3	1
Policy 2	Experiment 1	20	2	0.95
	Experiment 2	20	1	0.825

7.5.3 Input and Output Parameters

Before running the simulation, input parameters and their values need to be defined. There are seven basic input parameters considered in the simulation. The four input parameters—inter-arrival time of cars (minutes), parking duration (minutes), total parking spaces (i.e., capacity of the parking facility), and cars already present in the parking—are not varied in the simulation runs. As stated earlier, inter-arrival time of cars and parking duration follow binomial and geometric distributions, respectively. Total parking spaces and cars already present in the parking are considered as 80 and 60, respectively. Other three input parameters—price (Rs), time duration slot (hours), and demand factor (0–1)—are varied for different simulation runs. The output parameters considered are revenue (Rs), average occupancy (0–1), total number of car arrival in simulation time, and total number of cars reneging in simulation time.

7.5.4 Simulation Runs

A total of 13 experiments were conducted including policy 1 and policy 2 to get the optimal results. Simulation run was carried out for 600 min. Table 7.4 summarizes the results of simulation experiment.

The percentage change in revenue and reneging was compared relative to the existing policy. It is shown in Table 7.5.

Here, negative sign indicates that there will be an increase in percentage reneging.

Table 7.4 Results of simulation experiments

Policy	Experiment	Input parameter			Output parameter			
		Price (Rs.)	Time duration slot (H)	Demand factor	Revenue (Rs.)	Average occupancy (0–1)	Number of car arrival (in 600 min)	Number of cars reneging (in 600 min)
Existing policy	Experiment 0	20	3	1	18,640	0.694	979	35
Policy 1	Experiment 1	21	3	0.99	19,404	0.598	957	14
	Experiment 2	22	3	0.98	20,130	0.869	955	9
	Experiment 3	23	3	0.97	21,229	0.621	995	56
	Experiment 4	24	3	0.96	22,056	0.885	955	14
	Experiment 5	25	3	0.95	23,150	0.562	1014	65
	Experiment 6	26	3	0.94	24,232	0.724	977	20
	Experiment 7	27	3	0.93	24,057	0.809	929	17
	Experiment 8	28	3	0.92	25,816	0.675	921	9
	Experiment 9	29	3	0.91	26,796	0.63	930	10
	Experiment 10	30	3	0.90	27,360	0.677	924	12
	Experiment 11	31	3	0.89	27,993	0.633	905	0
Policy 2	Experiment 1	20	2	0.95	19,450	0.562	1014	65
	Experiment 2	20	1	0.80	21,180	0.718 8	31	0

Table 7.5 Comparison of experiments with existing policy

Policy	Experiment	Revenue	% Increase in revenue	Reneging	% Decrease in reneging
Policy 1	Experiment 1	19,404	4.10	14	60.0
	Experiment 2	20,130	7.99	9	74.3
	Experiment 3	21,229	13.89	56	−60.0
	Experiment 4	22,056	18.33	14	60.0
	Experiment 5	23,150	24.20	65	−85.7
	Experiment 6	24,232	30.00	20	42.9
	Experiment 7	24,057	29.06	17	51.4
	Experiment 8	25,816	38.50	9	74.3
	Experiment 9	26,796	43.76	10	71.4
	Experiment 10	27,360	46.78	12	65.7
	Experiment 11	27,993	50.18	0	100.0
Policy 2	Experiment 1	19,450	4.35	65	−85.7
	Experiment 2	21,180	13.63	0	100.0

7.5.5 Proposed Strategies

Out of four output variables, revenue and reneging play a very important role to decide the best scenario. Greater the revenue, the decision will be in favor of the parking owner. Lesser the reneging, the decision will be in favor of the customer. In case of average occupancy, we suggested that it should be less so that there will be potential to accept more customers in a parking facility.

For each experiment, revenue was more than the existing one, so any scenario out of all experiments was beneficial for parking owner. But maximum revenue was generated in experiment 11 of policy 1, so it was the best one. At the same time, reneging was 0 for the same experiment. But the price of parking is highest, i.e., Rs. 31 out of all experiment which may create a problem for customers. So, experiment 2 of policy 1 was preferred for customers' point of view where reneging was only 9 in 600 min and the price of parking was Rs. 22. It means only 9 customers will leave parking without getting space in 10 h. This scenario will be more economical for customers.

The main aim of policy 2 was to facilitate short time parking which will increase the parking turnover and, thus, parking problems will be reduced. In policy 2, experiment 2 was chosen as the best scenario because of no reneging. Here, the time duration slot for price was considered for one hour. It is already discussed above that there were 70% of customers for up to one-hour parking duration. So, 70% of customers will not be affected. Only, a few of customers out of remaining 30% of the customers who were using parking for long hours may leave the use of parking facility.

7.6 Conclusion

Discrete event system simulation is a method of simulating the behavior and performance of a real-life process or system. In this paper, we have seen the use of DES simulation to see the effect of the two proposed policies on parking revenue and reneging of the customers. At the railway station, pricing policy to prefer the parking for a short time duration over medium and long time duration to increase turnover of the parking facility and to reduce parking problems at peak time is proposed. Policies for any particular parking facility will definitely vary from one place to another place. Input variables and policies may be decided after data collection and decision of correct policy may be taken for any parking facility on the basis of output variables.

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Chapter 8
Assessing Benefits of Lean Six Sigma Approach in Manufacturing Industries: An Indian Context

Vikas Swarnakar, Anil kr Tiwari, and A. R. Singh

Abstract Lean manufacturing objective is to eliminate the waste from the manufacturing process, and six sigma is grasping the variations within the process and tries to reduce them. Lean manufacturing or six sigma alone cannot improve the quality, customer satisfaction rate, net earnings and also cannot reduce the overall production cost of the organization, but the combined approach may solve these issues. Lean six sigma (LSS) is a combined approach which maximizes the overall value and minimizes the production cost by applying their tools and techniques such as VSM, JIT, 5S, Kaizen, and Kanban. The objective of this paper is to assess the benefits of LSS approach in a manufacturing organization. The data are collected through convenient sampling approach from manufacturing organizations situated in India and analyzed through integrated relative importance index and simple regression analysis approach. The findings of the study contributed to manufacturing industries and lay down a few suggestions for implementing lean six sigma in case manufacturing organizations. The three different manufacturing organizations considered performing this study. The study concluded that the implementation of LSS supports the case industries to improve their quality, cost, delivery, production capacity, net earnings, overall savings, customer satisfaction and reduce their defects, inventory, cycle time, and machine breakdown. The study helps LSS practitioners and academician to better understand the benefits observed while implementing the lean six sigma approach in manufacturing organizations.

Keywords Lean manufacturing · Six sigma · Lean six sigma · Manufacturing process · Relative importance index · Regression analysis

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8.1 Introduction

In the recent competitive market, manufacturing organizations are rapidly moving toward continuous quality improvement methodologies such as lean manufacturing (LM), six sigma (SS), and total quality management [1]. These methodologies are not new in nature. Continuous quality improvement thinking for any organization helps toward achieving the quality and overall operational performance [5]. Thus, every manufacturing organization needs to adopt such a quality improvement approach which provides long-term benefits with appropriately maintaining their product quality to achieve the leadership position in the market.

Lean manufacturing is a waste elimination approach and the concept of origin through Toyota Production System (TPS) by Taiichi Ohno after the Second World War during the 1940s. Lean manufacturing objective is to eliminate non-value adding activities, and different types of waste occurred during the production process. The waste is also called 'Muda' in the Japanese language. Authors introduced generally seven types of wastes occurred in organizations like overproduction, over-processing, unnecessary motion, waiting time, rework, inventory, and defects that occurred in the final product [6, 10, 19]. In addition to these seven wastes, two more new wastes 'underutilization of people knowledge' and 'environmental waste' have been suggested by the [15]. Lean manufacturing also reduces the cycle time and lead time of process [6, 7]. It has many tools and techniques such as 5S, Kanban, Kaizen, cause and effect analysis, and value stream mapping.

Six sigma is defined as a defect reduction strategy which grasps the variation from the process. It helps to identify and eliminate defects, failures in the system or process with the uses of their statistical tools. The adaptation of six sigma results in improvements in product quality, net savings, increases bottom-line results, increases customer satisfaction and reduction in cost, reduces defects, and brings them to 3.4 defects per million [16]. These can be achieved through their use of different tools and techniques such as quality function deployment, statistical process control, failure mode and effect analysis, design of experiments, analysis of variances, and Kano approach.

In fact, the adaptation of lean manufacturing alone cannot remove variation and controls the statistical process from system and implementation of six sigma approach isolation which cannot eliminate all types of waste from manufacturing process [13]. Therefore, to prevent such type of problem, organizations decided to integrate both approaches for continuous quality improvement. The integration of these two approaches provides effective benefits and improvement in key metrics faster than alone implementation. The concept of this approach was used in one company named George Group in 1986. This company is situated in the UK, and the term lean six sigma was first introduced in the literature in 2000 as an evaluation part of the six sigma approach [15, 16]. The increase in demand toward deploying LSS in their organization has been noticeable that time, especially large, medium, and small manufacturing organizations such as Motorola, General Electric, and Honeywell. [3].

This study utilizes the benefits of LSS adaptation in manufacturing organizations. In this context, the study was conducted in three different manufacturing organizations located within India. The case organization is suffering problems related to defects occurring in the finished product, and struggling to adapt continuous quality improvement approach which overcomes such problems and sustains the organization for the long run. The main aim of this study is to assess the key benefits of adopting LSS in a manufacturing organization and suggest these three case organizations for further implementation. To perform such work, the study collected the data from selected 52 already LSS adopted manufacturing organization situated within India. Based on the collected data from various manufacturing industries ranks the benefits. The further hypothesis was formulated and tested to check the validity of response related to LSS approach adaptation in manufacturing organization using a simple regression approach.

8.2 Literature Review

A systematic literature review has been performed in the context of LSS implementation in manufacturing organizations and identifies their benefits. This regards 19 lean six sigma literature has been reviewed from the Scopus database with a key search such as lean six sigma and lean six sigma benefits and found that the benefits received from various manufacturing industries. In the literature, it clearly showed that the case studies have been performed in the various manufacturing organizations, in seven different regions, such as USA, India, UK, China, Taiwan, New Zealand, and Malaysia. The significant benefit observed in the literature during LSS implementation is shown in Table 8.1.

8.2.1 Research Gap

While the implementation of lean six sigma approaches in manufacturing organization, it provided extensive benefits and helps to improve the quality and performance of the organization. The various literatures are evident that the various benefits have been observed by the manufacturing industry. Most of the author reported theoretically knowledge about LSS benefits, limitations, motivation factor, barriers, success factor; challenges from the best of our knowledge and study of literature, no separate study existed on the ranking of LSS benefits and their validation with the help of structured case study. As a result, these gaps have formulated the direction of this study.

Table 8.1 Benefits of Lean Six Sigma implementation

Sl. No.	LSS implemented industry/country	Reason of LSS implementation	Tools and techniques used	Identified benefits	References
1	Honeywell International Inc./(USA)	To improve productivity, quality and reduce cost	SPC, FMEA, C&E analysis, process mapping, 5S	Reduction in manufacturing cost by 50%	[1]
2	Proprietary military products/	To reduce cost of production and cycle time	DOE, C&E, SPC, SIPOC, brain storming	50% reduction in overall cost	[2]
3	Automobile Component mfg./(India)	To reduce the defects occurring in product	CVSM, VOC, TPM, Pareto chart, DOE, control chart	Significant improvement in key metrics	[3]
4	Tire production company/(India)	To reduce defect occurring in production	Root cause analysis, VSM, 5S, C&E analysis	Reduction in overall defects by 15%	[4]
5	Small engineering company/(UK)	To examine the validity of the new integrated LSS approach	VSM, 5S, DOE, TPM, SPC, QFD	Increase OEE and production performance	[5]
6	PCB manufacture/(China)	To change the manufacturing process	ANOVA, 5S, FMEA, TPM, C&E, process map	Increase the production rate	[6]
7	Touch Panel Mfg./(Taiwan)	To improve the quality of the touch panel	SIPOC, ANOVA, VOC, C&E, SPC, DOE, CVSM	32.4% Reduction in defects	[7]
8	Large valve manufacturing/(USA)	To reduce cost, the cycle time of the process and improve the overall quality of product	5S, Kaizen, value stream mapping, root cause analysis, brainstorming	The average lead time was reduced from 180 to 40 days	[8]
9	Printing sample board manufacturing company/(USA)	To meet the demand of industry and increase customer satisfaction rate	SOP, Pareto chart, check sheet, E-Kanban system	Customer demand has been met successfully	[9]
10	Automotive valve industry/(India)	To reduce the defects and FTR	SIPOC, VOC, 5S, VSM, DOE, C&E	Increase the FTR by 99.8%	[10]

(continued)

Table 8.1 (continued)

Sl. No.	LSS implemented industry/country	Reason of LSS implementation	Tools and techniques used	Identified benefits	References
11	Industrial cleaning equipment manufacturing/(USA)	To reduce overall cost, eliminate waste, and increase capacity	SIPOC chart, VSM, Pareto chart, CTQ analysis, FMEA, root cause analysis	Reduction in cost $660,000 per year, 50% reduction in the work cell	[11]
12	Compressor airfoil factory/(USA)	To enhance the quality of the product and improve the efficiency of the process	Failure mode and effect analysis, cause and effect analysis	94% of defects has been reduced, increase sigma value 0.86–3.21	[12]
13	Armaments product/(USA)	To reduce overall cost and cycle time of product	TPM, 5S, VSM, XY metrics, C&E analysis, SPC, ANOVA, DOE	Improvement such as 91% in quality, 70% in cost, 67% in delivery, 84% in risk	[13]
14	Aircraft manufacturing company/(USA)	To improve the position in the market, to increase the company bottom-line result	Kanban, cause and effect analysis, Jaidoka	The observed increase in sales from 30 to 205 m/year	[14]
15	Rotary switches industry/(India)	To reduce rework cost and defects	VSM, 5S, Kanban, DOE, Poka-yoke	Reduction in key metrics	[15]
16	The home furnishing industry/(USA)	To improve the process performance and product quality	SIPOC, SMED, ANOVA, VSM, Pareto chart	Improved performance and production capacity	[16]
17	Automotive Ind./(Malaysia)	To reduce the production cost	5S, SPC, VSM, brainstorming	Significantly reduce cost	[17]
18	Gas and Engineering industry/(USA)	To eliminate non-value adding activities and defects	CVSM, 5S, Poka-yoke, Spaghetti diagram	Increase productivity by 18–48%	[18]

(continued)

Table 8.1 (continued)

Sl. No.	LSS implemented industry/country	Reason of LSS implementation	Tools and techniques used	Identified benefits	References
19	Valve manufacturing organization/(India)	To reduce the defects occurring in the final product and improve the bottom-line	VSM, Pareto chart, C&E, FMEA, Kanban, Kaizen, Work cell, SMED	Reduction in overall defects and improve performance	[19]

8.3 Research Methodology

In this paper, authors used both qualitative and quantitative research methodology approaches to gather the data related to the implementation impacts of the lean six sigma approach in various selected manufacturing industries situated in India. The methodology consisted of two parts: the first part includes identification, selection, and ranking of LSS attributes and next part includes validation of ranked benefits. The methodology adopted in this study is clearly shown in Fig. 8.1.

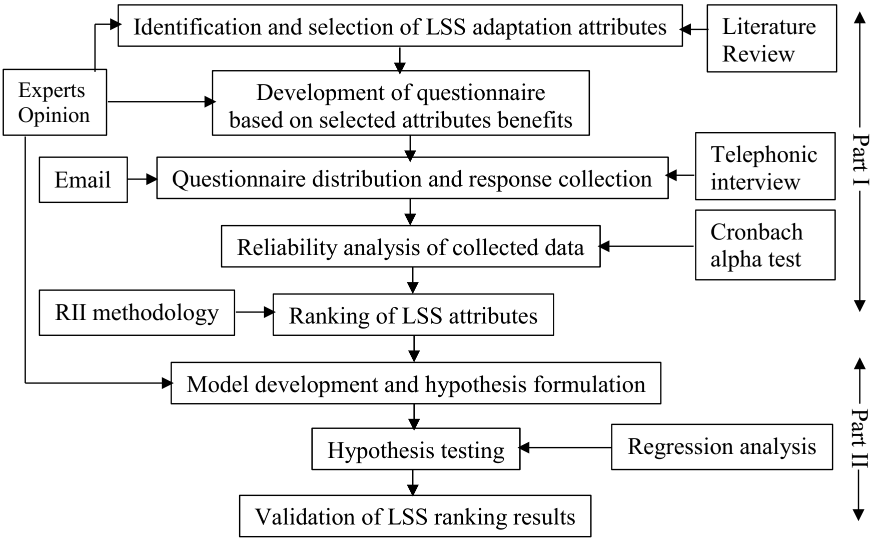

Fig. 8.1 Detailed research methodology

8.3.1 Relative Importance Index (RII)

The relative importance index technique is generally used to determine the rank of clusters. The RII has statistically ranked the clusters based on the responses data collected on a predefined scale from the various respondents. The 1–5-binary digit scale is mostly used to gather the response to analyze the data. The rank is obtained in this methodology using Eq. (8.1). This equation 'w' represents the weight given by the respondent for each attribute based on 1–5-Likert scale. The n_1 represents the minimum rating provided by the respondent, and n_5 represents the higher rating provided by the respondent on a given scale. The 'A' represents the highest weight (5 for this case), and 'N' shows the total number of response. The valid response data has been summarized in the Excel sheet and calculated using Eq. (8.1) [20–22].

$$\text{RRI} = \frac{\sum w}{AN} = \frac{5_{n5} + 4_{n4} + 3_{n3} + 2_{n2} + 1_{n1}}{5N} \tag{8.1}$$

8.3.2 Regression Analysis (RA)

Regression analysis (RA) is a powerful statistical methodology which allows for examining the relationship between two or more factors of interest. The different types are regression analysis such as simple, multiple, and logistics regression analysis that are existing in nature, and it used based on the nature of the problem. The regression analysis is generally used to identify the impact of an independent factor on the dependent factor. However, the identification of impact between both factors is performed using hypothesis formation and testing. Based on the identified standardized beta value and their significance obtained by the regression analysis, the hypothesis can be accepted or rejected. The standardized beta value also compares the impact strength of each independent factor on the dependent factor [23].

Part I: Identification, Selection, and Ranking

8.4 Case Study and Data Analysis

The various subsections describe the details about the case study and analysis of the data.

8.4.1 Problem Identification and Case Organization Description

The case organizations are suffering major problems related to defect occurs in the finished product. Thus, management of case organizations is struggling to adopt continuous improvement methodology such as LSS in their organizations. The three different manufacturing organizations such as a valve, cloth, and brake shoe manufacturing organization are considered to perform the study situated within different regions of India. The selection of case organization was based on getting permission to perform the study. The main aim of this study is to identify the benefits of LSS implementation in a manufacturing organization and further provide suggestions for the implementation in case organizations. In this context, the study identifies the main key benefits of LSS adaptation and gathered the responses from various LSS implemented manufacturing organizations located in India for prioritizing the possible key benefits after LSS implementation.

8.4.2 Identification and Selection of LSS Attributes

The various LSS benefits were identified through the literature review, and the keywords used to search are lean six sigma benefits, lean six sigma attributes, lean six sigma framework, lean six sigma from a different database such as Google Scholar and Scopus site. There are total of 10 benefits selected through expert's opinion in this study. The experts are having more than 10 years of experience in the concerned field. The selected LSS benefits are shown in Table 8.2.

Table 8.2 Selected LSS benefits

S. No.	LSS implementation benefits	References
1	Reduce overall defects in product	[1, 2, 9]
2	Reduction in inventory	[2–4, 11]
3	Reduce cycle time of product	[2, 3, 5, 12]
4	Reduction in machine breakdown time	[2, 6, 13]
5	Improvements in key performance metrics	[1, 2, 4, 6, 14]
6	Increase production capacity	[7, 12, 15, 16]
7	Improve product quality	[6–8, 15]
8	Reduction in overall production cost	[2, 4, 7, 16]
9	Increase customer satisfaction	[8, 9, 17]
10	Increase financial savings and profits	[7, 9, 10, 19]

8.4.3 Development and Distribution of the Questionnaire

The structured questionnaire was developed on the basis of ten selected LSS benefits with the help of experts. The questionnaire consisted four major parts: the first part includes general questions related to basic information about respondents; the second part includes basic information about the organization; the third part includes questionnaire itself, and the last part of the questionnaire consisted of suggestions and feedback. The questionnaire was distributed through email and direct meeting with industry managers, staffs, experts, suppliers, customers, and consultants of concerned manufacturing organization to analyze the impact of adaptation of the lean six sigma approach. The questionnaire has been mailed to respondents having at least 5 years' working experience in the selected organizations. The method for distribution was chosen based on the suitability of authors. The respondents were instructed to provide their responses based on the questions on the defined value of (1–5) Likert scale. The total 52 manufacturing organizations selected from the list of manufacturing organization found on Google. The selected organization consisted of three types of manufacturing organization situated in India. The all selected manufacturing organization is already implemented LSS approach either in whole or in a specific assembly line. From each manufacturing organization, six questionnaires were distributed and response collected from them. One organization with different stakeholder concepts was chosen to eliminate the biasedness of the data. The detailed survey is shown in Table 8.3.

8.4.4 Reliability Analysis

The questionnaire is shared with 312 different stakeholders of the selected manufacturing organizations and received total of 188 valid responses with 60.25% response rate. The details of the responses with the respondent profile and survey details are clearly shown in Fig. 8.2. The data reliability checks with the help of Cronbach's alpha test. The reliability analysis was performed using 'IBM SPSS Statistics 20' software. The consistency of the collected data was checked and found Cronbach's alpha value 0.795 that is good for the study.

8.4.5 Ranking of LSS Attributes

The collected data were analyzed using the relative importance index technique (RII). The RII is used in this study to rank the impacting factors. Equation (8.1) is used to calculate the RRI percent. The calculated RRI percentage of LSS attributes with ranking is shown in Table 8.4.

Table 8.3 Survey details

S. No.	Nature	Category	Questionnaire distributed		Response received		Total valid response	
			Email	Direct meeting	Email	Direct meeting	Email	Direct meeting
1	Organization type	Valve manufacturing	60	18	42	18	34	18
		Cloth manufacturing	114	24	89	24	61	24
		Brake shoe manufacturing	84	12	51	12	39	12
2	Organization size	Large	114	24	91	24	63	24
		Medium	84	12	57	12	39	12
		Small	60	18	51	18	32	18
3	Production type	Batch	228	36	103	36	95	36
		Mass	84	18	52	18	39	18
4	Respondent type	LSS experts	43	9	35	9	28	9
		Manager	43	9	33	9	25	9
		Head of staff	43	9	29	9	22	9
		Supplier	43	9	27	9	17	9
		Customer	43	9	33	9	18	9
		Consultant	43	9	36	9	24	9

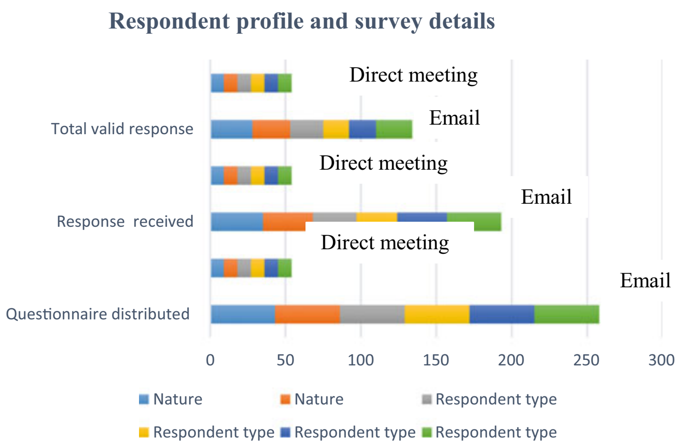

Fig. 8.2 Respondent profile and survey details

Table 8.4 Ranking of attributes based on relative importance index

Attribute name	No. of responses	Relative importance index percent (%)	Total score	Rank
Reduce overall defects in product	80	84.75	287	1
Reduction in inventory	80	83.50	252	2
Reduce cycle time of product	80	77.75	172	3
Reduction in machine breakdown time	80	75.50	272	4
Improvements in key performance metrics	80	70.75	273	5
Increase production capacity	80	66.75	241	6
Improve product quality	80	66.00	224	7
Reduction in overall production cost	80	64.75	214	8
Increase customer satisfaction	80	60.50	222	9
Increase financial savings and profits	80	60.25	274	10

Part II: Validation

8.4.6 Development of the Model

The research model for this study is developed with the help of area experts. For developing the model, ten LSS attributes are considered as independent factors and lean six sigma implementation benefits are considered as a dependent factor. The research model for this study is shown in Fig. 8.3.

8.4.7 Hypothesis Formulation

The hypothesis for this study is formulated with the help of an expert's opinion. The following hypothesis is formulated based on the developed model:

H1: The factor 'reduce overall defects in product' positively impacts on 'LSS implementation benefits.'

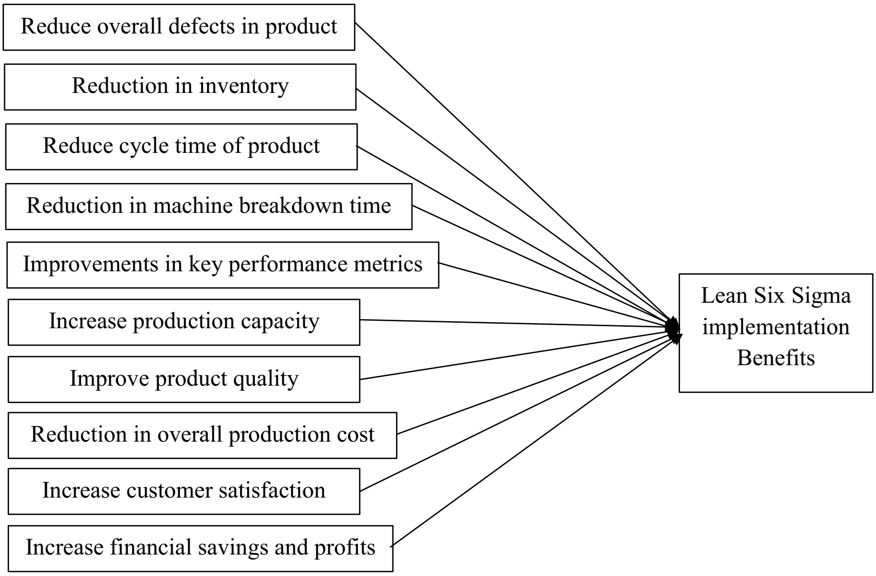

Fig. 8.3 Developed research model

H2: The factor 'reduction in inventory' positively impacts on 'LSS implementation benefits.'
H3: The factor 'reduce cycle time of product' positively impacts on 'LSS implementation benefits.'
H4: The factor 'reduction in machine breakdown time' positively impacts on 'LSS implementation benefits.'
H5: The factor 'improvement in key performance metrics' positively impacts on 'LSS implementation benefits.'
H6: The factor 'increase production capacity' positively impacts on 'LSS implementation benefits.'
H7: The factor 'improve product quality' positively impacts on 'LSS implementation benefits.'
H8: The factor 'reduction in overall production cost' positively impacts on 'LSS implementation benefits.'
H9: The factor 'increase customer satisfaction' positively impacts on 'LSS implementation benefits.'
H10: The factor 'increase financial savings and profits' positively impacts on 'LSS implementation benefits.'

8.4.8 Hypothesis Testing

Hypothesis testing is performed using regression analysis. The analysis is performed in 'IBM SPSS Statistics 20' software. The following steps are followed during the analysis of data to test the formulated hypothesis:

1. Open 'SPSS Statistics 20' software and copy or write all the 188 responses gathered from various respondents of LSS adopted industry on various independent as well as dependent factors.
2. Go to analyze (it could be seen in the upper side in software)—select regression analysis and select linear.
3. Place 'dependent factor response' independent section and select and place all 'independent factor response' independent section.
4. Click 'statistics' and tick on the following such as Estimates, Confidence intervals, Durbin–Watson, Casewise diagnosis, Model fit, Descriptions, Collinearly diagnosis than press continue.
5. Click 'plots' and place the 'ZPRED' responses (prediction values) in the *X* section and 'ZRESID' response in *Y* section than a parallel tick on the histogram and normal probability plot. After completion of the following task, click on continue.
6. Finally, press ok for the result.

The result obtained in this study is shown in Table 8.5.

Table 8.5 Regression analysis result

Independent factors	Dependent factors	
	Firm financial performance	
	Std. coeff. β	Sig.
Constant		0.463
Reduce overall defects in product	0.159	0.092**
Reduction in inventory	0.113	0.086**
Reduce cycle time of product	0.093	0.063**
Reduction in machine breakdown time	0.082	0.031*
Improvements in key performance metrics	0.063	0.048*
Increase production capacity	0.059	0.016*
Improve product quality	0.048	0.001*
Reduction in overall production cost	0.037	0.949**
Increase customer satisfaction	0.031	0.037*
Increase financial savings and profits	0.029	0.009*
R value	0.447	
R square value	0.997	
F value	2.078	

$P^{**} < 0.10$, $P^{*} < 0.05$, Std. Coeff. = Standardized coefficient, Significance = Sig.

The result of the analysis shows that the strength of the impacts of various LSS attributes on lean six sigma implementation benefits in any manufacturing organization. The impact strength can be observed with the obtained value of standardized coefficient beta value, and the hypothesis can be tested using the obtained significance value of all independent factors. In this study, hypothesis testing was done based on the obtained significance '*P*' value. The two '*P*' values considered in this study, and the difference between both is presented using star marks in Table 8.5.

8.5 Result and Discussion

Lean six sigma adaptation in manufacturing organizations provides certain benefits such as process performance improvement, financial enhancement, and increase rate of customer satisfaction. The successful adaptation of LSS also reduces machine downtime, product rejection rate, reduction in various inventories, changeover time, customer complaints. The case manufacturing organizations are suffering problem-related to defects occurring in the finished product and struggling to adopt a continuous quality improvement approach that can overcome such issues. After successful analysis, the gathered data from various stakeholders selected from different industries situated within India, and it found that the LSS attribute 'reduce overall defects in product' is prioritized as first LSS benefits, whereas 'increase financial savings and profits' prioritized as last key benefits using RII technique (the result are observed in Table 8.4). The prioritization of LSS attributes is shown in Fig. 8.4.

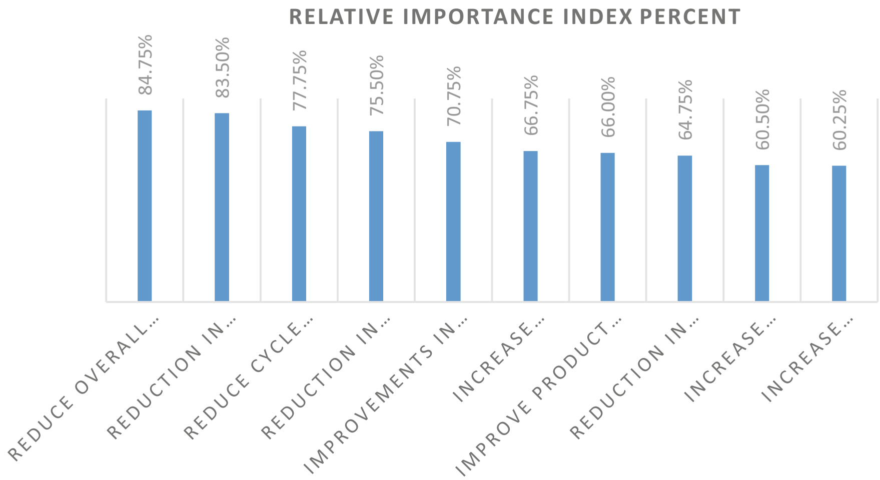

Fig. 8.4 Ranking of LSS attributes based on RII technique

To validate this result obtained from RII technique, the hypothesis testing is performed using regression analysis. Based on the result of regression analysis, the hypothesis is tested and found the following results:

H1 is accepted at a 0.10 level of significance.
H2 is accepted at a 0.10 level of significance.
H3 is accepted at a 0.10 level of significance.
H4 is accepted at 0.05 level of significance.
H5 is accepted at 0.05 level of significance.
H6 is accepted at 0.05 level of significance.
H7 is accepted at 0.05 level of significance.
H8 is accepted at a 0.10 level of significance.
H9 is accepted at 0.05 level of significance.
H10 is accepted at 0.05 level of significance.

The result of hypothesis testing indicated that all formulated hypotheses are having a positive impact on LSS implementation benefits which help for the further validation process. From the result of regression analysis, it is also observed the impact strength of LSS attributes on lean six sigma implementation on various benefits. It can be seen from Table 8.5, the standardized coefficient beta value indicated the impact strength. Based on the obtained beta value, the LSS attribute 'reduce overall defects in product' is prioritized as first LSS benefits, whereas 'increase financial savings and profits' prioritized as last key benefits. The other benefits are also obtained the same rank or priority as RII result. The prioritization of LSS attributes based on the result of regression analysis is shown in Fig. 8.5.

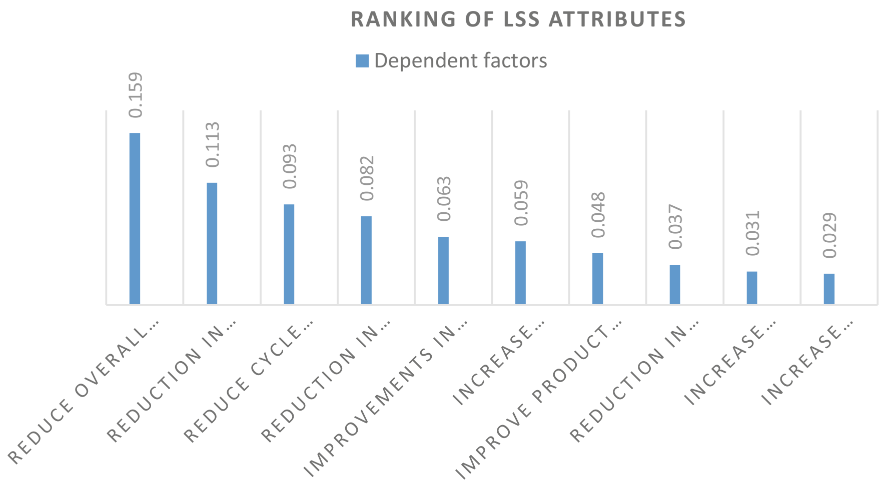

Fig. 8.5 Ranking of LSS attributes based on a regression analysis approach

8.5.1 Managerial Implications

Before implementing lean six sigma in any manufacturing organization, it needs to know about the main key benefits. The complete knowledge of LSS implementation benefits will help to recognize the purpose of implementation and compare it with the current problem for which they going to implement. If the purpose of implementation is matched, then management involvement assurance is needed for the further implementation process.

8.6 Conclusions

The findings of this study concluded that the adaptation of the lean six sigma approach providing an effective impact in manufacturing organizations to improve their bottom-line result. The result shows that significant improvement has been observed in LSS implemented industries based on the responses received from industry professionals. The study elaborated on the scope of lean six sigma implementation benefits in manufacturing organizations. The three most significant benefits have been observed such as reduce overall defects in the product, reduction in inventory, reduction in the cycle time of product having the relative importance index which are 84.75%, 83.50%, and 77.75%, respectively. The result of the present study indicated that the LSS principles are applicable to solve major issues or problems and provide an extra effort to manufacturing organizations to implement Lean Six Sigma in their process. The study observed that the adaptation of LSS strategy in case manufacturing organization provides extensive benefits such as the reduction in cycle time, lead time, workforce, inventory, defects and brings improvement in key metrics such as overall equipment effectiveness (OEE), first-time yield (FTY), and customer satisfaction. The success in adaptation of LSS will also bring the cultural changes in manufacturing organizations. Further, this study observed that the implementation of lean six sigma is starting only from the top management involvement of the organization and without it is not possible to implement in any aspects.

8.7 Limitations and Future Scope

This study has been performed by gathering the initial data related to LSS adaptation key benefits in 52 selected manufacturing organizations situated in India. The survey has been performed to identify and analyze the benefits of lean six sigma implementation of three manufacturing organizations. In the future, other manufacturing or service organization can also be considered. To validate this survey result, regression analysis approach is used, and in future the other methods such as graph theory (GT) and structural equation modeling (SEM) can be used with considering more organization. The author (s) is currently working on the development of a lean six sigma framework for manufacturing organization by continuously adopting the required lean six sigma tools and techniques.

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Chapter 9
On Comparison of Expansion Bellow Design Approaches

Ajit S. Palve, Suyog Shinde, and Kiran S. Bhole

Abstract Expansion bellows are critical components in process equipment and piping systems, which makes designing of bellow an important step. The bellows are designed based on guidelines provided by various codes/standards and understanding of such different approaches is crucial. Till now generalized comparative study among these codes and standards is not yet carried out. This paper provides a comparative study of bellow design using such diverse approaches and briefs about the methodology developed for design by analysis of expansion bellow using Finite Element Analysis (FEA). Finally, the design of various sample bellow cases have been performed using codes/standards as well as by FEA. The results have been studied to understand variation of bellow stresses and fatigue life in these approaches. This paper will help the practitioners and designers to understand code/standards used for designing expansion bellow, methodology for design of expansion bellow using FEA, and comparative understanding of design by different methods.

Keywords Expansion joints · Bellow stresses · Fatigue life · FEA · Comparative study

9.1 Introduction

Designing a bellow requires a detailed overview of the working conditions and environment along with a proper understanding of various parameters. Guidelines are provided by various code/standards like ASME, EJMA, EN [1–3] to help in designing expansion bellow. These codes/standards provide the limiting conditions and predict the stress pattern of bellow. The process of selection of dimensional parameters for expansion bellow is iterative which involves the initial design and

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further optimization. In general, the bellows are selected based on the following parameters:

1. Operating Conditions (Pressure and Temperature)

The key operating conditions are operating pressure and temperature. The physical properties and suitability of materials vary with temperature so careful selection of material is needed. The type, material, end fitting and method of fitting attachment decides the temperature limit.

While the nominal pressure ratings of an expansion joint vary according to type, material, and size. Under actual working conditions, pressure is affected by many other factors such as temperature, pulsating conditions, bending stresses, shock, vibration and external influences.

2. Flowing Media

An expansion joint may fail due to corrosion by both the material flowing through it and the outside environment. Thus, material for expansion joint is selected based on its suitability for the intended media.

3. Size of Expansion joint

The size of an expansion joint is specified by the nominal diameter of the pipe. The existing piping will normally dictate the size of the metal expansion bellow for a particular application.

4. Movements Required

An expansion joint is used to accommodate primarily thermal expansion and contraction (i.e., axial movement), to deal with problems of misalignment (that can be either lateral or angular movement), to provide flexibility in manual handling operations, to compensate for regular or constant movement, and to absorb vibration (that can be any of three moments or combination of them).

But the majority of manufacturers have their own procedures for the selection of expansion bellow for particular input conditions which mainly include the nominal diameter of pipe and the expansion required. Careful selection and installation are important for optimal service life of expansion joint. The flexibility of an expansion joint is determined by its mechanical design and the inherent flexibility of its material.

The guidelines mentioned above are thoroughly studied and validated by researchers like Anderson and Betch [4, 5]. W.f. Anderson was the one who put forth the criteria for the design of expansion bellows. At the start of 1981 C. Betch gave stress analysis criteria for metal expansion bellows in his study he discussed the various configurations of expansion bellows and their design criteria. Researchers explored the various design aspects related to expansion bellow. Kim [6] put forth a study on the effects of convolution geometry and boundary condition on the failure of bellows which was focused on the effect of convolution geometry and proposed the effect of dimensional parameters on stresses induced in bellow, Ando et al. [7] performs an experimental study on the ultimate strength of single and double type bellow under internal pressure to find the ultimate strength of bellow and validated the results with the FEA. Lu et al. [8] worked on the torsional stiffness of bellow and laid down a simple formula for its calculation. A combined numerical and experimental study on metal expansion bellows for STHE was performed by Gawande et al. [9], San-Vicente et al. [10] studied the ultimate capacity of expansion bellow. S. Ganguly determined the stresses in expansion bellow using FEA [11]. Pachpande et al. [12] used FEM based program in C# language for analysis of thick bellow configuration and validated the results using ANSYS. Palve et al. [13] gave a brief review on expansion joint in process equipment and piping systems also explained the procedure for the design of expansion bellow based on EJMA standard.

9.2 Types of Expansion Joints

In this study, the main concern is on the expansion joints that are used for pressure vessels and piping systems.

The expansion joints that are used in pressure vessels are of two types, (1) Thick type which is going to be attached on the shell of vessels, (2) Thin types which can be attached on the internals of pressure vessels or in the piping systems. Figures 9.1 and 9.2 shows the location of both types of joints.

Thick type of expansion joints are further classified as:

1. Flanged and flued type

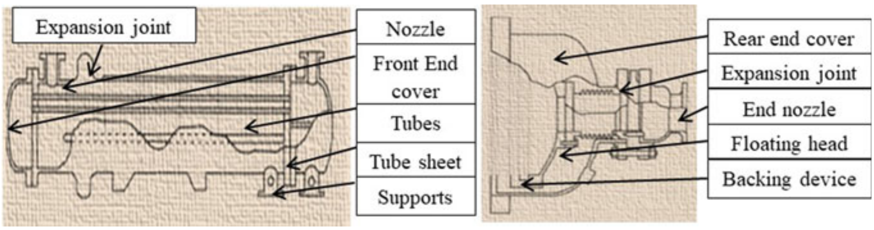
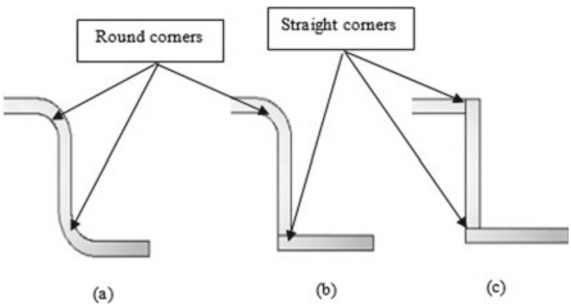


Fig. 9.1 Location of expansion joint

Fig. 9.2 Type of thick expansion joints [13]



2. Only flanged type
3. Flat type

Thin type can be further classified based on the following:

1. Reinforcement
   (a) Unreinforced
   (b) Reinforced
2. Movements to be incurred
   (a) Axial (Single and Double type bellows)
   (b) Lateral (Tied expansion joints)
   (c) Angular (Hinged and gimbal type bellows)
   (d) Combination of all above (Universal type bellows)
3. Shape of bellow
   (a) Round shape
   (b) Rectangular shape
4. Number of plies
   (a) Single ply
   (b) Multiply [13].

9.3 Stress Evaluation

The bellow is subjected to various stresses that arise due to pressure and displacement loadings. Code/standards provide guidelines to calculate the stresses and fatigue life of bellow. The stresses are evaluated at a tangent and convoluted portion of bellow. The bellow tangent is checked for circumferential stress against pressure loading (S_1) while convoluted portion is checked for circumferential (S_2), meridional (S_3), and bending (S_4) stresses due to pressure loading. Stresses are also generated due to movement of bellow caused due to expansion in the system. The bellow is checked for Meridional (S_5) and Bending (S_6) stresses due to displacement loading. Then the total longitudinal stress is to be obtained as a sum total of meridional and bending stress due to pressure and displacement loading which will be used to calculate the fatigue life (N_c) of the bellow. The location and behavior of the above stresses are summarized in Fig. 9.3.

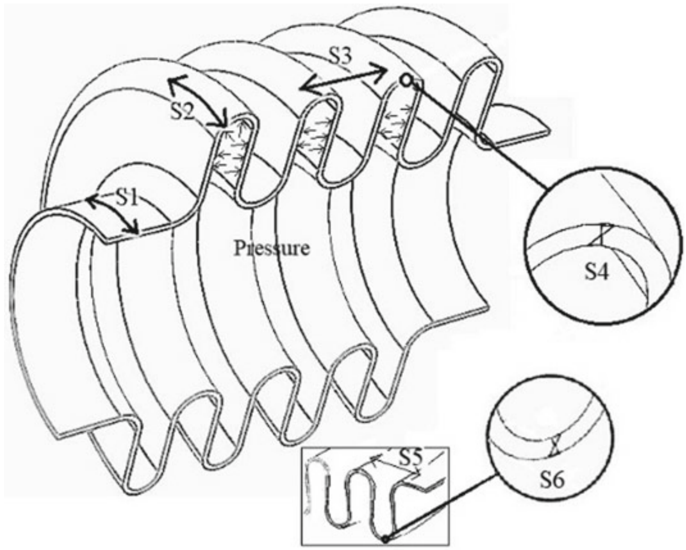


Fig. 9.3 Various stress in bellow

9.4 Case Study

In order to understand different guidelines provided by different codes/standards a case study was performed. In this study, a detailed investigation was carried out to understand the difference between the findings by analytical and FEA approaches. Demonstration of the outcome of this study is illustrated using below three sample examples. The material properties of bellow are selected from ASME section II part—D design code. The specifications of considered sample bellows are as shown in Table 9.1.

9.5 Analytical Approach

The general design procedure for expansion bellows can be summarized as below:

Step 1: Analyzing operating parameters based on requirements. (i.e., operating temperature and pressure).

Step 2: Deciding the material based on operating parameters and surrounding environment for bellow and other components.

Step 3: Obtaining material data from standard references or codes, i.e., allowable stress, yield stress, modulus of elasticity, poisons ratio, etc. for both the materials.

Table 9.1 Bellow models specifications

Design parameters	Symbol	Specification		
		Example 1 (Ex1)	Example 2 (Ex2)	Example 3 (Ex3)
Operating pressure	P	200 (psi)	100 (psi)	50 (psi)
Operating temperature	–	500 (°C)	400 (°C)	300 (°C)
Expansion joint material	–	Inconel 625		
Expansion joint type	–	Single unreinforced type (in as formed condition)		
Internal diameter of bellow	D_b	11.81 (in)	13.77 (in)	7.874 (in)
Length of bellow tangent	L_t	0.7874 (in)	0.7874 (in)	0.4724 (in)
Young's modulus for bellow at operating temperature	E_b	2.611E + 07 (psi)	2.697E + 07 (psi)	2.77E + 07 (psi)
Young's modulus for bellow at room temperature	E_o	2.99E + 07 (psi)	2.99E + 07 (psi)	2.99E + 07 (psi)
Active length of bellow	L_b	8.8575	9.18	5.249
No. of plies	n	1	1	1
Axial displacement	x	0.5527 (in)	0.5669 (in)	0.5734 (in)
Lateral displacement	y	0	0	0
Angular rotation	θ	0	0	0
No. of convolutions	N	5	11	7
Height of convolution	w	1.7715 (in)	0.8345 (in)	0.7649 (in)
Pitch of convolution	q	1.7715 (in)	0.8345 (in)	0.7499 (in)
Thickness of ply	t	0.063 (in)	0.07876 (in)	0.043318 (in)

Step 4: Deciding other geometrical parameters based on code like pitch, height, and thickness of convolution, number. of convolution, etc. (as well the dimensions for reinforcing member).
Step 5: Evaluating various stresses on bellow and checked for allowable stress.
Step 6: Then bellow is checked for column stability and in-plane stability.
Step 7: Finally, the life of bellow is calculated.

In the above procedure the stress evaluation by cade and standards. The major stresses generated in bellow are due to pressure and deflection loading. These stresses are categorized in terms of their direction and have to be evaluated as per code/standard guidelines for sizing the bellow. The stresses generated in unreinforced and reinforced bellow are explained below:

1. Bellows tangent circumferential membrane stress due to internal pressure (S_1)

$$S_1 = \frac{P(D_b + nt)^2 L_t E_b k}{2(nt(D_b + nt)L_t E_b + t_c E_c L_c D_c k)} \tag{1}$$

where,

D_b = Internal diameter of bellow
t = Thickness per ply & t_c = thickness of collar
E_b = Young modulus of bellow material at design temperature.
E_c = Young modulus of collar material at design temperature.
n = Number of plies
L_t = Length of tangent

2. Bellow circumferential membrane stress due to internal pressure (S_2)

$$S_2 = \frac{P D_m K_r q}{2A_c} \tag{2}$$

where,

$$K_r = \text{Stress concentration factor}$$

$$= \frac{2(q \pm e_x) + \frac{e_\theta}{K_\theta} + e_y}{2q}$$

$$e_x = \frac{x}{N}$$

$$e_y = \frac{3D_m y}{N(L_b + x)}$$

$$e_\theta = \frac{\theta D_m}{2N}$$

3. Bellows meridional membrane stress due to pressure (S_3)

$$S_3 = \frac{Pw}{2nt_p} \tag{3}$$

4. Bellows meridional bending stress due to pressure (S_4)

$$S_4 = \frac{P}{2n}\left(\frac{w}{t_p}\right)^2 C_p \tag{4}$$

5. Bellows meridional membrane stress due to deflection (S_5)

$$S_5 = \frac{E_b t_p^2 e}{2w^3 C_f} \tag{5}$$

where

$$e = e_x + e_y + e_\theta$$

6. Bellows meridional bending stress due to deflection (S_6)

$$S_6 = \frac{5E_b t_p e}{3w^2 C_d} \quad (6)$$

where,

C_p, C_d, C_f = Bellow factor that relates the design calculations of u shaped convoluted bellow with the simple strip beam

7. Total stress (S_t)

$$S_t = 0.7(S_3 + S_4) + (S_5 + S_6) \quad (7)$$

8. The fatigue life of bellow (N_c)

$$N_c = \left(\frac{a}{S_t - b}\right)^c \quad (8)$$

where,
a, b, c = constants based on various types of bellows.

The different codes and standards are compared based on the guidelines provided by them. The comparison summery is enlisted in Table 9.2.

Table 9.2 Comparison of various codes and standards

Sr. No.	Criteria	EJMA (standard)	ASME (code)	EN (standard)
1	Consideration for stress concentration factor	Yes	No	No
2	Consideration for tangent to bellow joint efficiency	Yes	No (considered it as 100%)	No (considered it as 100%)
3	Consideration for strain concentration during fabrication	No	No	Yes
4	Creep range	Capable of creep range design	only below creep range	only below creep range
5	Fatigue life equation	Has single formula over range	Equation varies based on range	Equation varies based on range
6	Fatigue life	More as compared with ASME	Less as compared to other standards	More than ASME but less than EJMA

9.6 Finite Element Analysis

Finite element analysis using commercial software Abaqus 6.17 has been performed to evaluate the stresses induced in bellow. As the loadings and geometry of bellow are symmetric about its own axis, 2D axisymmetric model was used as shown in Fig. 9.4.

The bellow model was meshed with 4-node bilinear axisymmetric (CAX4R) elements and elastic analysis was performed. Sufficient number of elements were considered across the thickness of the bellow to capture the stress values accurately. The meshed model of bellow is shown in Fig. 9.4.

Load cases with different boundary conditions considered for analysis are shown in Fig. 9.5 and explained in Table 9.3.

Stress classification lines (SCL) at various locations (as shown in Fig. 9.6) were identified for stress evaluation. The stress evaluation for each of the SCL was carried out as per guidelines in ASME section VIII, Division 2 edition 2017. The equivalent stress at SCL's was categorized as primary and primary plus secondary stresses as per code and the linearized equivalent stresses were evaluated with respect to allowable stress limits.

And to obtain the fatigue life, the procedure given in ASME code was followed. The steps of the procedure are as follows:

Step 1: Determine the stress tensors at the starting and endpoint ($\sigma_{11}, \sigma_{22}, \sigma_{33}$)
Step 2: Check for local thermal stresses.
Step 3: Find out Effective equivalent stress range as

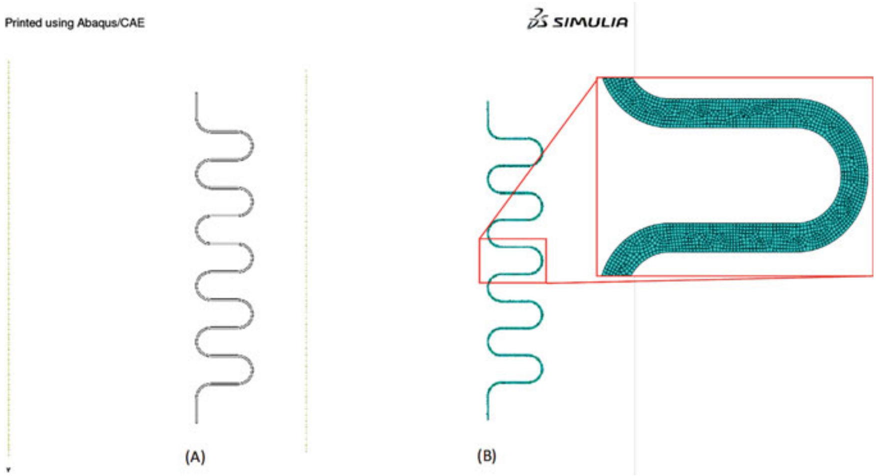


Fig. 9.4 **a** 2D-Axisymmetric model, **b** meshed model

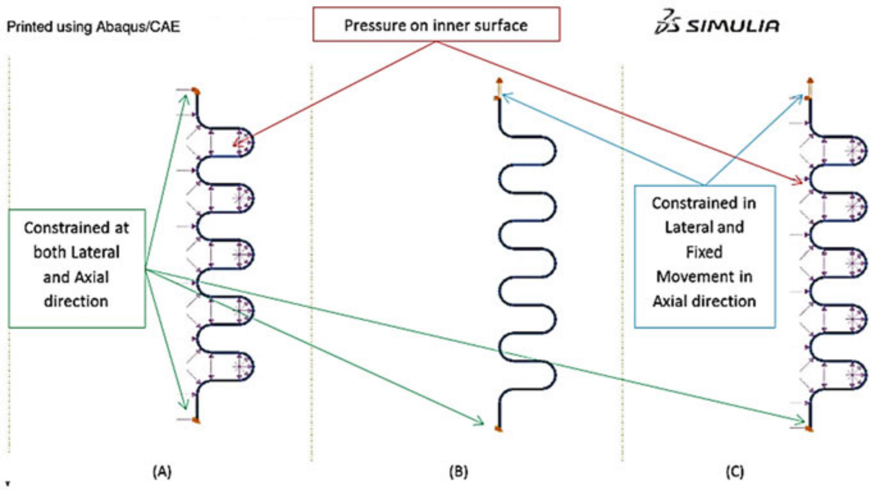


Fig. 9.5 Load cases considered for analysis

Table 9.3 Load cases considered for analysis

Load Cases	Internal pressure (Psi)			Displacement (mm)			
	Ex1	Ex2	Ex3	Bottom end (Same for all models)	Top end		
Load case 1	200	100	50	$U_x = U_y = 0$	$U_x = U_y = 0$	$U_x = U_y = 0$	$U_x = U_y = 0$
Load case 2	0	0	0	$U_x = U_y = 0$	$U_x = 0, U_y =$ 0.55	$U_x = 0, U_y =$ 0.56	$U_x = 0, U_y =$ 0.57
Load case 3	200	100	50	$U_x = U_y = 0$	$U_x = 0, U_y =$ 0.55	$U_x = 0, U_y =$ 0.56	$U_x = 0, U_y =$ 0.57

$$\Delta S_{\mathrm{p}} = \frac{1}{\sqrt{2}}\Big[(\Delta\sigma_{11} - \Delta\sigma_{22})^2 + (\Delta\sigma_{22} - \Delta\sigma_{33})^2 + 6(\Delta\sigma_{11} - \Delta\sigma_{33})^2 + 6\big(\Delta\sigma_{12}^2 + \Delta\sigma_{23}^2 + \Delta\sigma_{13}^2\big)\Big]^{0.5}$$

where $\Delta\sigma_{ij} = \sigma_{ij} - \sigma_{ij}^{\mathrm{Thermal}}$
Step 4: Determine effective alternating stress value as

$$S_{\mathrm{alt}} = \frac{K_{\mathrm{e}}\Delta S_{\mathrm{p}}}{2}$$

where $K_{\mathrm{e}} =$ Fatigue penalty factor
Step 5: Calculate the Number of cycles as directed below

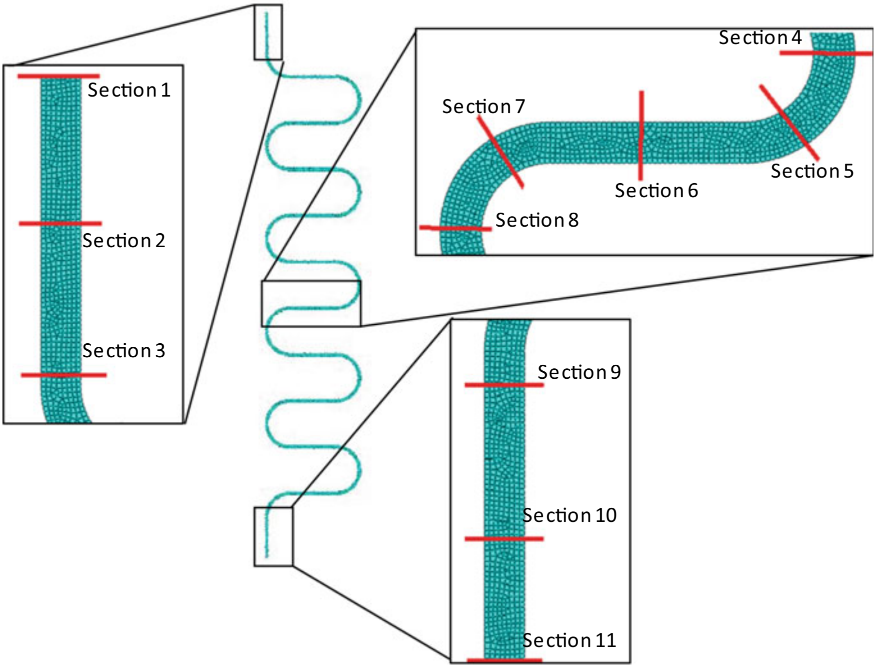


Fig. 9.6 Sections across the bellow

$$Y = \left(\frac{S_{\text{alt}}}{C_{\text{us}}}\right)\left(\frac{E_{\text{FC}}}{E_{\text{T}}}\right)$$

$$X = \frac{C_1 + C_3 Y + C_5 Y^2 + C_7 Y^3 + C_9 Y^4 + C_{11} Y^5}{1 + C_2 Y + C_4 Y^2 + C_6 Y^3 + C_8 Y^4 + C_{10} Y^5}$$

$$N = 10^X$$

9.7 Results and Evaluations

The bellow models were subjected to the three different boundary cases shown in Table 9.1. The data was evaluated according to the various stresses in tangent and convoluted portion of the bellow. Typical results obtained based on the three load cases are as shown in Fig. 9.7.

The maximum stress for tangent portion was found at the joint between tangent and convoluted portions. Also, the inner convoluted portion was subjected to more stress as compared to other sections in all cases. Comparative evaluation was done

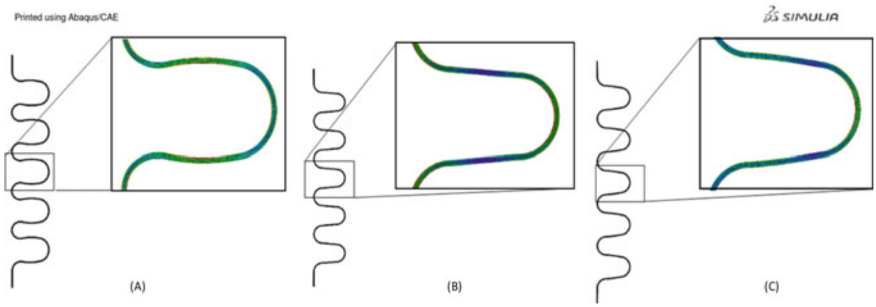


Fig. 9.7 Results of load cases considered for analysis

considering the stress and life results obtained by using the analysis approach and by various code/standards. The relative result of all the models is given in Table 9.4.

It is observed that results obtained using guidelines provided by the codes and standards have compatible matches with the FEA results. Except fatigue life equation, most EN standard equation matches with ASME code. Because of that, they share the same values in stress calculation. ASME gives very less life as the curve drawn by them consists of lots of safety margin so this can be considered as the minimum life given by the bellow. EN standards also considered most of the same safety margin as ASME but some were neglects based on certain assumptions. A more safe design can be obtained by EJMA standard as their guidelines consider factors like stress concentration which was not considered in other guidelines. But on the other hand, the empirical equation of life given by EJMA doesn't consider effect of some important factors (fatigue factor and variation in Young's modulus). Still, the fatigue life given by EJMA gives a better match with the life given by FEA as compare to other code/standards.

All the fatigue curves are based on the experiments carried by various researchers, but still, they differ from each other. Considering the need mentioned in the above study, the fatigue curves given by various codes/standards were studied. From the study, it was found that the major difference between the fatigue curves was due to consideration of temperature effect and different safety margins (on stress and Life cycles) considered by different standards. To understand the significance of both the aspects, plots of comparison between the fatigue curves were plotted as shown in Fig. 9.8.

From Fig. 9.8, it can be seen that the effect of temperature on bellow life was not that significant but for the safety margin, it was more significant in differentiation the different fatigue curves available with different codes and standards. Also, it can be observed that the safety margins (1.25 on stress and 3 on life) in the case of ASME was more than that of EJMA, that lead to the conclusion that the ASME can provide more conservative results as compare to that of EJMA.

After that typical case of unreinforced bellow was studied under different pressure and movement boundary conditions. The aim of this study was to find out the

Table 9.4 Deviation of FEA results from code/standards results

Example	Design parameters	Calculations by code/standards				% change w.r.t FEA		
		EJMA	ASME	EN	FEA	EJMA	ASME	EN
Example 1	S_1	14,496.30	14,496.30	14,496.30	12,299.00	15.16	15.16	15.16
	S_2	9533.65	8869.53	8869.53	8732.77	8.40	1.54	1.54
	S_3	1358.90	1358.90	1358.90	1388.61	−2.19	−2.19	−2.19
	S_4	12,321.17	12,321.17	12,321.17	10,821.10	12.17	12.17	12.17
	S_5	3537.69	3078.97	3078.97	2976.71	15.86	3.32	3.32
	S_6	160,976.70	140,103.39	140,103.39	125,396.00	22.10	10.50	10.50
	N_c	11,117.71	1436.12	3571.89	37,074.83	−233.48	−2481.60	−937.96
Example 2	S_1	4431.59	4431.59	4431.59	3780.44	14.69	14.69	14.69
	S_2	3974.41	3743.32	3743.32	3618.62	8.95	3.33	3.33
	S_3	547.06	547.06	547.06	562.83	−2.88	−2.88	−2.88
	S_4	3991.45	3991.45	3991.45	3819.64	4.30	4.30	4.30
	S_5	4468.76	4017.42	4017.42	3716.00	16.84	7.50	7.50
	S_6	166,375.51	149,571.59	149,571.59	142,005.00	14.65	5.06	5.06
	N_c	11,139.52	1460.26	3688.15	25,836.01	−131.93	−1669.28	−600.52
Example 3	S_1	2463.98	2463.98	2463.98	2006.40	18.57	18.57	18.57
	S_2	2234.93	2014.84	2014.84	1958.03	12.39	2.82	2.82
	S_3	463.55	463.55	463.55	473.73	−2.20	−2.20	−2.20
	S_4	5617.74	5617.74	5617.74	4994.50	11.09	11.09	11.09
	S_5	2866.97	2647.17	2647.17	2230.74	22.19	15.73	15.73
	S_6	166,395.94	153,638.92	153,638.92	143,238.00	13.92	6.77	6.77
	N_c	11,299.22	1471.16	3741.24	27,241.30	−141.09	−1751.69	−628.14

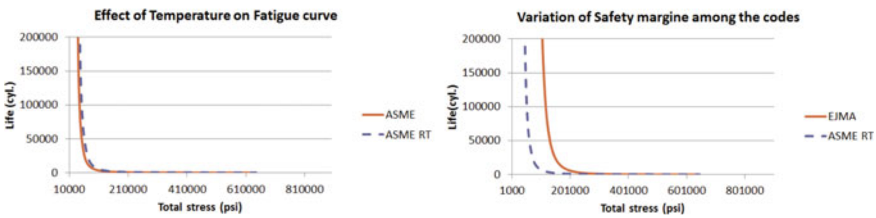


Fig. 9.8 Effect of temperature and safety margins on bellow fatigue curves

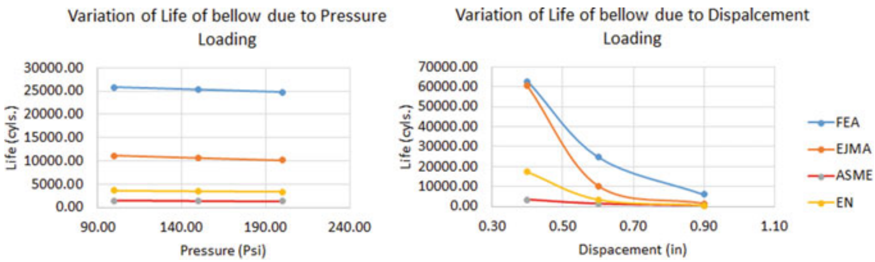


Fig. 9.9 Variation of life for **a** pressure loading, **b** Displacement loading

impact of operating pressure and expansion for bellow life. The results obtained are incorporated in Fig. 9.9.

From Fig. 9.9, it was observed that the extension of bellow has more impact on the fatigue life of bellow as compared to the impact of internal pressure. Thus sensitivity w.r.t. bellow extension needs to give more attention in order to design bellow for specific life.

9.8 Conclusions

After reviewing the overall design considerations of various codes and standards below are some concluding points made:

1. The sizing of bellow by consideration of various available guidelines along with a combination of geometric parameters will result in different designs. All of such designs may be safe considering specified conditions, however, the designer should possess the understanding of concepts related to all the available guidelines while designing the bellow.
2. The operating conditions that show a more significant effect on bellows fatigue life are deflection, but the consideration of pressure condition is also important bearing in mind the safety of design.

3. Safety margin shows a significant effect on fatigue life. So considering the safety margins, ASME code shows a more conservative approach than EN and EJMA. But for optimizing the design, designer can go for EJMA or EN standards.
4. Fatigue life obtained by various guidelines differs very much from actual life, so the designer should choose the guideline depending upon the required safety margin for end application.

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Chapter 10
Productivity Improvements in an Indian Automotive OEM using Heijunka, A Lean Manufacturing Approach: A Case Study

Pardeep Gupta and Sumit Kumar

Abstract This paper discusses the role of implementing Heijunka, a Lean manufacturing tool in improving the productivity of Indian automotive industry. Lean manufacturing is a business excellence strategy centered around waste reduction through continuous improvement resulting in improvement of productivity, competitiveness, quality causing greater customer satisfaction. Heijunka is aimed at smoothing the production and subsequently creating the opportunities to improve manufacturing environment. It prepares the industries to face the demand which is about to generate in the near future. The study reveals that the results of Heijunka implementation are quite substantial in terms of improvement in quality, productivity and customer satisfaction. The industry under the study transitioned its old-fashioned production system into tired production system. This was done to ensure pull production system. Heijunka flow was established in all the tiers in order to ensure smooth flow of the material without any unwanted inventory. Owning to the above changes industry reported improvements in human productivity, machine productivity by 63% and 39%, respectively, along with the morale of the employees.

Keywords Lean manufacturing · Heijunka · Productivity · Competitiveness · Quality · Tiered production system · Heijunka flow · Human productivity · Machine productivity

10.1 Introduction

The globalization has motivated various organizations to adopt business excellence strategies to survive global competitions. The term 'lean' was first used by Krafick [9]

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and later Womack et al. [16] described the Toyota production system as lean production system. Lean manufacturing operates on the philosophy aimed at the elimination of waste from all the activities resulting in the production of goods/services in a more efficient manner with the minimum resources. Womack and Jones [15] in their paper presented that lean can be applied to any organization/industry. Marvel and Standridge [10] argued that few organizations improved their performance with lean adoption. Grimaud et al. [6] concluded that when Heijunka used the demand fluctuations in customer orders does not directly transmit to the manufacturing system thus making the production smooth. Heijunka introduces regularity in mix in mixed loading and production and it also facilitates balanced production in all the production lines [8].

Lean practices lay a positive impact on inventory control, waste reduction, cost reduction, productivity and quality improvement in Indian process industries [13]. Lean implementation frameworks available are mostly specific and there is a scarcity of a comprehensive implementation framework [2]. The critical success factors play an important role in the implementation of lean and the available frameworks of lean implementation do not cover all critical success factors. The proposed framework comprises all critical success factors along with project-based integration [12]. The validity and reliability of available lean implementation frameworks in the Indian manufacturing industries environment were very important. For the study, 35 Lean Manufacturing frameworks (LM) were selected. The authors concluded that there is requirement of novel framework to Indian manufacturing industries in order to be competitive in the global market [14].

Lean manufacturing implementation varies from industries to industries due to specific requirements of industries. The success or failure of lean implementation depends on the contextual factors specific to the industry sector [5]. Marvel and Standridge [10] argued that few organizations improved their performance with lean adoption. Bob [3] reported that only 10% organization in the UK reported improvements after lean implementation and it was believed to be the incomplete understanding of lean that failed to transform the improvements also some authors reported that adoption of lean in the process industries leads towards the reduction in lead time, lead time variability and accuracy in demand forecasting [1, 4].

SWOT analysis of various lean implementation frameworks for identification of major success factors and ideal lean implementation framework resulted in the conclusion that every framework has its own strengths and weaknesses. Based on the above results, a more generic model has been developed to overcome the imperfection of the others [11]. An exhaustive lean framework comprising of 11 pillars and 83 elements after analyzing 39 selected frameworks out of 131 lean production related frameworks collected from literature review was proposed in order to overcome the gap of conceptual framework with respect to the others [14]. The increase in OEE of an industry due to the implementation of TPM directly increases the sales volume of that organization [7].

10.2 Implementing Heijunka for Improving Productivity

An XYZ ltd. (name changed) is an automotive spare parts supplier located in northern India. The company started his Heijunka journey in 2009. In the company was having issues related to Productivity (*P*), Quality (*Q*) and Delivery (*D*) with its suppliers. The company adopted Heijunka to resolve the following issues.

1. Frequent customer follow-ups and frequent unplanned changeover resulting in loss of productivity, stress on quality system and delivery constraints.
2. unplanned changeover, loss of productivity.
3. The supply chain was not consistent with the delivery of the parts as per the desired rate and quality.

The three approaches adopted to improve the above three issues were Heijunka flow, Tiered production system and pull production.

10.2.1 Design for Heijunka Flow

The design of flow mechanism is based on the principle which states that first material is moved then machines need to start processing and a human is required to run the machine so once the material flow is streamlined productivity is improved due to shorter lead time and stable utilization of resources, i.e. Heijunka. The Heijunka flow ensures that the production always linked to the demand and follows the same pattern. The three keys to creating an effective flow are follows.

1. Tiered structure production system
2. Heijunka flow (planning work load)
3. Pull system (scheduling execution and control).

10.2.1.1 Tiered Production for Heijunka Planning Flow

The company implemented the Tiered production system and replaced the traditional production system for improving production, quality and customer satisfaction. The Tiered structure is composed of two different tiers, i.e. Tier-1 and Tier-2 as shown in the Fig. 10.1. Tier-1 contains the assembly section and is placed close to the customer with an aim to produce small batches and deliver many parts every day, whereas Tier-2 is comprise manufacturing sections (in-house or supplier) to produce parts in large batches, store the parts and supply them as and when required.

Tier-2 is the immediate upstream process for Tier-1. After establishing sequential flow at Tier-1, filling up production was started in Tier-2. The manufacturing quantity in Tier-2 is same as consumed by Tier-1. V-map of the Tier-2 was formulated where all the processes have same trolley size and therefore same batch size. At the end of each Tier-2 sub-processes, a defined amount of inventory is decided to take care of consumption of Tier-1 and downstream Tier-2.

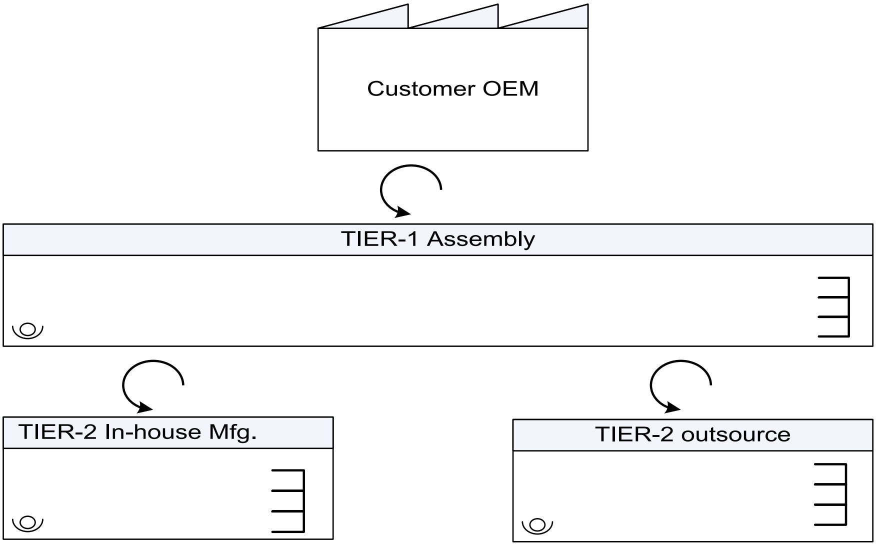

Fig. 10.1 Tiered production system

Production and delivery charts were superimposed on this v-map (Fig. 10.2) with the starting point at peripheral assembly (P. Assembly) shop as this was the pulling end. The Heijunka flow control at Tier 1 and Tier 2 was done with the help of Production Quantity (PQ) chart which is further used to monitor and control the production cycle pattern finalization, workload calculations, production sequence pattern finalization, Sequential Kanban and filling up Kanban.

Product Quantity (PQ)-Chart

The first step towards the Heijunka flow planning is to create a Product quantity chart in order to analyze the demand of the various parts. This PQ chart helps in deciding the frequency of the manufacturing of a part. Parts with large volume demands are manufactured every day whereas others are manufactured twice or once a week. The following data in Fig. 10.3 shows the demand for various parts.

Production Cycle Pattern

The next step towards Heijunka flow planning is to create a stable production cycle pattern. Table 10.1 shows a production cycle pattern derived on the basis of PQ chart. In the table Production cycle 1-1, 2-1 and 6-1 signifies production of items daily, on alternate days and once in a week, respectively. The derived production cycle pattern can be considered as a stable one on the basis of minimum number of changeovers

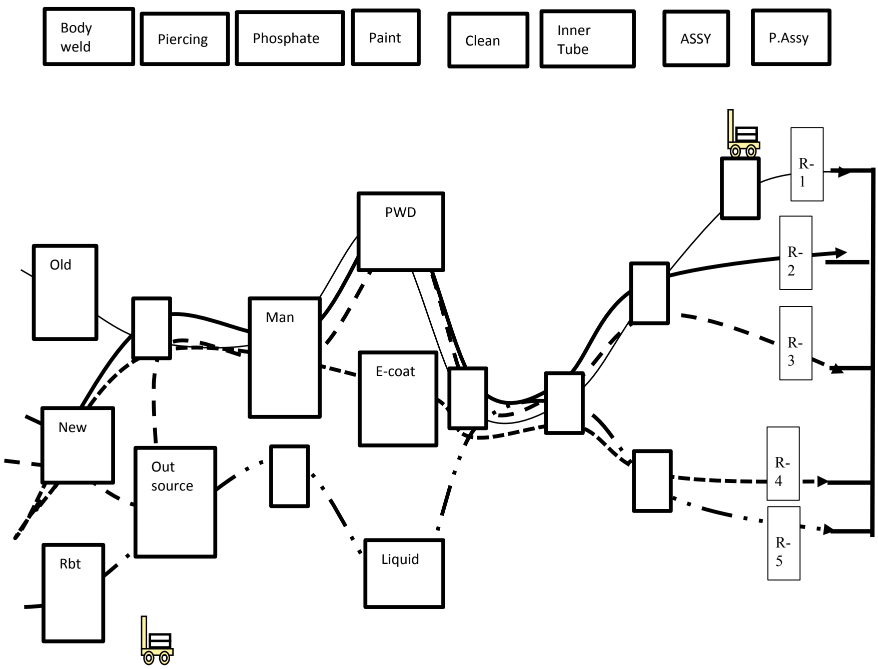

Fig. 10.2 V-map for tier-1

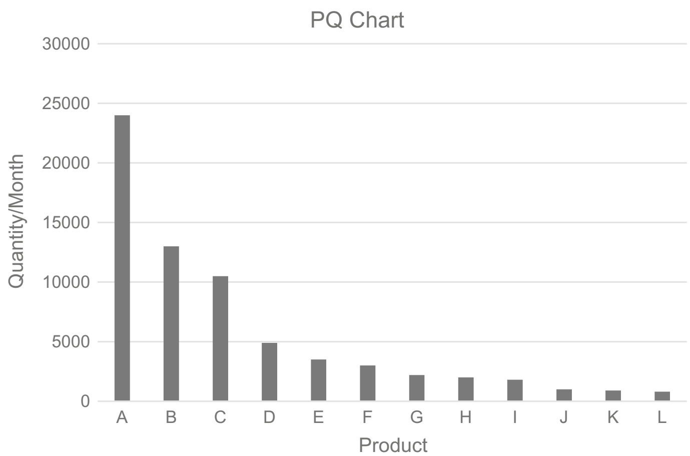

Fig. 10.3 Product-quantity chart

Table 10.1 Production cycle pattern

Production cycle	Products	1 June	2 June	3 June	4 June	5 June	6 June
Production cycle 1-1	A	1114	1114	1114	1114	1114	1114
	B	762	762	762	762	762	762
Production cycle 2-1	C	665		665		665	
	D		358		358		358
	E	150		150		150	
	J			73			
	K					55	
Total		2770	2535	2764	2499	2746	2404
Free slots			()		()		()
No. of change overs in a day (stable)		5	5	5	5	5	5

Table 10.2 Workload plan

S. No.	Work load plan—June	UOM	
1	Total required processing time/day	Min.	707.5
2	Planned total of C/O time	Min.	80.0
3	Estimated total of un-scheduled losses	% of time	154.8
4	Required loading hours (1 + 2 + 3)	Min.	942.3
5	Regular loading hours	Min.	860
6	Loading ratio $= \frac{\text{Required loading hrs.}}{\text{Regular loading hrs.}}$	%	1.10
7	Planned (=estimated) OEE $= \frac{\text{Total required processing time/day}}{\text{Required loading hrs.}}$	%	75%
8	Gaps in time to be made with over time	Min.	783

required and because of the free slots provided for the makeup of production loss due to some unwanted situation.

Workload Planning

On the basis of planned production cycle, the next step toward the Heijunka flow planning is workload planning. A sample workload plan is shown in Table 10.2. A revised workload plan is shown in Table 10.3 given below with the adjusted loading ratio.

Table 10.3 Adjusted workload plan

S. No.	Work load plan—June	UOM	
1	Total required processing time/day	Min.	635.2
2	Planned total of C/O time	Min.	80.0
3	Estimated total of un-scheduled losses	% of time	137.6
4	Required loading hours (1 + 2 + 3)	Min.	852.8
5	Regular loading hours	Min.	860
6	Loading ratio	%	0.99
7	Planned (=estimated) OEE	%	78%

Table 10.4 Production sequence

Date	S. No.	Model	QTY
1 June	1	A	1019
	2	B	516
	3	C	863
	4	E	160
	5	I	93
2 June	6	A	1019
	7	B	516
	8	D	358
	9	F	272
	10	Free slot	()

Production Sequence Finalization

The outcome of workload plan is the production sequence in which the organization is required to flow. The product sequence pattern is inclusive of free slots fixed for any loss makeup. A sample production sequence is shown in Table 10.4. The production is monitored using a manual checklist and counting the trolleys at both the Tier levels. If the number of trolleys is more than requires as per V-map immediate action is taken.

10.2.2 Monitoring of Production Sequence and WIP

A manual checklist was used to monitor the progress of trolleys in respective Tiers. This gave the information about the number of trolleys at a particular station at a particular time and if the number is more as compared to planned/calculated using v-map, immediate action is initiated. Also, kaizens can be utilized to reduce the WIPs.

Table 10.5 Heijunka sequence

Seq. No.	Heijunka sequence				
	Date	Part name	Planned quantity	Achieved quantity	Remarks
1	1-11-2017	A	600	580	Achieved
2	2-11-2017	B	500	500	Achieved
3	3-11-2017	C	300	270	Achieved
4	4-11-2017	D	200	200	Achieved
5	5-11-2017	E	500	500	Achieved
6	6-11-2017	F	500	500	Achieved
7	7-11-2017	G	700	700	Achieved

10.2.3 Pull Production

The pull system in the industry is implemented by three method ensuring the following in the system viz. sequential supply, i.e. synchronized way, filling up supply, i.e. supply first, fill up later, filling up plan, i.e. fill up in advance. The numbers of Kanban are calculated as follows:

$$\text{Required number of Kanban} = \frac{\frac{\text{Quanitity}}{\text{day}}}{\text{Kanban unit size}} x \left(\frac{a}{b}\right) x\, LT + 1 x \alpha \tag{1}$$

where *a*-*b*, *LT* is defined by type of production cycle, e.g. 1-1,1 $a = 1$, $b = 1$, $LT = 1$ and $\alpha = 0.5$–1.0 (allowance).

10.3 Heijunka Implementation at Tier-2

After the implementation of Heijunka at Tier-1, Heijunka implantation at Tier-2 was carried out in similar fashion as that of Tier-1. Tier-2 category was divided in three subcategories. Each category uses a filling up supply using kanban collected from the store. Tier-2 consume same size of production quantity as manufactured at Tier-1. The processes or sub-processes at Tier-2 had similar machining operations along with the same trolley size and at the end of each Tier 2 subprocess there is defined inventory to take care of consumption of Tier-1 and downstream Tier-2. Each sub-Tier-2 process has its own production sequence designed to make up lost at defined interval.

10.3.1 Filling Up Kanban

Filling up kanban is used for both triggering the production as well as for movement of material in Tier-2. Every trolley is attached with kanban. After completing all the processes at Tier-2, trolley rests at finished goods store. When Tier-1 calls one trolley kanban card is removed and kept in kanban collection and sorting box. During a specific production sequence, kanban is collected as per (1).

10.4 Heijunka Conformation Ratio

Heijunka confirmation ratio is that parameter which was monitored at the plant level and it reflects the health of the Heijunka in the organization. It has the following two components

1. Heijunka sequence adherence
2. Quantity adherence

It was very important that Heijunka sequence adherence should be 100% which pertains to the situation that even if the material is not fully available, the production of the item started at the scheduled. This creates a respectful feeling in the persons working in the organization about the schedule. The Quantity adherence factor can be less than 100%, which means that the balance quantity can be made up later in the week.

10.5 Results and Discussion

The Heijunka implementation in the organization resulted in several tangible and non-tangible benefits and some of them are discussed below.

10.5.1 Productivity Improvement by Cell Layout Changes

The cell layout was changed at Peripheral assembly cell to make it run with one operator. This resulted in the improvement of human productivity from 7.9 parts/man-hour to 13.9 parts/man-hour.

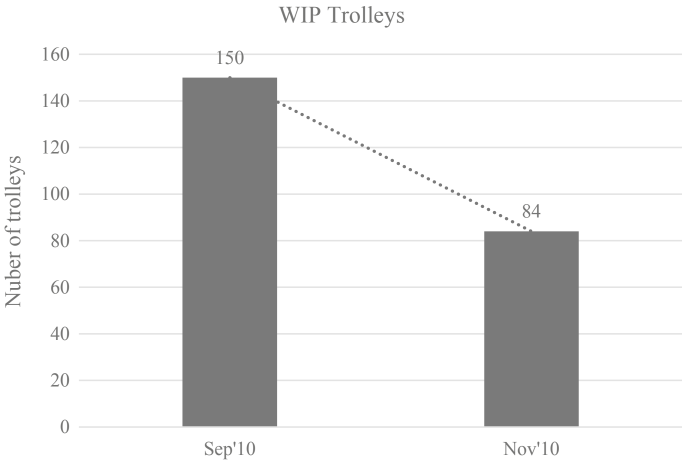

Fig. 10.4 Improvement in WIP reduction

10.5.2 V-Map, Kanban at Tier-1 and Tier-2

The improvement in the above parameters is shown in Fig. 10.4. V-Map for Tier-1 and Tier-2 was constructed to capture WIP and material flow in both the Tiers. The number of WIP trolleys in Tier-1 was reduced from 158 to 84 in number, i.e. reduction of 5000 parts.

10.5.3 Improvement in the Indices

The improvements in productivity, i.e. both human and machine productivity in parts manufactured per man-hour is shown in Figs. 10.5 and 10.6. From the graph, it is very much clear that there is improvement of 63% in human productivity, 39% improvement in machine productivity and 33% improvement in scraps reduction. The improvement of Indices at Tier-2 level is shown in Fig. 10.6 and from which it is very much clear that there is an improvement of 42%, 38% and 25% in human productivity, machine productivity and scrap reduction, respectively.

10.6 Heijunka Confirmation

The implementation of Heijunka flow in the production line was monitored and the following Tables show the Heijunka sequence and Heijunka confirmation. Table 10.6 shows that the Heijunka confirmation is 86% for the month of November Table 10.5.

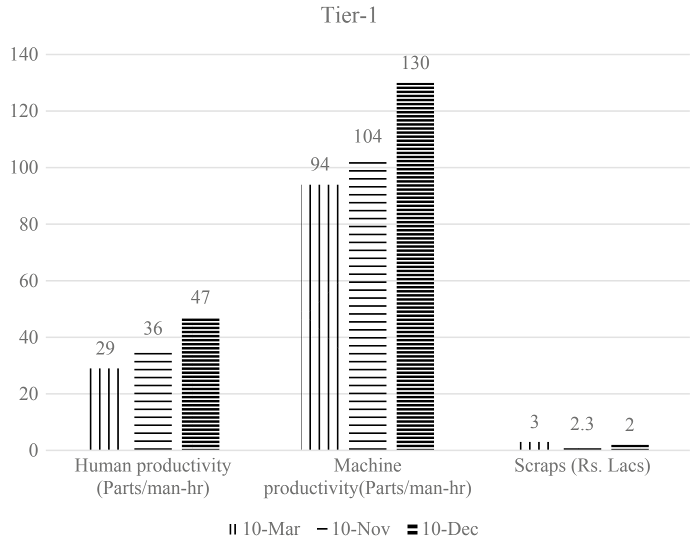

Fig. 10.5 Improvement in indices at tier-1

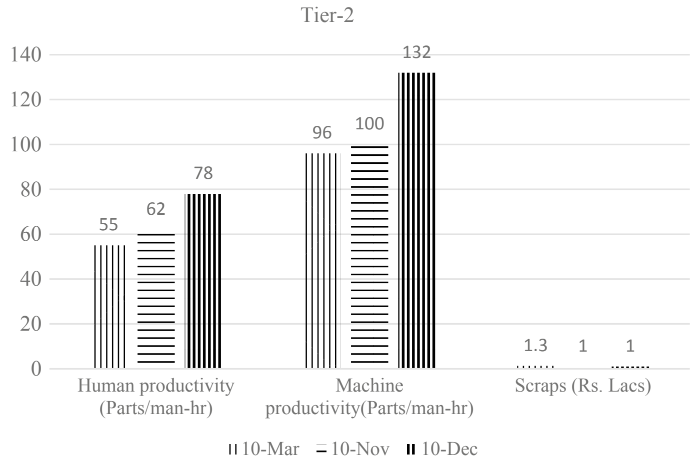

Fig. 10.6 Improvements in indices at tier-2

Table 10.6 Heijunka confirmation

Nov, 10	Planned sequence	Actual sequence	Percentage achievement
Week 1	15	12	75
Week 2	15	13	86.6
Week 3	13	9	69.2
Week 4	23	23	100
Total	66	57	86.3

10.7 Conclusions

The study was conducted in collaboration with XYZ Ltd. and has highlighted the role of Heijunka in improving Productivity (*P*), Quality (*Q*) and Delivery (*D*) for the organization. The Heijunka was chosen as a tool in order to eliminate the issues of the organization regarding loss of production, unplanned changeovers and inconsistent supply chain. The organization's top management showed strong and appreciable commitment towards the implementation of this tool. The traditional plant layout was changed to Tiered layout in order to establish pull production system which helped in the organization in lowering the inventory, determining the actual batch size, and thus plan the production. The Tiered production system was helped by the smooth Heijunka flow to create win–win situation for all the tiers thereby improving the efficiencies of the individual cells leading toward increased overall efficiency of the plant. Cell efficiency has a direct relationship with the efficiency of the human being, and it is improved by adopting the principle of standardization. The effectiveness of the system can be visualized in terms of achievement of the tangible benefits like improvement of 63% in the human productivity, 39% improvement in machine productivity and 33% improvement in scraps reduction at tier-1 and improvement of 42, 38 and 25% in the human productivity, machine productivity and scrap reduction at tier 2. The Heijunka confirmation is 86% for the month of November and it is targeted to be improved in the near future. Grimaud et al. [6] suggested the use of Heijunka in areas where there are demand fluctuations and the organization did the same thing in order to filter the unevenness. The above case study shows the results which agree with the [13] who advocated the benefits of Lean in the organization like improvement in productivity, better inventory control, waste reduction, cost reduction and quality improvement. Gupta and Vardhan [7] reported the increase in OEE due to implementation of TPM, the same improvements can be seen here in the Tables 10.2 and 10.3 where the OEE had been improved from 74 to 78% both due to Heijunka and allied systems like 5S.

10.8 Future Scope

This paper presents a case study conducted in one industry only. For the generalization of the results the more industries and be incorporated. A conceptual framework TISM model can be developed on the basis of the data collected from the industries and the developed model can be validated using SEM.

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Chapter 11
Generalized Design Methodology for Three-Arm Spiral Cut Compliant Linear Stage

Kiran Bhole and Sachin Mastud

Abstract This paper presents generalized design methodology of compliant mechanism-based linear stage consisting of three-arm spiral cut flexible linkages. Determination of geometrical parameters of spiral cut and other attributes of compliant mechanisms for required displacement is being major focus of the study. Hence, the study presents systematic investigation of effect of parameters of compliant mechanisms on displacement of stage as an outcome. This parametric study is conducted using finite element platform ANSYS. Various parameters considered in the study are spiral angle, thickness of the flexural plate, and width of spiral cut. These factors are varied at different levels to observe its effect on stiffness of the compliant mechanisms responsible for displacement of the linear stage. The findings of the simulation study are represented in dimensionless terms for its generalization and further validated through sample experiential study. Based on non-dimensional analysis, design chart is prepared for determination of geometrical parameters of similar class of compliant mechanisms.

Nomenclature

d	Outer diameter of flexural disc, mm.
l	Distance between stacks of flexural discs, mm.
m	Distance between consecutive flexural discs in a stack, mm.
n	Number of spiral arm.
t	Thickness of flexural spiral disc, mm.
w	Width of the spiral arm, mm.

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θ Spiral turn angle, degrees.
E Young's modulus of elasticity, N/m^2.
F Actuating force in z-direction, N.
P Pitch of the spiral arm, mm.
S Spiral cut width, mm.
Z Axial displacement of flexural system in z-direction under actuating force, mm.
K_a Axial stiffness, N/mm.
K_r Radial stiffness, N/mm.

11.1 Introduction

High accuracy and precision are the prominent features of compliant mechanisms. These features are attained due to bending of flexible elements of the mechanisms. Hence, these mechanisms are used in transmitting force and motion without any loss [1–6]. Joint-free linkages and no friction make mechanism highly accurate in transmitting motion. The absence of stiction and backlash are also important characteristics of these mechanisms. Further, these characteristics lead to maintenance and lubrication-free mechanisms. Here, it is to be noted that the flexible linkages are set to deform well below elastic limit for its successful execution. Hence, compliant mechanism is useful for low range of force and motion transmissions. Typically, flexures are used in micro-electromechanical systems, linear stages in micro-manufacturing [7–10], robotics, cryogenic applications [11, 12], and so on. Different designs of flexural systems are used by researchers to achieve different high-end requirements in sophisticated applications. Double parallelogram types of flexural systems are used for steering the laser beam in the opto-mechatronic system for on-axis micro-stereo lithography [8, 13–15] and compact disc of computing devices. Zero parasitic error due to compliant deformation of flexural beams enables flexures to allow exact linear steering of laser beam with nanometre resolution. Monolithic flexural mechanisms are also developed for guiding the cutting tool or workpiece in high precision micro-drilling and turning centres [3, 7, 9, 10]. Mechanism consisting of a parallel flexure hinge is utilized in ultra-precision turning operation to guide the moving platform and to preload the piezoelectric actuator. The developed mechanism has shown resolution up to 12 nm with reduced hysteresis and linearity of output. Furthermore, researchers have reported state-of-the-art design of the flexural mechanisms for nano-positioning of high-speed scanning probe used in video rate atomic force microscopy and probe-based nanofabrication.

Various geometrical variants of flexible elements are used in compliant mechanisms [2, 16–19]. Circular disc with spiral shape cuts through it is one of the variants of flexible elements [11, 20–22]. This spiral cut flexible element makes member low stiffness, thus making element easy to bend in axial direction under the application of axial force. Although axial stiffness is low, member intact its high radial stiffness [11]. These spiral cut flexural elements were used initially for measurement of earth vibrations due to its inherent high sensitivity. Further due to high accuracy in linear guidance with no requirements of lubrication, these are used in Stirling engine for cryogenic applications. Towards analysis of these flexible elements, study has presented parametric synthesis of single-disc spiral slot flexural linear stage through dynamic and modal loads [23]. Identification of best geometrical parameters for maximum life of linear stage and highest possible ratio of radial to axial stiffness were central theme of the study. Based on synthesis, the study has presented graphical data sheet to select best possible configuration of the flexural disc for the given input parameters. However, study also recommends the finite element (FE) analysis to tune the parameters. Spiral-shaped flexural elements with multiple discs in a stack and with such multiple stacks in assembly are used in applications for accurate linear movement with robustness. Design guidelines for such spiral cut flexural linear stage consisting of multistacked discs are not yet presented in generalized way. Hence, this paper presents the generalized design methodology for the multi-disc, multistage, three-arm spiral cut compliant mechanism. Design methodology is based on simulation and experimental study conducted on compliant mechanism. In derived design methodology, outer and inner diameters and thickness of the three-arm spiral cut discs are considered as input conditions. Geometrical parameters of the disc, viz spiral turn angle, width of spiral cut, and pitch of the spiral, are the typical outputs of the design procedure for the required linear displacement.

11.2 Configuration of Spiral Slot Flexural Stage

It is important to understand geometrical attributes and nomenclature of the spiral cut circular flexural disc used in the study. Figure 11.1 shows the flexural disc considered

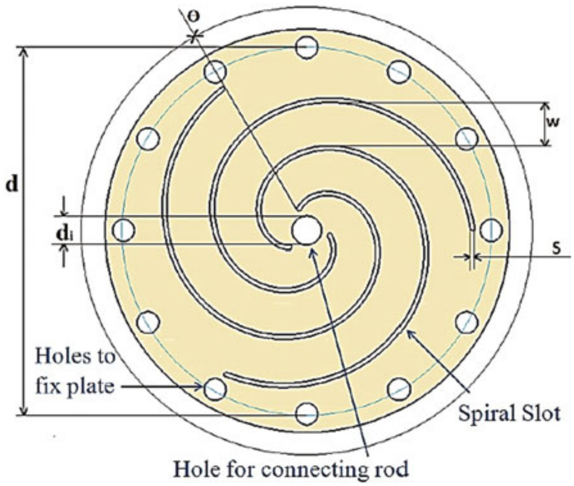

Fig. 11.1 Drawing of the spiral cut flexure disc for compliant linear stage

in this study. The spiral cut on the disc is normally done through wire cut electrodischarge machining process. Here, it is to be noted that the number of spiral-shaped cuts on the circular disc are referred as number of spiral arms. Further, the angle between start and end points of spiral cut is defined as spiral turn angle. Illustrated flexural disc in Fig. 11.1 demonstrates three-arm flexural discs with geometrical notations as defined in nomenclature. The assembly of these discs to form linear stage is demonstrated in Fig. 11.2. Assembly consists of two stacks of flexural disc (refer Fig. 11.2). Each stack of the flexural disc consists of two discs. These two flexural stacks are separated by intermediate spacers at the inner and outer periphery of the disc. Further, the formed stack of the flexural disc is connected with other stack with the help of rigid connector at the centre. The flexural discs are held fixed at the outer periphery, but free to bend along the central axis under the actuating force in *z*-direction. Specifically, this paper presents first the analysis of this form of the flexural assembly. In analysis, the linear displacement of the flexural assembly is measured against the actuating force, F. Desired linear displacement of the flexural assembly in the direction of actuating force (z direction) is of interest in the study. Various parameters of flexural disc and assembly considered in the study are presented in Table 11.1. These parameters are considered based on literature study [11]. Generally, stainless steel or copper beryllium (copper alloy with 0.5–3% beryllium) material is found most suitable due to their flexural properties in compliant mechanism. Copper beryllium is most preferred material in compliant mechanism due to ability of stress relaxing during bending [24]. Hence, copper beryllium material is considered in the study (refer Table 11.1 for properties of copper beryllium).

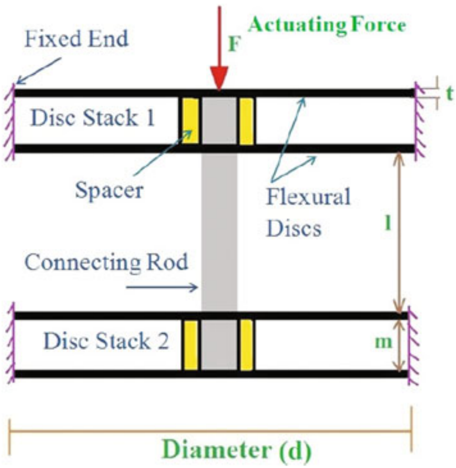

Fig. 11.2 Schematic of stack of flexure disc forming flexural linear stage

Table 11.1 List of parameters of system and material properties of flexural disc

Parameters	Value
Spiral arms	3
Number of flexural stacks	2
Number of flexural discs in stack	2
Distance between consecutive stacks	50 mm
Distance between consecutive discs	3 mm
Young's modulus of Copper Beryllium	165 x 10^9 N/m^2
Density of Copper Beryllium	8150 kg/m^3
Poisson's ratio of Copper Beryllium	0.3

11.3 Characterization of Spiral Arm Flexural Stage

Figure 11.3 shows the CAD model of flexural system prepared according to specifications (refer Table 11.1) in the modelling software CATIA. The prepared model is then imported in FE platform ANSYS for the purpose of characterization. The model consists of two-stage three spiral arm flexural linear stage. Dimensions of geometric attributes mentioned in Fig. 11.1 of the flexural bearing are shown in Table 11.1. The relation between arm width and slot thickness is given by derived parameter, pitch, by Simon Amoedo et al. [24]. Pitch changes with change in slot width for constant outer diameter and spiral angle. Equation (1) presents relation for pitch in terms of

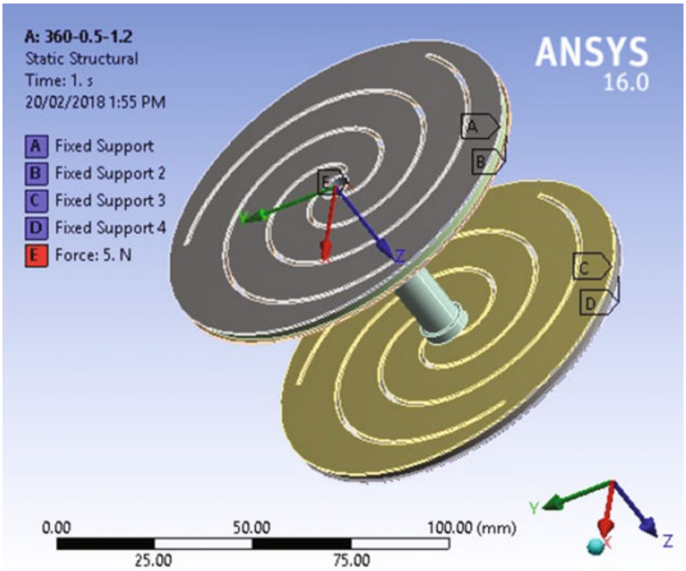

Fig. 11.3 Model of three-arm double discs and stacks flexural linear stage with boundary conditions

arm width, width of slot, and number of spiral arms [24].

$$P = w(n - s) \quad (1)$$

The flexural linear stage is characterized for its axial displacement and developed axial and radial stiffness for the actuation force using FE platform, ANSYS. The actuation force of 5 N is considered for the characterization. Study [24] has revealed factors, viz thickness of disc, slot width of spiral slot, and spiral turn angle being most important for controlling stiffness of the compliant mechanism. Design of experiments is conducted on the selected flexural linear stage. Table 2 shows the factors and their levels for the designed experiments. Four levels (L) of each of the three factors (F) are considered in the study (refer Table 2). To reveal accurate influence of parameters, full factorial design is proposed in the study. Hence, LF = 64, number of experiments were performed in finite element platform, ANSYS. In the analysis, boundary conditions prescribed on the linear stage as (1) rim of circular disc being fixed (refer Fig. 11.1), (2) central portion is free to move (in the direction of actuating force). The actuating force is applied on the central portion of the compliant linear stage in z-direction. Due to prescribed boundary conditions, the flexural elements (spiral cuts discs) bends (refer Fig. 11.4 resulting significant linear displacement in the direction of applied force. Before applying complete proposed design of experiments, the trial experiments are conducted on two stacks with two discs in stack assembly of compliant linear test stage. The spiral cut on the discs is having turn angle of 360° with width of cut being 1.2 mm. Further, plate thickness

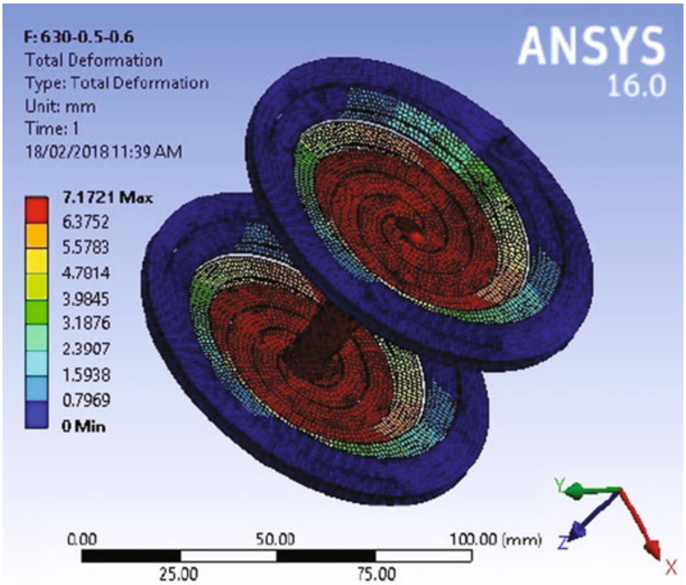

Fig. 11.4 Fe analysis for displacement of three-arm double discs and stacks flexural linear stage

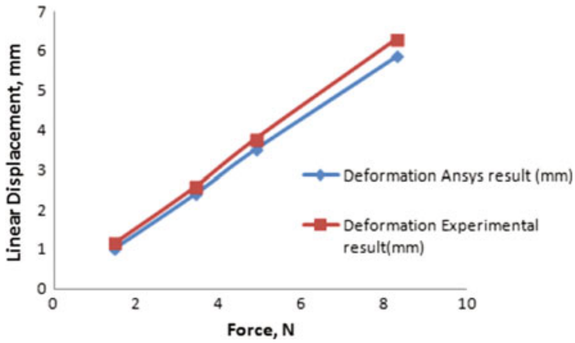

Fig. 11.5 Comparison of simulation and experimental results for validity

in fabricated compliant test stage is of 0.25 mm. The central static load is varied on the fabricated test stage from 2 to 10 N. Central displacement due to these static forces is measured with the help of linear encoder (Renishaw). The characteristics of this experimental test stage are shown in Fig. 11.5 along with the simulation results conducted on similar test model in ANSYS. Figure 11.5 shows good agreement between the simulation and experimental results. Henceforth, the simulations are conducted on different cases of compliant stage according to design of experiments.

Stiffness is one of the important characteristics in design of compliant system. The amount of linear movement of the compliant stage is dependent on its stiffness. Lower stiffness in the direction of desired direction of motion is desirable, while higher stiffness is required in the other mutually perpendicular directions. Hence, typically for the stage under study, low axial (z-direction) stiffness and high radial stiffness are required. Thus, in the characterization of this stage, central displacement (z-direction) and radial displacement under application of axial force are obtained through simulations. The axial actuating force is kept constant in all the simulations, while factors are varied at various levels (refer Table 2) for the wide range of simulation. From obtained axial and radial deformations, the axial and radial stiffness are determined. For generalization of the characteristics, the obtained displacement and stiffness are normalized. The outer diameter of the disc, thickness of the disc, total number of discs in the stack, number of discs in the stacks, and characteristics of spiral cut (profile of spiral, width of spiral cut, spiral turn angle, number of arms of spiral) are the parameters governing stiffness of the compliant stage. Overall among these various factors, it is very important to find factors having most influence on stiffness. For generalization of results, factors of the complaint stage are normalized by dividing them with outer diameter of the disc. Thus, axial displacement, slot width, thickness, and pitch are presented in dimensionless forms as z/d, s/d, t/d, and p/d, respectively. Further, axial and radial stiffness of the flexural bearing is presented in dimensionless form as $\frac{K_a \times 10^{-8}}{E \times d}$ and $\frac{K_r \times 10^{-8}}{E \times d}$, respectively. Inline with these normalized parameters, influence of factors on stiffness is presented in the following subsections.

11.3.1 Effect of Slot Width on Stiffness

Figure 11.4 shows one of the results for displacement of flexural system under the application of force 5 N in *z*-direction. Figure 11.4 depicts the zero displacement at the periphery of the disc due to applied boundary condition of fixed outer rim and maximum displacement at the central portion due to bending of spiral elements. For the characterization, maximum deformation at the central portion of the stage is recorded and presented as dimensionless displacement. Based on the maximum deformation, dimensionless axial and radial stiffness are evaluated. Figure 11.6 shows the effect of normalized slot width on the axial and radial stiffness of the flexural system of two stacks for cases consisting of two and three discs (layers) in a stack. In both the cases, 0.5 mm disc thickness and spiral angle 630° are considered. Figure 11.6 reveals decrease in axial and radial stiffness with increase in dimensionless slot width. This observation is similar in compliant stage consisting of double and triple flexural discs in a stack. This implies that complaint stage will provide more deformation with increase in slot width for constant actuating force. This is because increase in slot width decreases the rigidity of the system and increase in flexibility. Further, it is noted that the deformation in double-layer flexural system is more compared to the three layers flexural system as later is less flexible. This leads to high stiffness in triple-layer system compared to double-layer flexural system (see Fig. 11.6). Further, characterization shows that the change in axial stiffness is less as compared to the change in radial stiffness (refer Fig. 11.6). Hence, the slot width effect is more dominantly seen on the radial stiffness of spiral-based flexural system. From design aspects for the linear motion of the flexural system, the axial deformation of the system is most desired, while radial deformation of the system is not favourable. Hence, from this consideration, appropriate selection of spiral slot width shall be done based on obtained characteristics. Further to present design guidelines for deciding the spiral slot width and thickness of disc, characteristics presented in Fig. 11.6 are presented in terms of stiffness ratio (refer Fig. 11.7). This characteristic can be used to decide the spiral slot width based on selected axial and radial stiffness and normalized thickness of the flexural disc.

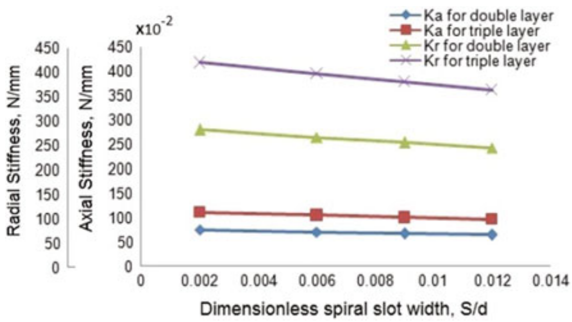

Fig. 11.6 Radial and axial stiffness against dimensionless spiral slot width

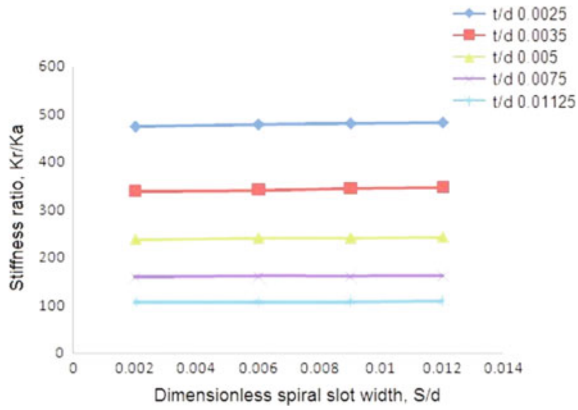

Fig. 11.7 Stiffness ratio against dimensionless spiral slot width

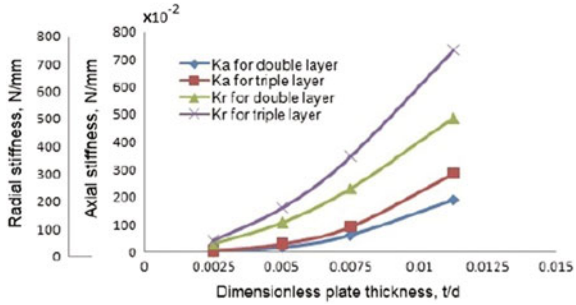

Fig. 11.8 Radial and axial stiffness against dimensionless thickness

11.3.2 Effect of Disc Thickness on Stiffness

Figure 11.8 shows the effect of thickness of disc on axial and radial stiffness. The stiffness characteristics are presented for constant dimensionless slot width of 0.006 (slot width of 0.6 mm for the case presented) and spiral angle of 1080° against dimensionless thickness. The characteristics show large change in both axial and radial stiffness (refer Fig. 11.8) beyond normalized thickness 0.0075. These characteristics are observed in case of both two- and three-layer flexural system. However, magnitude of stiffness of the three layers system is more compared to two layers as addition of layer contributes towards more rigidity of the system opposing flexibility or deformation.

11.3.3 Effect of Spiral Turn Angle on Stiffness

Figure 11.9 shows the effect of spiral turn angle on axial and radial stiffness of the compliant linear system. Characteristics (refer Fig. 11.9) depict decrease in axial

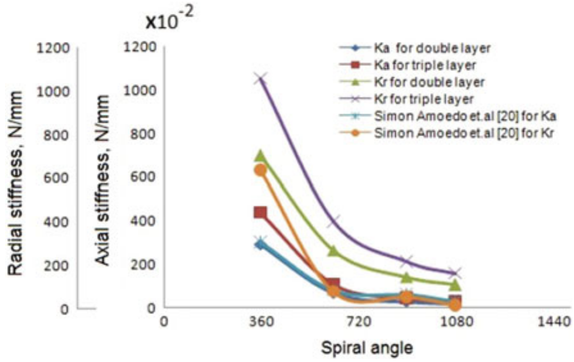

Fig. 11.9 Radial and axial stiffness against spiral turn angle

stiffness allowing more deflection with increase in spiral turn angle. This observation in characteristics is seen for both double- and triple-layer compliant linear system. Increase in spiral angle in constant diameter disc leads to decrease in arm width. This decrease in arm width leads to decrease in axial stiffness allowing more deformation of the system. The obtained characteristics are compared with the similar characteristics obtained by Simon Amoedo et al. [24]. Figure 11.9 also shows the decrease in radial stiffness with increase in spiral angle for the similar set of flexural system. Similar effect of decrease in arm width is responsible for attenuation in radial stiffness. The nature of characteristics for double and triple layers of discs in a stack is also similar to that in study presented by Simon et al. [24] for single-disc flexural element.

11.4 Discussion

Based on the analysis, following are the summary points from the designed experiments for characterization on the stiffness of the compliant linear stage:

1. Increase in slot width of spiral cut decreases both axial and radial stiffness.
2. Increase in thickness of spiral flexural disc increases both axial and radial stiffness.
3. Increase in spiral turn angle decreases both axial and radial stiffness.

It is logical that increase in thickness of flexural discs, number of stacks, and number of flexural discs increase rigidity of the stage and hence increase the stiffness of the disc. On other hand, increase in outer diameter of disc makes disc to deform more under bending, thus causing decrease in stiffness. Furthermore, similarly increase in characteristics of spiral cut (width of spiral cut, spiral turn angle, number of arms of spiral) makes discs more hollow resulting in decrease in stiffness.

For the purpose of generalization towards generating the design methodology for similar flexural system, the results of characterization are required to be presented in the form of ratio of dimensionless stiffness. Further, the axial displacement is one of the important requirements to be fulfilled while designing flexural system used as linear guide ways or scanning mechanisms. Considering these specific requirements, the characteristics are presented in terms of dimensionless displacement and dimensionless stiffness. Figure 11.10 shows the characteristics of the flexural system representing dimensionless axial stiffness against dimensionless displacement (feed), and Fig. 11.11 shows the dimensionless radial stiffness against dimensionless displacement for various dimensionless thicknesses. Figure 11.10 shows lesser variation in dimensionless axial stiffness against dimensionless displacement for lower dimensionless thickness (refer characteristics for dimensionless thickness 0.0054 and 0.0038 in Fig. 11.10). Further, it is observed that stiffness tends to saturate beyond dimensionless displacement of 0.08. However, the significant dependency of dimensionless axial stiffness on dimensionless thicknesses is noted from the characteristics. Figure 11.11 depicts that significant variation in dimensionless radial

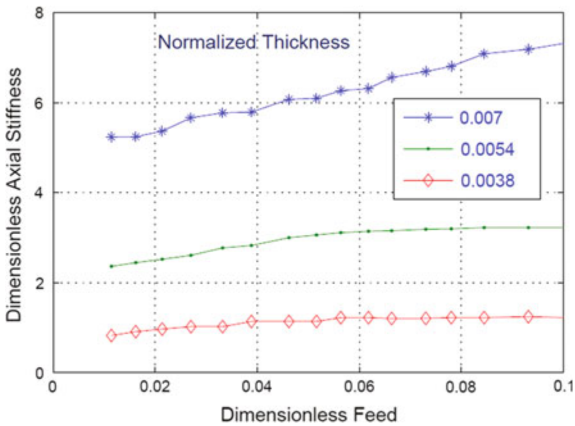

Fig. 11.10 Dimensionless axial stiffness against dimensionless displacement of the flexural linear stage

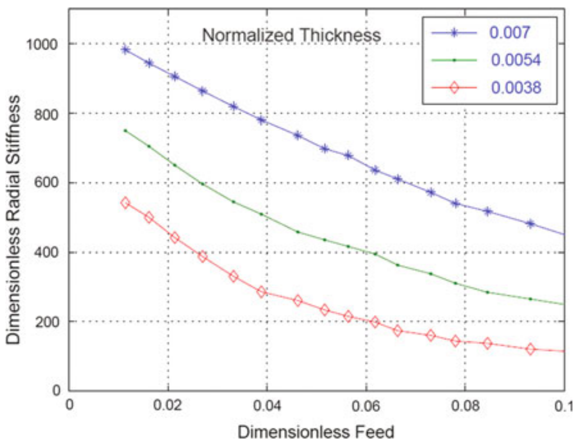

Fig. 11.11 Dimensionless radial stiffness against dimensionless displacement of the flexural linear stage

stiffness against dimensionless axial displacement. High dimensionless radial stiffness is observed at lower dimensionless axial displacement. Further, it is observed that dimensionless radial stiffness increases with increase in dimensionless thickness. Low axial stiffness provides good sensitivity for displacement in feed direction, while high radial stiffness signifies high resistance to deformation in lateral direction against applied force. Hence, characterization points that flexural stage gives better linear guidance for dimensionless feed within 0.08. Hence, the regime up to dimensionless feed 0.08 is recommended for the spiral type of flexural stages. Figures 11.10 and 11.11 depict consolidated view of the stiffness and geometrical parameters of the flexural system. Hence, this characteristic can be taken as one of the references for generating design guidelines for the flexural system.

11.5 Graphical Design Chart

Figure 11.12 shows the design chart for the three-arm, two-stack spiral-shaped flexural system based on the characterization presented in above sections. The methodology of graphical design tool presented is similar to the design methodology reported first time for single-disc flexural system by Simon Amoedo et al. [24]. This tool is developed to minimize the time required for optimizing the specific flexural system for application which requires large number of FE simulations. Set of parameters in this developed design tool are in dimensionless term to have generalization. For use of design chart, it is necessary to choose the basic input parameters of the flexural systems along with the desired requirement from the system based on the intended application. For the use of developed design chart, designer is expected to start with input parameters. Here, the designers input parameters are outer diameter and inner diameter of flexural system, material properties, and desired axial displacement "*z*". The designers seek parameters of flexural system, viz thickness of flexural disc, slot width, and spiral angle from the graphical design chart. The step-by-step procedure depicting use of developed design chart is presented in next section.

11.6 Design Procedure

To start with design, initially the designer has to decide final output desired from the stacked flexure assembly and predetermined diameters of the flexural discs for intended application. Typical of desired output for flexural system used for linear guide ways is axial displacement under applied actuating force. The desired axial displacement is generally needed with ideally zero radial displacement and stress in the flexural element below limiting level. This is taken into consideration in the development of design chart derived based on FE simulations discussed in the previous section. For the user, the design procedure to be adopted is summarized as below:

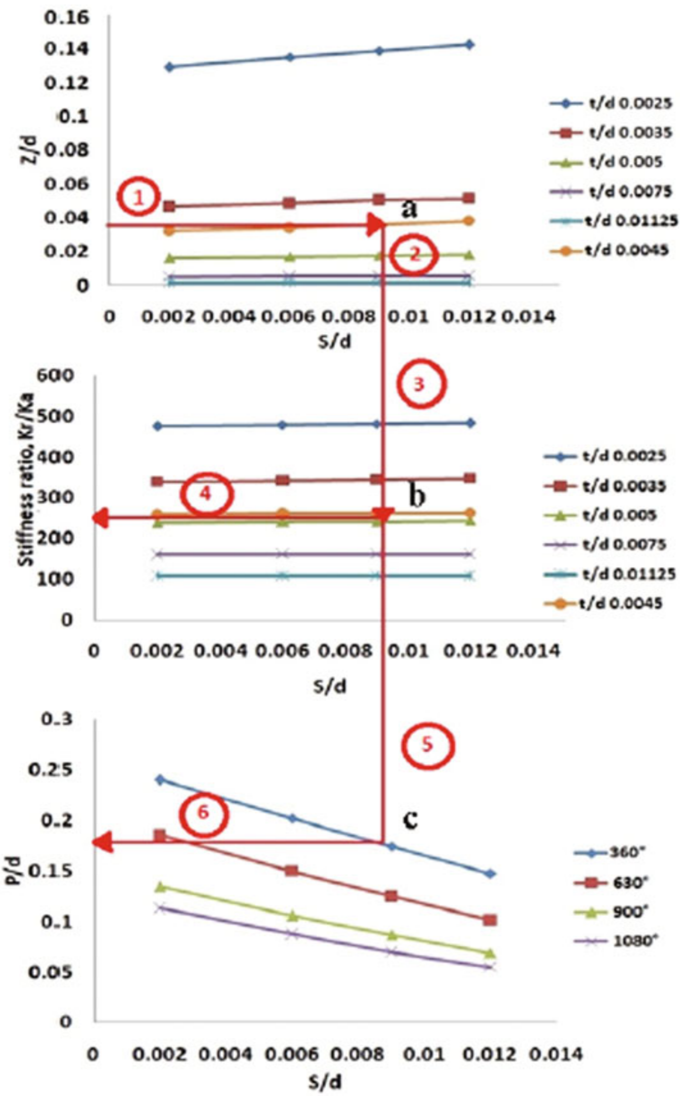

Fig. 11.12 Design chart and process methodology for two-stack three-arm flexure linear stage

1. Determine outer diameter, *d* of the flexural disc as design input.
2. Determine maximum axial displacement, *Z* as required for the application for which linear stage is to be designed.
3. Derive dimensionless axial displacement (Z/d) required as primary input to use design chart.
4. Draw horizontal line from dimensionless axial displacement obtained from step 3 (refer horizontal line 1 in graph Z/d versus S/d in Fig. 11.12).

5. Obtain point of intersection of constant dimensionless displacement line with lines of constant dimensionless thickness (t/d) (refer point "a" Fig. 11.12).
6. Calculate thickness of the flexural disc (t) from the dimensionless thickness obtained from Step 5.
7. Draw vertical line from point of intersection "*a*" on *x*-axis to obtain dimensionless spiral slot width, S/d
8. Calculate slot width of spiral from obtained dimensionless slot width of spiral.
9. Draw vertical line (refer vertical line 2 in Fig. 11.12) from point of intersection "*a*" to obtain point "*b*" on line of selected dimensionless thickness in graph of K_r/K_a versus S/d in Fig. 11.12.
10. Obtain K_r/K_a from point of intersection "*b*". Review the ratio K_r/K_a of the system (refer horizontal line 4 in Fig. 11.12). Low K_r/K_a ratio is desirable for the flexural system used for accurate linear positioning application with better sensitivity for displacement in axial direction. Designer may seek alternatives to get optimum K_r/K_a considering accuracy and sensitivity. If designer seek alternatives shall iterate steps 1–10 for best fit in design.
11. Draw vertical line from point "*b*" (refer vertical line 5 in Fig. 11.12) on graph P/d versus S/d to get point of interaction "*c*" for desirable spiral turn angle. Here, various options for spiral turn angle are available for the designer.
12. From point "*c*", dimensionless pitch can be obtained from graph P/d versus S/d (refer horizontal line 6 in Fig. 11.12). From obtained P/d, pitch can be calculated. Calculated pitch can be used to determine width of spiral arm from Eq. (1). Width of the spiral arm will be dependent on the spiral turn angle selected. Consideration of design for manufacturing may be applied to select the spiral turn angle and thus arm width.

From application of above steps, it is possible to design three-arm two stacks with each stack of two-disc spiral-shaped flexural system. Based on the developed design methodology, compliant linear feed stage is designed. Figure 11.13 shows the developed compliant linear feed stage for micro-drilling workstation. In the design of the feed stage, the linear displacement of 6.5 mm is considered for the two-disc two-stack compliant linear stage. Further, outer diameter of flexural disc is considered to be 110 mm. With these input data, the developed methodology is applied to obtain various parameters of spiral cuts. On application of the derived data in developed linear complaint stage, the desired linear displacement is obtained for the micro-drilling.

11.7 Conclusions

FE analysis is carried on different combination of parameters for spiral flexure assembly consisting of three arm and two stacks (each stack consists of two discs). Effect of these parameters on radial and axial stiffness is studied, and the results are plotted in the form of charts for simple understanding. Further, the effect of these

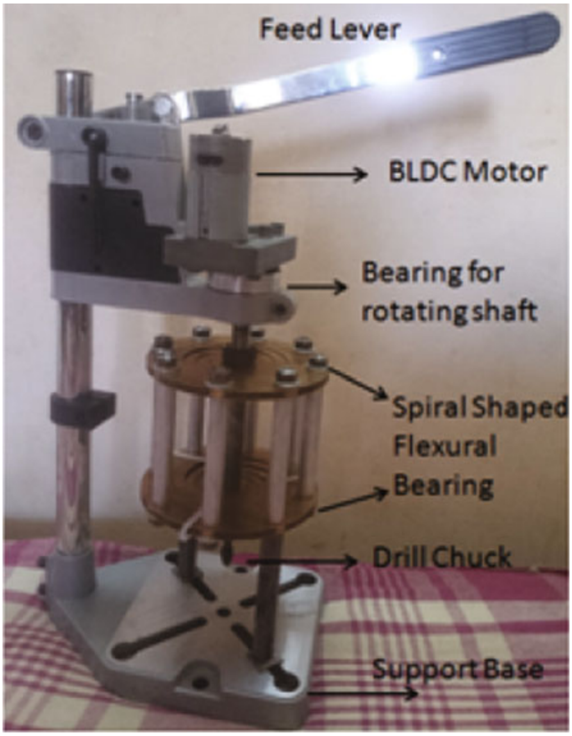

Fig. 11.13 Photograph of developed compliant linear feed stage for micro-drilling

parameters on axial displacement is also studied. Based on this characterization, a design procedure is developed for system designer. Developed design chart enables designer to choose optimum geometrical dimensions of flexural discs in flexure assembly for desired outcome (typically the axial displacement of flexural system). The design procedure is recommended for constant distance between plates, three-arm spiral and two-stack system. Effect of these parameters can be studied further to seek more alternatives in design.

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Chapter 12
Life Cycle Assessment in Sustainable Manufacturing: A Review and Further Direction

Prince Ranjan, Rajeev Agrawal, and Jinesh Kumar Jain

Abstract The main objective of this paper is to review and analyze the current scenario of life cycle assessment in different manufacturing sectors from the sustainable manufacturing aspect. All recent concept of sustainable manufacturing is given and figure out in this literature review paper. In the present review paper we have reviewed the life cycle assessment, system boundary and sustainable manufacturing topics. The literature review is used to search the idea of "sustainable manufacturing" connected to processes and tasks in manufacturing industries. This review paper is based on the present reserach trends, the advancement made up in sustainable manufacturing until now, issues experienced and issues divulged by the early acceptation and execution, what is settled what still should be worked upon. This will help the researchers and industry people from manufacturing sector to take useful process for sustainable manufacturing.

Keywords Sustainable manufacturing · Life cycle assessment · Sustainable product design · Life cycle inventory · Life cycle impact assessment · International organization for standardization

12.1 Introduction

The idea of sustainability rise during the mid of 1970s and 1980s was to a great extent inspired by environmental events and calamities just as fears about substance pollution and asset exhaustion [1]. Sustainability is defined as "meeting the needs

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of the present without compromising the ability of future generations to meet their needs" [2]. Sustainability substance at the item, procedure, and framework levels for empowering sustainable manufacturing (SM) [3]. Sustainable manufacturing is defined as "use of processes which do not harm the environment, employees and consumers during and after the manufacturing" [4, 5].

Customarily, items were structured and created without thinking about their opposite effects on the earth. Components considered in item configuration included capacity, quality, cost, ergonomics, and security, among others. No thought was offered explicitly to the ecological parts of an item all through its whole life cycle. Customary end-of-pipe guidelines concentrated distinctly on the discharges from the assembling procedures of an item. In many cases, be that as it may, unfavorable effects on the earth happened from the other life cycle stages, for example, use, transfer, appropriation, and crude material procurement. Without tending to ecological effects from the whole life cycle of an item, for the item plan, one can't resolve the fundamental issues accumulating from the creation and utilization of the thing.

As of late, numerous organizations perceived the significance of the environmental impacts of their products and started to fuse natural angles into their item structure and advancement forms. This requires recognizable proof of key natural issues identified with the item all through its whole life cycle [6]. The key problems incorporate tricky exercises, procedures, and materials related with the question from crude materials obtaining, fabricating, dispersion, use, and transfer, at the end of the day, the whole life cycle. Since an item can't be planned, made and promoted without materials, segments, transportation, transfer, and vitality, recognizable proof of key natural issues related with the item all through its whole life cycle is a muddled procedure. Therefore, there is a requirement for a deliberate diagnostic device for the natural appraisal of an items' entire life cycle. This instrument is a Life Cycle Assessment (LCA) [7].

Alert must be worked out, in any case, in utilizing LCA for item plan. LCA is an instrument for the assessment of an item just from the perspective of the earth. There are different viewpoints, for example, financial, social, and specialized ones to be considered in any item structure and advancement. In this regard, life cycle costing, material stream investigation, and other specialized assessment methods ought to be an indispensable piece of the item structure and improvement. Exchange offs among ecological, financial, social, and specialized perspectives must be made.

Hence, LCA gives guarantee for the development of sustainability in all industries. LCA is one of the different administration tools for assessing environmental concerns. There are various dangerous factors responsible for the growth in environmental effects, but the major one is global warming. Global warming acts the outcomes of great haul development of Green House Gases (GHG) (CFCs, CO_2, and so on) in the all primary layer of earth's atmosphere [8]. The emanation of GHG is responsible for serious naturally harmful human operations, for example, land-use changes, deforestation, and burning of fossil fuel [9]. Perhaps in light of the fact that GHG discharges can be more promptly measured than different effects, they have pulled in most consideration from researchers and policymakers, however, GHG outflows are very important parameter responsible for the calculation of environmental effect. Others are eutrophication, toxicity, ozone depletion, resource depletion, water consumption, etc. [8].

In brief, by delineating a refreshed view of LCA in the types of different assessment phases and system boundaries, this literature review will help for creating an SM by the use of LCA.

12.2 Research Concepts

12.2.1 Life Cycle Assessment (LCA)

It is critical to perceive that SM ideas are not simply worried about the manufacturing or assembly process itself, however, incorporates the total product cycle from raw materials extraction to the end of life (Fig. 12.1). The expression "LCA" is connected to systems that give subjective or in perfect world quantitative outcomes to assess the complete environmental impact of a product [10].

Life cycle assessment is the best-known sustainability tool. LCA is used for quantitative analysis of environmental aspects of a product overall its life cycle stages. An LCA is a precise tool that empowers the examination of environmental heaps of an item all through its whole life cycle and the potential impact of these heaps on the earth. LCA has a significant advantage as a sorting tool to separate major and minor environmental impacts from each other. As per ISO, LCA is an organized procedure created in four phases: goal and scope definition, inventory analysis (LCI), impact assessment (LCIA), and interpretation of the results [12].

- Goal and scope definition

Why perform LCA? who are the intended interest groups? and what is the product under LCA think? These are the issues to be tended to by the goal definition. The scope

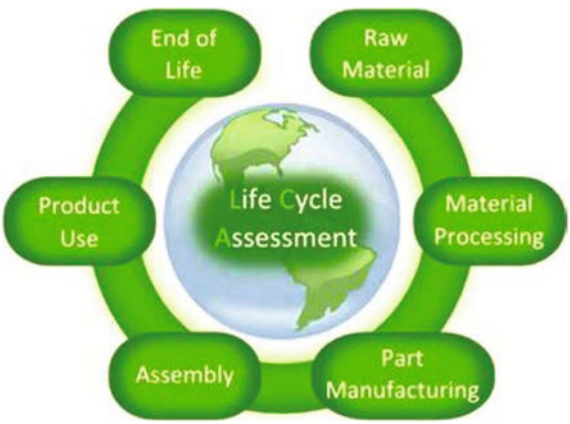

Fig. 12.1 Life cycle assessment: the complete cycle from cradle-to-grave. *Source* Ref. [11]

definition is considerably more confounded than the goal definition. It incorporates characterizing product system boundary, functional unit, data parameters, a target for data quality, impact assessment methods, among others [12].

- Life Cycle Inventory (LCI)

Life cycle inventory analysis involves data collection and calculation to quantify inputs and outputs of materials and energy associated with a product system under study. Here, "related to" means "dividing by" either the unit process main output or the final product of the product system [13].

Product system consists of the manufacturing process of a product under study, plus the up and downstream operations of the product. A process tree or process flow diagram represents the interrelationship among unit processes in the product system (Fig. 12.2).

- Life Cycle Impact Assessment (LCIA)

The criticalness of potential natural effects of an item framework dependent on life cycle stock outcomes is assessed by utilizing LCIA [15]. The LCIA comprises of a few components. They are classification, characterization, normalization, and weighting. Of these four components, normalization and weighting are viewed as discretionary, while the initial two are required components in LCIA [14].

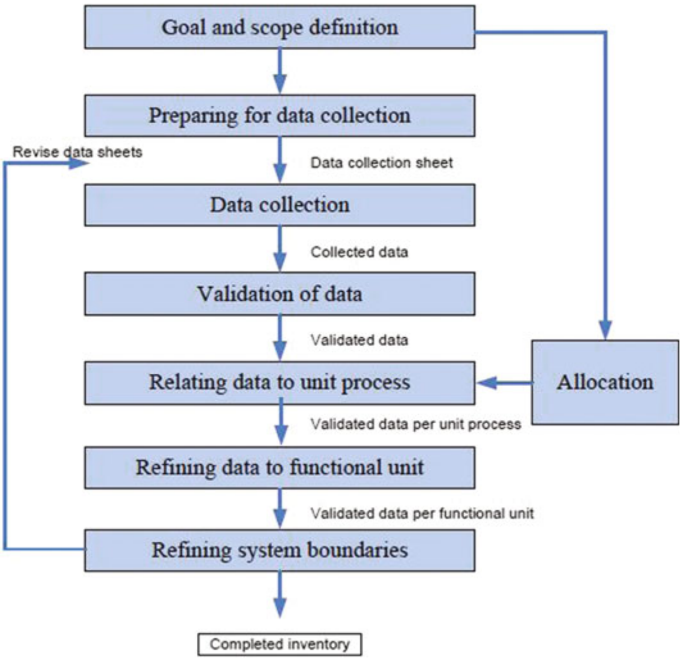

Fig. 12.2 Systematic steps for inventory analysis [14]

- Life cycle interpretation

Consequences of life cycle stock examination and life cycle sway appraisals have been investigating for different angles, for example, fulfillment, affectability, and consistency. What's more, key issues that contribute primarily to the natural effect of the item framework are additionally distinguished. Critical issues in this setting can mean essential procedures, materials, exercises, and parts or even an actual existence cycle organize [14, 16].

There are three key components in life cycle translation as characterized by ISO 14043. First is the recognizable proof of crucial issues, second is the assessment (counting checking culmination, affectability, consistency), and third is the advancement of ends together with suggestions [17].

Operating an LCA can be both complicated and time-consuming, as there is a regularly vast amount of information included. In like manner, most experts do LCA utilizing devoted programming. Among the better realized industrially accessible programming bundles are GaBi and SimaPro [18].

For understating the concept of SM, a case study of paper production is investigated. In this, an LCA methodology was used for creating a green product by using a concept of SM. LCA was operating for two different kinds of paper, first was conventional paper and the other was wood waste produced paper. The investigation was done on two options, first principal that was keen on the paper production from the last output gotten after a chemical treatment was taken on waste wood, and other option was exited to the generation of paper from the conventional technique. The first process for production of conventional paper was cooking then after pulp washing takes place and the last was papermaking whereas for the chemical treatment of wood waste were crushing, sieving, hydrolysis, and delignification. System boundary for the paper production was gate-to-gate, i.e., for only production phase. The goal is to differentiate the environmental impact results of conventional paper production from the chemical treatment of wood waste. The functional unit of this case study is 1 ton of paper production which is chemically processed until the pulp is obtained and the paper is produced [19].

The conventional paper production method creating a great negative effect on our earth's environment whereas for wood waste produced paper method gave very low negative effect on our earth's environment with respect to conventional paper production method. The effect of aquatic acidification is due to the hemicelluloses hydrolysis reaction which is already formed in acid solution (Fig. 12.3). For SM, we will wisely select the wood waste produce paper method for paper production. Hence, LCA methodology gives a complete overview of the selection of green process or SM.

LCA has risen as an important tool decision to support devices for approach creators and manufacturing units in examining the cradle-to-grave effects of any item or procedure. The three main principle factors for driving decision support device are, first is the government guidelines are going toward "life cycle assessment", the thought that a maker is dependable for direct manufacturing impacts as well as for those related to item inputs, purpose, transport and dumping. The middle one,

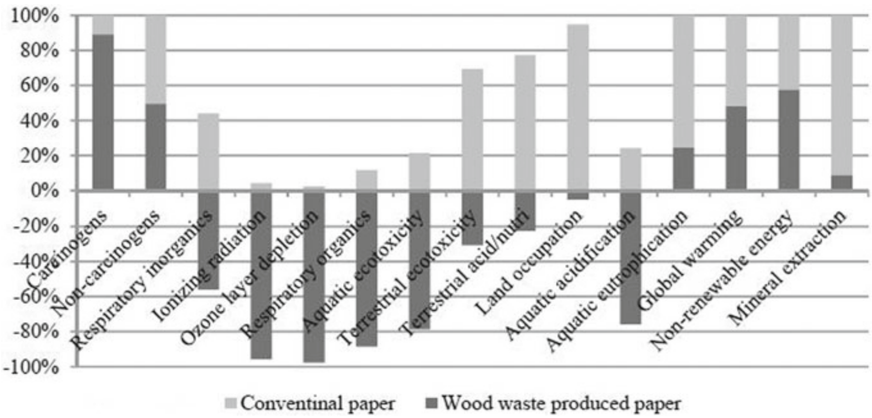

Fig. 12.3 Case study result [19]

organizations are taking an interest in deliberate activities which include different LCA and item stewardship issues. Last one, "environmental idealness" has to be risen as a standard for both purchaser markets and government acquisition rules. Together, all these elements have prompted LCA playing an important role as an instrument for examines cradle-to-grave effects of all items. Today, a significant number of the world's driving and best-realized industries have LCA programs set up [10].

12.2.2 Sustainable Product Design (SPD) and Sustainable Manufacturing (SM) Process

Product design is an essential phase that will decide the conduct of the product in different consequent stages [13]. The parts of sustainability should be inserted as ahead of schedule as probable amid the product design phase so as to move the general public toward sustainability [20]. Maybe the most critical parts for SM are the product design. As per the EU, 80% of total natural effect for any items and administrations can be resolved at early phases of design. Notwithstanding, a big issue confronting the "green" designer is that an assorted variety of components impact plan notwithstanding environmental examination [10]. A portion of the examinations in the literature has featured that SMD and advancement can be a design procedure that has the reason for decreeing or wiping out dangerous materials, reduce scrapes [21].

In general, manufacturing processes greatly affect the environment since they expend a lot of energy and they produce unwanted waste in all three stages, i.e., solid stage, liquid stage, and gaseous stage [22]. Various activities have been created to decrease the effect of manufacturing processes on earth. By and large, the vast majority of these activities mean to diminish energy consumption or CO_2 outflows, minimize undesirable wastes, recuperate assets, and utilize materials [3, 23, 24].

12.2.3 Research Methodology

As a result of immeasurability of different manufacturing fields, a complete literature overview was executed and an assortment of databases and library lists were investigated from various books, journals, conference papers, PhD thesis, and various reports. These databases come from various research platforms comprising Google Scholar, Emerald, Scopus, Elsevier, Science Direct, etc. The estimation things utilized in the overview comprise of existing estimates taken from the different literature reviews which were approved by the different scholars and many more new estimation things.

On the basis of LCA in SM, many papers and reports were assembled from all above sources.

12.2.4 Review of LCA Studies

When manufacturing industry needed an internal decision for the making of a product, an increasingly valuable route is to play out an assessment with a gate-to-gate boundary at the production site. LCA studies for the various manufacturing industries have been reviewed and listed in Table 12.1 the whole literature review is based on the newly published paper.

12.2.5 Result

In Table 12.1 all the studies are based or focused on life cycle assessment and most from gate-to-gate phase, i.e., for only production phase. All [25–36] studies mainly thinking of environment aspects for making green products. It is additionally progressively valuable from a manufacturer's point of view, that's helps making the internal policy for developing sustainable manufacturing. In the following passages, the literature reviewed were examined dependent on these topics: LCA, system boundary, sustainable manufacturing, and utility of results. Additionally, the methodological troubles to perform thorough and all-encompassing evaluations were likewise discussed.

Table 12.1 Literature review

S.No.	Manufacturing field	Methodology	System boundary	Description	References
1.	Food manufacturing	LCA	Gate-to-gate	An environmental evaluation at the procedure level that incorporated the handling and bundling activities were finished. Major information was only considered at the production phase for different products	[25]
2.	NC (numerical control) machining process	LCA	Gate-to-gate	The investigation led to an environmental evaluation at the unit procedure level. Be that as it may, the examination was constrained to just for the environmental aspect	[26]
3.	Cement industry	LCI-based assessment	Gate–to–transportation	In the study, environment assessment was considered at the process level with transportation	[27]
4.	Wood manufacturing	LCA	Gate-to-gate	A manufacturing stage environmental evaluation was embraced for the production of oil palm-based plywood wood. Firstly data collection and life cycle inventory analysis was studied then after life cycle impact assessment study was done	[28]

(continued)

Table 12.1 (continued)

S.No.	Manufacturing field	Methodology	System boundary	Description	References
5.	Food manufacturing	LCA	Cradle-to-grave	Environmental analysis and assessment are only considered for manufacturing. Nonexclusive sort and "the entire of the manufacturing plant" based information was utilized which did not permit specific analysis and commitment of procedures and different factors. The other two important sustainability dimension, i.e., social and economical were not considered	[29]
6.	Food manufacturing	LCA (frontier-access)	Cradle-to-transportation	A segment level investigation was attempted, in this 33 United States food manufacturing different sub-areas were examined for outer announcing and approach definition purposes. The other two important sustainability dimension, i.e., social and economical were not considered	[30]
7.	Jewelry manufacturing	Life cycle inventory-based assessment	Gate-to-gate	In this study, a environmental-based assessment was conducted. This analysis was done at process level, in spite of the fact that with less information also, it could be reached out to the facility level	[31]

(continued)

Table 12.1 (continued)

S.No.	Manufacturing field	Methodology	System boundary	Description	References
8.	Titanium dioxide manufacturing	LCA	Gate-to-gate	In the study, environment assessment was considered at process level. It was an essential quantitative analysis at the production process, in spite of the fact that with less information also, it could be reached out to the facility level The other two important sustainability dimension, i.e., social and economical were not considered	[32]
9.	Food product (tomato)	LCA	Cradle-to-transportation	In the study, environment assessment was considered at the product level. The other two important sustainability dimension, i.e., social and economical were not considered	[33]
10.	Iron casting process	LCA	Gate-to-gate	In the study, environment assessment was considered at a unit manufacturing process. The important sustainability dimension, i.e., social was not considered	[34]
11.	Wood manufacturing	LCA	Cradle-to-grave	In the study, environment assessment was taken at a unit manufacturing process of sawmilling	[35]

(continued)

Table 12.1 (continued)

S.No.	Manufacturing field	Methodology	System boundary	Description	References
12.	Various manufacturing sector	LCA	Gate-to-gate	The study based on the quantify environment pressure of policy building plan for different manufacturing sectors US economy was studied for the nation level assessment and correlated with different manufacturing sectors	[36]

12.2.6 Further Direction

Literature review exhibit that the vast majority of the LCA thinks about were directed on the product, organization, and process levels in the entire manufacturing sector. All things considered, there is as yet an urgency to concentrate more on plant and process level evaluations to accomplish the SM destinations. The economic and social signals should be increasingly comprehensive and ought to be approved and regulated for manufacturing sectors.

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Chapter 13
Sustainability Assessment of Organization Performance: A Review and Case Study

Vishal Verma, Jinesh Kumar Jain, and Rajeev Agrawal

Abstract The purpose of this study is improving the organization performance advancement by an efficient literature survey (ELS). The ELS is chosen after fundamentally dissecting the different kinds of writing surveys. The actual articles on sustainability assessment appearance the review—papers based are absence on sustainability assessment how to improve the performance of any organisation. The review based on two sections of sustainability assessment: first, many types of approach and process are used and second, a design for sustainability assessment. There are three pillars of sustainability assessment which is reviewed. The review shows that their search on sustainability assessment is mainly experimental using qualitative knowledge. The paper indicates the scope, approach, and areas of sustainability assessment. The main aim of this review is improving the performance in organization sector: new product development (NPD) consumer needs, financial and human sources, admin. Tool and technique-based assessments have given way to outcome-based assessment using non-financial and qualitative parameters. This paper expects to help to research scholar those who are working in this field.

Keywords Efficient literature survey · Key performance indicators · Environmental protection agency · Triple bottom-line · Approach · Ganzheitlichen Bilanzierung · New product development

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13.1 Introduction

Performance assessment is the method for assessing work and activities inside the framework about its ability, capability, productivity, and adequacy to satisfy certain targets. Various elements, like sustainable manufacturing, green manufacturing, and clean manufacturing, brought about by different specialists amid 1987–1997 [1]. Sustainability manufacturing has been utilized as corporate sustainability, business sustainability, or industrial sustainability. These may contrast in detail yet all concur that sustainability aims at satisfying economic, social, and natural objectives [2]. Manufacturing organization is currently working in not so much secure and more complex environments. This in turn centers their business and manufacturing facilities to cater for a wider range of scope of requests so as to stay focused.

The various assets—cash, power, water, buildings, air, and persons—are able to configure, produce, and convey a product. The fundamental target of a manufacturing organization is to develop and convey product to customer and the aim of improving the organization performance without the development of sustainability [3]. The arrangements aid the choice appropriate signs for the sustainability performance. General process is identified with the organization execution evaluated in terms of profitability, adaptability, responsive, and so on while organization products have a specific performance, processes, and arrangement in terms of sustainability. Sustainability approaches help to frame configuration.

Make and convey the products in a sustainable form. In this way, the three basic components of sustainability assessment are sustainability strategies, product sustainability, and process sustainability; some independent study has been done in the output sustainability [4–6].

The objective of sustainability assessment is improving the organization performance. This study is used for the metrics of the sustainability and enhancement. The organization is unable for that kind of changes, and the sustainability cannot be improved [3].

13.2 Review of Sustainability

13.2.1 Sustainability

The meaning of "sustainability" is the methodology of how natural system function remains disparate and produces everything that it needs for the ecology to remain in equal. It additionally recognizes that human civilization takes assets to continue our cutting edge lifestyle. Tools of sustainability and the pillars of sustainability assessment are used for that kind of parameters. In which the using of, the direction of expenditures the orientation of technological development, improvement and institutional change are all in harmony and enhance both current and future potential to meet human needs and aspirations.

For many in the field, sustainability is defined through the following interconnected domains or pillars: environment, economic and social, in which according to [7] is based on the principles of system thinking. A review of the literature is used to explore the concept "sustainable manufacturing" that applied to processes and operations in manufacturing organizations. The review of the literature enlightens the current scenario, the progress made so far, issues encountered and problems unveiled by the early adoption and implementation, what is resolved, and what still needs to be worked upon [8]. Sustainable development consists of equal local and global efforts to meet basic human needs without destroying or degrading the natural environment [9, 10]. First pillar is future generation, which emphasizes the long-time thinking associated with sustainability [11]. And other that considers sources are use and financial sustainability as two more pillars of sustainability. Therefore, sustainability is made up of three pillars: economy, society, and the environment. These principles are also informally used as profit, people and planet [12].

13.2.2 Sustainability Performance

In these days, the industrial performance metrics move from economic centric performance measure by the sustainability assessments [13–15].

Conceptual framework: Literature review based on this study is found no further improvements in TBL of sustainability performance environment, economic, and social aspect (Fig. 13.1).

The three pillars of sustainability

Economic Development: The 2005 World Summit on social development identified sustainable development goals, such as economic development, social development, and environmental protection [17]. Sustainable development consists of equality local and global efforts to fulfill basic human needs without destroying, harm full, or degrading the natural environment [9]. The question then becomes how to represent the relationship between those needs and the environment.

Social Development: The social development is the promotion of sustainable society; its positive and negative impacts on business or industry; its protection of the health of industry working person from impactful chemical, process, and release of carbon

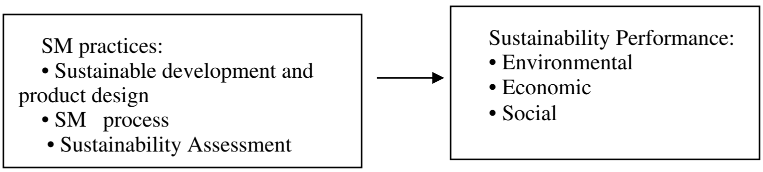

Fig. 13.1 Conceptual framework proposed in this study [16]

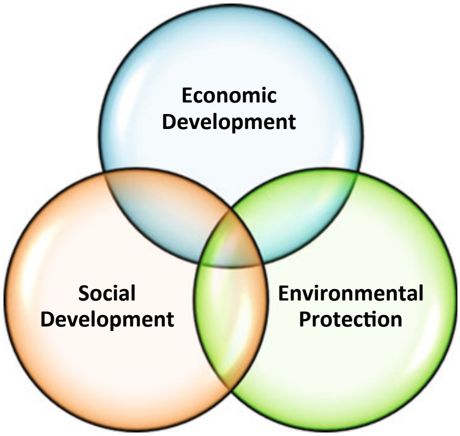

Fig. 13.2 Pillars of sustainability

contents. It is May about maintenance of the improving the organization performance. It means improving the revolutions of the industry like organizational performance encompasses three specific areas of firm outcomes: (a) financial performance (profits, return on assets, return on investment, etc.). The major aspect of the social development in any organization is making the sustainable house and how to design a better manner. The last thing is that qualification is to join the people with environmentally and eco-friendly sustainability and thought him about the impact on human life as well as environment.

Environmental Protection: Nowadays, we know what we need to do to protect the environment, which is reducing and recycling our power consumption by switching electronic devices off and uses standby mode. Business is coordinated to prevent pollution and remains that their own carbon emission is low. Environmental protection is the third pillar and to many, the firstly concern of the further of humanity. In the environmental protection it is described the quality of air, purification and resource of sustainability are used and centered those element who are impact to the environment. It is aimed at maintaining (and recovering when necessary) a healthy natural environment. Sustainable development embraces environmental, social and economic objectives, to deliver long-term equitable growth which benefits current and future generations. The environmental protection agency is to develop the biotechnology for the source of sustainability, protect the environment, and make the green future (Fig. 13.2).

13.3 Methodology

This research is to describe the performance related to the Indian manufacturing industries which developed the sustainability. The some participating manufacturing industries in this research were electrical, automobile and electronics, machinery

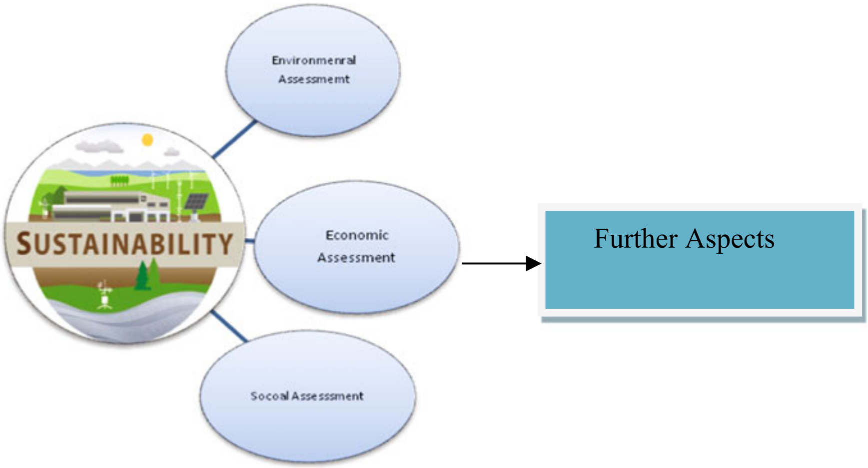

Fig. 13.3 Sustainability assessment

and process industries. The research methodology is based on the literature review through a focus of study which is cross-sectional and described the research problem that was selected based on gap identified in the literatures.

The keywords that are used in the literature review are sustainability, sustainability manufacturing, organizations, manufacturing practices, green production, assessments, and many more. The database is obtained from various types of journal, publications, thesis, and Internet sources (Fig. 13.3).

For the sustainability assessment of organization, performance is taken as an example of small-scale industries like cement, mines and mineral, manufacturing, chemical, steel, chemical, corporate (Table 13.1).

13.4 Case Study

The study was based on the small-skilled corrugated box manufacturing firm. The study was based on the "gate-to-gate"-based study. Increasing trend in Indian paperboard usage and environmental consciousness, many individuals or organizations look closely at environmental characteristics. The main aim of this research is finding the environmental potential analysis throughout the lifecycle assessment of the corrugated box producing, used, disposal in India, and further, we are trying to improve suggestion to reduce the environmental burden by using lifecycle assessment. The production stage of the packaging system is reported to be the principal cause for the major impacts. Increasing recycling rates and reducing weight in the primary package are environmentally more efficient [18, 19].

The cardboard was invented by the Chinese in 1600. The first commercial cardboard invention was created in 1817. American Robert Gair produced the first really

Table 13.1 Literature reviews for sustainability assessment performances an organization based on different types of approaches and methodologies

S. No	Key findings	Techniques	References
1.	A few investigations of process level of manufacturing, thinking about every one of the three parts of sustainability. Placed on triple bottom-line pointers, the sustainability grade determinated and development methodologies were classified	VSM-based study	[22]
2.	The research was based on a car manufacturing work cell. The environment and economic assessments are done in this study. For environment, the GHG emission focused and the study on gate-to-gate process	Sustainability cone	[23]
3.	In this paper, the level of sustainability assessment was done by taking the three pillars of sustainability. This study was easy and showing the quick result. This paper provides the full description in analysis in different phases in overall analysis-based	Index-based technique	[24]
4.	The sustainability performance is done in this paper at the enterprise level by using expert approach. The study was based on three aspects of sustainability; this paper produces only single process unit and not to be compared to each individual process	Fuzzy logic	[25]
5.	In this paper, the organization-level sustainability assessment was studied. The three indicators of SM are used. The all over organization data are used in improving the organization performance	Fuzzy multi-criteria method	[26]
6.	In this paper, the sustainability assessment is having the multiple manufacturing processes; this is considered as the heating instrument by using the three pillars of sustainability manufacturing process. The literature review: it was improving the process levels and environmental potentials	Analytical hierarchy process (AHP)	[27]

(continued)

Table 13.1 (continued)

S. No	Key findings	Techniques	References
7.	This paper is to improve the each and every process machine and its environmental performance. The study was based on machining process point of view. It performs a simple term of sustainability perspectives; it performs impact assessment by using some indicators of SM	Unit process-based	[28]
8.	This study of metal-forming unit process: it is useful in research which compares the manufacturing machinery in the form of sustainability performance including the economic and environmental indicators and the study that done is not performed in the organization performance; it is not saved the cost of the product and energy of the manufacturing process	Compared-based	[29]
9.	It was based on the three pillars of sustainability manufacturing, and the level of organization assessment was done in this category. The firm was overall sustainability index and was estimated in the form of assessment factors	A holistic sustainability index-based measurement	[30]
10.	In this study, the three pillars of sustainability manufacturing. In the overall analysis, the info was provided and collected from the branch. The overall impact performance was viewed in this study	Value evaluation and sustainability assessment	[31]
11.	This study is aimed to reduce and optimize the cost and time to make a sustainable. The three aspects of sustainability under taken and overall sustainability impact are looked in this study	Model based on analytical technique	[32]
12.	This study provides the earliest assessments with very lack of details. This study is also based on the three indicators of sustainability	Rapid assessment and holistic approach	[33]

(continued)

Table 13.1 (continued)

S. No	Key findings	Techniques	References
13.	This study is calculating the sustainability's. The focus of the study was to analysis the sustainability's basis and the details of each unit are compromise. The stuffing unit development was not considered in this study when assessments	Weighted fuzzy approach	[34]

efficient cardboard box in 1879s. Since then, cardboard boxes have been widely appreciated for being strong, light, inexpensive, and recyclable.

Cardboard boxes were popular for their strength, durability, lightness, recyclability, and cost-effectiveness.

Corrugated boxes are **used** for shipping variety of items.

Thousands of small-skilled industries are making this product.

Corrugated boxes are sustainable product, easy to customize, and reusable.

To avoid the plastics and polythene-packaging bags, after the ban on plastic packaging product, the corrugated box is widely used.

Corrugated Box: The corrugated box plays an important role in the packaging industry. The box is made by the paperboard corrugated which is having the contents of the air and row columns. The columns make the flutes stronger than average cardboard with the air acting as a cushion for any items inside of them. The ridges inside offer flexibility and strength, as usually intended in packaging. These boxes are known to be eco-friendly because they are biodegradable and made of recycled boxes and reused.

The main purpose of this project is to find the environmental impacts analysis by throughout the lifecycle assessment of the corrugated box producing, used, disposal in India; in this research the case study is based on the corrugated product it is all about the cardboard products. Further, we are trying for the improvement options for reducing the environmental impacts by using lifecycle assessment (LCA) (Fig. 13.4).

Methodology used for this case study: The lifecycle assessment method is used for this case study work. This methodology is used to classify the environmental impact of the one unit product throughout its lifecycle "gate-to-gate". In LCA approach, the first aim is to find the corrugated box system boundary and the second aim is to classify the data input and outputs of each and all stages of the lifecycle (resources use, energy use, raw material use, waste generation, water and air emission). The goal of this work finds impact on environment. The biggest important data relevant to corrugated box manufacturing was possessed from semi-skilled medium size factory with individual process. The GaBi 8.7 was used for optimization and data process is to calculate and compile all process which used and analyzed the emission to the environmental impact on one piece of corrugated box. gate-to-gate is one value-added

Fig. 13.4 Corrugated boxes

process in the whole manufacturing process; gate-to-gate section may be linked in their appropriate manufacturing to form a entire cradle-to-gate assessment. As a result of these efforts, consensus has been achieved on an overall LCA framework and a well-defined inventory methodology.

The four phases of LCA methodology

Goal and Scope Definition—where the study's primary goals are described in the system's functional units and limits. The functional unit is a representative element of the studying scheme and is the foundation on which to calculate all inputs and outputs. The inputs and outputs to be taken into account rely on the specified limit (Fig. 13.5).

Inventory Analysis or Lifecycle Inventory (LCI)—consists of calculating/collecting all the material/energy flows and procedures required for the functional unit. The materials and procedures to be regarded rely on the objectives and system boundaries identified in the preceding step.

Fig. 13.5 Phases of LCA methodology

Impact Assessment or Lifecycle Impact Assessment (LCIA)—where the effect of the inventory listed in the previous phase is assessed on the environment. Using characterization variables, inventory values are transformed to midpoint level using characterization factors. These midpoint categories can be aggregated into fewer damage categories (endpoint categories) depending on the LCIA technique used. Different LCIA techniques will take into account varying categories of midpoints and endpoints. A normalization factor can then be used to normalize the endpoint categories. The standardized outcomes can be multiplied by a weighting factor (allocated based on their relative significance to each effect category) and the weighted outcomes can be added to calculate a single score.

Results Interpretation—It consists of evaluating and interpreting the outcomes of the three preceding steps in order to recognize the system hotspots being studied and propose feasible changes. Analysis of Pareto can be used to define categories of critical effect. It not includes the transport of resource supplies, supply of beer containers, waste treatment, shipping, and recovery from the market and estimated only CO_2 emission. In the case study and the results of applying the LCA methodology to this research in further steps.

- First of all, it decides the product for doing the lifecycle assessment study and after that go for selecting the company to done the project work.
- After selecting the company, it analyzes all process and makes the flowchart for each and every process.
- Then it collects the data for each and every steps of the process which is done for the production of corrugated box.
- After collecting the data, it calculates the actual data for the development of model on software.
- The LCA model was created using the GaBi 8.7 Educational Version Software System for lifecycle assessment and developed by the PE international. The database that contained in the GaBi Software provides the lifecycle inventory (LCI) data for the raw and process material used in the background system.
- Then the result obtained from GaBi analyzed impact categories, which are harmful for the environment.

Flow Diagrams of Process and Machine

In this study, the sustainability tool "lifecycle assessment" is used. In other words, the paper includes the manufacture of corrugated box transport, processing in covers those steps. In the system boundary the process diagram is to express the adhering is joint process and the pasting of flutes layer by layer of the paper and the cutting operation of jointed fluting then slot cutting is the cut the different dimensions to add in the corrugated box for shaping then in and stitching and panting and clothing operation [20]. The outcome was performed lifecycle assessment by using International Reference Lifecycle Database ILCD recommendation in the GaBi 8.7. This tool consists of eleven impact categories, and these are global warming, acidification human toxicity cancer, human toxicity non-cancer smog formation, ozone layer depletion, etc. This study research is performed the impact assessment of the environment. The ILCD method is generally used and analyzed the impact product manufacturing process [21] (Fig. 13.6).

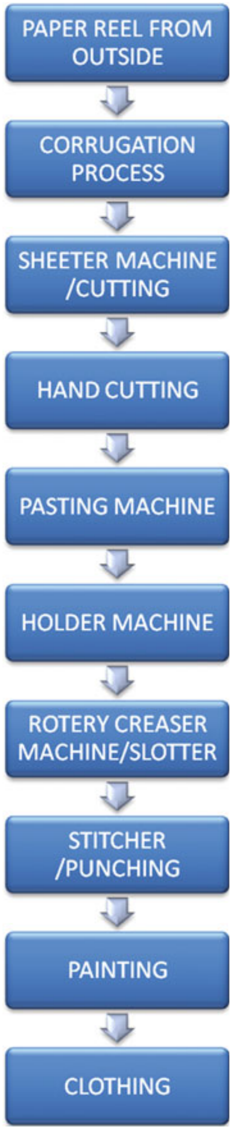

Fig. 13.6 Manufacturing process

13.5 Results

The results obtain from GaBi (Version 8.7) show the environmental impact of each stages of corrugated box. The credit impact was obtained from input and output processes. The impact resources were adhesives, electricity, paper, lubricants, and steel wire in this gate-to-gate analysis.

That is production phase, in this phase, the impacts on environment are very low. The GaBi is having an own database for each and every process. The result from the organization of International Lifecycle database is used to calculate the environmental impact, and the charts of all potentials show the impact of resources and flows are used in the production of the corrugated box (Table 13.2).

In Table 13.2, the four colures are shown the impact amount in the environment. The **red color** is showing the major impact on the process of all eleven environmental potential according to ILCD database. The **green color** is showing the low impact on

Table 13.2 Impact data of corrugated box production case study

Impact Potentials	Total	Electrici-ty	DE steel Wire	Electricity Grid	Lubricants
Gwp	1.87	1.83	0	0.023	0.011
Human Toxic	2.48E-09	2.35E-09	0	2.90E-9	9.20E-9
Acidifi-cation	0.267	0.263	0	0.003	0.001
Ozone Deplation	3.36E-12	3.32E-12	2.00E-12	4.10E-12	1.00E-12
EP Ma-rine	0.028	0.027	0	0	0
Water	1.49	1.52	-0.0045	0.018	-0.008
Terres-trial Ep	0.31	0.3	0	0	0
Ionizing Human Heath	0.21	0.2	0	0	0
Particu-lar Mater	0.0304	0.03	0	0	0
Chemi-cal ozone Formation	0.086	0.085	0	0.01	0
Eco Tox	1.91	1.85	0	0.2	0.03
Human Toxic	1.42E-07	1.39E-07		1.70E-07	0

environmental impacts. Yellow color is showing the medium category impact, and light green is very low amount of impact category.

13.6 Conclusions

This review shows the ELS of reviewed conference and journal articles on sustainability manufacturing to understand the various kinds of approaches and subjects. The ELS combine three phases: economic, environmental, and. In total, 45–50 paper is studying for these findings. Papers were based on the studies on three aspects of sustainability manufacturing. They are as used sustainable assessment, sustainability in manufacturing, sustainability in organization, sustainability in supply chain, sustainability in product development, sustainable in. In the case study, LCA technology in sustainability manufacturing is important to appraise environmental impacts and defense of the production phase. In the study, the lifecycle of corrugated box is having of many processes. The main source of environmental impacts is land filling, and electricity consuming having a more impact of the corrugated box manufacturing. If the intensity of land filling is more than 60%, then it is the most responsible for environmental impacts. It is also responsible for the main source of global warming and acidification and for the development of sustainability assessment in an organization performance to waste-based sustainable manufacturing to be used.

From the case study, some changes can be improved the organization performance in corrugated industry.

If the recycling phase is used for whole product, then it is safe for environment.

Used interchangeable machinery for the production of corrugated box for the development of sustainability to improve the organization performance.

Include use phase and end of life treatment.

Improvement focus on the reduction of electricity use.

13.7 Future Scope

Further, the papers are identified with these three pillars of sustainability to be used for sustainability assessment: based on assessment tool and technique, outcome and waste elimination, mixed assessment. The scholar is improving the sustainability assessments by using tool and technique. Nowadays, the scholar-centered outcome is based on assessment. Similarly, the aim of sustainability assessment is to measure the NPD, human resource, financial, production process, suppliers and develop and improving the organization performance from these parameters. The future of automatic corrugation line is very bright. In upcoming 2020th, the corrugated product is very widely used. The current project was performed on Gate to Gate system boundary, for good performed considering the reusing as the alternative and performing it by Cradle to Grave and the data can help to other scholars who want to do study on this field. This thesis can be used for improving the sustainability in improving the organization performance.

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Chapter 14
Evaluation and Improvisation of Overall Equipment Effectiveness in a Sheet Metal Parts Manufacturing Industry

Abhaya M. Borkar and Atul B. Andhare

Abstract This chapter presents a case study of evaluation and improvisation of Overall Equipment Effectiveness for the machines like CNC Laser Cutting and CNC Panel Bender present in a small-scale industry involved in the fabrication of steel furniture. The calculations and analysis of Overall Equipment Effectiveness for the machines are carried out by measuring the time required for various steps involved during the manufacturing of the parts and also through conversation, interrogation and observations over a period of one week. After the current status of Overall Equipment Effectiveness is known, the lean tools and techniques like Root cause analysis, Six Big Losses, Kaizen and Single Minute Exchange of Die was used. The Kaizen team was formed and was led for four days. Also, the suggestions were implemented with the assistance of the Kaizen team. After the implementation of the tools and techniques again Overall Equipment Effectiveness was calculated and it was found to have improved. Later, the scheduling of the CNC Laser Cutting and CNC Panel Bender was also carried out with the assistance of scheduling software "LEKIN" for further improvement of Overall Equipment Effectiveness.

Keywords Overall equipment effectiveness · Root cause analysis · Six big losses · Kaizen · Single minute exchange of die

14.1 Introduction

In any industrial sector, efficiency and effectiveness should be implemented so as to be increasingly beneficial. Manufacturing industries can possibly remain in a focused market if their manufacture facilities are available and productive. Thus maintenance has become a competitive weapon for any industry to survive in the

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competitive market. In the 1980s, the total productive maintenance (TPM) philosophy, propelled by Nakajima (1988), lead to a metric called Overall Equipment Effectiveness (OEE). Overall equipment effectiveness is a measurement tool used in identifying and measuring the productivity of machines in the industry [1]. The literature reveals that to determine OEE, no standard exists. It is very broad and can be applied to any manufacturing organization. It can be used to measure the efficiency of product lines, a section of the plant and even the entire plant. OEE is essentially the ratio of fully productive time to planned production time. In practice, however, OEE is calculated as the product of its three contributing factors [2]:

$$\text{OEE} = \text{Availability} \times \text{Performance} \times \text{Quality} \tag{14.1}$$

14.2 Brief About the Industry

This case study is carried out in a small-scale industry—Onkar Furnitech established in 1983 at Nagpur, Maharashtra. The company is engaged in manufacturing and supplying a wide range of Hospital Furniture, Panchakarma Equipment, Kitchen and Wardrobe and Bedside Lockers, etc. using optimum quality raw material and latest equipment. Machinery like CNC Laser Cutting, CNC Panel Bender, CNC Press Brake are the preceding machines that are operated by skilled workers whereas Spot welding, MIG welding, Bench Grinding, Hand Grinding, Power Press machine, Pipe Bending Machine and Drilling machine are also used. This case study mainly focuses on the CNC Laser Cutting machine and CNC Panel Bender machine.

14.3 Research Method

The research strategy is a case study which consists of interviews and observations. That is the reason that both qualitative and quantitative methods are used in the project. When interviews are conducted it is said to be a qualitative method whereas when the data is collected and analyzed it is said to be a quantitative method [3]. The author collected the data by time study method with the help of stopwatch and also received the data from the company employees. The motive of the data collection is explained to the workers involved in the information so that suitable and reliable data can be collected.

14.4 Details of Manufacturing Activities

The company is working in a single shift from 8:30 am to 5:00 pm. including a 30-min lunch break. It is a make to order based company that manufactures various customized products. The company works for six days in a week and has off every Wednesday. It has the following important machines.

14.4.1 CNC Laser Cutting Machine

The CNC Laser Cutting Machine work according to the program fed to the machine with two numbers of workers working on it. The setup time, downtime and operation time are determined by the stopwatch method for a week. The average actual speed for cutting one meter of sheet is 0.41 min; but average theoretical cutting speed is 0.30 min for one-meter cutting. There is no defect found during the observation period.

14.4.2 CNC Panel Bender Machine

The CNC Panel Bender Machine is operated by a worker who is responsible for all the operations and maintenance of it. The program is fed by the operator according to the material available for doing the operation. The operations involve loading of sheet, feeding program, unloading the parts and hemming of parts. The cycle time of each part shown on the dedicated computer screen is noted as well as the actual cycle time of each part is calculated by the stopwatch method. No such defects were found during the observation period.

14.5 OEE Computation

To improve anything, we need to know the current status of it. After the data collection, the calculation of availability, performance and quality rate is done. This will help to know where the actual problem is in the CNC machines for further improvements.

14.5.1 CNC Laser Cutting Machine

The Laser Cutting Machine is available for eight and a half hours, i.e., 510 min including a lunch break of thirty minutes. For each day, the time required for maintenance of the machine is almost thirty minutes which includes cleaning of the machine, nozzle checking, cylinder checking, tool checking, etc. The planned downtime includes setup time for the machine, lunch break, maintenance time and off time of the machine. The unplanned downtime is the unproductive time which includes short stoppages like waiting for an order list, taking sheets out on the table, cylinder change time, etc. Table 14.1 illustrates the calculation of the OEE without improvement in the current operating process. Equation (14.1) is used to calculate the OEE of the machine whereas Eqs. (14.4), (14.5) and (14.6) are used to calculate the availability, performance and quality rate. The Performance rate is determined with the theoretical time to the actual time for cutting a one-meter sheet.

$$\text{Planned Time} = \text{Total Available Time} - \text{Planned Downtime} \tag{14.2}$$

$$\text{Operating Time} = \text{Planned Time} - \text{Unplanned Downtime} \tag{14.3}$$

$$\text{Availability} = \frac{\text{Operating Time}}{\text{Planned Time}} \times 100 \tag{14.4}$$

$$\text{Performance} = \frac{\text{Theorotical Time}}{\text{Actual Time}} \times 100 \tag{14.5}$$

$$\text{Quality} = \frac{\text{Total Quantity} - \text{Total Defect}}{\text{Total Quantity}} \times 100 \tag{14.6}$$

14.5.2 CNC Panel Bender Machine

The OEE calculation of CNC Panel Bender is almost the same as that of the CNC Laser Cutting Machine, only the performance rate is calculated with the help of the theoretical cycle time and actual cycle time of each part whereas the planned downtime includes hemming operation also. Equation (14.4) is used to calculate the availability rate in which the operating time that includes unplanned downtime is mainly due to the waiting of parts for processing, operator busy in other work, parts handling, parts checking, etc. (Table 14.2).

Table 14.1 CNC laser cutting machine OEE without improvements

CNC laser cutting before OEE improvement		6–Nov–18	12–Nov–18	16–Nov–18	17–Nov–18	18–Nov–18	19–Nov– 18	3–Dec– 18	Overall values
A	Total available time	510	510	510	510	510	510	510	3570
B	Planned time	284	249	365	345	392	60	300	1995
C	Operating time	224	189	305	255	302	40	195	1510
D	Availability	78.87	75.90	83.56	73.91	77.04	66.67	65.00	75.69
E	Theoretical time for cutting 1 m sheet	0.32	0.42	0.33	0.22	0.29	0.34	1.23	0.45
F	Actual time for cutting 1 m sheet	0.48	0.49	0.43	0.24	0.39	0.48	1.75	0.61
G	Performance	66.67	85.71	76.74	91.67	74.36	70.83	70.29	73.94
H	Total defect	0	0	0	0	0	0	0	0
I	Total quantity	1	14	6	8	23	1	14	67
J	Quality	100	100	100	100	100	100	100	100
K	OEE %	52.58	65.06	64.13	67.75	57.29	47.22	45.69	55.97

Table 14.2 CNC panel bender OEE without improvements

CNC panel bender before OEE		7–Dec–18	8–Dec–18	9–Dec–18	10–Dec–18	14–Dec–18	24–Dec–18	Overall Values
A	Total available time	510	510	510	510	510	510	3060
B	Planned time	410	348	382	304	373	410	2227
C	Operating time	125	193	152	124	58	170	822
D	Availability	30.49	55.46	39.79	40.79	15.55	41.46	36.91
E	Theoretical time	29.13	49	23.5	24.15	9.73	29.52	165.03
F	Actual time	31.65	52.65	25.33	26.15	10.48	32.03	178.29
G	Performance	92.04	93.07	92.78	92.35	92.84	92.16	92.56
H	Total defect	0	0	0	0	0	0	0
I	Total quantity	6	4	4	2	1	5	22
J	Quality	100	100	100	100	100	100	100
K	OEE %	28.06	51.61	36.92	37.67	14.44	38.21	34.17

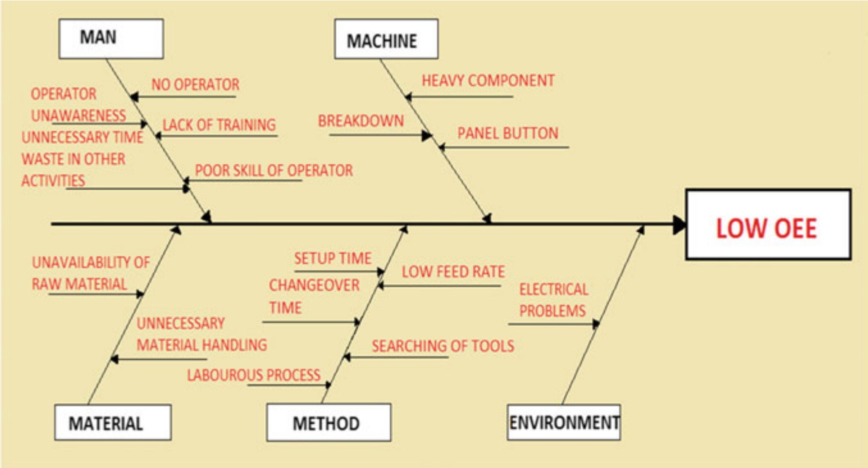


Fig. 14.1 Root cause analysis of CNC laser cutting machine and CNC panel bender machine

14.6 Improvement Techniques

The tools and techniques used for the improvements are discussed below with respect to the CNC machines.

14.6.1 Root Cause Analysis

Root cause analysis is a problem solving techniques that helps to recognize the root cause of faults or problems. There are problems in all aspects of OEE that was calculated for the CNC machines. Hence, the cause and effect diagram helps to find the causes of the low OEE. This analysis is done with the help of brainstorming method and the previous record of the breakdown of the CNC machines as shown in Fig. 14.1.

14.6.2 Six Big Losses

The Primary causes shown in Fig. 14.1 are used to find out the six big losses to find out the critical causes of the CNC machines. Table 14.3 shows the six big losses with respect to the CNC Laser Cutting machine and CNC Panel Bender machine.

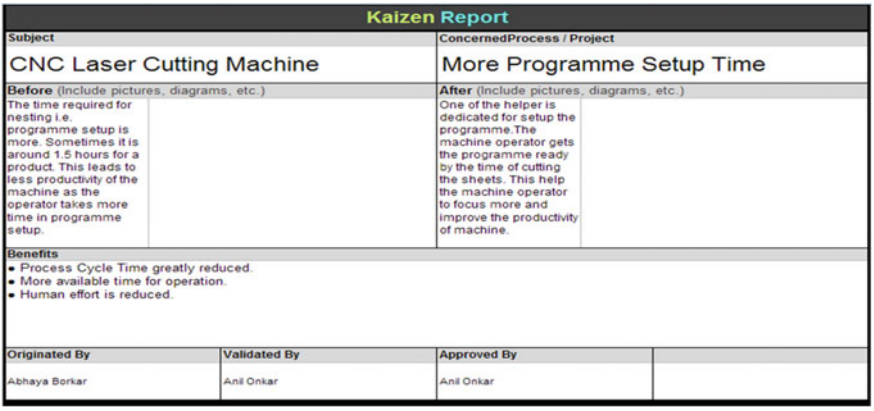
This analysis will further help in distinguishing the Value added, Non-value added and Non-value added but necessary activities for improvements in the process and in the machines.

Table 14.3 Six big losses with respect to CNC machines

Factors	Loss category	Six big losses category	Event problems with respect to CNC machines
Availability	Downtime loss	Breakdown	• Electrical problems
		Setup and adjustment	• No operator • Lack of training • Operator unawareness • Poor skill of operator • Busy operator • Searching of tools
Performance	Speed loss	Small Stops	• Unavailability of raw material • Unnecessary material handling • Heavy component • Machine worn-out
		Reduced speed	• Low feed rate • Dimension check
Quality	Quality loss	Start-up reject	Nil
		Production reject	Nil

14.6.3 Kobetsu Kaizen

"Kaizen"—a Japanese term—means continuous improvement, taken from words "Kai, which means continuous and "zen" which means improvement [4]. It is a lean tool that is used for minimizing waste. The Kaizen Event was conducted with the help of a Kaizen team that includes white-collar employees to blue-collar employees. With the assistance of this Kaizen team, the process of improvement and suggestions were led for four days. The Kaizen report which shows the scenario of before improvement and after improvement are illustrated in Figs. 14.2, 14.3 and 14.4. Figure 14.2 shows



Kaizen Report

Subject	ConcernedProcess / Project
CNC Laser Cutting Machine	More Programme Setup Time
Before (Include pictures, diagrams, etc.)	**After** (Include pictures, diagrams, etc.)
The time required for nesting i.e. programme setup is more. Sometimes it is around 1.5 hours for a product. This leads to less productivity of the machine as the operator takes more time in programme setup.	One of the helper is dedicated for setup the programme.The machine operator gets the programme ready by the time of cutting the sheets. This help the machine operator to focus more and improve the productivity of machine.

Benefits

- Process Cycle Time greatly reduced.
- More available time for operation.
- Human effort is reduced.

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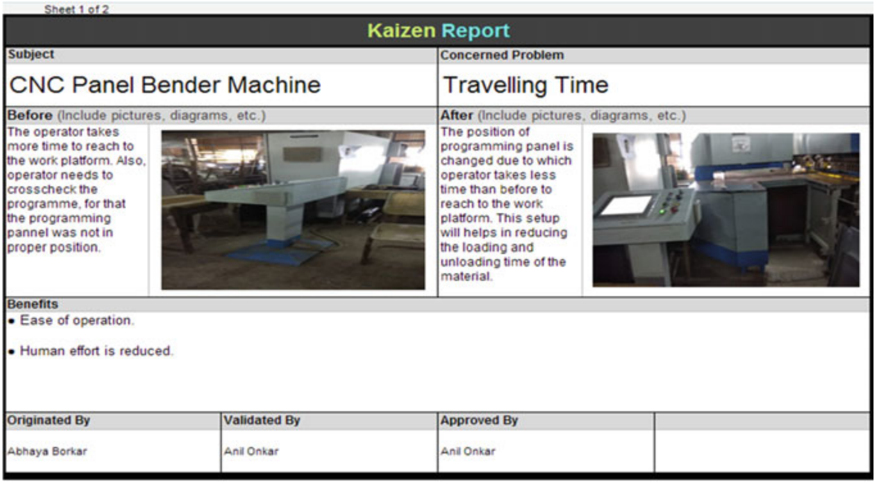
Fig. 14.2 The Kaizen event report of CNC laser cutting machine



Sheet 1 of 2

Kaizen Report

Subject	Concerned Problem
CNC Panel Bender Machine	Travelling Time
Before (Include pictures, diagrams, etc.)	**After** (Include pictures, diagrams, etc.)
The operator takes more time to reach to the work platform. Also, operator needs to crosscheck the programme, for that the programming pannel was not in proper position.	The position of programming panel is changed due to which operator takes less time than before to reach to the work platform. This setup will helps in reducing the loading and unloading time of the material.

Benefits

- Ease of operation.
- Human effort is reduced.

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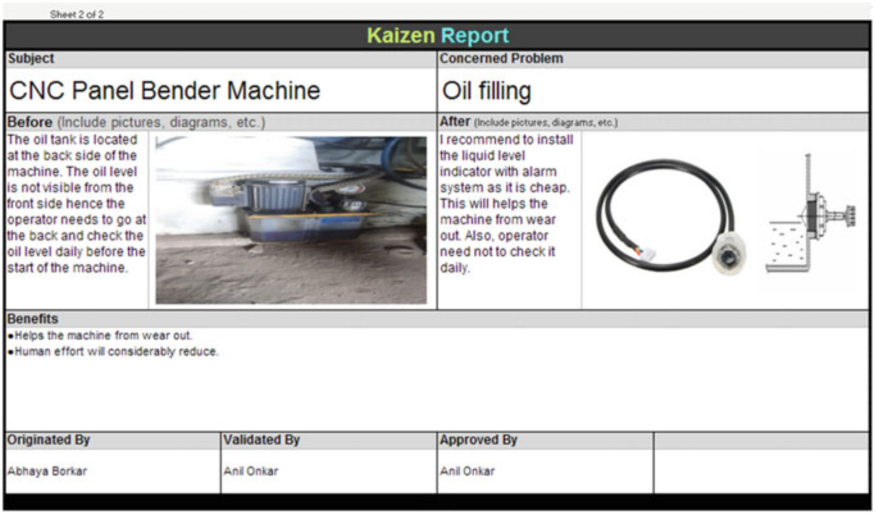
Fig. 14.3 The Kaizen event report 1 of CNC panel bender machine



Sheet 2 of 2

Kaizen Report

Subject	Concerned Problem
CNC Panel Bender Machine	Oil filling
Before (Include pictures, diagrams, etc.)	**After** (Include pictures, diagrams, etc.)
The oil tank is located at the back side of the machine. The oil level is not visible from the front side hence the operator needs to go at the back and check the oil level daily before the start of the machine.	I recommend to install the liquid level indicator with alarm system as it is cheap. This will helps the machine from wear out. Also, operator need not to check it daily.

Benefits

- Helps the machine from wear out.
- Human effort will considerably reduce.

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Abhaya Borkar	Anil Onkar	Anil Onkar	

Fig. 14.4 The Kaizen event report 2 of CNC panel bender machine

the Kaizen report of CNC Laser Cutting Machine whereas Figs. 14.3 and 14.4 show the Kaizen report of CNC Panel Bender Machine.

In CNC Laser Cutting Machine, from the observation and data, the main reason of losses are found to be the setup time and small stoppages whereas, in CNC Panel Bender, there was no such problem with the setup time but the other unplanned time like short stoppages, waiting for material, material handling, etc. was more. For doing hemming of parts, the operator requires more time. To overcome this, a lean tool SMED was implemented with the help of the Kaizen team.

14.6.4 SMED-Single Minute Exchange of Die

SMED is an element of Kaizen and Total Productive Maintenance created by Shigeo Shingo in the 1950s. SMED lessens the setup time by eliminating wastes and unwanted processes and furthermore improves the current setup process and manufacturing flexibility [5]. The following methodology was used to implement SMED as shown in Fig. 14.5. Firstly, the methodology was adopted on the CNC Laser Cutting Machine and then the CNC Panel Bender Machine that results in distinguishing the operation between internal setup and external setup. The internal setups are those which are carried out when the machine has stopped whereas the external setups are those which are carried out when the machine is running. The internal setup activities found in both CNC machines are program setup, loading, and unloading.

In CNC Laser Cutting Machine, the program setup operation was carried out by the same operator responsible for doing the other operations of the machine due to which the planned time and operating time reduces. This internal setup activity is converted to external setup activity by appointing a new skilled operator and a new computer along with software for setting the program in laser machine are used because of which the time required by the machine operator for program setup gets reduced. This helps in increasing the operating and planned time to do more work. Thus, increases the availability rate of CNC Laser Cutting.

In CNC Panel Bender, the main losses found are small stoppages like busy operator, loading and unloading time, blade change time, hemming time for which operator had to go to the power press machine, etc. All these losses are taken into consideration to improve the productivity of the machine. Now, two operators are working on CNC Press Break, each operator gets a specific operation to do. Due to which, the time required for processing the parts is minimized with reduced losses. By doing this, the hemming operation which was internal setup activity is now converted to

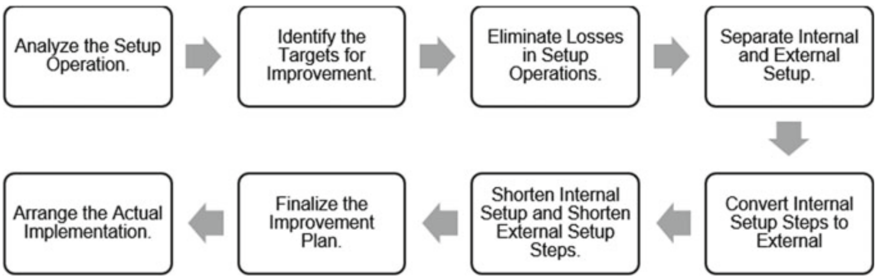

Fig. 14.5 Methodology to implement SMED

Table 14.4 Comparison of machine idle time of sample data

Algorithm used	CNC laser cutting machine in minutes	CNC panel bender in minutes
FCFS	390	510
SPT	380	500
General SB routine	360	480
Local search	230	350

the external setup activity. When the hemming operation is carried out by the other operator on a power press machine, the main operator performs the operation on the other available parts.

14.6.5 Scheduling of CNC Laser Cutting and CNC Panel Bender

For Scheduling, software "LEKIN" is used which is an interactive scheduling system for a machine environment which is a freely available source. This software compares different machine shop scheduling algorithms like Shortest Processing Time (SPT), Longest Processing Time (LPT), First Come First Serve (FCFS), General SB Routine, etc. [6]. In present, the orders are processed in First Come First Serve manner. Using optimized (least make-span time) scheduling, i.e., reducing machine idle time, the further OEE improvement can be done. The author recommended scheduling the data by using LEKIN software. A sample data was taken to analyze the difference in machine idle times for different scheduling algorithms shown in Table 14.4.

The Gantt chart is generated by LEKIN software which shows worst condition as using FCFS rule and best condition as using Local Search Algorithm shown in Figs. 14.6 and 14.7 respectively.

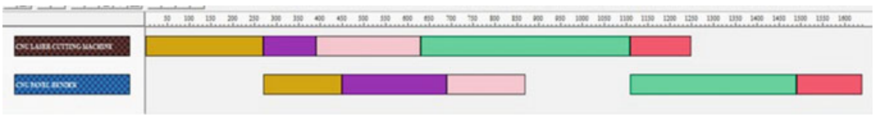

Fig. 14.6 Scheduling using FCFS rule

Fig. 14.7 Scheduling using local search algorithm

14.7 Results and Conclusion

After the implementation of the lean tools and techniques, the calculation of OEE of CNC Laser Cutting and CNC Panel Bender with improvements are done and is illustrated in Tables 14.5 and 14.6 respectively which shows that the availability rate of both the machines has increased that leads to increase in OEE of both the machines.

The recommended value of OEE for a continuous production process is 85%. The main reason for the difference between the recommended value and the actual value of both the machines is the availability factor. With improvements, the availability rate of CNC Laser Cutting Machine has increased from 75.69 to 80.01% whereas the availability rate of CNC Panel Bender has increased from 36.91 to 59.07%. The overall OEE of the CNC Laser Cutting and CNC Panel Bender are increased by 2.65 and 18.85% shown in Table 14.7.

The above results show that although the OEE values of the machines are not as per recommended value but it has been improved from the actual value. The recommended value of OEE is difficult to achieve as it requires continuous production run. Kaizen is a never-ending process. More Kaizen event should be conducted for further improvements.

Table 14.5 CNC laser cutting machine OEE after improvement

CNC laser cutting after OEE		1–Mar–19	3–Mar–19	4–Mar–19	10–Mar–19	11–Mar–19	14–Mar–19	16–Mar–19	Overall
A	Total available time	510	510	510	510	510	510	510	3570
B	Planned time	320	403	50	108	196	292	282	1651
C	Operating time	275	343	30	78	136	237	222	1321
D	Availability	85.94	85.11	60.00	72.22	69.39	81.16	78.72	80.01
E	Theoretical time for cutting 1 m sheet	0.28	0.3	0.32	0.31	0.3	0.31	0.29	0.30
F	Actual time for cutting 1 m sheet	0.4	0.39	0.4	0.43	0.43	0.43	0.4	0.41
G	Performance	70.00	76.92	80.00	72.09	69.77	72.09	72.50	73.26
G	Total defect	0	0	0	0	0	0	0	0
I	Total quantity	6	6	1	1	1	1	1	17
J	Quality	100	100	100	100	100	100	100	100
K	OEE %	60.16	65.47	48.00	52.07	48.41	58.51	57.07	58.62

Table 14.6 CNC panel bender machine OEE with improvement

CNC panel bender after OEE		2–Mar–19	5–Mar–19	7–Mar–19	12–Mar–19	15–Mar–19	22–Mar–19	Overall
A	Total available time	510	510	510	510	510	510	3060
B	Planned time	127	90	115	120	68	103	623
C	Operating time	87	50	55	85	33	58	368
D	Availability	68.50	55.56	47.83	70.83	48.53	56.31	59.07
E	Theoretical time	38.33	28.8	39.05	38.87	14.5	20.88	180.43
F	Actual time	41.62	30.83	48.95	41.85	15.52	22.23	201
G	Performance	92.10	93.42	79.78	92.88	93.43	93.93	89.77
H	Total defect	0	0	0	0	0	0	0
I	Total quantity	4	3	10	4	1	3	25
J	Quality	100	100	100	100	100	100	100
K	OEE %	63.09	51.90	38.15	65.79	45.34	52.89	53.02

Table 14.7 Comparison between recommended value and actual value before and after implementation [7]

OEE factors	Recommended value (%)	Actual value before improvement		Actual value after improvement	
		CNC laser cutting (%)	CNC panel bender (%)	CNC laser cutting (%)	CNC panel bender (%)
Availability	90	75.69	36.91	80.01	59.07
Performance	95	73.94	92.56	73.26	89.77
Quality	99.90	100.00	100.00	100	100
OEE	85	55.97	34.17	58.62	53.02

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Chapter 15
Lean Management in a Medium-Scale Foundry to Improve Productivity

Dhruv P. Parmar and Yogesh M. Puri

Abstract In the present, highly competitive market, foundries need to implement lean principles to cope up with demands and to supply superior-quality casting products. Foundries need to produce quality castings with minimum production cost and lead time. Lean manufacturing is generally inspired by the Toyota Production System which has been expended on the subtraction of seven types of waste and refining the client's delight. This chapter addresses the identification of critical product by Pareto analysis of previous year sales data of the medium-scale foundry. The current state Value Stream Map of Critical Product was drawn to understand material flow and information flow. After that, the Kaizen event was conducted with the assistance of the Kaizen team for five days to identify bottleneck activities and the Kaizen report was generated for the possible elimination of it. The Special Purpose Venting Machine was designed and developed to make venting operations faster and more accurate. The drying mold system is recommended to improve mold drying process regarding the elimination of casting defects like blow holes and substantially less time in drying operation. With the help of future state Value Stream Map, the possible improvements are exposed.

Keywords Lean management · Pareto analysis · Value stream mapping · Kaizen · Foundry · Sand mold venting machine

15.1 Introduction

A foundry is a manufacturing facility that produces metal castings. Metal casting is one among the oldest metal shaping approach acknowledged. Sand Casting interprets as the pouring of molten metal into a sand mold and letting it solidify inside the mold [1]. Molds are generally provided with a cavity of the shape to be made. The pattern is used to build a mold cavity. Geometry and dimension of the pattern are the same as the final part to be cast with some allowances like shrinkage allowance, draft allowance,

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machining allowance [1]. Relying on production volume, different pattern materials especially wooden, aluminum, ferrous metal are utilized in practice. Sand casting contributes approximately 60% of total metal casting worldwide. Lean is outlined as a technique for achieving vital continuous improvement in performance through the elimination of all wastes of resources. Lean manufacturing is a methodology that specializes in minimizing seven types of waste inside the production system at the same time as concurrently maximizing productivity. The seven types of waste are Overproduction, Inventory, Waiting, Motion, Transportation, Rework and Over processing [2]. Lean manufacturing is based on some the unique concepts, together with Kaizen. Kaizen is a Japanese word that means continuous improvement, the word ‘Kai’ means continuous and ‘Zen’ means improvement. Kaizen thinking may be pragmatic to any workplace situation due to its simple nature [3].

The Indian foundry industry manufacturers metal cast components for applications in Auto, Tractor, Railways, Machine tools, Sanitary, Pipe Fittings, Defense, Aerospace, Earth Moving, Textile, Cement, Electrical, Power Machinery, Pumps/Valves, Wind turbine generators, etc. Foundry Industry has a turnover of approx. USD 19 billion with export approx. USD 2.7 billion in FY 2018–2019. There are approx. 5000 units out of which 90% can be classified as MSMEs (source: Foundry Informatics Centre). Hence foundry is the backbone of other industries. The growth of other industries depends on the foundry. The foundries are the mother of other industries and the development of industrialization and industrial success will be measured by the progress of this foundry industry of a nation. India has emanated as the third-largest casting manufacturer in the world followed by China and the United State of America, respectively. India has installed capacity of 15 million tonnes per year but actual annual casting production bent on between 6 and 9.5 million tonnes which mean 9,000,000 tonnes (60%) to 550,000 tonnes (37%) per year lagging behind of total capacity (refer Figs. 15.1 and 15.2) [1]. This statistics illustration itself that improper utilization of available recourses in India. Thousands of MSME foundry units have tackled the threat of a shutdown. When the government of India is concentrating on employment generation with persuasive attention on skill development, the foundry is a sector that faces thousands of skilled workers

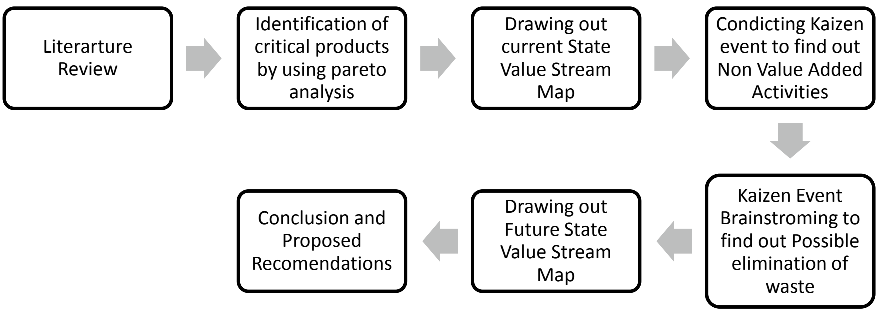


Fig. 15.1 Methodology of project

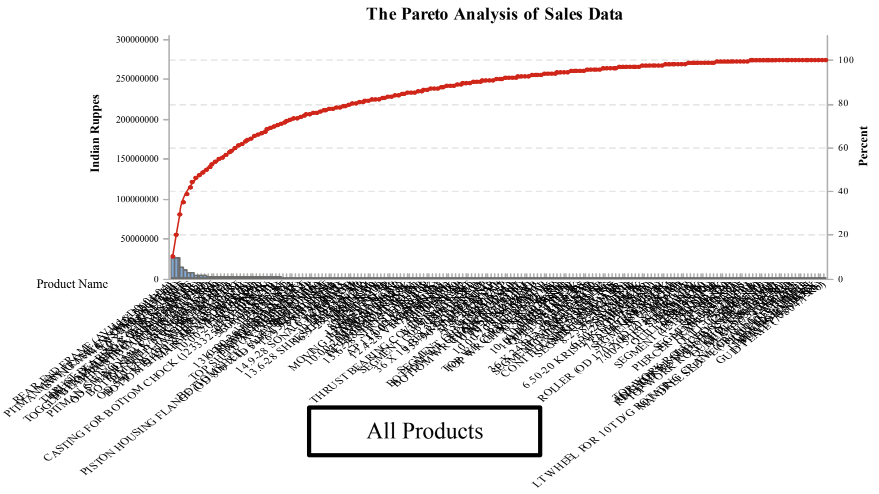


Fig. 15.2 The Pareto analysis of sales data of the financial year 2017–18

leaving this industry to choose alternative means of survival. Also, due to ensure government policy, the next generation of existing foundry unitholders has initiated migrating into high yielding sectors including information technology and others. Thus, a homogeneous approach is needed to long-term development of this foundry sector.

The foundries are underneath lots of pressure because of the increasing sophistication of markets and frequent changes in decisions of customers and international competition. It is evident that there is a priority to the boost performance of the product development process, as the time taken to introduce a new product in the market is critically necessary for competitiveness and long-term survival of the product. So, in this post-capitalist society organizations must perform continuous process improvement in their production processes and be innovative to achieve success. From the past few years, industrial organizations view Continuous Improvement (CI) as a tool to attain a competitive edge through better control of the production process and product quality. The foundries are underneath lots of pressure because of the increasing sophistication of markets and frequent changes in decisions of customers and international competition. It is evident that there is a priority to the boost performance of the product development process, as the time taken to introduce a new product in the market is critically necessary for competitiveness and long-term survival of the product. So, in this post-capitalist society organizations must perform continuous process improvement in their production processes and be innovative to achieve success. From the past few years, industrial organizations view Continuous Improvement (CI) as a tool to attain a competitive edge through better control of the production process and product quality.

Lean Manufacturing (LM) is seen as a major advance method and is widely employed by major industries all over the globe. The goal of LM is to retrenchment the production cost and lowering Cycle Time (CT) by eradicating the Non-value-added Activities (NVA). The concept of LM is to make a production system pull production system. In the pull production system flow of material is driven by downstream as opposed to traditional batch-based production in which production is pushed from upstream to downstream based on a production schedule. The LM suggests that the finished product is the sum of all value-added-activities in the company. But in reality, there are three types of activities arise in the company.

These three types of activities are the following:

1. Value-added Activities (VA) (for these activities customer pays).
2. Necessary Non-value-added Activities (NVA) which support the value-adding activities.
3. Unnecessary Non-value-added Activities (NVA).

15.2 Methodology

A case study is conducted at Shree Steel Casting Pvt. Ltd. Higna, Nagpur, Maharashtra which is a medium-scale foundry. The methodology used is shown in Fig. 15.1.

15.3 Identification of Critical Products Using the Pareto Analysis

The Pareto principles state that in any situation, 20% of inputs or activities, are responsible for 80% of outputs or results. The principal named after an Italian economist, Vilfredo Pareto and it's also known as 80/20 rule. But the inverse is also true, which means the other 80% of inputs are only generating 20% of results.

It is better to concentrate on products that earn a major percent share of the total revenue of the Shree Steel Castings Pvt. Ltd. These products can be discovered from Pareto analysis as shown in Fig. 15.2. The Pareto analysis identifies that 20% of the input creates 80% of the result. The author has congregated the data by himself and received from the employees of Shree Steel Castings Pvt. Ltd. in terms of two genera, qualitative and quantitative [4].

The qualitative method is used when interviews are conducted and the quantitative method is used when the data is collected and analyzed. In the financial year, 2017–2018 the Shree Steel Castings Pvt. Ltd. has sold 201 different castings with different quantities and earned revenue of ₹273,875,140/-, in which 40 castings has earned revenue of ₹202,288,790/- that is 74% of total revenue. Pareto analysis has been done on sales data of the financial year 2017–2018 and found that 20% of product generated 74% share of total revenue.

15.4 Current State Value Stream Mapping

A value stream is a set of all actions (value-added as well Non-value-added) which might be required to convey a product (or a group of products that use the same resources) through the main flows, beginning with raw material and ending the customer [5]. The Value-added ratio (VAR) defines as value-added activity time to the lead time. The Value Stream Map of ‘Rear-end frame’ shown in Fig. 15.3 is drawn because it is a critical product that shares 10% revenue of total revenue. It is found that lead time (LT) and Value-added ratio (VAR) for ‘Rear-end frame’ is 15,589 min and 24.50%, respectively.

15.4.1 Takt Time

Takt time is the maximum amount of time wherein a product needs to be produced so that it will fulfill customer demand. Mathematically takt time is the ratio of available time for production to the production demand [6]. The takt time calculation of ‘Rear-end frame’ is the following:

- Available production time $= 7.5\,\text{h/shift} \times 2\,\text{shift/day} \times 26\,\text{days/month}$
  $\times\, 12\,\text{months/year}$
  $= 280{,}800\,\text{min}$

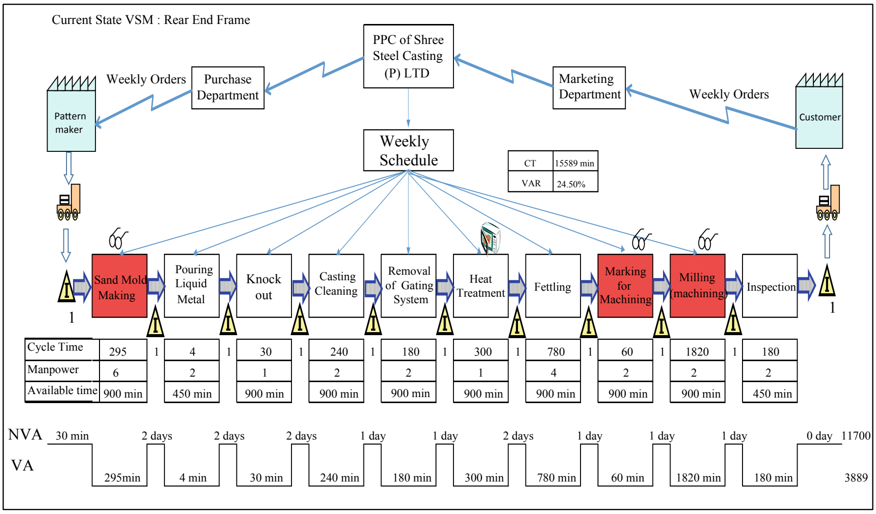


Fig. 15.3 Current state VSM of rear-end frame

- Customer demand in the past 10 years is shown in Table 15.1

$$\text{Takt time} = \frac{280{,}800\ (\text{min available time per year})}{33.3\ (\text{average demand per year})}$$
$$= 8432.43\ \text{min/Rear-end frame.}$$

If lead time and takt time of the product are equal that means on-time delivery of the product to the customer. In this case, a lead time is approximately 15,589 min and takt time is around 8432 min that means takt time very less than lead time. The Shree Steel Castings Pvt. Ltd. recently facing a problem of delivery date mismatching which leads to penalties and customer dissatisfaction.

15.4.2 Kaizen Event

Kaizen, or continuous incremental improvement, refers to a philosophy that is a manner of thinking and behaving. It is about empowering and unleashing the innovative power of individuals who actually do the work, with a purpose to design greater effective and efficient processes [7]. The Kaizen event was conducted at the Shree Steel Castings Pvt. Ltd. for 5 days and Kaizen charter is prepared which is shown in Fig. 15.4. The targeted department was pattern inventory, sand molding and machining shop. In this Kaizen event, four waste (Muda) is identified which is inventory of casting pattern, under processing of vent hole-making operation at molding section, under processing of mold drying process at molding section and waiting at the machine shop. The Kaizen event charter contains every detail of the Kaizen event and some of the details are the following:

- The scope of the Kaizen event is to find out bottleneck activities or activities that are not adding any value to the material.
- In the Kaizen event charter, the areas or particular station is mentioned which contains waste (Muda). In this Kaizen charter targeted areas are pattern inventory, molding shop, marking for machining and machining shop.
- The team member and their belonging department are also mentioned in the Kaizen event charter.
- The metrics are selected to optimize them, in this Kaizen charter mold cycle time, pattern withdrawal time from pattern inventory and machining time is selected to optimize.
- In the end, short term and long-term objectives are mentioned.

Table 15.1 Customer demand in the past 10 years

Year	2008–2009	2009–2010	2010–2011	2011–2012	2012–2013	2013–2014	2014–2015	2015–2016	2016–2017	2017–2018	Average demand
Demand	9	15	18	20	30	25	45	40	58	73	33.3

SHREE STEEL CASTING PVT LTD						Date: 23/02/2019
Kaizen Event Charter						
Event No.	1	Event Date	21-02-2019		Scheduled Hours or Days	5 Days
Scope	To find out bottleneck activities using Value Stream Mapping and reduce CT of these activities by applying KAIZEN methodology				Event Priority	H M Y L
					Area	
Facilitator	Mr.Mahesh Khanderkar	Assistant	Mr.Kalpesh Tiwari		Pattern Inventory, Molding shop, Marking for Machining and Machine Shop	

Team Members	Department	Role	Team Members	Department	Role
Arun Sharma	Molding	Supervisor	Dhananjay	Machine Shop	Supervisor
Rajan	Molding	Molder	Sunil Shrivastav	Machine Shop	Operator
Rohit	Closing	Molder			
Akhilesh	Closing	Helper			

Current State Description

Cycle Time of Rear Frame End is around 22,639 minutes (15.72 days). As per initial study there are four processes found bottleneck based on its working conditions and amount of labour.The processes are Withdrawal of Pattern from Pattern Inventory, Molding making, Mold Closing, Machine shop Scheduling. By initial study the cycle time of this bottleneck processes are found and that are listed as :

Metrics

Metric	Value
Molding Productivity	3 molds/Day
Molding Cycle time	295 minutes
Pattern Withdrawal time	30 min
Machining time	1820 min
Total C.T.	22,639 min

Short-Term Objectives	Long-Term Objectives
• Foundry productivity to be increased by some percentage. • Lead time reduction by some percentage. • Making all Bottleneck processes correct. • Labour productivity to be increased.	• Increse employee involvement in process decisions • Improve the Overall Quality of castings • To satisfy customers by providing on-time delivery

Fig. 15.4 Kaizen event charter

15.4.3 Kaizen Event Brainstorming Sheet

The brainstorming sessions have been done with top to bottom level employees and finally brainstorming sheet is prepared which describes corrective action, the feasibility of an idea, complexity to make it possible and possible potential returns illustrated in Table 15.2.

The brainstorming sessions can give birth to new ideas to improve current foundry practices. The brainstorming session has done with the Kaizen team at Shree Steel Casting Pvt. Ltd. As the Kaizen team having members from each department, all kinds of ideas for improvement can be possible.

The best ideas are noted in a sheet that includes the feasibility of the idea, complexity of the idea and potential return out of the idea. Based on the scale of 1–3 these parameters are evaluated. The best possible solutions are mentioned in this table.

15.5 Kaizen Reports

A Kaizen report is a document that illustrates a summary of continuous improvement activities. It is used to share improvements and best practices across an organization, division or group. The Kaizen event report documents that characterize the results after the completion of the Kaizen event. A Kaizen Report is a form that leaflets and

Table 15.2 Brainstorming sheet for Kaizen event

SHREE STEEL CASTING PVT LTD 28/02/2019					
KAIZEN EVENT BRAINSTORMING SHEET					
Sr. No.	Corrective action description	Feasibility (Y/N)	Complexity	Potential Return	Comments
1	Properly sorting out of Pattern Inventory	Y	1	2	Pattern withdrawal time will be less and less chance of deterioration of pattern which leads to the more useful life of pattern
2	Designing Special Purpose Venting Machine	Y	2	3	Initial cost is moderate but the operation of making venting holes makes easier, fast and accurate
3	Use of mold drying system	Y	2	3	Initial cost is moderate but using mold drying system reduces heating time as well as uniform heating across the mold
4	Use of Compressed Air Coating Gun then Brush in Coating	Y	1	2	Coating Time will be saved
5	Application of Big surface plate for dimestion marking	Y	1	2	By using big surface plate, two rear end frame can marked
6	Use of LEKIN Scheduling software for Machine shop	Y	1	2	Using Scheduling software leads to saving in WIP invetory
1 = Low ; 2 = Medium ; 3 = High					

recapitulates continuous improvement activities. It is used to share improvements and best practices across the foundry. There are many ways to share Kaizen reports including public display boards, dedicated Kaizen bulletin boards, emails and the intranet. In all cases, Kaizen activities should be written clear and simple so that every team member can easily understand them. Additionally, Kaizen reports with photos and drawings tend to capture more attention.

15.5.1 5S in Pattern Inventory

In Shree Steel Castings Pvt. Ltd., the withdrawal time of casting patterns is significantly high and fluctuating. As shown in figure casting patterns are set haphazardly in pattern inventory. Implementing 5S will solve this problem and preserves the casting pattern. The guideline for 5S implementation is shown in Fig. 15.5. Guidelines for 5S in a pattern inventory is shown in Table 15.3. In the Kaizen event, it is observed that patterns are set haphazardly and unorganized in the inventory which is shown in Fig. 15.6.

The withdrawal time of pattern for making a mold is uncertain and considerably large because of this messy inventory of patterns.

The Kaizen report 1 is shown in Fig. 15.5 which illustrates the before vs after situation and advantages. The benefits of 5S in pattern inventory is the following:

Sheet 1 of 6

Kaizen Report

Subject	Concerned Process / Project
5S	Pattern Inventory

Before (Include pictures, diagrams, etc.)

Average withdrawal time of pattern for casting is 30 min (approx), because inventory in a haphazard fashion

After (Include pictures, diagrams, etc.)

Implementing 5S in Pattern Inventory lead to less withdrawal time as well as less tendency to damage the pattern

5S: Sort (Seiri)
Set In Order (Seiton)
Shine (Seiso)
Standardize (Seiketsu)
Sustain/Self-discipline (Shitsuke)

Benefits

- Pattern withdrawal time can be reduced upto 66.66%
- Pattern damage chances will be less
- Well organized inventory

Originated By	Validated By	Approved By	
Mr. Dhruv Parmar	Mr. Mahesh Khanderkar	Not yet	

Fig. 15.5 Kaizen sheet 1

Table 15.3 5S guidelines for pattern inventory

Sort (Seiri)	Worn-out patterns and sodium tank should be removed from pattern inventory
Set in order (Seiton)	Patterns should be kept based on annual usage (i.e. FSN analysis) fast-moving patterns should be placed in close proximity, in an easy to reach the spot and in a logical order which is heavy patterns should be kept at bottom and the light one is at top
Shine (Seiso)	When a pattern is in contact of moisture it will expand as most of the patterns made of wood, so dimensions will be deteriorated hence dust-free as well as moisture-free environment is a must
Standardize (Seiketsu)	Launch procedures and schedules to guarantee the recurrence of the first three 'S' practices
Sustain (Shitsuke)	Ensure that the 5S approach is followed by organizing training sessions

- The withdrawal time of the pattern will be less as the location of each pattern is documented.
- The material of the pattern is wood and characteristics of wood are to absorb moisture which leads to change in geometry and dimension. Careful preservation and protection can abolish this scenario.

Fig. 15.6 Pattern inventory at SSCPL

- A well-organized pattern inventory tends to declines the damage of wooden patterns, hence improvement in useful life and lessens pattern repair cost.
- A clean and pleasant work environment enhances the morale of workers towards their job.

15.5.2 Special Purpose Venting Machine

The vent holes are made to escape hot gasses when molten metal is poured in a mold cavity. Making venting is tedious, repetitive and laborious work. As shown in figure Special Venting Machine is designed in SolidWorks2013 which can reduce the time of venting operation and centre distance vent hole will be accurate (refer Fig. 15.7).

The venting operation in mold making is time-consuming and laborious. Also, vent holes of cope and drag mismatch their alignment because it made randomly by workers. An unaligned vent hole does not permit to pass hot gasses easily when pouring molten metal into the mold. These unescaped gasses stay in the mold and generate blow holes in casting part. Hence there is a need to design a machine that reduces the cycle time of operation and reduces human intervention. The special purpose venting machine is designed after rigorous brainstorming with the Kaizen team to semi-automate the venting operation.

The special purpose machine can reduce the cycle time of operation and align the vent holes of cope and drag which facilities the hot gases to pass. Here the word 'special' is used because this machine is not universal for every mold box (flask), but it covering the domain of 2500 mm × 1800 mm size of the mold box.

In Fig. 15.8 the CAD model of the special purpose venting machine is shown with each component of the machine. This machine contains the structure frame made by 2″ × 2″ of angle which having sliding rod. The array of venting rods is

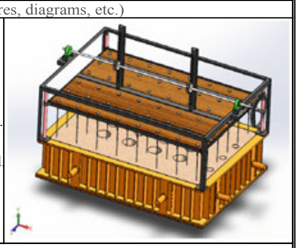
Sheet 2 of 6			
Kaizen Report			
Subject		**ConcernedProcess / Project**	
Special Purpose Venting Machine		Mold Making	
Before (Include pictures, diagrams, etc.)		**After** (Include pictures, diagrams, etc.)	
For CO_2 gas filling the operator needs to dig venting holes in both top and bottom mold box and then have to fill the gas in each hole that takes around 30 mins.		We made design of Special Venting Machine. By using this machine approx. 70% process step time will be reduced	
Benefits			
• Process Cycle Time greatly reduced. • It is versatile machine can be used on many castings which is casted in 2500mm x 1800mm mold flask • Center distance between two vent hole will be accurate. • Vent holes of cope and drag align with each other which facilates hot gases to eascape easily. • Human effort is reduced up to huge extent			
Originated By	**Validated By**	**Approved By**	
Mr. Dhruv Parmar	Mr. Mahesh Khanderkar	Mr. Mahesh Khanderkar	

Fig. 15.7 Kaizen sheet 2

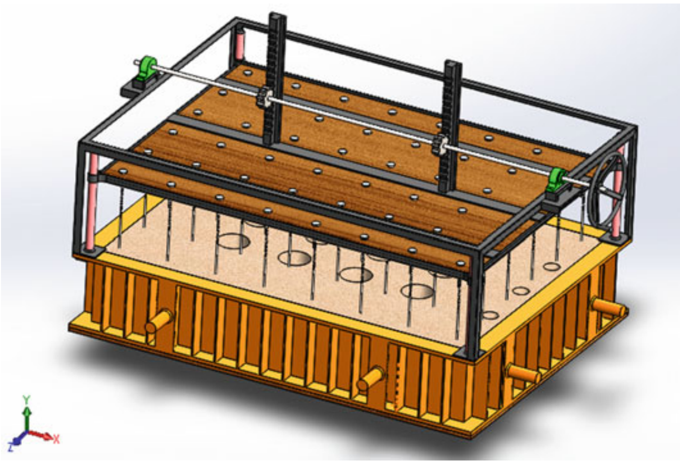


Fig. 15.8 The CAD model of the special purpose venting machine

assembled with a piece of wood which reciprocates in sliding rod. The manual handle is provided having rack and pinion arrangement with a wooden piece of an array of venting rods. In Fig. 15.10 the exploded view of the special purpose venting machine is shown.

The alignment of the vent hole of cope and drag can be achieved by the special purpose machine is shown in Fig. 15.9.

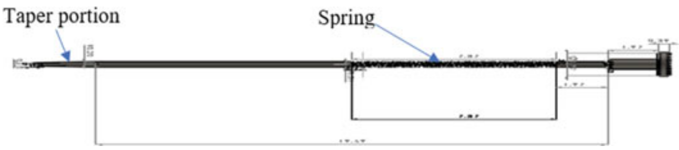


Fig. 15.9 The CAD model of venting rod

The optimum distance between two vent holes is one foot, total 48 vent hole is required for the mold of the rear-end frame. The spring is provided with venting rod to deflect vent rod when it touches the pattern inside the sand mold, the CAD model of venting rod is shown in Fig. 15.10.

The alignment of the vent hole of cope and drag can be achieved by the special purpose machine is shown in Fig. 15.11. The optimum distance between two vent holes is one foot, total 48 vent hole is required for the mold of the rear-end frame. The spring is provided with venting rod to deflect vent rod when it touches the pattern inside the sand mold.

The first step is to place the machine on the mold box with the help of Electric Overhead Traveling (EOT) crane and then handwheel is rotated by the worker. The torque applied on handwheel by the worker is transfer via a shaft to pinion and pinion to rack. The rotary motion of pinion is converted in a reciprocal motion of rack. This rack is fabricated with trolley or assembly structure which contains an array of venting rods. The required force to make vent hole is calculated using thumb rule.

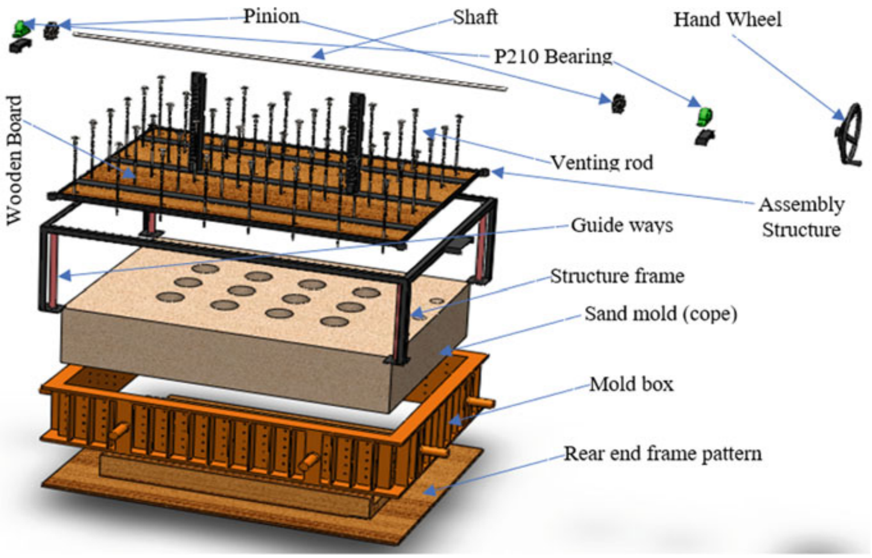


Fig. 15.10 The exploded view of the special purpose machine

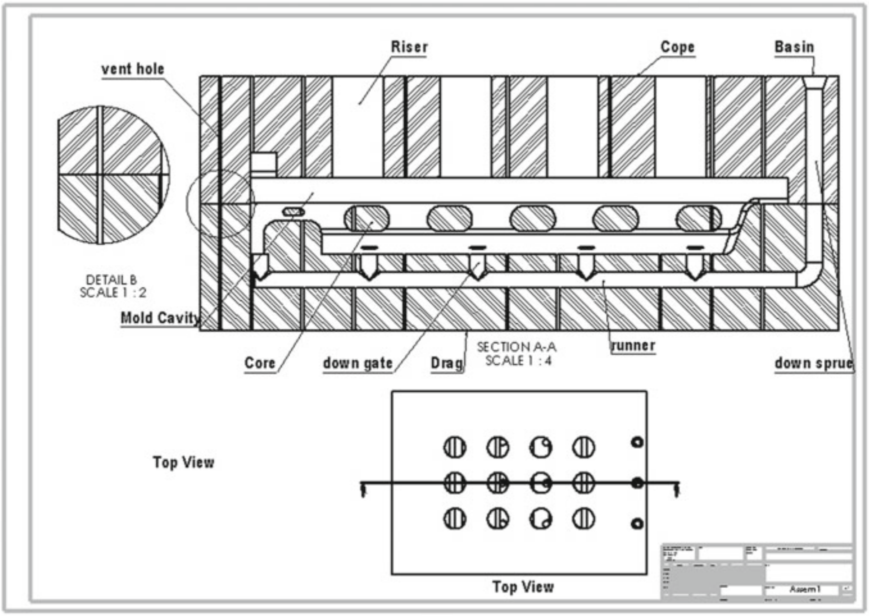


Fig. 15.11 A vent hole alignment of cope and drag

The weight of the wooden board, venting rod and structure exerts the force downwards so this force is also calculated and considered here. The force calculation is given below:

- Weight of Wooden Board = Required Volume × Density of Teak Wood

$$= 0.12\,\text{m}^3 \times 630\,\text{kg/m}^3$$
$$= 72.33\,\text{kg}$$

- Weight of Assembly Structure = Require Volume × Density of Cast iron Angle

$$= 0.02\,\text{m}^3 \times 7200\,\text{kg/m}^3$$
$$= 135.05\,\text{kg}$$

- Weight of one venting rod = Require Volume × Density of Steel

$$= 0.000066\,\text{m}^3 \times 7870\,\text{kg/m}^3$$
$$= 0.52\,\text{kg}$$

  – Weight for 48 venting rod = 0.52 kg × 48 venting rods

$$= 24.96\,\text{kg}$$

- Total Weight = Weight of Wooden Board + Weight of Assembly Structure + Weight of 48 venting rod

$$= 72.33 + 135.05 + 24.96$$
$$= 233.89\,\text{kg}$$

- The Gravitational Force = Total Weight × Gravitation Acceleration

$$= 233.89\,\text{kg} \times 9.81\,\text{m/s}^2$$
$$= 2294.47\,\text{kg m/s}^2$$
$$= 2.30\,\text{kN}$$

- Total Force = Number of venting rods × Cross-section area of venting rod (mm^2) × Resisting stress of Sodium Silicate (N/mm^2)

$$= 48 \times \frac{\pi}{4}(5)^2 \times 10.20$$
$$= 9608.4\,\text{N}$$
$$= 9.6\,\text{kN}$$

- Required Force = Total Force − The Gravitational Force

$$= 9.6\,\text{kN} - 2.3\,\text{kN}$$
$$= 7.3\,\text{kN}.$$

15.5.3 *Mold Drying System*

The mold drying system can uniformly remove moisture from the sand mold. Moisture-free sand mold can produce defect-free casting parts [8] (refer to Fig. 15.12). The moisture-free mold can produce defect-free castings. The biggest opponent of casting is moisture content in a sand mold. Especially in monsoon and winter season, the moisture content is very high in the atmosphere. In current practice, foundries are using a gas flame torch to heat up the mold to remove the moisture. But in this method moisture remains in the boundary portion of the mold and non-uniform heating of sand mold which leads to defect like blowholes. The mold drying system is designed to eliminate this problem completely. The Kaizen report 3 is shown in Fig. 15.13 which explains the benefits of the mold drying system.

The following are components of the drying mold system:

- Blower
- Heater

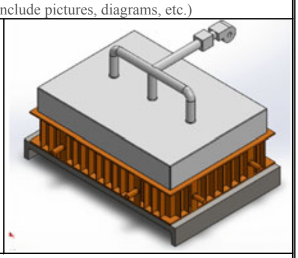
Sheet 3 of 6			
Kaizen Report			
Subject		**Concerned Process / Project**	
Mold drying system		Mold Closing	
Before (Include pictures, diagrams, etc.)		**After** (Include pictures, diagrams, etc.)	
After Coating has applied on both the mold(Cope and Drag), for mold heating molder uses gas flame torch and heats both halves of mold by flame torch which took around 20 min		Mold drying system is available in US patent. Using this sytem moisture can be removed effectively and efficiently	
Benefits			
●Process Cycle Time greatly reduced. ●It is versatile machine can work on all the standard mold box. ●Human effort will considerably reduce. ●Quality of casting will also improve due to uniformly heating across the mold			
Originated By	**Validated By**	**Approved By**	
Mr. Dhruv Parmar	Mr. Mahesh Khanderkar	Not yet	

Fig. 15.12 Kaizen sheet 3

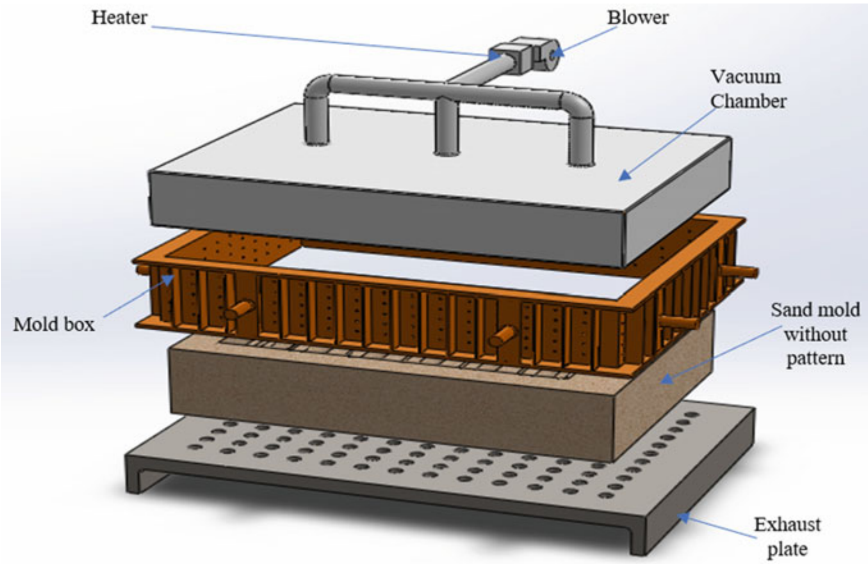


Fig. 15.13 The exploded view of the mold drying system

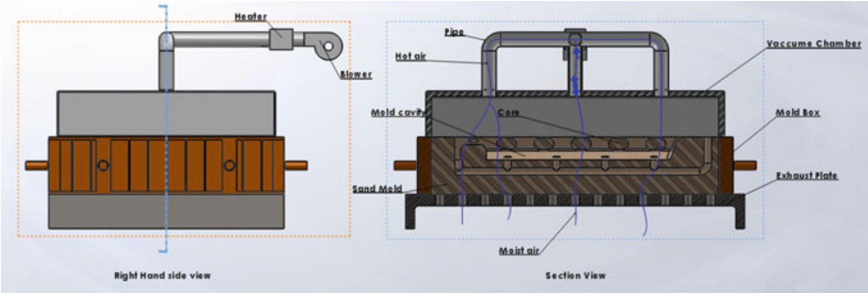


Fig. 15.14 The working of the mold drying system

- Vacuum Chamber
- Exhaust Plate

In Fig. 15.13 the components of the mold drying system are clearly shown.

The heated air is passed through the entire mold to uniform eradication of moisture. The heater raises the temperature of air blown by a blower which enters to vacuum chamber fitted on the top portion of the sand mold via a pipe. This hot air passes uniformly through entire sand mold and exits from exhaust plate. At the exhaust plate, hot air will be moist air as it absorbs the moist from the sand mold. The working of this system is shown in Fig. 15.14.

15.5.4 *Spray Gun*

The coating is done on the mold cavity surface to get a good surface finish of the casted part. Unevenly coated surface will produce a poor surface finish. This problem can be eliminated by using a compressed air spray gun. The benefits of using spray gin are displayed in the Kaizen report 4 (refer Fig. 15.15).

15.5.5 *LEKIN Scheduling Software*

LEKIN is interactive scheduling system for machine environments which is a freely available source. The LEKIN system is capable of scheduling various machine environments: (1) Single machine (2) Parallel machine (3) Flow shop (4) Flexible flow shop (5) Job shop. In this case, study Single machine scheduling is done. This software can compare different machine shop scheduling algorithms like SPT (shortest processing time), LPT (longest processing time), FCFS (First come first serve), General SB Routine, etc. [9] (refer Fig. 15.16).

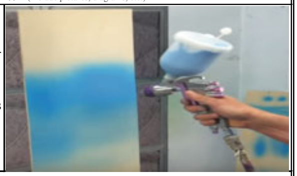
Sheet 4 of 6			
Kaizen Report			
Subject		**ConcernedProcess / Project**	
Coating of Mold & Cores		Mold Closing	
Before (Include pictures, diagrams, etc.)		**After** (Include pictures, diagrams, etc.)	
Mold and core coating is done using hand brush and that requires approx. 20 minutes. It is labourious task and big size molds can not be evenly coat.		Using compressed air spray coating gun, molder can coat the entire mold and core within 10 minutes minutes and thus 50% time can be reduced.	
Benefits			
●Process Cycle Time will be half reduced. ●Evenly Coat will be applied on entire mold and core.			
Originated By	**Validated By**	**Approved By**	
Mr. Dhruv Parmar	Mr. Mahesh Khanderkar	Mr. Mahesh Khanderkar	

Fig. 15.15 Kaizen sheet 4

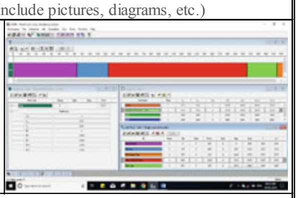
Sheet 6 of 6			
Kaizen Report			
Subject		**ConcernedProcess / Project**	
LEKIN Scheduling software		Machining	
Before (Include pictures, diagrams, etc.)		**After** (Include pictures, diagrams, etc.)	
Waiting time of casting is to machines is significanlty high		Using LEKIN Scheduling software company can generate schedule plan which can reduce waiting time of castings to be machined	
Benefits			
● The waiting time of rear end frame is reduced by 110 min ● Maximum Ultilization of resources.		●Reduces Work in process inventory	
Originated By	**Validated By**	**Approved By**	
Mr. Dhruv Parmar	Mr. Mahesh Khanderkar	Mr. Mahesh Khanderkar	

Fig. 15.16 Kaizen sheet 5

15.5.6 The Big Surface Plate

The marking is done to identify unwanted material in casted parts. For rear-end frame 2 × 1 m surface plate is used for marking and requires time to mark is 60 min. If 3 × 2 m surface plate is used then two rear-end frames can be marked and cycle time will be reduced by 50%. Further details are mentioned in Fig. 15.17 Kaizen report 6.

Sheet 5 of 6

Kaizen Report	
Subject	**ConcernedProcess / Project**
Big Surface Plate	Dimension Marking
Before (Include pictures, diagrams, etc.)	**After** (Include pictures, diagrams, etc.)
For marking the dimentions of rear end frame, 2x1 meter surface plate is used. Only one part is marked at a time and that is why it takes 1 hour for each part 	Using bigger surface plate in size 3X2 meter will take less time as at a time 2 parts can simultaneously marked, so it will consume around 50% less dimension marking time. 

Benefits

- Dimension marking Time will 50% reduced.
- Big Surface plate will be used for inspection of every size casting components.
- Dimensions will be more accurately measured because of no size constraints

Originated By	Validated By	Approved By	
Mr. Dhruv Parmar	Mr. Mahesh Khanderkar	Mr. Mahesh Khanderkar	

Fig. 15.17 Kaizen sheet 5

15.6 Future State Value Stream Map

The future state VSM displays the improvements by Kaizen blitz. In the molding shop three improvements are done which are venting operation, mold drying operation and mold coating. Here, the value-adding activities are optimized. In a machine shop, one improvement is done, the waste as await is reduced. The summary of improvements is shown in Table 4.5. The future state VSM is shown in Fig. 15.18

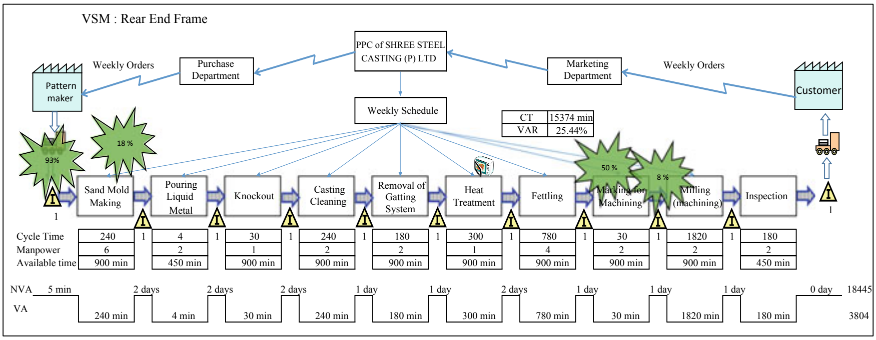


Fig. 15.18 Future state VSM of rear-end frame

Table 15.4 Current state versus future state

Improvements	Current state VA (min)	Future state VA (min)	Improved productivity	Remarks
5S in pattern inventory	30	5	83.33% reduction in withdrawal time of pattern	Reduction in necessary Non-value-added activity which is transportation waste (Muda)
Venting operation	30	10	66.66% cycle time reduction in venting operation	Optimization in a value-added activity
Mold drying	20	5	75% cycle time reduction in mold drying	Optimization in a value-added activity
Mold coating	25	10	60% cycle time reduction in mold cavity coating	Optimization in a value-added activity
Marking for machining	60	30	50% cycle time reduction in marking operation	Optimization in a value-added activity
LEKIN interface in scheduling	120	110	8 % reduction in WIP	Reduction in Non-value-added activity which is waiting waste (Muda)

15.7 Conclusion

This chapter demonstrates the recommendation of Continuous Process Improvement on a medium-scale foundry. The objective here was to optimize Value-added activities, reduction in necessary Non-value-added Activities and eradication of unnecessary Non-value-added Activities. In current state VSM, Value-added ratio and the lead time was 24.5% and 15,589 min, respectively. After a conducting Kaizen event, Future state VSM was drawn and found that VAR and LT are now 25.44% and 15,374 min, respectively. In Table 15.4 Current state vs future state is summarized with improved productivity. Continuous improvement is a never-ending cycle, more Kaizen events should be conducted for further improvements.

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Chapter 16
Measurement of Critical Factors: A Case of Telecommunication Industry

Arnuv Mishra, Deepak Kumar, Mohd Shuaib, Mohit Tyagi, and Ravi Pratap Singh

Abstract The pragmatic objective of this research was to provide a basis for the telecom firms to evaluate and understand the factors which affect their regular decision making. It is essential to understand the interrelationships and complexity of such factors that affect the competency and profitability of a telecom firm. In this paper, ten key factors were identified which affect the telecom industry. It can be concluded that no single factor would be self-evaluating for the firm; therefore, it becomes essential to identify the interdependency of the factors. ISM procedure is utilized to establish such interdependency among different factors for every facet of the telecom industry. The outputs of ISM are fed into the MICMAC analysis for identifying the driving and dependence power of the respective factors. Therefore, this analysis provides a systematic framework to understand such relations and hence eases the manager's burden of decision making to enhance productivity.

Keywords Supply chain management (SCM) · Structural Self-Interaction matrix (SSIM) · Critical factors · Telecommunication industry · ISM model

16.1 Introduction

In a supply chain system, on the basis of description, there should be a 'product' that is generated by 'the points of origin' and dispersed at 'the points of consumption' [1]. Telecom Industries also referred to as the fast-evolving industries (FEIs) are characterized by increased degree of product improvement [2], Increased-goods/service diversity and reduced- product/service life or replenishment cycles [3] and highly knowledgeable consumers [4] By this definition it can be observed that FEIs is a major contributor to high value-added industries in developed countries, for example,

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electronics and telecommunications [5], semiconductors [6], fast-moving consumer goods [7], pharmaceutical goods [8], video games, advertising [9] and music [10, 11] As the lives of citizens become more digitized through the ubiquitous connectivity because of the application of digital devices, firms are now able to gather a huge amount of extensive information in real-time, and thus, know substantially more about their customers. Companies could leverage this growing body of data and developing relevant services based on customer demands accordingly. One industry compelled to benefit by utilizing customer information is the telecom industry due to fierce competition and a need for innovation in a saturated market [12].

Supply chain forms the basis of a strong foundation of any telecom firm. A system of facilities and dispersion alternatives that serves the purpose of acquiring materials, conversion of these materials into intermediate and finished products, and the dissemination of these finished goods to consumers is referred to as a supply chain. Supply chains are prevalent in both service and production firms, although the complication may vary in different situations [13]. Many definitions of SCM have been given but most of these incorporate choosing, synchronization and motivation of independently operating suppliers in at least a three-tier chain [14]. In spite of a core concept of SCM being close relationships, industrial experience has proven working across inter-organizational frontiers can be difficult. Sharing both the risks and impetus among the partners of the supply chain is indispensable for achieving this [15]. In the modern telecommunications industry, supply chain management (SCM) requires authentic design and diverse equipment for regulating the material flow. The goal for efficient SCM is optimizing inventory, lead times and related costs to ensure timely deliveries from production units to the customers. Supply chain management (SCM) is the amalgamation of art and science that contributes to the improvement of the way the company finds the raw components it needs to make a product or service and disseminate it to the customers [8]. Several alternatives for determining optimal operations and logistics strategies have been examined for competing in the global marketplace; hence, promoting the globalization of firms. Due to the progress made in technology and globalization of markets, firms have had to better their internal processes in order to stay competitive. Not only is the speed of business increasing, but the scope is also getting broader [16]. The telecom industry is not only prevalent in the service industry but rather competing in the market with various tangible products it has to offer. Direct to home connections and broadband lines are examples for the same. The normative belief in service management is that service functions should be dealt with differently because they have unique attributes not found in production. Pure services are impalpable, labour-intensive, diverse, cannot be stored and transported because manufacturing and usage take place at the same time, have an increased level of consumer effect, and have a hard to evaluate quality criterion [15, 17].

The above-provided characteristics of the telecom firms are assimilated within the various factors which influence the telecommunications industry. In this paper, ten factors have been recognized taking into account the literature review and the views of experts from academia and industry. The relationship matrix was developed by using the opinions from a group of experts, which was later used in establishing the ISM model. The main objectives of this paper are to identify the factors, and establish relationships among the observed factors by making use of ISM, and find out driving and dependence power of factors using MICMAC analysis in order to get an in-depth clarity about the operation of telecom industries.

16.2 ISM Methodology

Interpretive structural modelling (ISM) is a well-known procedure for analyzing interdependency of factors that define a problem statement [18, 19]. The methodology of the ISM methodology has been illustrated in Fig. 16.1. The model so formulated depicts an intricate issue or problem in a well-structured framework implying visuals along with the text. The authentic technique of interpretive structural modelling (ISM) is used for determining the connections between selected factors, which define a problem statement. Numerous factors may also be taken into account for an intricate problem. Rather than taking an individual factor into consideration, the direct and indirect interconnections between the factors provide a more precise picture in the approach used. Hence, collective understandings of these relationships are possible. Identification of variables, which are relevant to the problem or issue, comprises the initial stage of ISM, and then subsequently it is followed by multiple problem-solving approaches. A structural self-interaction matrix (SSIM) is formulated based on the pairwise comparison of variables. Subsequently, the SSIM is transformed into a reachability matrix (RM) and its transitivity is analyzed. A matrix model is obtained after transitivity embedding is complete. After this, the elements are segregated and

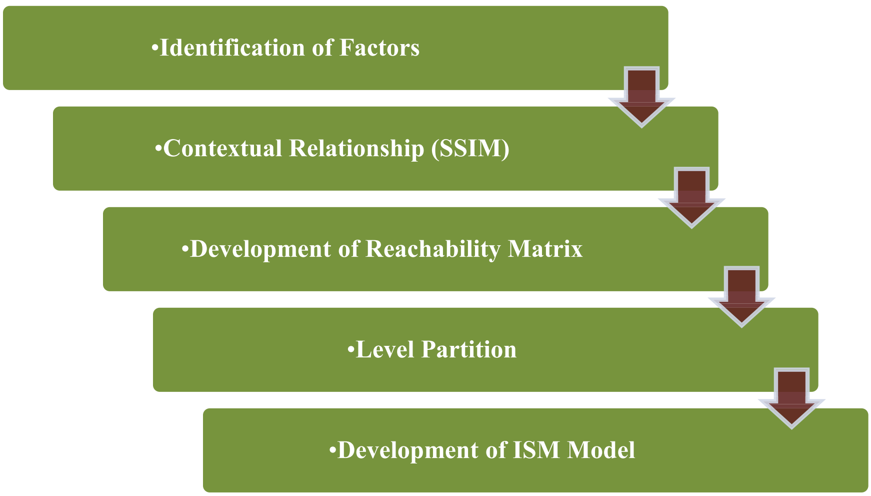

Fig. 16.1 ISM methodology

extracted to obtain the structural model called ISM. This method incorporates an organized application of some preliminary principles of graph theory in which the theoretical, conceptual and computational leverage are exploited to elaborate the intricate framework of mutual relationship among a set of variables.

The research framework of the proposed research involved the following steps:

- The existing factors of supply chain management in the context of the telecommunication industry were identified and enlisted.
- As recognized in step 1, a relationship for every pair of elements was established;
- A structural self-interaction matrix (SSIM) was formulated for factors which indicate binary relationships among factors of the system under scrutiny;
- A reachability matrix from the SSIM was developed and the matrix was verified for transitivity;
- Partitioning of reachability matrix into different levels;
- A flow graph without indicating transitive links was drawn on the basis of the established relationships in the reachability matrix;
- The resultant digraph was converted into an ISM by replacing driver nodes with statements;
- Conceptual inconsistencies were checked for and necessary modifications were made.
- The driving and dependence power of these factors was visually presented using MICMAC analysis.
- Relationship statement was represented as a model for the drivers under study and conclusions were drawn.

16.2.1 Identification of Factors

For analyzing the factor related to the telecom industry, ten factors have been identified as shown in Table 16.1 based on the literature review and the views of academicians and industry experts.

These factors comprehensively evaluate the performance of the telecom industry which is a fast-evolving industry. Industries known as Fast-Evolving Industries (FEI's) are characterized by increased-product/service variety, augmented innovation and differentiation, low-usage life cycles and highly aware consumers, Dynamism is observable globally in economies and life cycles in many industries are shortening. Since demands are highly fragmented in FEIs, resource design and allocations in these industries are highly strategic and complex. Higher the volatility in the industry the larger is the impact of supply chain management (SCM) on the competitiveness of the firm [20]. Speedily changing markets of the FEIs are creating an ever-increasing need for flexible and responsive supply chain [21, 22]. Supplier integration is a precondition for meeting this need [23]. Although market structure for FEIs is often volatile, a stable supply chain is required. Hence, the more stable the supply network, the more responsive it will be [24]. It is difficult to work across inter-organizational borders.

Table 16.1 Identification of factors

S. No.	Factors	Definitions	References
F1	Government regulations	These are the protocols and regulations of the state which each service provider needs to follow in order to render their services. All the decisions taken by the operator come within its ambit. From the process of spectrum allocation to distribution of the services, the operator is accountable to the government	[15]
F2	Innovation	The Improvement in the telecom industry's services and/or products to cater to the probable future needs of the consumers. It is done in response to the fluctuating needs of the consumers and to establish the competitive priority of the operator in the market	[3, 11]
F3	Uncertain customer demand	The fluctuating/unpredictable consumer needs/wants. Due to dynamism in the telecom industry, there is always a transition happening to new technologies. The uncertain consumer demands affect and is in turn influenced by these transitions	[11, 21, 28]
F4	Firm's competitiveness	The ability of a telecom firm to remain prevalent in the market over the other firms by approaches like new product development, forecasting, quality control and price optimization	[11, 20]
F5	Organizational business strategy	The unique set of internal protocols/strategies/ethics, a firm abides by in making decisions. These are indispensable for accountability, coordination, organization and motivation of the employees	[15, 29]
F6	Product service life	The span of time after which the consumer replaces/discards a particular product/service. It is the useful life of the product/service until which it has some value addition to the consumer's life by its usage	[21]

(continued)

Table 16.1 (continued)

S. No.	Factors	Definitions	References
F7	Technology outsourcing	The process of obtaining valuable technology from other states/countries which is not available indigenously. The main aim of outsourcing is to get the latest technology cost effectively	[15]
F8	Technological adaptability	The ability of a telecom firm to provide services/products with available technology. It is dependent on the preparedness of a firm to adapt to new technology	[3, 4, 11]
F9	Allocation of telecom spectrum	The governmental auctioning of the telecom spectrum (band of frequency). It is conducted by the department of telecommunications	[30, 31]
F10	Risk-sharing	There are various capacities, technological; financial constraints that the entities in a telecom supply chain may face. The transfer of these risks to various stakeholders refers to the concept of risk-sharing	[14, 32]

Both risks and rewards must be shared among the entities of the supply chain to achieve this [25] by looking at the purchasing organizations' involvement in risk analysis and risk management. Main supply risks comprise of business risk (e.g. supplier's financial capability); supplier capacity limitations (e.g. shortage of tools, manpower or materials); changes in production technology(e.g. current technology becomes obsolete), product design changes (due to fluctuating consumer needs); and disasters in the field of business logistics, these important risk-sharing issues are often mentioned but not further elaborated in [14]. The factors such as outsourcing of manufacturing and R&D to suppliers, shorter product life cycles and compressed time-to-market (i.e. increased clock speed) add value in enhancing the synergistic mechanisms in the telecom industry. Outsourcing is also extensively used in the telecom industry which is also one of the distinct features which define it. Even production activities are outsourced. Uncertain demand is also an essential feature of the telecom industry. The dynamism of the telecom market along with the mitigated product usage cycles, makes the forecasting difficult for the needed supply chain capacity. Operators may emerge on a regular basis and the bringing in of new technology in the market comes under the ambit of governmental policies regarding timing and coverage, causing a very fast ramp-up of volumes.

Table 16.2 Structural self-interaction matrix

Factors	10	9	8	7	6	5	4	3	2	1
F1	V	V	V	V	V	V	V	O	X	
F2	A	X	X	V	O	V	X	A		
F3	O	V	V	V	O	X	X			
F4	V	X	V	X	O	X				
F5	O	A	V	O	X					
F6	A	V	V	O						
F7	A	X	A							
F8	A	X								
F9	A									
F10										

16.2.2 Structural Self-interaction Matrix (SSIM)

The opinions of academicians and industry experts are taken on the basis of diverse approaches like brainstorming, nominal group technique, etc., in formulating the interrelationships between factors. These experts should be familiar with the problem under analysis.

For assessing the factors, a contextual relationship is chosen which determines whether the factor is a driving one or is driven by other factors. It concludes that one factor influences another factor. On the basis of this, connections between the identified factors are established. The structural self-interaction matrix is developed as shown in Table 16.2.

Four symbols have been utilized to demonstrate the direct relation among different factors, i.e. for any element a_{ij} in SSIM: V: for i leading to j; A: for j leading to i; X: for i and j leading to one another; O: for no connection between i and j.

16.2.3 Reachability Matrix

The initial reachability matrix was established from SSIM after executing the values of VAXO as depicted in Table 16.3. Subsequently, an initial reachability matrix is made. For this, SSIM is transformed into the initial reachability matrix by swapping the notations (i.e. V, A, X or O) of SSIM by 1 or 0 s in the initial reachability matrix. The principle for the substitution is as follows:

[I] Input corresponding to the (k, l) cell in SSIM is 'V', then the (k, l) input in the reachability matrix becomes 1 and the (l, k) input becomes 0.

[II] Input corresponding to the (k, l) cell in SSIM is 'A', then the (k, l) input in the matrix becomes 0 and the (l, k) input becomes 1.

Table 16.3 Initial reachability matrix

Factors	1	2	3	4	5	6	7	8	9	10	Driving power
F1	1	1	0	1	1	1	1	1	1	1	9
F2	1	1	0	1	1	0	1	1	1	0	7
F3	0	1	1	1	1	0	1	1	1	0	7
F4	0	1	1	1	1	0	1	1	1	1	8
F5	0	0	1	1	1	1	0	1	0	0	5
F6	0	0	0	0	1	1	0	1	1	0	4
F7	0	0	0	1	0	0	1	0	1	0	3
F8	0	1	0	0	0	0	1	1	1	0	4
F9	0	1	0	1	1	0	1	1	1	0	6
F10	0	1	0	0	0	1	1	1	1	1	6
Dependence power	2	7	3	7	7	4	8	9	9	2	

[III] Input corresponding to the (*k*, *l*) cell in SSIM is ‘X’, then the (*k*, *l*) input in the matrix becomes 1 and the (*l*, *k*) input also becomes 1.

[IV] Input corresponding to the (*k*, *l*) cell in SSIM is ‘O’, then the (*k*, *l*) input in the matrix becomes 0 and the (*l*, *k*) input also becomes 0.

The initial reachability matrix is formulated by using these rules.

1* inputs denote the transitivity to bridge the gap, if any, in the opinions gathered during the progression of the structural self-interaction matrix. After including the transitivity approach as elaborated above in the initial matrix, the final reachability matrix was established as shown in Table 16.4.

Table 16.4 Final reachability matrix

Factors	1	2	3	4	5	6	7	8	9	10	Driving power
F1	1	1	1*	1	1	1	1	1	1	1	10
F2	1	1	1*	1	1	1*	1	1	1	1*	10
F3	1*	1	1	1	1	1*	1	1	1	1*	10
F4	1*	1	1	1	1	1*	1	1	1	1	10
F5	0	1*	1	1	1	1	1*	1	1*	1*	9
F6	0	1*	1*	1*	1	1	1*	1	1	0	8
F7	0	1*	1*	1	1*	0	1	1*	1	1*	8
F8	1*	1	0	1*	1*	0	1	1	1	0	7
F9	1	1	1	1	1	1	1	1	1	1	10
F10	1	1	0	1	1	1	1	1	1	1	9
Dependence power	7	10	8	10	10	8	10	10	10	8	

Table 16.5 First iteration of level partition

Factors	Reachability set	Antecedent set	Intersection	Level
F1	1,2,3,4,5,6,7,8,9,10	1,2,3,4,8,9,10	1,2,3,4,8,9,10	
F2	1,2,3,4,5,6,7,8,9,10	1,2,3,4,5,6,7,8,9,10	1,2,3,4,5,6,7,8,9,10	
F3	1,2,3,4,5,6,7,8,9,10	1,2,3,4,5,6,7,9	1,2,3,4,5,6,7,9	
F4	1,2,3,4,5,6,7,8,9,10	1,2,3,4,5,6,7,8,9,10	1,2,3,4,5,6,7,8,9,10	
F5	2,3,4,5,6,7,8,9,10	1,2,3,4,5,6,7,8,9,10	2,3,4,5,6,7,8,9,10	I
F6	2,3,4,5,6,7,8,9	1,2,3,4,5,6,9,10	2,3,4,5,6,9	
F7	2,3,4,5,7,8,9,10	1,2,3,4,5,6,7,8,9,10	2,3,4,5,7,8,9,10	I
F8	1,2,4,5,7,8,9	1,2,3,4,5,6,7,8,9,10	1,2,4,5,7,8,9	I
F9	1,2,3,4,5,6,7,8,9,10	1,2,3,4,5,6,7,8,9,10	1,2,3,4,5,6,7,8,9,10	I
F10	1,2,4,5,6,7,8,9,10	1,2,3,4,5,7,9,10	1,2,4,5,7,9,10	

16.2.4 Level Partition

For the level partition, the final matrix was segregated into different levels to find the reachability set for every factor. The reachability set, which is common in the antecedent set can, subsists at level I. In the next level the factors found at the first level are eliminated in the subsequent iteration. This progression is repeated continuously until the levels of each factor have been attained. The reachability set and antecedent sets are deduced for each factor from the final reachability matrix. The reachability set comprises of the factor itself along with the factors that it may influence, whereas the antecedent set contains the factor itself and the other factor that may influence it. Subsequently, the intersection of these sets is obtained and levels of the various factors are deduced.

The factors for which the reachability and the intersection sets are the same occupy the top position in the ISM hierarchy. The highest level factors comprise of those factors that will not drive the other factors above them. After the top-level factor is identified, it is eliminated. The same procedure is reiterated for determining the factors in the subsequent levels. This process is continued until the level of each factor is determined. The digraph and the ISM model are formulated using these levels. The first iteration of the level partition is shown in Table 16.5. The intermediate iterations, i.e. the second, third and fourth are, respectively, depicted in the Tables 16.6,16.7 and 16.8. The final iteration is obtained in Table 16.9.

16.2.5 Development of ISM Model

The ISM model has been formed based on the above analysis and shown in Fig. 16.2. As per the ISM model the 'Uncertain Customer Demand (F3)' forms the base and is the fundamental driving factor that drives all other factors. It refers to the fluctuating

Table 16.6 Second iteration of level partition

Factors	Reachability set	Antecedent set	Intersection	Level
F1	1,2,3,4,6,10	1,2,3,4,10	1,2,3,4,10	
F2	1,2,3,4,6,10	1,2,3,4,6,10	1,2,3,4,6,10	II
F3	1,2,3,4,6,10	1,2,3,4,6	1,2,3,4,6	
F4	1,2,3,4,6,10	1,2,3,4,6,10	1,2,3,4,6,10	II
F6	2,3,4,6	1,2,3,4,6,10	2,3,4,6	II
F10	1,2,4,6,10	1,2,3,4,10	1,2,4,10	

Table 16.7 Third iteration of level partition

Factors	Reachability set	Antecedent set	Intersection	Level
F1	1,3,10	1,3,10	1,3,10	III
F3	1,3,10	1,3	1,3	
F10	1,10	1,3,10	1,10	III

Table 16.8 Fourth iteration of level partition

Factors	Reachability set	Antecedent set	Intersection	Level
F3	3	3	3	IV

Table 16.9 Final iteration of level partition

Factors	Reachability set	Antecedent set	Intersection	Level
F1	1,3,10	1,3,10	1,3,10	III
F2	1,2,3,4,6,10	1,2,3,4,6,10	1,2,3,4,6,10	II
F3	3	3	3	IV
F4	1,2,3,4,6,10	1,2,3,4,6,10	1,2,3,4,6,10	II
F5	2,3,4,5,6,7,8,9,10	1,2,3,4,5,6,7,8,9,10	2,3,4,5,6,7,8,9,10	I
F6	2,3,4,6	1,2,3,4,6,10	2,3,4,6	II
F7	2,3,4,5,7,8,9,10	1,2,3,4,5,6,7,8,9,10	2,3,4,5,7,8,9,10	I
F8	1,2,4,5,7,8,9	1,2,3,4,5,6,7,8,9,10	1,2,4,5,7,8,9	I
F9	1,2,3,4,5,6,7,8,9,10	1,2,3,4,5,6,7,8,9,10	1,2,3,4,5,6,7,8,9,10	I
F10	1,10	1,3,10	1,10	III

and unpredictable consumer needs which lead to innovation in the industry. It is an indispensable factor to be considered for service providers. Producing dependable estimates of the needed supply chain capacity becomes very difficult due to uncertainty in the market, and the small product life cycles.

The next level comprises of the governmental intervention in the telecom markets. The government regulates the working of the telecom circles after ‘Allocation of

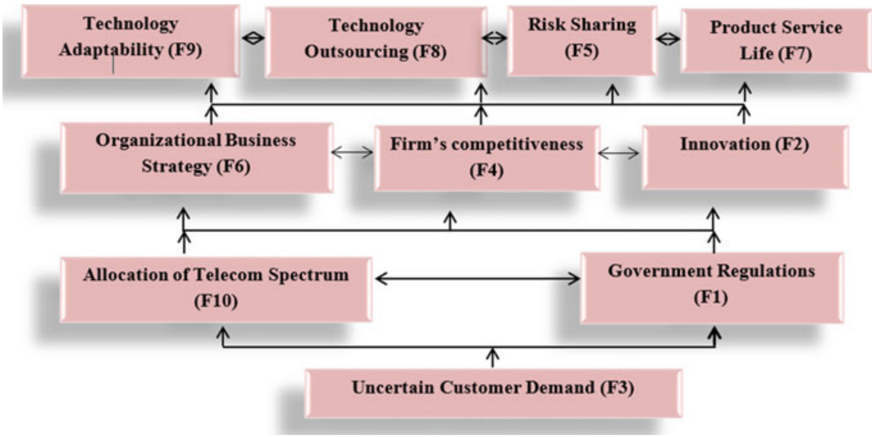

Fig. 16.2 ISM model

Telecom Spectrum (F10)' or bandwidth to the service providers. The spectrum allocated is the frequency at which a telecom service provider operates. Telecom industry is a dynamic industry in which new operators emerge, and the induction of these telecom structures is dependent on 'governmental regulations (F1)' based on timing and coverage, causing a rapid increase of volumes. Substantial orders must be delivered continuously to remote areas in different countries. These dynamics are within the regulations of government protocols.

The subsequent level deals at the firm level which incorporates factors like 'Firm's Competitiveness (F4)', 'Innovation (F2)' and 'Organizational Business Strategies (F6)'. These factors directly take into account the decisions taken by the firm to capture the market. Telecom industry is a fast-evolving industry that is characterized as changing and dynamic in nature. Telecom firms have to innovate in order to remain competitive in the industry and ensure customer's goodwill. Hence, there are increased levels of improvement and differentiation, increased-product/service variety and less-product/service life or replenishment cycles and increasingly knowledgeable customers. Every organization has a set of internal codes and regulations which tend to promote the organization's strategy, competency, ethics and goodwill on a global forum.

The technological factors such as 'Product Service Life (F7)', 'Risk-Sharing (F5)', 'Technology Outsourcing (F8)' and 'Technological Adaptability (F9)' make up the final level of the ISM model. Risk-sharing includes many key supply risks such as, i.e. business risk (e.g. supplier's economic stability); supplier capacity limitations (e.g. shortage of machines, labour or material to handle demand fluctuations); quality; changes in manufacturing technology, e.g. current technology becomes redundant), changes in product design (e.g. because of dynamic consumer demands); and mishaps. The risk may be influenced by another integral factor, i.e. 'Technology Outsourcing' which is a distinguishing feature of the industry. Increasing the use of outsourcing of production and research and development to suppliers adds to a rising need for enhanced synchronization techniques in the telecom industry, the smaller useful life of the product and mitigated time-to-market (i.e. higher clock speed). At the same time, it is important to consider that all the outsourcing and innovation done within a telecom firm is within the technological adaptability of the firm. A distinguishing example being that blockchain may not be applied in firms not having adequate resources to adapt to it. Hence, all these technological factors ultimately affect the 'Product Service Life' which refers to the useful life of a product/service after which it is usually replaced or discarded. It is measured from the customer's paradigm.

16.3 MICMAC Analysis

The MICMAC analysis is performed according to the driving and dependence powder in the final reachability matrix [26]. The driving and dependence power of the considered factors are determined by classifying them into four clusters. MICMAC stands for Matriced' impacts croises-multiplication applied to classification. Multiplication properties of the matrix are the root of the MICMAC analysis [27]. This analysis has been depicted in Fig. 16.3. Based on their dependence power and driving power, the drivers in the present case have been classified into the following four categories as shown in Fig. 16.3.

Category I: These have low dependence power and low driving power. These are referred to as autonomous drivers. Therefore, they have less impact on the system and do not have much influence on other factors. Factor F6 (Organizational Business Strategy) and F10 (Allocation of telecom spectrum) fall in this category.

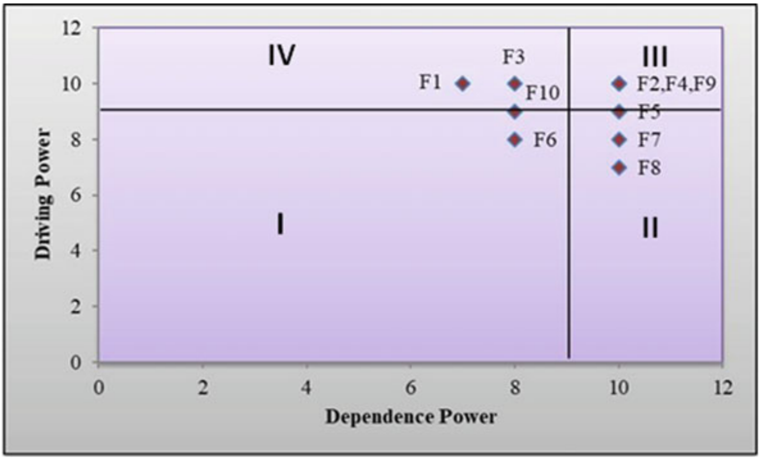

Fig. 16.3 MICMAC analysis

These are relatively distinct from the system with which they may have a link, which may be very strong.

Category II: These have high dependence and low driving power. Therefore, they do not have much impact on the system and are dependent on other factors. Factors: F5 (Risk-Sharing), F7 (Product Service Life) and F8 (Technology Outsourcing) fall in this category.

Category III: These have increased driving and dependence power. They are vulnerable since any change in these factors will influence other factors and also have an effect on them. Factors: F2 (Innovation), F4 (Firm's Competitiveness) and F9 (Technological Adaptability) fall in this category.

Category IV: These have a high driving and low dependence power. This means that these factors have a strong impact on the system while being immune to changes in other factors. Factors: F1 (Government Regulations) and F3 (Uncertain Customer Demands) fall in this category.

16.4 Conclusions

In this paper, an attempt to systematically present the intricacy and interdependency of each factor that affects the telecommunication business has been done. Based on the systematic analysis the 'Uncertain Consumer Demand' (F3) has the highest driving power of all other factors and is the main influencer of the telecom industry. 'Government Regulations' (F1) is also an essential driver and affects the decision making of a telecom firm. Technological factors such as 'Innovation' (F2), 'Firm's Competitiveness' (F4) and 'Technology Adaptability' (F9) are characterized by a high driving and dependence power and hence are sensitive to changes. The dynamic balance between these is essential for stability. Other high dependence and low driving factors like 'Organizational Business Strategy' (F6), 'Product Service Life' (F7) and 'Technology Outsourcing' (F8) doesn't play a very significant role in a firm's decision making as these are highly dependent on other factors. These factors are to be taken into account for the daily decision making in the telecom business. The advantages of this study would mainly be experienced by the businesses which are investing in telecom businesses and seeking good returns. The managers and employees of the organization in the telecom industry, suppliers and partners should able to understand these basic factors and utilize the suggested framework to evaluate their standing and understand the scope of improvement. Mainly, this research is of benefit to the businesses which have stakes in the telecom domain with the belief of achieving results. The Heads, managers, workers of the firms, suppliers, partners who all are involved in the supply chain configuration should be able to comprehend the nuances of SCM and apply the model to gauge their standing and obtain solutions for further development. Members of SCM Steering committees, Heads of Systems Units, Systems Analysts, System Auditors and consultants would be provided with a basis as well as a readymade tool for planning, analysis, regulation & innovation. Academicians will find this work useful and this work would also facilitate further research on this topic. Many problems are discussed and yet numerous others came to the forefront laying further stones towards getting rid of the technology paradox and achieving a seamless merger of technology and business.

16.5 Future Scope

This Research paper incorporates determining the main factors which influence the decision-taking in the telecom industry. After applying ISM methodology and MICMAC analysis of these factors, the paper succeeded in building a hierarchical framework between these factors. This paper set a precedent for exploring the uncharted territories of understanding the dynamism of the telecom industry. Though, a good effort but still a lot more can be contributed to the development of the paper with the lapse of time.

The factors selection was quite broad and doesn't quite do justice to the minute intricacies of the telecom industry. Many more sub-factors can be included under these broad factors to understand the telecom industry better. This study was based only on the ISM methodology and MICMAC approach. Other techniques may also be applied to get a better insight into the evaluation of the factors.

The industry experts and academia were consulted for determining and validating the factors used in the study. For inducing more elements of pragmatism in the study, after forming a complete framework of the factors including the factors and the sub-factors, it should be evaluated individually by the major telecom operators prevalent in the market. The study should also include a cushion of flexibility to adapt to the future changes which may come up in the industry.

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Chapter 17
Modified Savings Algorithm for Capacitated Vehicle Routing Problem: Development and Analysis

A. Madhav, N. C. M. Reddy, K. Ratna Kumar, and R. Sridharan

Abstract Fuel consumption accounts for a larger and increasing part of transportation costs. This chapter proposes an approach to solve the Fuel Capacitated Vehicle Routing Problem (FCVRP). The aim of this research is to identify, analyze and model various factors that are involved in calculating and optimizing fuel consumption in VRPs. Through an extensive literature review, the major factors on which fuel consumption depends were identified. A formula for calculating fuel consumption is modelled to include these factors. Clarke and Wright algorithm is modified to develop a set of routes with minimum fuel consumption based on fuel savings. The algorithm is integrated with Google application programming interfaces to work with real locations. As a case study, the VRP for a gas agency in the northern region of Kerala is solved using the proposed modified savings algorithm. The results show that the fuel consumed could be reduced by 6% compared with that of the classical Clarke and Wright algorithm.

Nomenclature

FCVRP	Fuel capacitated vehicle routing problem
VRP	Vehicle routing problem
FCR	Fuel consumption rate

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FC	Fuel consumption
FS	Fuel savings

17.1 Introduction

Fuel consumption costs generally reach up to 60% of total transportation costs. For a road transportation firm in a developing country, the fuel cost accounts for 67.41% of the total transportation cost [1]. Reduction of fuel consumption results in environmental and economic benefits. Governments in developing and developed countries are imposing stringent emission rules and carbon taxes on firms in an attempt to reduce the Carbon footprint. In addition to these strict rules, there is a continuous increase in fuel prices. Hence, even a little reduction in the fuel consumption results in huge cost savings.

The cost of a vehicle travelling along a route depends on two sets of factors. The first set of factors includes distance, load, speed, road conditions, traffic, and fuel consumption rate. These factors have a direct relationship with the vehicle route and can be regarded as variable costs [2]. The second set of factors includes depreciation and maintenance of vehicles, driver wages and taxes. These factors have no relationship with the vehicle route. Though there are many forms of VRPs, most of them minimize the cost by minimizing the distance without considering the first set of factors mentioned above. The amount of fuel consumed should be of greater concern than the distance travelled for firms that pursue the objective of minimization of costs. Most studies on VRPs deal with Euclidean distances, hypothetical locations and tend to overlook the existence of multiple routes between two locations. Hence, there is a need for re-modelling VRPs to better match the real conditions. The Clark and Wright algorithm is one of the simplest and widely used heuristics for the vehicle routing problem. Of late, many heuristics and metaheuristics are developed to deal with a variety of VRPs. In the present work, fuel savings algorithm is proposed to include real-life factors like capacity, gradient, speed and load. The effectiveness of the proposed algorithm is determined by comparing it with the Clark and Wright algorithm.

The rest of the chapter is organized as follows: Section 2 discusses the contributions of various researchers to the field of VRP. Section 3 describes the proposed methodology for solving a Fuel Capacitated Vehicle Routing Problem (FCVRP) in a detailed manner followed by a case study in Sect. 4, which illustrates the construction of routes, calculation of fuel consumption and distance travelled. Finally, in Sect. 5, concluding remarks are presented along with the scope for future work.

17.2 Research Background

Vehicle routing problem is a well-known and frequently used model since it is introduced by Dantzig and Ramser as vehicle dispatching problems [3]. Several researchers have studied different variants of VRP by adding constraints. Laporte et al. [4] introduced the capacitated vehicle routing problem. Ichoua et al. [5] introduced time-dependent vehicle routing problem. Many other models of VRPs such as multi-depot VRP, VRP with time windows, VRP with pickup and delivery and so on also exist. The reviews of the various models of VRP can be found in Toth and Vigo [6]. In recent years, research is more focused on green routing to reduce carbon emissions. Sbihi and Eglese [7] explained that it is essential to include factors like fuel consumption and emissions of vehicle. Erdogan and Hooks [8] proposed a green vehicle routing problem (GVRP) which could reduce carbon emissions. An extensive survey on the VRP models with green routing variants can be found in Golden et al. [9].

A ship routing problem of selecting the type of ship was presented by Fagerholt [10]. In this problem, shape, size and distance sailed are considered while calculating fuel consumption. Xiao et al. [11] extended the capacitated vehicle routing problem (CVRP) with the objective of minimizing fuel consumption. A mathematical optimization model to formally characterize the fuel consumption rate considering the CVRP (FCVRP) was presented by them. A simulated annealing algorithm with a hybrid exchange rule is developed to solve the FCVRP. A model for calculating fuel consumption for a given routing plan was developed by Kuo et al. [12] and a simple tabu search heuristic was used to optimize the routing plan. Three main factors such as speed, load and distance are considered while calculating fuel consumption. An optimization software is used to optimize routes for solid waste collection and transportation by Tavares et al. [13], wherein gradient is considered as an important factor in fuel consumption. The effects of traffic congestion in vehicle routing problems were addressed by Kok et al. [14]. Four strategies were proposed to avoid traffic congestion and a speed model was developed to investigate the impact of these strategies in the realistic setting. A low carbon routing problem (LCRP) by incorporating fuel consumption and carbon emission into traditional vehicle routing problem was proposed by Zhang et al. [15]. Costs such as fuel consumption costs, usage costs and carbon emission costs were considered in solving the LCRP. A formula for calculating fuel consumption considering load, speed, distance travelled and gradient was proposed by Suzuki [16] and a truck routing problem similar to travelling salesman problem was solved using this approach Erodgan [17] considered the fuel tank capacity of the vehicle while minimizing the fuel consumption. He used the modified Clarke and Wright algorithm and density-based clustering algorithm to solve the VRP. Poonthalir and Nadarajan [18] used the triangular distribution of speeds to calculate the fuel consumption. They modelled the FCVRP to minimize both route cost and fuel consumption using goal programming. The problem is solved using particle swarm operation with greedy mutation operator and time-varying acceleration coefficient. Eglese and Wen [19] used a heuristic algorithm to

Table 17.1 Summary of the literature review

Author and year	Green routing	Fuel	Distance	Speed	Capacity	Traffic congestion	Time window
Tavares et al. (2008)	✓	✗	✗	✓	✗	✗	✗
Kuo (2010)	✗	✓	✓	✓	✓	✗	✗
Xiao et al. (2011)	✗	✓	✓	✗	✓	✗	✗
Kuo et al. (2011)	✗	✓	✓	✓	✓	✗	✗
Suzuki (2011)	✗	✓	✗	✓	✓	✗	✓
Erdogan et al. (2012)	✓	✓	✓	✓	✓	✗	✗
Ene et al. (2013)	✓	✓	✓	✓	✓	✗	✗
Wen et al. (2014)	✗	✗	✓	✗	✗	✓	✓
Qian et al. (2015)	✓	✗	✓	✓	✓	✗	✗
Zhang et al. (2017)	✓	✓	✓	✗	✗	✗	✗
Feng et al. (2017)	✓	✓	✓	✗	✗	✗	✗
The present study	✗	✓	✓	✓	✓	✓	✗

minimize the total cost which includes driver cost and fuel cost. Table 17.1 provides a summary of the literature reviewed. The present research extends the Suzuki's model for the computation of fuel consumption by including traffic congestion.

17.3 Methodology

The methodology considered in the present work is evolved from the Clark and Wright Savings Algorithm and the model proposed by Suzuki to minimize fuel consumption. In the present methodology, to calculate the fuel consumption FC_{ij} between location i and j, factors having direct relationship with the vehicle route such as speed of the vehicle, gradient of the route and traffic congestion of the route are considered. A formula for calculating FC_{ij} is obtained by modifying the formula proposed by Suzuki [16] as follows:

Table 17.2 Fuel Penalty for various cases of traffic congestion

Traffic congestion characteristic	Average waiting time (s)	Penalty (ml)
Toll gate	35	70
Urban traffic signal	50	100
Highway traffic signal	100	200

$$\mathrm{FC}_{ij} = \frac{d_{ij}}{c_{ij} g_{ij} + p_{ij}} \tag{1}$$

Here, d_{ij} is the distance of the route from i to j. g_{ij} is the gradient factor which signifies the effect of the gradient of the route (if gradient is positive, $g_{ij} > 1$ and if the gradient is negative, $g_{ij} < 1$). c_{ij} is the fuel consumption rate between the nodes i and j and is given by the following relationship:

$$c_{ij} = aS_{ij} + b \tag{2}$$

Here, S_{ij} is the average speed of the vehicle from location i to j and a, b are the regression coefficients mentioned in Suzuki [16]. Traffic congestion has a greater influence on FC_{ij}. The vehicle consumes greater amount of fuel when it is in idling condition or operating at very low speeds in heavy traffic since rich air-fuel mixture is required. Therefore, a penalty (p_{ij}) is considered to account for the effects of traffic congestion. Penalties are assigned for specific cases of traffic congestion as shown in Table 17.2.

Using Eq. (1), the fuel consumption matrix is constructed by calculating the fuel consumption for each pair of locations i and j. The fuel consumption savings matrix is constructed from the fuel consumption matrix in the same way as the distance savings matrix is constructed in the classical Clarke and Wright algorithm [3]. Figure 17.1 shows the steps involved in constructing the routes based on the fuel consumption savings matrix.

Step 1: Fuel consumption savings matrix is calculated and is stored in a list in descending order of fuel savings (FC_{ij}) between i and j, in which each entry is of the form [location i, location j, FC_{ij}]

Step 2: A list named Routes list is initialized. This list at the end of the calculation will store the individual route data in the following format:

Routes list: [[location 0, location 1, location 2, …], [location 3, location 4, location 5, …], …]

Step 3: A list named Route is initialized. At the end of route construction, this list will store the locations visited in this route in order in the following format:

Route: [location 0, location1, location 2, …]

Step 4: An entry with maximum FC_{ij} is selected from the sorted savings list first and checked whether the merging of the two of its nodes will exceed the capacity of the vehicle or not. If the capacity of the vehicle is not exceeded, the nodes are marked

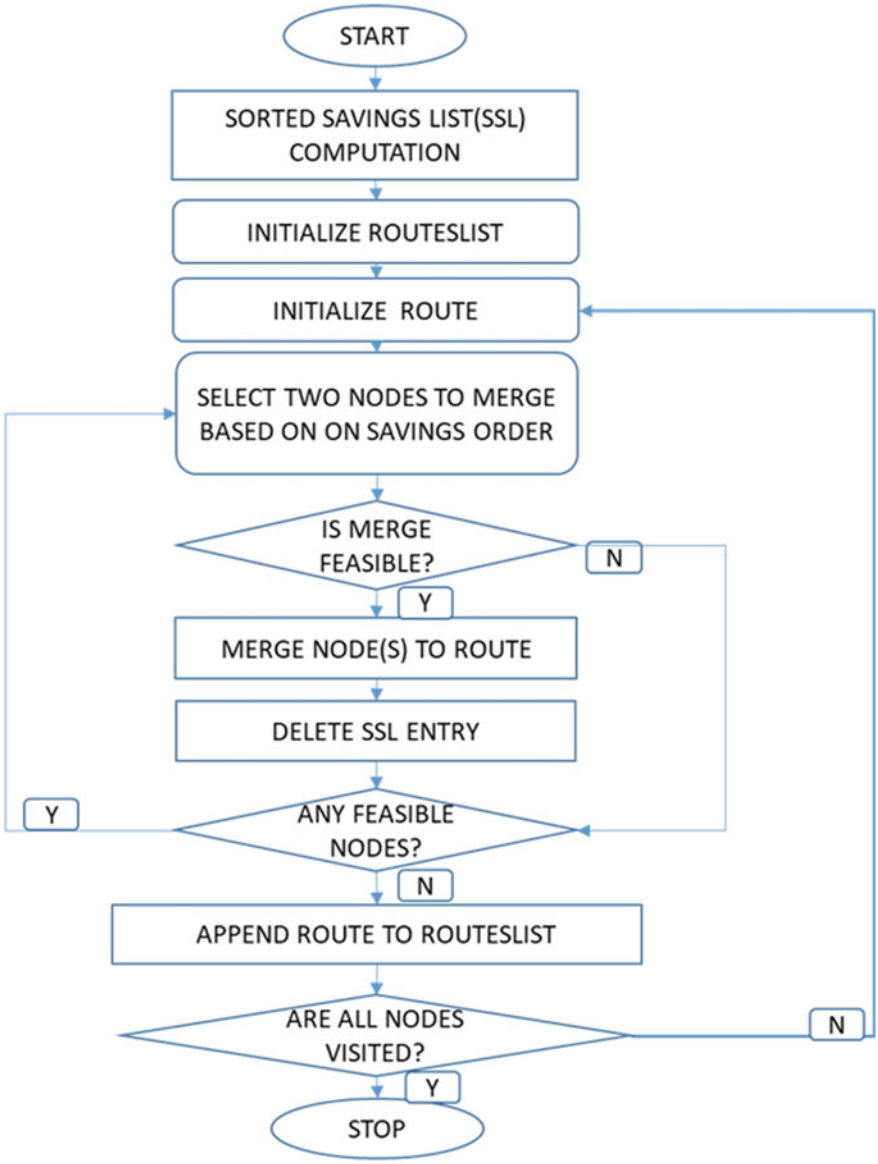


Fig. 17.1 Flow diagram for developing the set of routes

visited, merged to the route and the entry is deleted. If the capacity of the vehicle is exceeded, another entry is considered and the process is repeated until there are no feasible nodes.

Using the routes obtained, Fuel consumed (FC) and Distance covered in a Route [location 0, location 1, location 2, …, location x, location 0] are calculated as follows:

$$\mathrm{FC} = \mathrm{FC}_{01} + \mathrm{FC}_{12} + \cdots + \mathrm{FC}_{x0} \tag{3}$$

$$d = d_{01} + d_{12} + \cdots + d_{x0} \tag{4}$$

Fuel consumed in a route is calculated in two ways. First, for the forward route and then, for the backward route. The route which consumes lesser fuel is appended to the Routes list.

In the classical Clarke and Wright algorithm, while only distance is considered in the construction of routes, fuel consumption is calculated using the following formula:

$$\mathrm{FC} = \frac{d}{\mathrm{FCR}} \tag{5}$$

Here, FCR is the fuel consumption rate of the vehicle (kmpl).

Step 5: Steps 3 and 4 are executed till all the locations are visited.

The total fuel consumed for satisfying the demand at all the locations is obtained by the summation of FC's of all routes and the total distance travelled is obtained by the summation of all d's of all routes.

17.4 Case Study

Problem statement: Given a single depot and a fleet of homogeneous vehicles, the problem is to meet the requirements at 50 customer locations of a Gas Agency in the Northern Region of Kerala. Each customer requires a certain known quantity of LPG gas cylinders that is to be delivered from the depot. The distances among the customer locations as well as from the depot to the locations are known. There is a fleet of nine homogeneous vehicles of known capacity, fuel consumption rate and its variation with the load. Each vehicle starts from the depot and returns to the depot after meeting the requirements of a certain number of customers. The objective is to determine the routes by minimizing fuel consumption while considering speed, gradient, vehicle load and traffic congestion.

The input data required for solving the proposed algorithm is obtained as follows: Google maps distance matrix API is used to obtain the distance matrix of the set of locations. Google distance matrix API is a service that provides travel distance and time for a matrix of origins and destinations. Average travel speed is calculated for a particular vehicle type in a route with travel distance and time for the route. The gradient between two locations is calculated using the Euclidean distances and the elevation difference obtained from Google geocoding API and Google elevation API, respectively. Traffic congestion penalties are considered as explained in Table 17.2.

This problem is solved using the proposed algorithm in Sect. 3 and compared with the solution obtained using classical Clarke and Wright savings algorithm.

Tables 17.3 and 17.4 show the routes obtained for the Clarke and Wright algorithm and the proposed fuel savings algorithm, respectively. To highlight the advantage of the proposed fuel savings algorithm, the results obtained using the proposed algorithm and the classical Clarke and Wright algorithm are compared and tabulated in Table 17.5.

Table 17.3 Clarke and Wright algorithm method

S. No.	Routes	Demand
1	0 → 10 → 38 → 39 → 40 → 41 → 21 → 35 → 34 → 3 → 47 → 0	46
2	0 → 8 → 36 → 37 → 18 → 22 → 23 → 0	46
3	0 → 26 → 30 → 27 → 28 → 29 → 11 → 0	46
4	0 → 14 → 15 → 20 → 25 → 17 → 16 → 0	46
5	0 → 46 → 45 → 12 → 13 → 1 → 19 → 0	45
6	0 → 33 → 42 → 43 → 9 → 48 → 49 → 0	44
7	0 → 31 → 5 → 6 → 7 → 50 → 0	43
8	0 → 24 → 44 → 2 → 32 → 0	34
9	0 → 4→0	14

Distance travelled = 432.3 km; Fuel Consumed = 154.39 L

Table 17.4 Fuel savings algorithm method

S. No.	Routes	Demand
1	0 → 47 → 34 → 3 → 36 → 23 → 22 → 38 → 39 → 40 → 21 → 10 → 0	46
2	0 → 8 → 35 → 18 → 41 → 37 → 0	46
3	0 → 48 → 11 → 29 → 27 → 28 → 25 → 26 → 0	46
4	0 → 46 → 14 → 16 → 17 → 20 → 30 → 31 → 0	46
5	0 → 19 → 12 → 13 → 15 → 45 → 49 → 0	46
6	0 → 33 → 42 → 43 → 9 → 24 → 0	46
7	0 → 2 → 1 → 6 → 7 → 50 → 0	41
8	0 → 44 → 4 → 5 → 0	41
9	0 → 32 → 0	6

Distance travelled = 497.8 km; Fuel Consumed = 145.22 L

Table 17.5 Comparison of route determination methods

S. No.	Method	Distance (km)	Fuel consumed (L)
1	Clarke and Wright algorithm	432.3	154.39
2	Fuel savings algorithm	497.8	145.22

The fuel consumption obtained using the proposed fuel savings algorithm is lesser than that obtained using Clarke and Wright algorithm by about 6%. The fuel consumption value obtained using the fuel savings algorithm is a better approximate estimate than that obtained using Clarke and Wright savings algorithm since none of the factors that affect the fuel consumption are considered in the latter.

To validate the effects of the input parameters namely, gradient and fuel consumption rate, the input parameters are varied within ±10% with 5% intervals. For a given input, the fuel consumed is calculated for five replications while traffic congestion is varied and a total of 125 values are obtained. The results thus obtained are grouped and plotted as shown in Figs. 17.2 and 17.3.

From Figs. 17.2 and 17.3, it is observed that as the gradient is increasing for a particular level of fuel consumption rate (FCR), the fuel consumption was decreasing. It is also observed that as the levels of FCR are increased, the fuel consumption is increasing. The fuel consumption at a particular level of gradient is observed to increase as the fuel consumption rate is increased. The reasons for the observed behaviour can be attributed to the following reasons. An increase in fuel consumption rate increases the amount of fuel consumed for covering a particular distance and an increase in gradient (downwards) decreases the amount of fuel consumed for covering a particular distance.

Fig. 17.2 Average fuel consumption versus gradient at constant fuel consumption rate

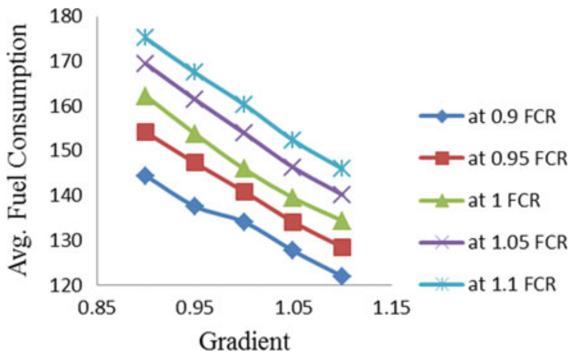
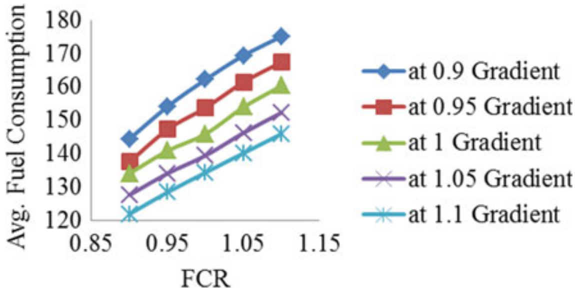


Fig. 17.3 Average fuel consumption versus fuel consumption rate at constant gradient



17.5 Conclusion and Scope for Future Work

The research presented in this chapter proposes a method to solve FCVRPs by modifying the savings algorithm. The factors such as speed, traffic congestion, fuel consumption rate and load of the vehicle are investigated and included in the formulation of fuel consumption. This formula provides a more reliable quantitative measure of fuel consumption. The case study presented in this paper illustrates the process of obtaining routes and calculation of fuel consumption. The validation of the algorithm used in the case study ensures the robustness of the algorithm used. It is shown that the proposed variant of Clarke and Wright algorithm results in routes with lesser fuel consumption compared to the classical Clarke and Wright algorithm. In this research, load is not considered in the construction of routes. Further studies may improve this method by devising a scheme wherein load is considered in the routing process which will provide a more realistic idea of the effect of load on fuel consumption. In the present work, speed was considered to be an average value for a route. Future works may consider different distributions for speed. Moreover, real-time speed data can help in determining fuel consumption more accurately.

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Chapter 18
Analysis of Barriers and Enablers of Sustainability Implementation in Healthcare Centers

Ashish Bhalchandra Chate, E. N. Anikumar, and R. Sridharan

Abstract The objective of this chapter is to identify and analyze various barriers and enablers for implementing sustainability practices in healthcare centers in a district in an Indian state. The list of barriers and enablers are identified from an extensive literature review. From a pilot questionnaire survey, barriers and enablers are reduced for further analysis from experts' point of view. Decision-making trial and evaluation laboratory (DEMATEL) method is used to analyze the data. DEMATEL is used to first prioritize the importance of these criteria and then construct the causal relations among the criteria. The data for this study are collected from a questionnaire-based survey of hospitals. The decision makers in the top level management can use this model to recognize and prioritize the barriers and enablers which are dominant in the implementation of sustainable supply chain practices.

Keywords Healthcare · Sustainability · Enablers · Barriers · DEMATEL

Nomenclature

DEMATEL	Decision-making trial and evaluation laboratory;
B & E	Barriers and Enablers.

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18.1 Introduction

The economic performance indicator like gross domestic product (GDP) in the Indian economy is showing a growing tendency over a period of time even when the majority of the rest of the countries are showing a downward trend. Even with this better economic performance, the reports published by the United Nations show that the human development index (HDI) of the country is very low. This shows that if the country can reduce the HDI performance, and even better economic performance is easily achievable. When comparing with other nations, the infrastructure facilities and manpower resource strength are some of the major reasons for India's poor performance in HDI ranking. The HDI rankings published by the UN shows that between the periods 1990–2017, the HDI value has increased close to 50% to reach a value of 0.640 from 0.427. Studies conducted by various agencies show that there is no significant increment in the gross domestic product (GDP) share for healthcare expenditure in India. This means that the GDP share for healthcare expenditure is lesser relative to the high population of the country. To provide quality healthcare facilities to people in the urban as well as rural areas of the country, infrastructure facilities, human resource strength, insurance to meet healthcare expenses and implementation of sustainable practices are essential. Healthcare institutions are planning to improve the overall patient experience by improving the overall efficiency of healthcare delivery, at the same time cutting down the overall expense. The implementation of sustainable practices in hospitals and its supply chains is one of the methods to achieve this objective.

Hospital is a place in which the health concept is strongly intertwined with well-being, ethics, and environmental aspects. It is a complex system in which all the aspects addressed by the World Health Organization (WHO) come to life: "health is a state of complete physical, mental and social well-being and not merely the absence of disease or infirmity". UN Global Compact in 2015 defined sustainability as "Management of environmental, social and economic impacts and the encouragement of good governance practices throughout the lifecycle of goods and services". Despite the fact that sustainability principles and feasible improvement are incorporated within the business models of numerous associations, healthcare organizations have faced the implementation of sustainability issues only recently. Also, there are some factors that help to fulfill sustainability.

The objectives of this chapter are (i) to model and analyze the inter-relationships among the enablers for implementing the sustainable practices in the healthcare centers considered for the study and (ii) to model and analyze the barriers for implementing sustainable practices in the healthcare centers considered for the study. The knowledge about the inter-relationships among the enablers as well as between the barriers will help the managers in the healthcare centers to identify the significant enabling factors in the process of sustainable practice implementation in their healthcare centers. Similarly, the present study will also help the managerial people to identify the significant barriers in implementing sustainable practices in their centers. The rest of the chapter is organized as follows: Sect. 18.2 provides a review of the relevant literature while Sect. 18.3 concludes the outcomes of the literature review. Section 18.4 describes the methodology adopted for the present study. Section 18.5 explains the modeling of the enablers as well as the barriers considered in this study. Section 18.6 discusses the results obtained from the modeling and Sect. 18.7 provides the conclusions of the present work.

18.2 Literature Review

The structured review is very useful for managing the assorted information base for an academic purpose. It allows us to explain the summary of the literature review. As highlighted by Beske et al. [2], "the literature review demonstrates the essential theories, arguments and controversies in the field and highlights the ways in which research in the area has been undertaken by others".

Figure 18.1 shows the process of literature review. It starts from how to search potential papers by using keywords. It is followed by analyzing and categorizing the content.

The implementation of sustainable practices in hospitals provides diverse advantages to the organization. The successful implementation helps to achieve a much healthier hospital environment. This leads to improvement in the public perception and the corporate social responsibility of hospitals. Generally, organizations follow the economic component of sustainability, while the social component and the environmental component are not considered by many researchers.

The literature review has shown that there exist several types of obstacles or barriers in implementing sustainable practices in a healthcare center. Walker et al. [17] established the barriers for sustainability practices experienced by the healthcare centers after a structured analysis and review. It includes both internal as well as external barriers. Analytical hierarchy process methodology was used to prioritize the identified barriers based upon the judgments of hospital administration. Muduli and Barve [10] have identified various barriers in adopting green practices in the healthcare waste sector from an Indian perspective. The researchers have shortlisted ten significant barriers and modeled the inter-relationship among them using interpretive structural modeling methodology. Muduli et al. [11] have identified various factors and sub-factors hindering green supply chain management practices in the mining industry. Dixit et al. [4], Dubey et al. [5] and Tobescu and Seuring [16] have

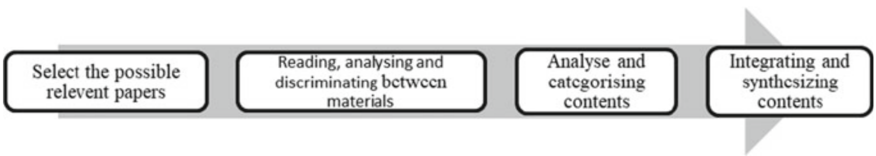

Fig. 18.1 Process of literature review

identified different types of enablers on the basis of a questionnaire-based survey and applied different techniques to analyze the collected data.

DEMATEL method is a well-known method used for the constructing relationship among the criteria for decision-making. Various researchers have used this technique for decision-making purposes. Shieh et al. [15] in 2010 have used DEMATEL to identify the importance of success factors of hospital service quality. Seker [14] adopted DEMATEL method for analyzing occupational risks in construction sites in Turkey.

18.3 Outcome of the Literature Review

From the review of the literature, major barriers and enablers in implementing sustainability practices in healthcare centers are identified as described in the following sub-sections.

18.3.1 Enablers

The adoption of SSCM practices in the manufacturing sector all over the world has got wider acceptance due to the intervention of various international agencies and other stakeholders. The implementation of SSCM practices in the service sectors is slowly getting momentum and one of the significant service sectors which is a major contributor to environmental pollution, energy consumption, water consumption, and hazardous as well as municipal waste generation source is healthcare sector. Recently, the healthcare sector institutions in various countries have started to follow sustainable practices throughout their supply chains. The healthcare institutions in India are very slow in adopting sustainable practices in their premises and supply chains. Hence, some external motivators are required to successfully implement the SSCM practices in the healthcare sector.

Currently, due to government regulations and environmental conscious public, the healthcare institutions have started to adopt implement the SSCM practices in their premises. Currently, the pollution of air, water and land as well as the consumption of resources such as energy and water by the healthcare sector is as equivalent to any other manufacturing sector organization. Hence, the identification of enablers in implementing SSCM practices in the healthcare sector is very important.

Diabat et al. [3] have analyzed the enablers in implementing sustainable practices in Indian industries. The objective of the study was to identify the enablers which have the most impact on SSCM implementation. The researchers have used interpretive structural modeling methodology to analyze the shortlisted enablers. Sajjad et al. [13] have performed an exploratory case study in New Zealand and identified various motivators and barriers in implementing SSCM practices in a supply chain. The researchers have shortlisted various motivators or enablers and barriers

Table 18.1 List of enablers for implementing SSCM practices in healthcare

Sl. No.	Barrier type	Source
*E*1	Economic advantages	Golinska and Romano [6], Grzybowska [7]
*E*2	Market demand	Dubey [5], Golinska and Romano [6]
*E*3	Motivation to suppliers and vendors toward sustainable practices	Golinska and Romano [6], Grzybowska [7]
*E*4	Commitment from top management	Dubey [5], Golinska and Romano [6]
*E*5	Decision-making strategies	Golinska and Romano [6]
*E*6	Government policies and supportive systems	Golinska and Romano [6]
*E*7	Customer satisfaction	Dubey [5], Golinska and Romano [6]
*E*8	Standards in human resources	Dubey [5], Grzybowska [7]
*E*9	Adoption of a cleaner technology	Golinska and Romano [6]
*E*10	Health and safety issues	Dubey [5], Grzybowska [7]

for implementing SSCM practices in a supply chain. In the present study, various enablers are identified through the review of research articles, and shortlisted enablers for further analysis after discussion with healthcare experts are shown in Table 18.1.

18.3.2 Barriers

Similar to the enablers, healthcare institutions are facing certain obstacles in implementing the SSCM practices. Some of the important barriers applicable to the healthcare sector are identified through the literature review and finalized the most significant barriers after discussion with experts from the healthcare sector institutions considered for the study. Narayanan et al. [12] have shortlisted, analyzed, and modeled the barriers in implementing SSCM practices in an Indian manufacturing sector environment. The researchers have used an integrated interpretive structural modeling and fuzzy analytic hierarchy process to find the inter-relationship among the barriers and to prioritize them based on an expert committee opinion. Gupta and Ramesh [8] have used interpretive structural modeling tools to analyze various barriers of healthcare supply chain in an Indian scenario. The researchers have used twelve important interacting factors that are affecting the Indian healthcare supply chain operations. Zaabi et al. [19] have identified different barriers in implementing SSCM and classified the barriers based on their impact on SSCM implementation process. Using interpretive structural modeling the researchers have analyzed the inter-relationship between the barriers. The major barriers applicable to the present study are provided in Table 18.2.

Table 18.2 List of barriers for implementing SSCM practices in healthcare

Sl. No.	Barrier type	Source
*B*1	Limited availability of resources	Ansari et al. [1], Mathiyazhagan [9]
*B*2	Financial constraints	Mathiyazhagan [9], Muduli and Barve [10]
*B*3	Need for extra human resources	Mathiyazhagan [9], Narayanan et al. [12]
*B*4	Problem in maintaining environmental suppliers	Ansari et al. [1], Mathiyazhagan [9]
*B*5	Lack of environmental knowledge	Mathiyazhagan [9], Muduli and Barve [10]
*B*6	Inhibits innovation	Ansari et al. [1], Muduli and Barve [10]
*B*7	Lack of corporate social responsibility	Mathiyazhagan [9], Muduli and Barve [10]
*B*8	Lack of segregation practices knowledge	Ansari et al. [1], Muduli and Barve [10]
*B*9	Inadequate awareness and training programs	Ansari et al. [1], Muduli and Barve [10]
*B*10	High cost of hazardous waste disposal	Ansari et al. [1], Mathiyazhagan [9]

18.4 Methodology

In the present chapter, decision-making trial and evaluation laboratory (DEMATEL) method is used for identifying the causal relationships among the elements. DEMATEL method is a renowned and wide-ranging method to prioritize the importance of the criterion and to build the casual relationships between complex real-world criterion (Wu and Tsai [18]). The difference between DEMATEL method and other traditional methods is that DEMATEL method considers the factors which are independent in nature of system to build the casual diagram (Shieh et al. [15]).

In this study, a pilot survey is conducted on the basis of a questionnaire-based survey from the experts' point of view. In this scenario, hospitals' administrative people are experts in this field. A five-point scale is provided to the respondents for specifying the importance of the B & E for implementing sustainability in health care centers. All the experts have more than five years of experience. Seven experts were requested to fill the survey and to rate their opinion with 1 as the least score and 5 as the highest score. From the above survey, the most seven important barriers and enablers are selected. For these barriers and enablers, mean and standard deviation of the score is calculated. Based on this analysis, the first seven barriers and enablers shown in Sects. 18.3.1 and 18.3.2 are selected for further study. After the seven key barriers and enablers are selected, the second questionnaire is developed for DEMATEL method to assign rank to the criteria and then to develop causal relationship among the criteria.

18.5 Modeling

Notations used for this method:

x^i Influence matrix of ith respondent
T Total relation matrix
A Average matrix
D Normalized initial direct-relation matrix
r_i row sum of matrix "T"
c_j Column matrix of matrix "T".

The steps involved in DEMATEL are as follows:

Step 1 Influence matrix is developed from an experts point of view. The development of influence matrix is explained in Sect. 18.5.1
Step 2 Calculte the average matrix. Average matrix is constructed by taking average of each cell of all influence matrix as $A = (a_{ij})$ where $a_{ij} = \frac{1}{H}\sum_{K=1}^{H} x_{ij}^{K}$
Step 3 Aveage matrix is normalized by dividing the maximum of row sum is called normalized directs relation matrix (D). $D = A \times S$ where $S = \frac{1}{\max_{1 \le i \le n} \sum_{j=1}^{n} a_{ij}}$
Step 4 Construct the total relationship matrix (T). Total relationship matrix can be calculated as $T = D \times (I - D)^{-1}$, where I is identity matrix of order n.
Step 5 Set up the threshold value. Total relationship matrix T provides the information about one factor affecting another factor so it is necessary to set up threshold value. The threshold value will tell the effect of one factor on another. There are various methods are available to calculate the threshold value, but a very common way is by taking average of matrix T.
Step 6 Plot the diagraph. The diagraph is also known as cause and effect diagram. It can be constructed by using co-ordinates $(x, y) \equiv (r_i + c_j), (r_i - c_j)$. $(r_i + c_j)$ gives the degree of importance of that criteria. $(r_i - c_j)$ provides the net effect that factor j contributes on the system.

18.5.1 Construction of Influence Matrix

Each respondent was requested to fill the questionnaire. They need to evaluate direct influences between two factors with a given score: 0—no influences, 1—low influence, 2—medium influence, 3—high influences. From the responses, 7×7 non-negative matrices are established as $x^k = \left[x_{ij}^{k}\right]$, where k is the number of respondents and n is number of factors. In this study, $n = 7$ and $k = 30$ for each enabler and barrier.

Non-negative 7×7 influence matrix of respondent 1 for barriers is shown below as an example.

$$x^1 = \begin{bmatrix} 0\,3\,3\,3\,3\,3\,3 \\ 2\,0\,2\,2\,2\,2\,1 \\ 2\,2\,0\,2\,3\,3\,2 \\ 1\,1\,2\,0\,2\,2\,1 \\ 3\,2\,3\,2\,0\,3\,1 \\ 3\,2\,3\,2\,3\,0\,1 \\ 1\,2\,2\,1\,2\,2\,0 \end{bmatrix}$$

18.6 Results

As described in Sect. 18.5.1, a questionnaire-based survey is conducted from administrative personnel as a experts. With the responses obtained, the influence matrix is constructed. Each respondent will give one matrix for the enabler and one for the barrier. The total number of respondents involved in this survey is thirty. Hence, there are 30 influence matrices for barriers and 30 for enablers. After the construction of all the influence matrices, step by step calculation is done and results are tabulated. This process provides total relation matrix and diagraph.

18.6.1 Barriers

The total relation matrix (T) and diagraph for the barriers are given below:

$$T = \begin{bmatrix} 0.6891 & 0.8365 & 1.0704 & 0.9223 & 1.0558 & 1.0577 & 0.8075 \\ 0.8770 & 0.8192 & 1.1695 & 1.0261 & 1.1541 & 1.1664 & 0.9230 \\ 0.9442 & 0.9956 & 1.1051 & 1.0827 & 1.2666 & 1.2883 & 0.9913 \\ 0.8562 & 0.9674 & 1.1649 & 0.8793 & 1.1582 & 1.1704 & 0.90111 \\ 0.8409 & 0.8928 & 1.1278 & 0.9550 & 0.9701 & 1.1331 & 0.8553 \\ 0.8800 & 0.9172 & 1.1778 & 09993 & 1.1630 & 1.0237 & 0.9057 \\ 0.6256 & 0.7167 & 0.8927 & 0.7648 & 0.8880 & 0.9069 & 0.6051 \end{bmatrix}$$

The threshold value of the matrix is 0.97. This value is used to construct the relations among the barriers. From the matrix, any values higher than this threshold value means that the factor is affected by another factor. Consider cell 3 × 1, this value is greater than threshold value, so barrier 3 is being affected by barrier 1.

In the diagraph, seven points shows barriers based on the $(r_i + c_j)$ value and $(r_i - c_j)$ value. Based on diagraph as shown in Fig. 18.2, the ranking of importance of criteria is 3-6-5-4-2-1-7 based on the $(r_i + c_j)$ value. The most important barrier is "Lack of top management commitment" with $(r_i + c_j)$ value of 15.42 and least important barrier is "inhibits Innovation" with $(r_i + c_j)$ value of 11.37. On the basis

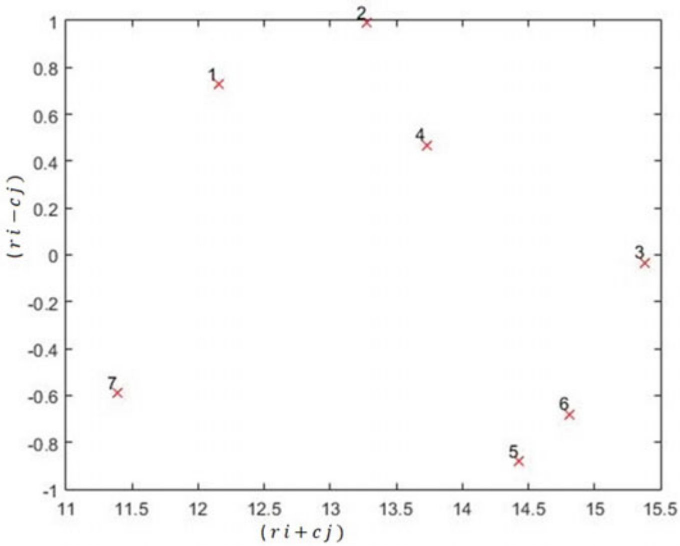

Fig. 18.2 Diagraph for barriers

of $(r_i - c_j)$ value, Financial constraints causing overall effect on the system. All positive $(r_i - c_j)$ values barriers will affect the system and negative $(r_i - c_j)$ values barriers will be affected.

18.6.2 Enablers

The total relation matrix (T) and diagraph for the enablers are given below:

$$T = \begin{bmatrix} 0.6130 & 0.8704 & 0.9336 & 0.8462 & 1.0041 & 0.9317 & 0.6564 \\ 0.6666 & 0.7153 & 0.8825 & 0.8394 & 0.9672 & 0.9137 & 0.6143 \\ 0.8097 & 0.9675 & 0.8712 & 0.9401 & 1.1027 & 1.0587 & 0.7416 \\ 0.6286 & 0.8115 & 0.8541 & 0.6659 & 0.9279 & 0.8927 & 0.6117 \\ 0.7136 & 0.8507 & 0.9038 & 0.8114 & 0.8183 & 0.9179 & 0.6186 \\ 0.7596 & 0.8773 & 0.9165 & 0.8369 & 0.9949 & 0.8070 & 0.6551 \\ 0.5211 & 0.6757 & 0.7032 & 0.6408 & 0.7253 & 0.7132 & 0.4204 \end{bmatrix}$$

Figure 18.3 shows the diagraph for the enablers. The threshold value will be average of total relation matrix. Threshold value is 0.78. This value depicts the effect of enablers on each other. It is similar to the barriers. The effects include direct and indirect effects.

$(r_i + c_j)$ indicates the degree of importance that factor i plays in the entire system. On the contrary, the difference $(r_i - c_j)$ depicts the net effect that factor i contributes

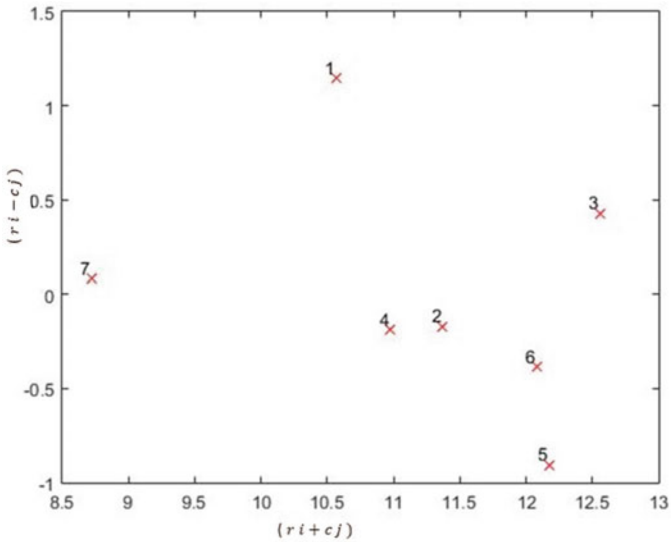

Fig. 18.3 Diagraph for enablers

to the system. In this case, the importance of criteria is ranked as 3-5-6-2-4-1-7. According to $(r_i + c_j)$ value, "Decision-making Strategies" is the most important enabler with value of 12.52 and the least important enabler is "Competitiveness of other centers" with value of 8.59. Based on diagraph, "Economic advantages" affects the system based on $(r_i - c_j)$ value.

18.7 Conclusion

DEMATEL method is a structured directional framework for analyzing the various data and provides a realistic picture. This method is used to determine the nature of barriers and enablers. DEMATEL method does not require any assumption. However, DEMATEL method requires experts opinion to construct the initial influence matrix. Because of this requirement, their preferences may involve bias; hence, it would affect the results. From this study, it is inferred that health care centers like hospitals appear to have various barriers and enablers to implement sustainability practices.

From the literature review, the list of 11 key barriers and 10 important enablers in implementing sustainability practices are identified. This study has explored that "Lack of Top Management Commitment" as the most important barrier and "Inhibits innovation" as the least important barrier. Also, among the enablers, "Decision-making strategies" and "Competitiveness of other centers" have the most and the least importance, respectively. This study reveals that the barrier "Financial Constraints" causes overall effect on the system. The enabler "Decision-making Strategies" causes overall effect on the system.

The present study can be extended by analyzing the feedback received from the implementation of sustainability practices. Such a study will enable to identify the effect of barriers and enablers in the implementation of sustainability practices.

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Chapter 19
Performance Evaluation of Ankle Foot Orthosis on Lower Extremity Disabled Persons while Walking using OpenSim

Prashant Kumar, Piyush Sharma, Harish Kumar Banga, Parveen Kalra, and Rajesh Kumar

Abstract Ankle foot orthosis (AFO) is externally applied device that is used to support and control the foot and ankle joint of patients having foot deformity. Foot drop is caused by a deficiency in the ankle joint which results in the weakness of ankle and toe dorsiflexion. The aim of this research was to study the motion of ankle by using OpenSim. The performance evaluation of ankle foot orthosis was carried out using OpenSim. Gait analysis was performed on six patients having foot drop, from the motion analysis system in the Gait Lab. The data from the Gait Lab was then imported into the OpenSim to create a biomechanics simulation to extract the joint angle and joint moments. The results show a considerable effect of the use of the AFO by drop foot patients in terms of ankle angle and ankle moments. Furthermore, the muscular analysis in terms of activation and forces also suggests that the dorsiflexors are assisted by the AFO during gait and the activation of the plantarflexion is considerably less during the lifting of the foot of the ground. The optimization of AFO was carried out, and the results show the improvement of 39.66% in ankle angle and 18.72% in ankle moment with AFO.

Keywords Gait analysis · Inverse kinematics · OpenSim · Ankle foot orthosis · Inverse dynamics

Nomenclature

AFO	Ankle foot orthosis
BM	Biomechanics

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GA Gait analysis
ID Inverse dynamics
IK Inverse kinematics
OS OpenSim

19.1 Introduction

The population of foot drop disabled person is increasing in India and now represents 2 billion people, i.e., 10% of the world population, which leads to increasingly demand for orthotic device [1, 2].

Ankle foot orthosis (AFO) is a brace worn on the lower leg supporting the ankle and foot holding them in the proper alignment with the correct foot drop [3]. AFOs can be rigid or hinged at the angle joint depending on the required ankle mobility. They are used by children and youth who have medical conditions such as cerebral palsy or stroke, and by adults who have neuromusculoskeletal conditions [4]. Ankle foot orthosis (AFO) is used to control the movement of foot who are unable to lift toe during gait. They are worn in the lower extremity of the leg or on the part of the foot. AFOs have been proposed to correct and control or cure the bending and any shortcoming in the movement. AFOs can be rigid or have a hinge at the angle joint depending on the degree of ankle mobility that is required. They are used by children and youth who have medical conditions such as cerebral palsy or spina bifida, and by adults who have neuromusculoskeletal conditions. This research paper will focus on AFOs used by adults with multiple sclerosis or who have had a stroke.

AFOs have been known to control the drop foot, which is the inability to lift the front part of the foot. The inability is caused by:

1. Paralysis of anterior muscles of the lower leg
2. Inability to dorsiflex at the ankles and toes.

Drop foot causes the toes to drag along the ground while walking. It can happen to one or both feet at the same time and can happen at any age. This pathology may be temporary as well as permanent.

The common causes may include:

1. Neurological conditions
   (a) Stroke
   (b) Multiple sclerosis
   (c) Cerebral palsy
   (d) Charcot-Marie-Tooth disease
2. Conditions that cause the muscles to progressively weaken
   (a) Rupture of tibialis anterior
   (b) Fracture of fibula

   (c) Compartment syndrome
   (d) Diabetes
   (e) Alcohol abuse

3. Injury to the peroneal nerve
   (a) Sports injury
   (b) Hip or knee replacement surgery
   (c) Childbirth

4. Injury to the nerve root in the spine.

19.1.1 Types of AFO

Two categories of AFOs, static and dynamic, have been developed to reduce gait pathologies. Two categories of AFOs, static and dynamic, have been developed to reduce gait pathologies. Static orthoses restrict movement in all planes, providing rigid stability and control of the ankle and subtalar joint. While these devices provide rigid support, the full restriction of movement inhibits normal progression through the three rockers during the stance phase of gait. To improve forward progression, dynamic AFOs permit limited motion in the sagittal plane, restricting plantar flexion during stance phase. These simple functional objectives can be addressed through thermoplastic and carbon fiber AFO designs, improving patient ambulation while maintaining light and cosmetically acceptable devices.

19.1.1.1 Static AFO

A static orthosis is adaptable or inflexible L molded AFO with the upstanding part behind the calf and the lower partition running under the foot. The static AFO is utilized to help the debilitated or deadened body parts in a specific position (e.g., drop foot from a stroke). An adaptable AFO can give some dorsiflexion help (e.g., powerless shin muscles) to the lower leg joint; however, it does not give much soundness to the subtalar joint. An inflexible AFO can square lower leg developments and balance out the subtalar joint. The inflexible static AFO can be intended to help control adduction and snatching of the forefoot.

The simplest static orthotic design is the solid ankle AFO as shown in Fig. 19.1, designed to hold the foot and ankle in a constant neutral position. The design encompasses the posterior and inferior surfaces of the shank and foot, limiting all motion [5]. The resistance to plantar flexion in swing and dorsiflexion during stance are controlled by forces applied to the ankle, shank, and foot by the AFO surface, proximal strap, and footplate/shoe [6].

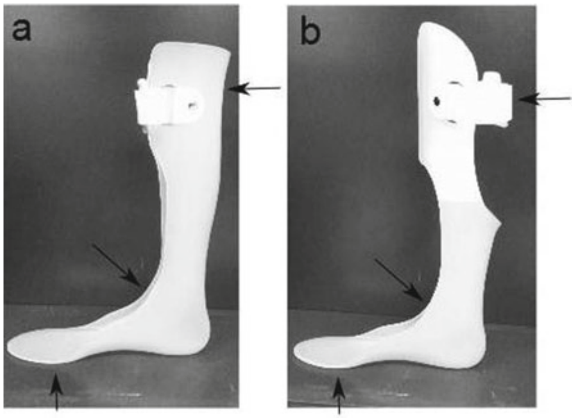

Fig. 19.1 Static AFO showing three-point bending force

19.1.1.2 Dynamic AFO

A dynamic ankle foot orthosis (DAFO) is a brand name for some lower furthest braces that give thin, adaptable, outer help to the foot, lower leg, and additionally lower leg. They have the identity to fit solidly the lower leg and right compactly the foot deformation inside extraordinary weight focuses. It is expressed to help in improving versatility and soundness of the lower leg joint on CP patients; proof demonstrates that prompt gross engine work improved with the utilization of DAFOs as well. Intended to enable a patient to keep up a useful position, a DAFO can improve strength for effective standing and walking.

To minimize gait deviations and assist forward progression, dynamic AFOs permit limited dorsiflexion during stance. One dynamic design, the posterior leaf spring AFO, shown in Fig. 19.2, is traditionally fabricated from thermoplastic materials, assisting rollover at the first rocker during loading response, as well as resisting plantar flexion during swing this device is used to counteract dorsiflexor weaknesses and impaired motor control. Unlike the solid ankle AFO, the posterior leaf spring design features shallow medial and lateral trim lines, reducing sagittal and frontal plane stability [7].

19.1.2 OpenSim Software

OpenSim is an uninhibitedly accessible programming bundle that empowers the client to fabricate, trade, and examine PC models of the musculoskeletal framework and dynamic recreations of development. OpenSim form 1.0 was presented at the American Society of Biomechanics Conference in 2007, and with variant 2.0, an application programming interface (API) has been included, enabling scientists to get to and tweak OpenSim center usefulness. The software gives a stage on which the biomechanics network can assemble a library of reproductions that can be traded,

Fig. 19.2 Dynamic AFO [8]

tried, dissected, and improved through multi-institutional coordinated effort. The center programming is written in C++, and the graphical UI (GUI) is written in Java. OpenSim module innovation makes it conceivable to create modified controllers, investigations, contact models, and muscle models in addition to other things. These modules can be shared without the need to change or aggregate the source code. Clients can analyze existing models and simulations and grow new models and simulations from inside the GUI.

OpenSim is an open source software package that allows user to create the model of musculoskeletal and dynamic simulation of movement [9]. Some models of human like lower extremity, upper extremity, cervical spine, and whole-body model have already exist. Dynamic simulation can be used on these existing models to extract some results. Its applications include biomechanics research, medical device design, ergonomic analysis and design, sports science, education, etc. The software provides a platform through which the biomechanics simulations can be exchanged, tested, analyzed, and improved. OpenSim complements and augments the functionality of SIMM and the SIMM Dynamics Pipeline by providing advanced simulation and control capabilities. In addition, the object-oriented, modular design of OpenSim allows users to extend its functionality and share functionality with other OpenSim users.

OpenSim is a self-contained modeling and simulation environment that does not require additional software components or licenses to generate dynamic simulations (Fig. 19.3).

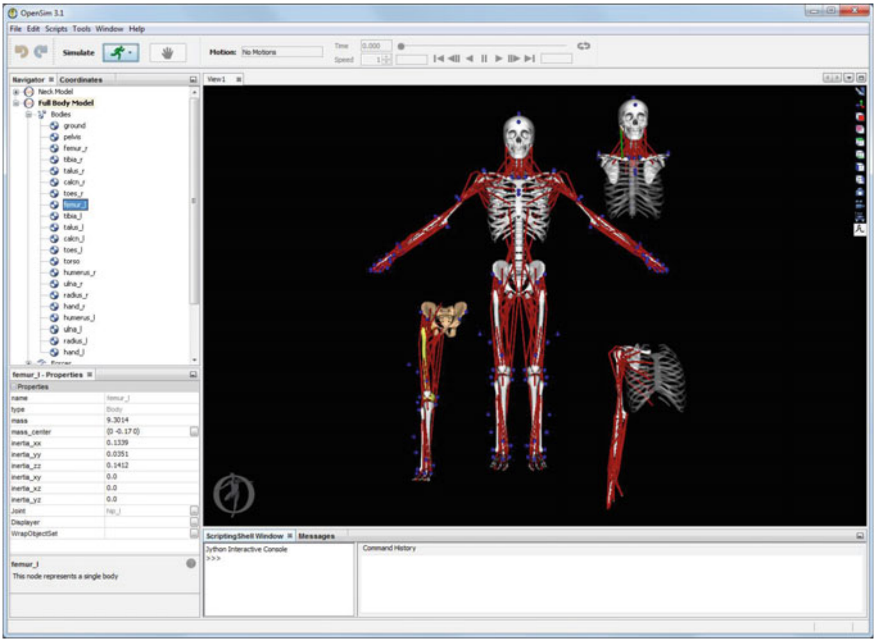

Fig. 19.3 OpenSim software GUI [9]

19.1.3 Human Gait

Sandra J. Shultz depicts step as: "… someone's way of ambulation or velocity, includes the absolute body. Gait speed decides the commitment of each body section. Normally walking speed fundamentally includes the lower limits, with the arms and trunk giving dependability and equalization. The quicker the speed, the more the body relies upon the furthest points and trunk for drive just as equalization and security. The legs keep on doing the most work as the joints produce more prominent scopes of movement trough more noteworthy muscle reactions. In the bipedal framework the three noteworthy joints of the lower body and pelvis work with one another as muscles and energy push the body ahead. How much the body's focal point of gravity moves amid forward interpretation characterizes proficiency [10, 11]. The body's inside moves both side to side and here and there amid step."

Whole gait cycle is primarily divided into two stages: the stance phase and swing phase. The stance phase covers 60% of the gait cycle, while swing phase covers 40% of it [12]. The stance and swing phases are completed in eight stages:

1. Heel strike
2. Loading response
3. Midstance
4. Terminal stance
5. Preswing

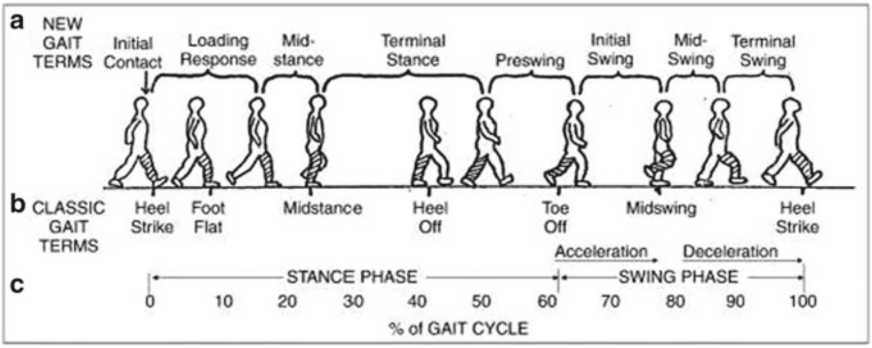

Fig. 19.4 Timing of single and double support during a single GAIT cycle from right heel contact to right heel contact [13]

6. Initial swing
7. Midswing
8. Late swing (Fig. 19.4).

19.2 Methodology

19.2.1 Selection of AFO

enlargethispage24ptThe methodology that was employed in this study is depicted in Fig. 19.5. It is imperative to mention that the AFO used in this study is designed and

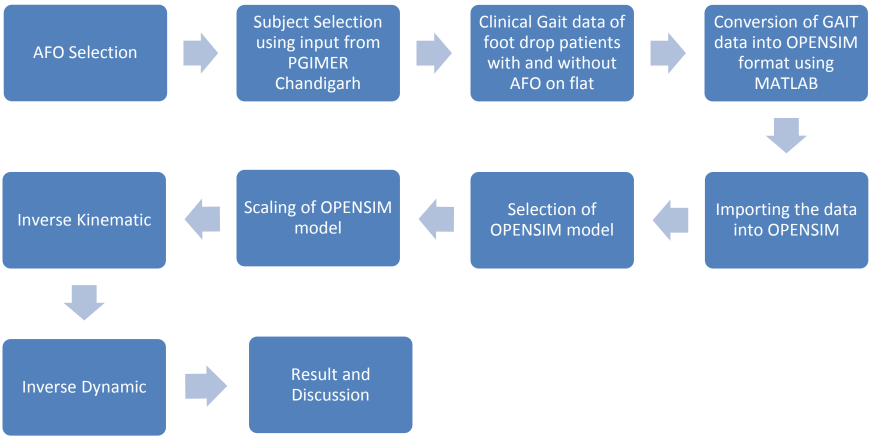

Fig. 19.5 Workflow of methodology

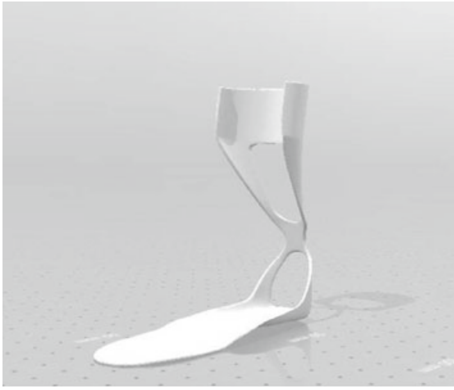

Fig. 19.6 AFO used in study

developed by Banga et al. [1]. Its design is depicted in Fig. 19.6.

19.2.2 Participants

Gait analysis was performed on six-foot drop patients. The gait data acquisition starts with the gathering of the anthropometric measurements of the patients, which is then followed by the marker positioning on the patients' bodies. Then, the motion analysis system is calibrated for acquisition. After this, the data is acquired with the help of the BTS Smart-Clinic software which is the part of the motion analysis system. The gait measurement techniques used in the Gait Lab of the Department of Physical and Rehabilitation Medicine at PGIMER, Chandigarh.

19.2.3 Conversion of Gait Data

The motion capture system provides us the data in .c3d format. Therefore, to continue working with OS, we have to extract the required data, i.e., marker trajectories (.trc file) and motion data (.mot) file from the .c3d file format. For this purpose, the mechanism that has been incorporated in this work includes the tools for using different aspects of OS within the MATLAB environment. Motion capture data from .c3d files were converted into the required files (marker files {.trc}, motion files {.mot}, GRF files {.XML}) through OpenSim-MATLAB pipeline tool.

19.2.4 OpenSim Simulation

OpenSim is software for displaying people, creatures, robots, and the earth and recreating their communication and development. OpenSim has a graphical UI (GUI) for envisioning models and creating and examining recreations. The open source and extensible programming likewise incorporates an application programming interface (API) that designers can use to expand the software.

For simulating the motions of foot drop patients with AFO and without AFO, the main focus is on the lower extremity of the human body. The work is done with the "gait10dof18musc" model contained within OS to simulate the desired scenario. It consists of the trunk, leg, and pelvis segments. It has 10 degrees of freedom and has 18 muscles of the lower extremity.

Scaling is a tool used to change the measurement of a model so that it matches according to the subject as closely as possible. The Scale Tool can be used to allocate virtual markers for evenly match according to the experimental data.

Inverse Kinematics was executed on the scaled model by using the walking .trc file obtained from the walking .c3d file. Experimental markers are compared by virtual markers throughout the motion by increasing the joint angles (generalized coordinates) through time. By performing **IK** desired angles and force files are obtained, and after that, a plot of different angles is obtained.

Inverse Dynamics is a tool used to calculate the net joint moment and torque responsible for a given movement. Given the kinematics describing the change in motion of a model and portion of kinetics (external load) applied to the model, to complete the action of Inverse Dynamics, ID Tool uses this data. External loads can also be specified manually on the subject that may affect the movement of the subject. These external loads comprise of the ground reaction data that is supplied to the tool in the. mot format in addition to the. mot output from the inverse kinematics.

19.3 Results and Discussion

The ankle motion during subject walking is studied by the OS tool. The results are depicted in the term of ankle angle and ankle moment. In the normal gait, at heel strike, the dorsiflexors cause a controlled plantarflexion to prevent foot slap. In this state, the dorsiflexors act like a linear spring. At toe off, dorsiflexors provide dorsiflexion to prevent foot drag. In this state and in swing phase, a position control is needed which provides external torque to push foot upwards.

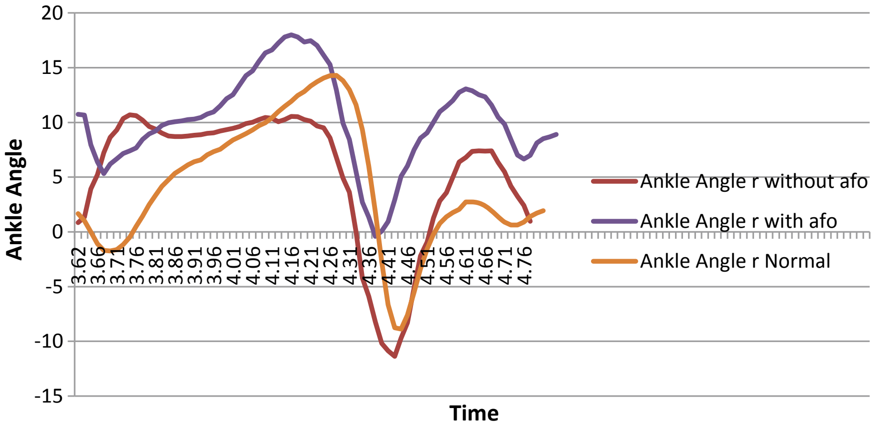

Fig. 19.7 Comparison graph between right ankle angle with time (with/without AFO)

19.3.1 Ankle Angle

The OpenSim simulations of foot drop patients give the values and trends of ankle angle with and without AFO as shown in Fig. 19.7. It is evident from the right ankle angle results that at the start of the cycle there is evident dorsiflexion of the right (affected) foot.

An improved ankle angle in each case depicts that the AFO assists the foot drop patient in achieving healthy gait.

Ankle angle without AFO represents that foot is dragging after heel strike in stance phase because the trend in the foot drop curve shows the patient dorsiflexion failure.

19.3.2 Ankle Angle Moment

The ground reaction force (GRF) produced dorsiflexion moment during the first half of stance phase and plantar flexion moment during the second half.

Thus, the ankle torque underestimated the dorsiflexion moment just after heel contact and plantarflexion moment at push off.

Moment of the ankle in foot drop patient also shows that ankle does not have required moment to provide dorsiflexion control.

The graphic representation of the ankle angle values depicts the affected portion that ranges from 3.71 to 4.21 s. This time range explains the disability to bring variation in the movement and have no more change in ankle angle. However, with the implementation of AFO to similar subject, it was observed that ankle angle increases with change in time.

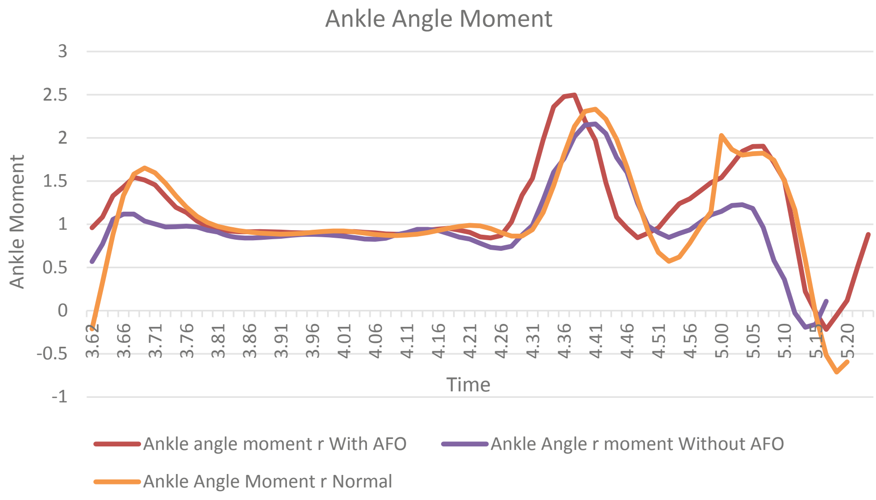

Fig. 19.8 Comparison graph between ankle moment and time (with/without AFO)

The graphical representation of ankle moment denotes how defective ankle moment is responsive for not bringing the variations from the same time range. But in contrary, when AFO was introduced to the similar subjects at same time range, the ankle moment is achieved near about of the normal person ankle moment as shown in Table 19.1.

Table 19.1 Comparison study of time versus ankle angle and ankle moment

Time (s)	Right ankle angle (°)			Right ankle angle moment (N m)		
	With AFO	Without AFO	Normal	With AFO	Without AFO	Normal
3.62	10.75	0.84	1.66	0.96	0.57	−0.2121
3.73	7.16	10.36	−1.16	1.32	0.97	1.47
3.83	9.72	9.033	4.16	0.92	0.87	0.945
3.93	10.45	8.89	6.59	0.903	0.871	0.89
4.03	13.44	9.64	8.68	0.915	0.843	0.911
4.13	17.24	10.056	10.98	0.903	0.94	0.885
4.23	17.03	9.68	13.72	0.85	0.78	0.98
4.33	5.52	0.026	11.61	1.97	1.28	1.13
4.43	2.92	−11.37	−8.76	1.48	2.05	2.21
4.53	10.02	1.264	−0.212	1.107	0.85	0.57
4.63	12.89	7.36	2.04	1.69	1.21	1.41
4.78	6.989	0.97	1.3	−0.218	0.107	−0.517

19.4 Conclusion and Future Scope

The biomechanical simulation of pathologies such as drop foot using musculoskeletal models of the human body is an effective way of analyzing the effect of these pathologies on the human body. Analysis of the drop foot patients, using OpenSim, with and without AFO has given us a new approach and advantage in terms of the traditional EMG-based systems for evaluation of muscle activity. These biomechanical simulations can be used in assessing the parameter of human gait and other kinematic parameters to design and develop user-specific orthosis. The kinetic and kinematics analysis of the foot drop patients shows a significant difference in the joint angle and moment of the hip, knee, and ankle. The ankle angle with the use of AFO shows that the AFO improves 39.66% dorsiflexion in the foot and at the same time ranges from 3.71 to 4.21 s.

Future works in the dynamic simulation of the ankle foot orthosis will focus on the designing of the orthosis by importing the different AFO models in the OpenSim GUI and analyze its interaction with the musculoskeletal model of the human body. OpenSim tools like forward dynamics and computed muscles control can be used to create dynamic simulations.

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Chapter 20
Analyzing the Effect of Different Maintenance Policies on the Performance of Flexible Manufacturing Cell

Rajiv Kumar Sharma and Puneet Kumar Agarwal

Abstract Flexible manufacturing cells (FMC) are used to process a variety of products in the system and provide higher productivity. The components of the system such as robots and machines are more likely to fail when compared with the traditional manufacturing system due to their higher operating rate. Literature studied reveals that the failures of the machines have a high impact on the production rate of the system. In this work, two types of failures are considered i.e. wear-out failure and random failure. Wear-out failure can be eliminated by applying some maintenance plans but random failures are difficult to eliminate. So simulation experiments along with maintenance plans are studied to eliminate such failures. We also discussed two types of failure rate distributions i.e. exponential, and Weibull distribution and their effect on the throughput of the FMC. In this analysis, ARENA simulation model is made and simulation experiments were performed to analyze the throughput of FMC that consists of 2 machines in parallel and a robot for material handling. We assumed that failure is occurring in machines only and the robot is reliable throughout the simulation.

Keywords Flexible manufacturing cells · Reliability · Maintenance · Simulation · Production rate

20.1 Introduction

The requirement of the production systems that are flexible is created by the increasing demand for low cost, low-to-medium volume production of the modular goods with many different variations [1, 2]. Now a days the product demand and specification changes so rapidly. Due to which the manufacturing systems face so

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many challenges in the market due to fluctuations in the product demand. So the manufacturing systems need to accomplish these fluctuations as soon as possible so as to be a successful competitor in the market. So to obtain the desired products, Flexible Manufacturing Systems (FMSs) come into picture to get high productivity and higher flexibility. FMS is a production system composed of workstations having some Computer Numerical Control (CNC) machine and/or Numerical Control (NC) machines connected by a material handling system which is able to produce a batch of products having some set of variations and is controlled by an automated computer-controlled system. It includes material handling system also. The parts and products made by this flexibility fall under mid-volume- mid production range, in which the production volume varies from 5000 to 75,000 parts per year. If the annual production falls below this range, an FMS likely becomes an expensive alternative for the conventional manufacturing system. And if the volume of the production reaches above this range, then more sophisticated production system like transfer lines should also be taken into consideration. Groover [1] presents a list of various benefits that can be taken out of an FMS installation includes increment in machine utilization, fewer machine required, reduction in factory floor space required, greater responsive to change, reduced inventory requirements, lower manufacturing lead times, opportunities for unattended operations, reduced direct labor requirements and higher labor productivity [1].

20.2 Related Work

Patil et al. [2] Reliability analysis of CNC turning center based on the assessment of trends in maintenance data. Ghavijorbozeh and Hamadani [3] discussed application of the mixed Weibull distribution in machine reliability analysis for a cell formation problem. Vineyard et al. [4] discussed failure rate distributions for flexible manufacturing systems. Lin et al. [5] have considered imperfect PM models sequence that consists of improvement factors of the effective age and hazard rate. Savasar [6] has developed the mathematical models to compare and study the operation of the unreliable and fully reliable flexible manufacturing cell (FMC). Dessouky and Bayer [7] considered the model of maintenance process that provides the systematic approach to study the maintenance process of buildings that are fully occupied with the help of mechanical, plumbing and electrical system. Rupe and Kuo [8] presented an assessment framework for optimal FMS Effectiveness. Gupta et al. [9] presented about the selection of maintenance strategy for aircraft systems using multi-criteria decision making methodologies. Moustafa et al. [10] developed optimal major and minimal maintenance policies for deteriorating systems. Rezg et al. [11] developed the simulation model to study the optimal inventory control and the preventive maintenance strategy for a failing production system randomly that supplies the operation of assembly line on the basis of just in time configuration. Kuo and Chang [12] developed an integrated production scheduling and preventive maintenance planning for a single machine under a cumulative damage failure process. Savsar and

Aldaihani [13] studied and demonstrated the performance of the FMS considering preventive, corrective and opportunity-triggered maintenance policies. Maheshwari and Sharma [14] investigated unreliable flexible manufacturing cell with common cause failure. Tuysuz and Kahraman [15] presented modeling of a flexible manufacturing cell using stochastic Petri nets with fuzzy parameters. Sharma and Sharma [16] developed a complex system of mechatronic, i.e. modular automated production system that consists of electronic, mechanical and software subsystems to analyze the reliability aspect of the mechatronic systems. For this, they used the fault tree analysis to study the reliability of the system. Gaula and Sharma [17] developed the hybrid framework by incorporating the quantitative and qualitative techniques to analyze and model the failure aspects of FMC. Philip and Sharma [18] developed a stochastic reward net approach for reliability analysis of a flexible manufacturing module. For other studies undertaken by researchers in the area readers can refer to references [19–22].

20.3 Maintenance Strategies Applied in FMC

To find the optimum balance between the costs and benefits, researchers have concentrated their studies on preventive maintenance strategies. Age and block-based models are the two well known maintenance policies [1, 3]. In both models, equipment is carried out by scheduling preventive maintenance. In this paper, four maintenance policies have been implemented and evaluated on an FMC [6, 13].

1. **Corrective maintenance only policy (CM)**: When any equipment fails, corrective maintenance policy is applied. A certain distribution is applied to assume time between failures. In this paper, we applied the exponential distribution because it facilitates the analysis to eliminate wear-out failures.
2. **Block-based PM with CM policy (BB)**: In this case, Preventive maintenance s applied at the equipment at the end of each shift to remove the wear-out failures during the shifts. As compared to CM operations, PM operations are scheduled at the end of the shifts without affecting the production schedule. Evaluation of this policy has been studied under different mean time between failures and repair cases. This policy is shown by Fig. 20.1.
3. **Age-based PM with CM policy (AB)**: In this policy, the preventive maintenance changes when a corrective maintenance is applied. Suppose T hours is fixed as time between PM operations. If after applying the PM operations and the equipment get failed and CM operations are applied before the next PM, the next

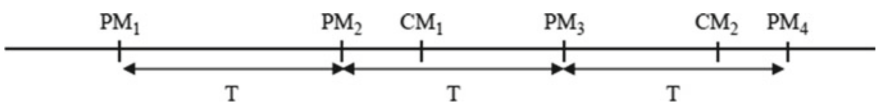

Fig. 20.1 Block-based PM policy

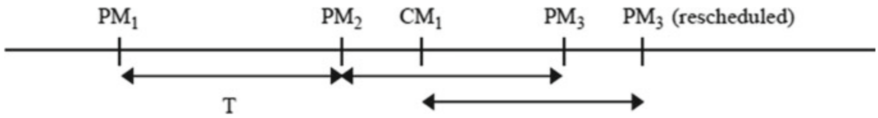

Fig. 20.2 PM operations under age-based policy

PM is scheduled *T* hours after the CM operation time. In simple words, we can say that PM operations are rescheduled when the CM operations are applied. This process is shown in Fig. 20.2.

4. **Opportunity-triggered PM with CM policy (OT)**: In this policy, PM operations are applied when the failure mechanism occurs. In other words, we can say that if system fails, it requires both operations PM operation as well as CM operation. This is known as triggered preventive maintenance. As both operations are applied together, some parts are maintained by CM operations; hence PM time is expected to reduce. Certain percentage of reduction is assigned in the PM operations. In our case, we have taken 50% reduction in the PM time. These maintenance policies are applied under similar operating condition by using the simulation model. The FMC throughput is measured for each maintenance policy.

20.4 Objectives and Solution Methodology

The major objectives of the work are summarized as follows:

- To compute the parametric values for failure rate distributions.
- To develop the model using Arena Simulation Software (Student version [23]).
- To simulate the model for different maintenance policies.
- To study the different cases under maintenance policies.

Solution methodology consists of

- Failure data gathering and obtaining the parametric values for failure rate distribution
- Designing the system for the obtained parametric values
- Analyzing the production rate for different maintenance policies.

In this study, we examined the failure and repair time data of CNC turning center as well as robot. We have considered only failure and repair data of machine to obtain parametric values of failure rate distributions. Data for failure and repair time of machine is given in Table 20.1.

Table 20.1 Failure data of CNC machining center [2]

Failure time of machine tool (h)	Repair time of machine tool (h)	Failure time of robot (h)	Repair time of robot (h)
1276	25.1	110	9
720	26.2	115	8
1135	24	114	7
1854	22	120	11
1687	22.3	130	15
2570	21.2	132	14
2440	23.6	134	12
2547	27.9	109	11.5
1100	26.7	107	12.4
2117	28	129	8.8
1876	24.2	136	10.4
1633	25.9	117	16.8
2646	26.8	131	17.9
1556	28.2	140	16
2470	29.9	135	13
1250	23.2		
1895	23		
2607	24.8		
896	29.8		
401	30		

20.5 Simulation Modeling of FMC Maintenance Policies

To analyze the performance measures of FMC, simulation model of fully reliable and unreliable along with maintenance policies is developed. Simulation models are developed by using ARENA simulation software. We selected ARENA simulation because it is based on SIMAN language and it provides high flexibility and facilitates modeling of manufacturing system with various manufacturing-related programming blocks.

In our study, FMC consists of two machines and a robot (reliable) as shown in Fig. 20.3. Machines are having same failure rate arranged parallel to each other. Apart from this, it consists of two stations. One is input station, and another is output station.

For the given data in Table 20.1, we obtained the parametric values for different failure rate distributions and as shown in Tables 20.2 and 20.3.

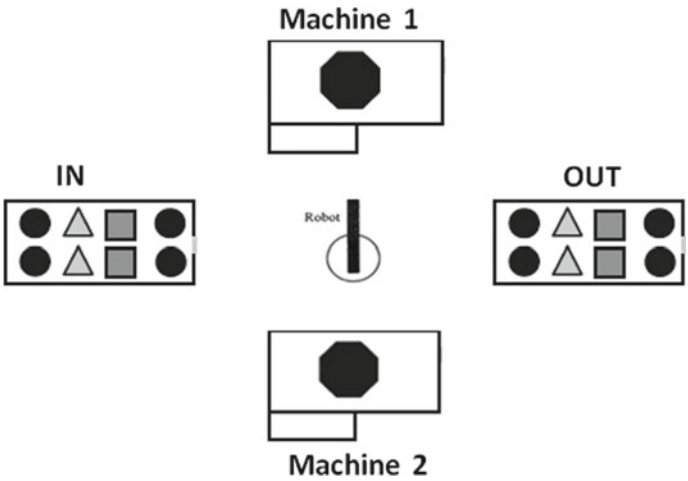

Fig. 20.3 A flexible manufacturing cell with 2 machines and 1 robot

Table 20.2 Time to failure of machine

Distributions	Parameters
Exponential	$\lambda = 1733.8$
Lognormal	$\mu = 7.35946$ $\sigma = 0.497851$
Weibull	$\alpha = 1946.48$ $\beta = 2.8937$

Table 20.3 Time to repair of machine

Distributions	Parameters
Exponential	$\lambda = 25.64$
Lognormal	$\mu = 3.23877$ $\sigma = 0.10649$
Weibull	$\alpha = 25.64$ $\beta = 10.5777$

λ = Mean for exponential distribution, μ = Log location parameter, σ = Log scale parameter
α = Scale parameter for Weibull, β = Shape parameter for Weibull

20.5.1 Conceptual Design

The conceptual design for the simulation model that determines the maintenance strategy is presented. There are three distinct phases (as shown in Fig. 20.4) while designing the model: experimental setup, process simulation, and maintenance strategies.

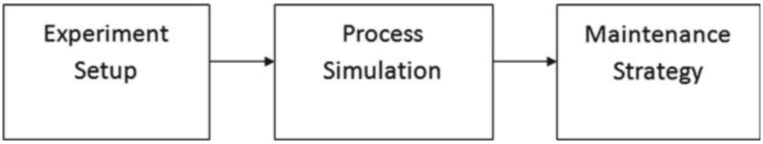

Fig. 20.4 Conceptual design

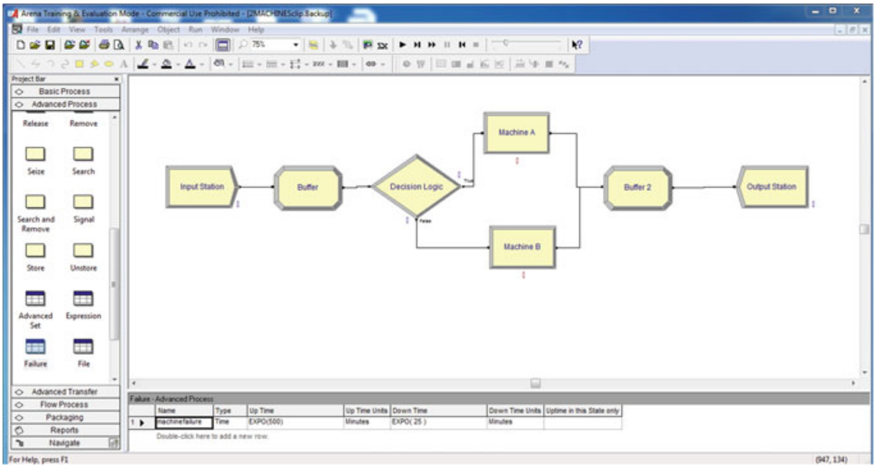

Fig. 20.5 Model in ARENA simulation software

Figure 20.5 shows the manufacturing model consisting of two machines with same failure rate. This model was developed using ARENA simulation software.

20.5.2 Simulation Experiments

A number of simulation experiments are carried out to learn the performance of FMC operations under different maintenance policies. The performance measure measured was the production output rate during the simulation period. With the aim to compare different maintenance policies and to conclude their effects on FMC performance, the case of fully reliable cell is also incorporated in our study. A simulation model was also developed for the fully reliable cell as well as five simulation models developed for unreliable cells with five maintenance policies. Thus, a simulation model was developed for each of the cases as: (a) a FRC; (b) a cell with CM; (c) a cell with BB; (d) a cell with AB; (e) a cell with OT. All simulation experiments were carried out for the function of the production cell over a period of 1 month (20 working days and 8 h per day or a period of 9600 min). In the case of PM, it was assumed that PM time of 30 min (or 15 min when combined with CM) is added to 480 min at the end

Table 20.4 Production rate of FMC with time between failures for unreliable and full reliable cell

S. No.	Time between failures (TBF)	Production rate (Unreliable)	Production rate (Reliable)
1	500	370	610
2	1000	375	610
3	1500	379	610
4	2000	385	610
5	2500	390	610
6	3000	450	610
7	3500	500	610
8	4000	505	610

of each shift. Ten simulation replications are made, and the performance measure, the average production output during the month, was obtained for each case. Other simulation associated parameters are given for each experiment.

20.5.2.1 FMC Case 1

This case shows the comparison between production rate for full reliable FMC and FMC with failure, i.e., unreliable. In this case, we took the time between failure exponentially distributed varying from 500 to 4000 min. In this case, we did not implement any maintenance policy. Comparison between production rate of reliable and unreliable cell is shown in Table 20.4. In Table 20.4, we can see that with increasing time between failures, production rate of full reliable remains constant but production rate of unreliable gets increased with time between failures.

Figure 20.6 depicts the production rate for different time between failures. From Fig. 20.6, we can conclude that there is steep increase in the production rate from 390 to 500 at 2500 min to 3500 min MTBF, respectively.

20.5.2.2 FMC Case 2

In this experiment, times between failures are taken exponentially distributed from 0 to T for the two machines taken in our proposed FMC (2 machines and 1 robot). In the unavailability of the preventive maintenance, the failure of the machine can take place anytime between 0 to T. But, when the PM (preventive maintenance) is implemented, failures due to wear-out are eradicated; only the random failures of chance causes stay that has constant failure rate and hence follow the exponential distribution that has mean time between failures of T. In this case, we took the value of T between 500 and 4000 min, in the increment of 500 min. Repair time is also taken exponentially distributed with mean 25 min for each machine. If we apply PM (preventive maintenance) on machine, it is supposed that the PM is completed in

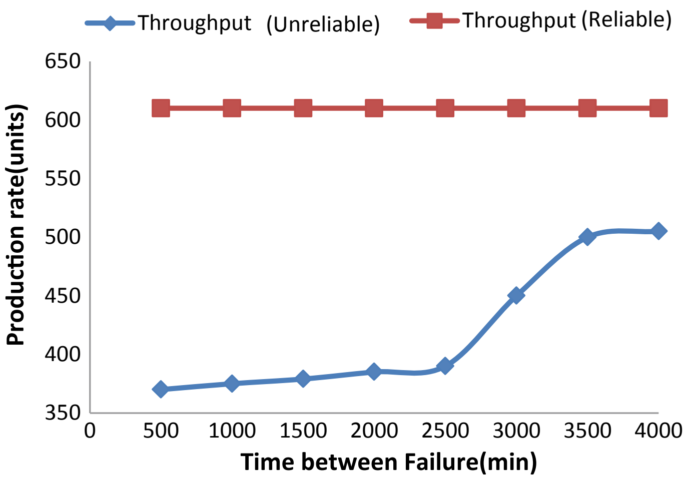

Fig. 20.6 Comparison of reliable and unreliable cell

the end of each shift and the machine takes 30 min for the preventive maintenance. If the CM (corrective maintenance) triggers PM and both are applied at the same instant, then there is a decrement of 50% in the PM time and the PM time comes down to 15 min, since CM tasks is also applied with it. Production output rate for each of the maintenance policies has been shown in Table 20.5. Production output rate obtained as the mean of ten simulation run and is considered as the mean of sum of the products manufactured during that month.

The fully reliable cell tells us the maximum possible production output (Pi) and is taken as a base to compare other maintenance policies. As it is seen from Fig. 20.7, implementing only CM without any PM is the worst policy of all. On the other hand, the best policy appears to be the opportunity-triggered maintenance policy (OT), ignoring negligible random fluctuations.

Table 20.5 Production rate of FMC under different maintenance policies for exponential MTBF

S. No.	MTBF (min)	Production rate (units)				
		CM	BB	AB	OT	FRC
1	500	370	483	485	490	610
2	1000	375	490	495	496	610
3	1500	379	510	520	524	610
4	2000	385	520	522	538	610
5	2500	390	525	528	550	610
6	3000	450	529	530	555	610
7	3500	500	530	533	560	610
8	4000	505	545	547	565	610

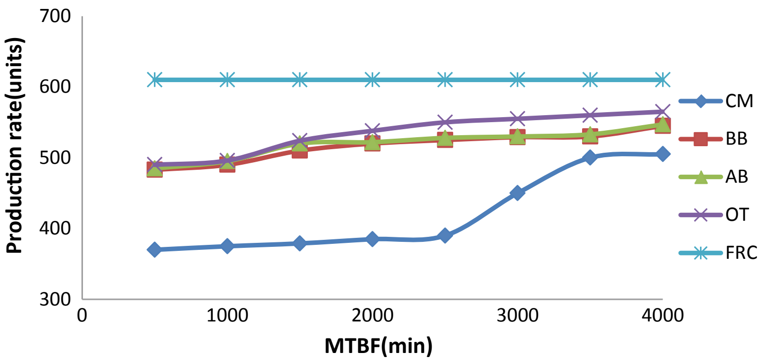

Fig. 20.7 Production rate for different maintenance policies for different TBFs

Between the age- and block-based policies, the age-based policy (AB) gives better results. Among all the policies with PM, block-based policy (BB) comes out to be the worst policy. As the mean time between failures (MTBF) increases, all of the policies reach a steady-state level relating to operational availability, but the gap between them is nearly the same at all levels of MTBF. In case of CM only policy, the production output rate sharply increases at the first increase of MTBF from 2500 to 3500 min.

20.5.2.3 FMC Case 3

In this case, we will follow the Weibull distribution and examine the throughput of cell for different maintenance policies discussed in Sect. 2. Firstly, we will determine the Weibull parameters for each time to failure.

For Weibull distribution that has MTBF $= \beta\,\Gamma\,(1/\alpha)/\alpha$, where these both parameters signifies α as shape parameter and β as scale parameter. These both parameters have to be calculated. For example, if MTBF $= 1500$ and $\alpha = 2$, then $\beta = 1692.2$. Similarly for MTBF $= 500$, $\alpha = 2$ and $\beta = 564.2$, for MTBF $= 2500$, $\alpha = 2$ and $\beta = 2820.95$ and for MTBF $= 4000$, $\alpha = 2$ and $\beta = 4513.5$ are used. Table 20.6 signifies the Weibull parameters for different times between failure that is calculated by using the Weibull formula. Table 20.7 shows the production rate for different maintenance policies under different mean time to failure that is Weibull distributed using the Weibull parameters.

Figure 20.8 depicts production rate under different maintenance policies for different MTBFs (Weibull distribution). Table 20.7 shows the values of production rate under different maintenance policies. This case shows the same trend as shown by the case 2 but production output rate under Weibull distribution is more than the exponential one that was discussed earlier. Here also the space between each maintenance policies is same, and they are increasing with the same rate. In this case, we find that even in the Weibull distribution, opportunity-triggered maintenance policy

Table 20.6 Parameters of Weibull distributions (α = shape parameter and β = scale parameter)

TBF	α	β
500	2	564.2
1000	2	1128.2
1500	2	1692.2
2000	2	2257.3
2500	2	2820.95
3000	2	3386
3500	2	3950.3
4000	2	4513.5

Table 20.7 Production rate for different maintenance policies for Weibull distribution

S. No.	MTBF (min) Weibull distributed	Production rate (units)				
		CM	BB	AB	OT	FRC
1	500	400	412	415	430	610
2	1000	452	475	481	495	610
3	1500	503	520	521	530	610
4	2000	511	525	529	538	610
5	2500	521	537	540	551	610
6	3000	530	540	545	559	610
7	3500	535	549	555	565	610
8	4000	545	561	565	571	610

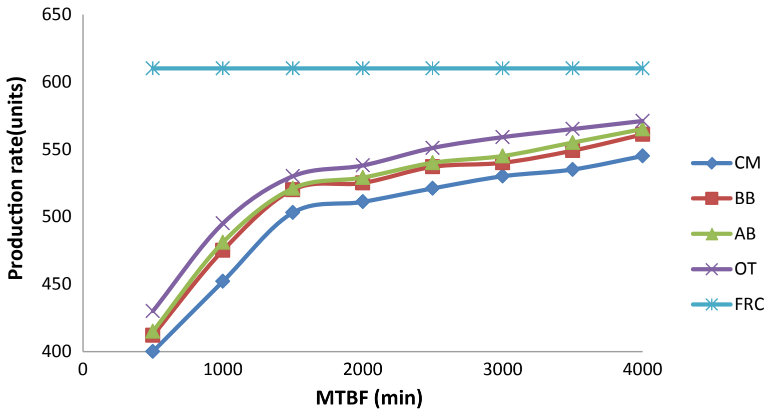

Fig. 20.8 Production rate under different maintenance policies for different MTBFs (Weibull)

is the best policy and the only corrective maintenance policy is worst among all maintenance policies as shown in Fig. 20.8.

20.6 Results and Conclusion

In this work, we analyzed the FMC using two failure rate distribution, i.e., exponential distribution and Weibull distribution, and along with it, we applied four different maintenance policies on the FMC. In this work, five cases have been discussed. The first case shows the comparison between reliable and unreliable cells. For reliable cell, production rate comes out to be 610. But for unreliable cell with the increase of mean time between failure, production rate increases. There has been a sharp increase in production rate from MTBF of 2500 to 3500 min. After that, it becomes constant. The second case shows the comparison of production rate under different maintenance strategies for different MTBFs that are exponentially distributed. The results of the second case show that CM policy is the worst among all other policies. But after MTBF of 3500 min, it reaches close to other maintenance policies. The third case represents the comparison of production rate under different maintenance policies for different MTBFs that follow Weibull distribution. The parametric values were calculated for Weibull distribution. The results of this case show that production rate of all maintenance policies increases with the same rate. The space between all maintenance policies is almost the same throughout the simulation. They increase sharply from MTBFs of 500 to 1500 min. After that, they increase at a slow rate. When we compared the production rate for two different failure distributions, we found that failure rate of Weibull distribution gives better result than the exponential distribution, but trend is same for different maintenance policies. It is because failure of the machine is not occurring at constant phase and failure data is most fitted to the Weibull distribution rather than the exponential one. Hence, we can say out of the two distributions, Weibull distribution comes out to be the best for maximum production rate. Also if we compare the maintenance policies implemented in failure time as well as repair time, CM only policy does not give the better result when it is compared with other maintenance policies. The maintenance policies that apply with PM are BB, AB, and OT. Out of these three policies, OT gives the best results, and between BB and AB policy, AB policy gives the better result. Hence, for the study of FMC, it was observed that we should consider the three things carefully. The first thing is the choice of simulation software. It should have high flexibility regarding the simulation and user. The second thing is the choice of failure and repair rate distribution that to which distribution our data is best suited or which distribution shape our data follows. The third thing is the choice of maintenance policies. It should be selected on the basis of production output rate.

20.7 Future Scope

Future studies can be done on analyzing the performance measures for three machines as well. The failure aspects of robots can also be included along with the machines during simulation. We analyzed the performance measures for exponential and Weibull distribution. Future studies can be done taking other failure rate distributions like lognormal distributions. Maintenance cost can also be investigated while performing the FMC under different maintenance policies.

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Chapter 21
Achieving Lean Through Value Stream Mapping for Complex Manufacturing with Simulation Technique

Shyamal Samant and Ravi Prakash

Abstract Lean manufacturing has enabled companies to achieve multiple goals of productivity, quality, reduced wastage and resource optimization. Achieving lean orientation has helped companies in enhancing the competiveness of their production systems. There are many tools to achieve lean orientation. Value Stream Mapping (VSM) occupies an important place in the available tools. Although, VSM is very useful tool, but it suffers from several shortcomings. It provides only a static snapshot of the production scenario. VSM cannot be easily applied to complex manufacturing situations, e.g., production involving having multi-product, multi-level (BOM) scenario. This paper proposes a solution to this problem. The solution framework proposes usage of lean box scores, coupled with discrete event simulation (using Extendsim software). The unique evolutionary optimizer available in Extendsim helps in achieving lean results through optimization approach. The framework has been demonstrated using a case study of lamp post production.

Keywords Lean manufacturing · Value stream mapping · Discrete event simulation

21.1 Introduction

The manufacturing companies are today facing tremendous global competition. The manufacturers are operating with extremely thin profit margins. The situation has been especially accentuated with the advent of Chinese manufacturing juggernaut. The organizations are leaving no stone unturned in enhancing their competitiveness. This has forced companies to reduce all possible wastages from their production systems. This is where lean manufacturing assumes special significance.

Lean manufacturing is a systematic method of waste (Muda) minimization. The production has to be carried out with an emphasis on waste minimization [1]. The activities which are wasteful have to be eliminated systematically. There are multiple

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tools to achieve “lean” during the production process. Some of the common tools are value stream map (VSM), poka-yoke, standardized work etc. VSM has emerged as one of the powerful technique of lean implementation. This explains the popularity of the VSM tool.

VSM process begins with the identification of the “value stream.” The “value stream” is what adds value during conversion of raw material to the final product. This is a workplace efficiency tool, where all the material and information flows are recorded in the form of icons and symbols. The analyst then creates current value stream map.

The bottlenecks during the flow are identified. This helps to come up with improvement kaizen ideas. The implementation of these improvement kaizens leads to the proposed new value stream map [2].

VSM has emerged as one of the most popular technique for achieving lean orientation. However, VSM has serious limitations, especially when it is applied to complex manufacturing situations. Some of the shortcomings are given below:

1. Static Snapshot: This is a pencil and paper technique. In other words, it provides a static snapshot of the production system. It fails to capture dynamic changes.
2. Lack of financial insight: It shows material and information flows. It fails to provide any financial insight into the production system.
3. Lack of insight into layout related issues: It does not provide any insight into layout related issues experienced within the production system.
4. Failure to handle complex manufacturing situations: VSM fails to handle complex manufacturing situations. Examples of complex manufacturing situations include multi-level bill of material (BOM) or multi-product scenario.
5. There is a no focus on overall improvements. It is left to the analyst to figure out the kaizen improvement ideas. In a complex value streams, he/she may miss details. There is no emphasis on the “big picture.”

To overcome these limitations, this research paper proposes an innovative framework involving lean box score, coupled with discrete event simulation (using Extendsim software). The evolutionary optimizer available within the Extendsim package, together with lean box score [3] makes this approach very innovative and powerful. Table 21.1 given compares the traditional VSM process with the proposed framework.

One of major handicaps of the VSM process is that it is static in nature. To overcome this, proposed approach develops a discrete event simulation model, combined with lean box score. The evolutionary optimization engine helps in achieving lean orientation. The proposed methodology is demonstrated for a lamp post manufacturer case.

Table 21.1 Comparison of conventional VSM with the proposed methodology

Requirements	Conventional VSM	Proposed approach
Static approach	●	●
Application to complex production streams	○	●
Dynamic approach	○	●
Finding optimal level of resources (man and machine resources)	○	●
Insight into financial performance	○	●
Prioritization of kaizen continuous improvement initiatives	○	●
Ability to perform feasibility check	○	●
Achieve global optimization	○	●

21.2 Literature Review

Lean manufacturing concept was pioneered at Toyota Motor Corporation. This concept emerged as a powerful production philosophies, called as Toyota production system [4, 5]. This is a set of practices and management principles to efficiently organize the workplace, streamline the logistics and the work flow etc., with the overall objective of reducing wastage (Muda). This concept was a precursor of the concept of "Lean." This has emerged as one of the central philosophies powering the manufacturing businesses today.

VSM has emerged as a tool for analyzing the current state of a production system to achieve lean orientation. VSM as a tool was pioneered by Rother and Shook in their work "Learning to see" [2]. VSM is a power methodology for achieving lean orientation. Despite its obvious advantages it suffers from various shortcomings as discussed in previous section.

Researchers have tried various approaches for overcome these limitations. The approaches range from heuristics based methods, approximations, discrete event simulation and many more. Some of the selected works have been summarized in Table 21.2.

From Table 21.2, it is evident that achieving lean through value stream mapping has not been explored sufficiently. There is a space for an alternate methodology for achieving lean for a complex value stream. This is especially true for complex value streams, as it is difficult to achieve lean orientation using traditional VSM approach. For a complex value stream, journey of achieving lean is not very straightforward.

Table 21.2 Literature review (summary of selected works) research gap and aim of research

Author(s)	Contribution
Khaswala and Irani [6]	Suggested value network mapping (VNM) approach for complex flows
Braglia et al. [7]	Suggested improved VSM approach (IVSM) approach for complex production streams
McDonald et al. [8]	Using discrete event simulation (DES) for lean for engineering-to-order (ETO) products
Lian and Van Landeghem [9]	Proposed DES for lean
Abdulmalek and Rajgopal [10]	Proposed VSM combined simulation (for steel mill—process industry)
Seth et al. [11]	Proposed, simplifications, and approximation in VSM
Bal et al. [12]	Combined VSM with DES for a emergency unit
Braglia et al. [13]	Suggested fuzzy algebra with VSM
Parthanadee and Buddhakulsomsiri [14]	Demonstrated achieving lean through DES
Samant et al. [15]	For a chassis production system, suggested the use of VSM combined with DES
Seth and Gupta [16]	Improvement of productivity, reduction of WIP for automotive company for suppliers
Serrano Lasa et al. [17]	To explore whether VSM is applicable to production system redesign with disconnected flow lines
Tapping et al. [18]	Step by step method for achieving lean using value stream map (VSM)

One tends to loose big picture. The motivation for the proposed innovative methodology for achieving lean for a complex value stream is derived from this research gap.

21.3 Methodology

As discussed in Sect. 21.1, VSM suffers from several shortcomings. The main reason for this is that VSM is a pencil and paper tool. This makes it a static tool. It enables the analyst to study the current value stream map, analyze the sources of wastes. The analyst then comes up with Kaizen continuous improvement ideas. These ideas lead to a new improved value stream map. This process of improvement is easy for simple single product VSM. This is not very straightforward and simple for complex manufacturing value streams, e.g., complete product, product involving multi-level BOM. This is a serious limitation for VSM.

This paper overcomes these limitations through the use of discrete event simulation, lean box score, and evolutionary optimizer (refer Fig. 21.1). This research paper

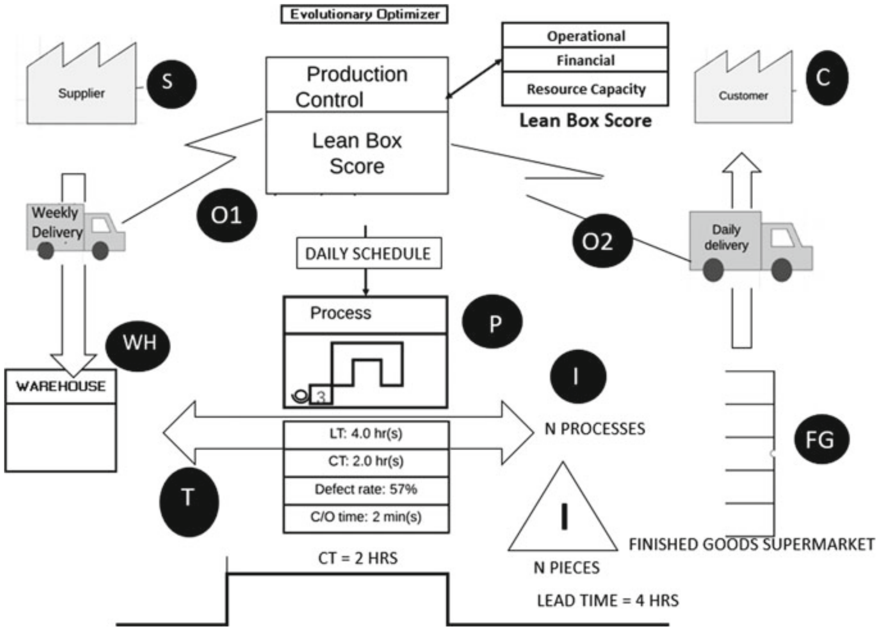


Fig. 21.1 Proposed framework (VSM modeled using interconnected IMs)

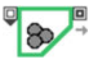
proposes that the components of VSM are modeled as "simulation components" capable of dynamically representing the manufacturing shop floor. In this research paper these simulation based components are called intelligent modules (IMs). Each IM represents a certain functional area. These IMs are intelligent enough to pass messages, store information, move toward an optimal solution etc. For example, process box in the VSM is modeled as workstation block combined with resource pool block in the Extendsim software. The VSM is modeled as a combination of IMs. The simulation model for the value stream is comprised of interconnected network of the IMs (refer Fig. 21.1). IMs interact among themselves by passing message to one another. The simulation model ensures that lean box scores is kept updated. The evolutionary optimizer strives to achieve lean orientation.

Table 21.3 summarizes implementation of selected IMs.

This proposed framework is demonstrated through the use of a case study of a lamp post base (refer Fig. 21.2). This product is made up of two components: plate, tube. The process flow diagram for manufacturing the product is given in Fig. 21.3. Current demand expected is 500 pieces per week.

The unique feature of this research is that most lean manufacturing projects are carried out when full scale production is in progress. But this company is striving to achieve lean orientation when the product is still in design/prototyping stage. The rationale behind this is that lean manufacturing planning has to be carried out, as early as possible, so as to achieve lean manufacturing when full scale production

Table 21.3 IMs implemented in this research

Intelligent module (IM) (dark colored circles)	Functional area covered	Extendsim implementation (simplified)	Parameters (I = input) (P = optimization parameters)
Process (P)	Process module implements one (or a group) of workstations achieving manufacturing, e.g., a group of drilling machines	 Workstation block	Duration (I) man and machine resources [$x1$, $x2$, …](P) Each workstation processes raw materials in designated time using specified number of resources
Inventory (I)	Material held for a period of time to serve a purpose	Average (raw material entered—finished goods left). Implemented with the combination of holding tank, equation block etc.	Material entering (I), Material leaving (I) Inventory holding rate (I) Size of inventory (P)
Transport (T)	A batch of material transported, e.g., a batch of material transported through a trolley	 Batch block	Batch size (P) Transport time (I)
Raw material, finished goods warehouse (FG, WH)	Temporary storage	 Resource items	Number of items (P)
Other IMs	Remaining functional areas	Part of suggested future research	–

(continued)

Table 21.3 (continued)

Intelligent module (IM) (dark colored circles)	Functional area covered	Extendsim implementation (simplified)	Parameters (I = input) (P = optimization parameters)
Optimizer module	Optimize the input parameters for achieving the desired values of the lean box scores	 Optimizer block	Selected parameters to be optimized (p) for achieving desired objective function

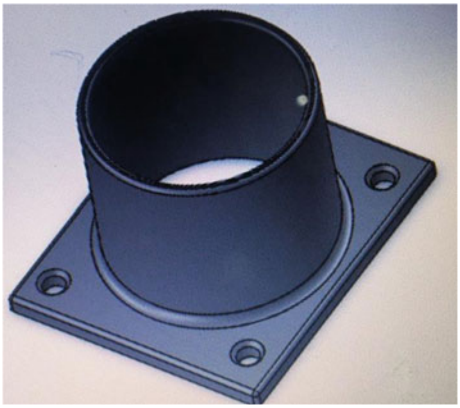


Fig. 21.2 Lamp post base

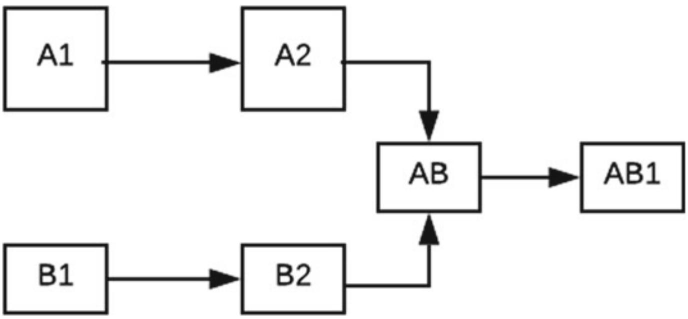
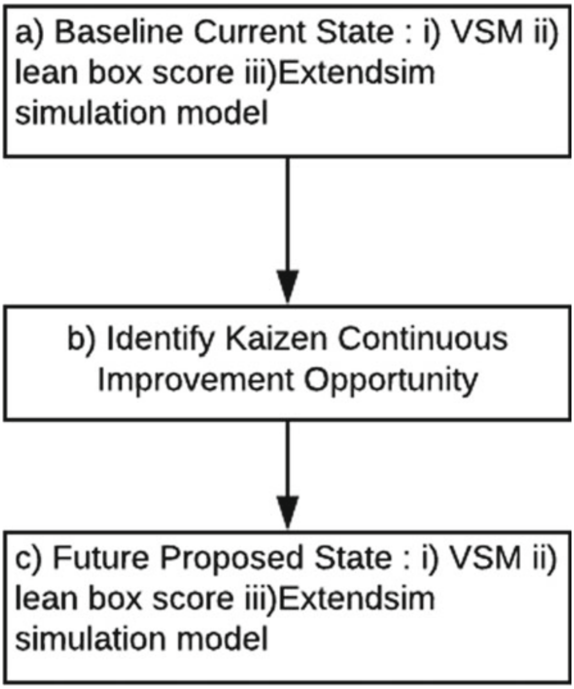


Fig. 21.3 Process flow diagram

Fig. 21.4 Steps to achieve lean orientation



commences. Besides that, all the capital expenditure decisions are taken early during project commencement cycle.

Typically, achieving lean orientation follows the following steps (refer Fig. 21.4):

Step 1. Baselining of the current state is carried out. The value stream map for the current state (initial state) is given in Fig. 21.5.

The current process parameters (estimated) during initial stage (current value stream map) are given in Table 21.4.

This value stream map is obtained during initial un-optimized state of the production system. The process parameters are starting parameters for the production system (refer Table 21.4).

The lean box score is given in Table 21.5.

Step 2. Identify kaizen improvement opportunity.

From the lean box score (refer Table 21.5) it is evident that most significant cost is conversion cost. The parts of lean box score that need urgent attention have been highlighted. The conversion cost is the most significant portion of the total cost. This can be reduced by resource optimization. Other components of the lean box score have to be addressed later.

Step 3. The resource optimization is carried out by Extendsim optimizer. The Extendsim optimizer is an evolutionary optimizer. This optimizer is an

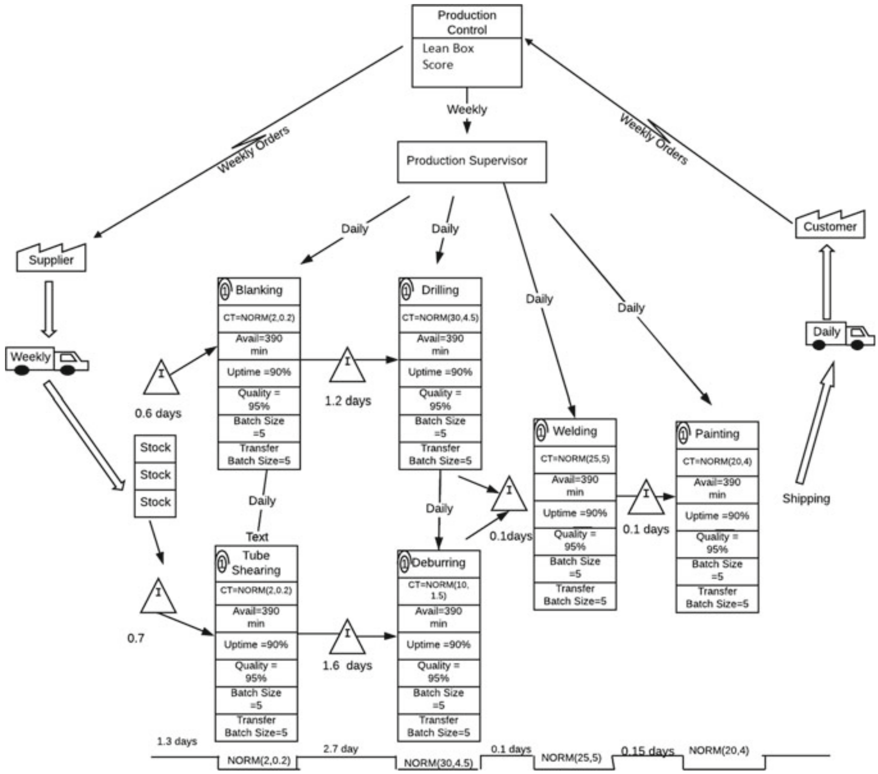


Fig. 21.5 Value stream map

integral part of the software Extendsim (discrete event simulation software). The optimizer is based on evolutionary algorithm. It mimics the common biological evolutionary processes such as mutation, recombination and selection.

Selected parameters from the optimization model shown in Fig. 21.6 are linked to optimizer. The optimizer seeks the desired goal. The optimizer block within Extendsim is presented in Fig. 21.7. Top part of the optimizer window stores the parameters to be optimized. These parameters are derived from simulation model. These parameters are linked to the parameters within the simulation model. The objective function is stored in the bottom part of the window. The simulation model is run multiple times with different values of the parameters. The evolutionary optimizer tries to come up with an optimal solution with favorable values of the lean box score (objective function). Here the lean box score parameter: value stream profit is the objective function. The decision variables are the resource (man and machine) whose optimal values are being sought.

Table 21.4 Process parameters (current state)

Process name	Process code (refer Fig. 21.3)	Cycle time (min)	Set-up time (min)	Transfer batch size (initially assumed value)	No of machines	No of operators	Weekly depreciation cost (USD)	Operating cost (per operation) (USD)
Welding	AB	Normal (2, 0.2)	6	5	9	40[a]	11.5	0.068
Painting	AB1	Normal (30, 4.5)	7	5	7		5.8	0.036
Deburring	B2	Normal (10, 1.5)	2	5	6		1.9	0
Drilling	A2	Normal (30, 4.5)	4	5	11		11.5	0
Blanking	A1	Normal (2, 0.2)	4	5	5		96.2	0
Tube Shearing	B1	Normal (2, 0.2)	6	5	5		2.2	0

[a]Shared between operations; cost of operator $99 (per week); number of operators 25; number of trolleys 25

Table 21.5 Lean box score

Lean box score		
Operational	Dock-to-dock days	3
	First time through (FTT)	90%
	On time delivery/service level	100%
	Floor space	–
Utilization	Productive	*[0.6, 0.6, 0.4, 0.6, 0.1, 0.1]*
	Non-productive	[0.03, 0.04, 0.01, 0.02, 0.03, 0.04]
	Available	[0.4,0.3,0.6,0.4,0.9,0.9]
Financial	Sales per person (USD)	320
	Inventory value	11
	Revenue	8000
	Material costs	5000
	Conversion costs (USD)	*3308*
	Value stream profit (USD)	*−319*
	Sales per product (USD)	16

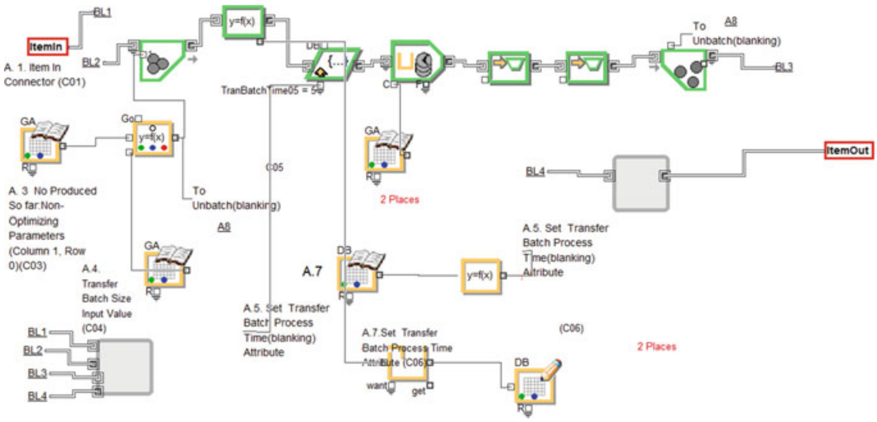


Fig. 21.6 Extendsim simulation model (for a single process)

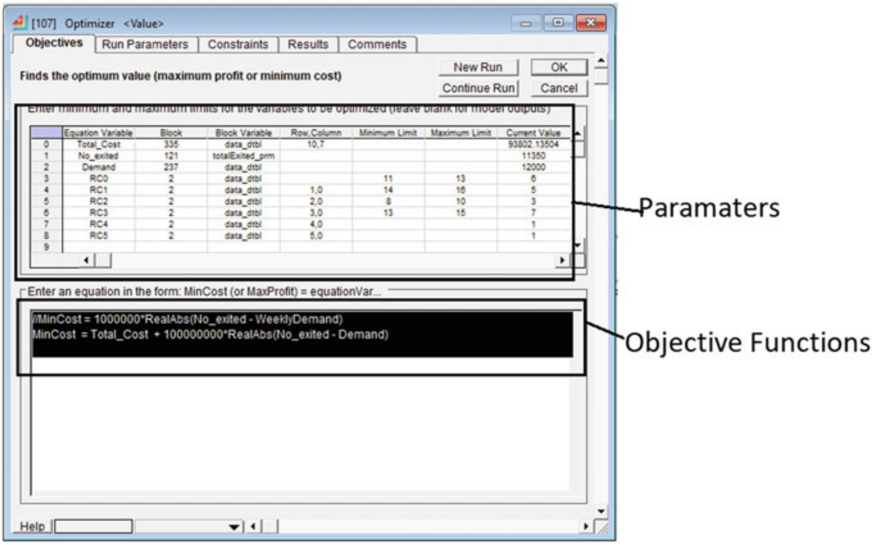


Fig. 21.7 Extendsim evolutionary optimizer

Optimization model:

Value Stream Profit	$\sum_{1}^{n}(\text{Mi Si}) - \left(\sum_{1}^{k}(\text{Hm Rm}) + \sum_{1}^{t}(\text{Ho Oo})\right);$
Mi	Number of pieces of product sold of type *i*
Si	Price of product *i*
Hm	Number of hours resources a resource of type m employed
Rm	Resource rate of type *m*
Ho	Time of operations of type *o*

Table 21.6 Lean box score (future state)

Lean box score		
Operational	Dock-to-dock days	5
	First time through (FTT)	90%
	On time delivery/service level	100%
	Floor space	–
Utilization	Productive	[0.9, 0.8, 0.7, 0.9, 0.4, 0.4]
	Non-productive	[0.04, 0.06, 0.03, 0.02 0.17, 0.20]
	Available	[0.1,0.1, 0.3, 0.1, 0.4, 0.4]
Financial	Sales per person (USD)	320
	Inventory value	317
	Revenue	8000
	Material costs	5000
	Conversion costs (USD)	1631
	Value stream profit (USD)	1052
	Sales per product (USD)	16
	Cost per product (USD)	14

Oo Operation cost of type *o*.

After the optimization, we are one step closer to lean orientation. The lean box score are shown in Table 21.6. The resource optimization leads to line balancing as well.

21.4 Results and Discussions

The lean box score results achieved through evolutionary optimizer are given in Table 21.6.

The proposed methodology is very useful for achieving lean orientation for the complex value stream. It helps to optimize on the relevant parameters of the complex VSM. It helps to focus and prioritize the kaizen improvement ideas. It helps to check feasibility of the future state VSM through the optimization of lean box score [3]. Some of the unique advantages of this innovative approach:

1. Ability to achieve lean orientation for a complex value stream
2. Unique plug and play and approach in modeling the value stream made up of standardized components
3. Ability to prioritize kaizen improvement ideas
4. Ability to perform feasibility checks, i.e., whether a certain kaizen improvement ideas is feasible. The parts can be produced with the available resources at the required performance level.

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Chapter 22
A Framework Development and Assessment for Cold Supply Chain Performance System: A Case of Vaccines

Neeraj Kumar, Mohit Tyagi, R K Garg, Anish Sachdeva, and Dilbagh Panchal

Abstract Vaccines supply chain is the soul for the success of immunization program in any developing or developed country. A poor performing vaccine cold chain will result into failure of immunization program and may cause millions of death from vaccine-preventable diseases. In this research work, an attempt has been made to identify the key performance factors (criteria) which are responsible for reduced performance of vaccines cold supply chain. So far, many researches have been done to identify these performance factors of vaccines cold supply chain performance but the questions such as how these factors will affect the performance, what will be the relationship among them, and what will the best possible solutions to tackle these concerns are not answered systematically. This paper provides systematic answers to these questions. In order to visualize the effect of these performance factors on the of vaccines supply chain and to suggest the best possible alternative, the whole research work is divided into three segment—in the first segment Delphi method has been used to select the most critical factors and best possible alternatives (eight criteria and five alternatives) for the performance of vaccine cold chain, in the second segment research work propose AHP approach to find out the priority weights of selected criteria, and in the third segment TOPSIS approach has been used to provide the ranking for selected alternatives. The results of the research work show that the criteria 'vaccine instability' is most critical and should be taken into consideration at first while establishing the benchmarks for vaccines cold chain. The results of the research work also show that the alternative 'continuous monitoring of vaccine cold chain functionality status' can be adopted as the best solution to improve the performance of vaccines cold supply chain.

Keywords Vaccines supply chain · Delphi method · AHP · TOPSIS · Healthcare industry · MCDM problem

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22.1 Introduction and Background

Vaccine supply chain is a very critical and complex structure of a healthcare industry. The emergence of new vaccines in healthcare sector has widened the competitiveness and scope of healthcare industry. For very long time, it is serving as a lifesaving industrial sector and playing a very vital role in preventing heath-related diseases such as hepatitis B, measles, mumps, polio, tetanus, pneumococcal, and rotavirus. Though the vaccine supply chain has amended as lifesaving industry, it faces several challenges while implementing its objective of saving the people from vaccines-preventable diseases. The areas where the surrounding temperature is too high or too low, i.e., the vaccines exposed temperature is out of the recommended temperature range, it is very difficult to maintain the integrity and potency of the vaccines and sometimes it may lead to death of the vaccinated person. This instability due to temperature variation in terms of quality and potency in vaccines takes place throughout the whole supply chain from laboratory to end point [1]. This may lead to the necessity of the vaccines cold supply chain, the objective of which is to insure the integrity, potency, and stability of vaccines by maintaining the recommended sustainable temperature of the vaccines from primary vaccine stores to the state where vaccination has to be done (end user at the health facility). For maintaining the vaccine stability, WHO recommend that temperature-sensitive vaccines should be stored within a temperature range of +2 to +8 °C [2]. It becomes very difficult to maintain this temperature range where the frequency of power shortfalls is very high and traditional technologies of refrigeration are used [3]. In the developing countries during the power shortfalls, the refrigeration equipment stops functioning and sometimes it takes too long time to retain this sustainable temperature and the vaccines often lost their potency. Vaccines which are biological products lost their quality and potency not only because of exposing them to the heat but also due to freezing of vaccines in the region where the exposure temperature is below the recommended exposure temperature of vaccines [4]. To avoid the unnecessary freezing of the vaccines, it is recommended to follow the continuous temperature monitoring of vaccines state conditions and close examination of the surrounding conditions [5]. WHO estimates that though about 2–3 million deaths are prevented every year due to vaccination, about 1.3 million deaths are caused by vaccines-preventable diseases just because of unreachability of immunization. Chandra and Kumar, 2018, presented ineffectiveness in the vaccines supply chain as the primary reason behind the unreachability of immunization program in developing countries [6]. Though the immunization programs have covered about 85% of the world population, millions of children died from vaccines-preventable disease. The reason behind the failure of immunization program in developing countries is the lack of sufficient cold storage facility to store the vaccines and limited financial resources [7]. Many researchers have done a lot of work for identifying the key challenges in the performance measure of vaccines supply chain. The common objective of those researches was to reduce the death rates due to vaccines-preventable diseases by achieving maximum coverage of immunization by providing potential, safe, and effective vaccines. Geographical barriers also play a significant role in the performance of vaccines cold supply chain [6]. In the rural areas or where the transportation facilities are not so good, it is always difficult for the health workers to reach the location where vaccination has to be done. The regions where the surrounding temperature is too high such as African and some Asian countries, it becomes difficult to maintain the quality and potency of the vaccines and sometimes it leads to the death of vaccinated person. The implementation of cold chain regulatory acts and proper training to handling staff will result into a significant improvement in the performance of cold chain and will reduce the waste due to lost quality and potency [8].

22.2 Model Formulation

To carry out this research work, a deep study of previous researches related to vaccines supply chain and Delphi method has been conducted. Delphi method has been conducted to find out the field experts opinions about the issues and their possible alternative. To carry out the Delphi method, a brainstorming session with filed experts has been conducted. Field experts belong to vaccines industrial sector and different academia located near Jalandhar district in Punjab state of India. On the basis of existing literature review and opinions obtained from field experts during brainstorming session, eight criteria and five alternatives have been selected. Criteria namely—vaccine instability ($C1$), dependency on unreliable power supply ($C2$), lack of sufficient cold chain capacity ($C3$), poor coverage of immunization program ($C4$), vaccines wastage due to poor handling ($C5$), poor distribution structure ($C6$), use of damaged and inefficient cold chain equipment ($C7$), and lack of performance management system ($C8$).

Selected alternatives are continuous monitoring of vaccine cold chain functionality status ($A1$), adoption of passive cold devices ($A2$), routine maintenance of cold chain equipment ($A3$), more focus on vaccines cold chain regulations and guidelines ($A4$), and continuous gap analysis and health worker training ($A5$). To achieve the desired objective of the research, a hierarchy-based performance measurement model for vaccine cold supply has been constructed which is shown in Fig. 22.1.

22.3 Research Methodology

As a part of research methodology, AHP and TOPSIS methods have been used as a hybrid approach. AHP has been used to prioritize the criteria weights while in order to rank the alternatives, TOPSIS method has been used. The purpose of using this hybrid approach is to provide the robust outcome with ease in calculation work [9].

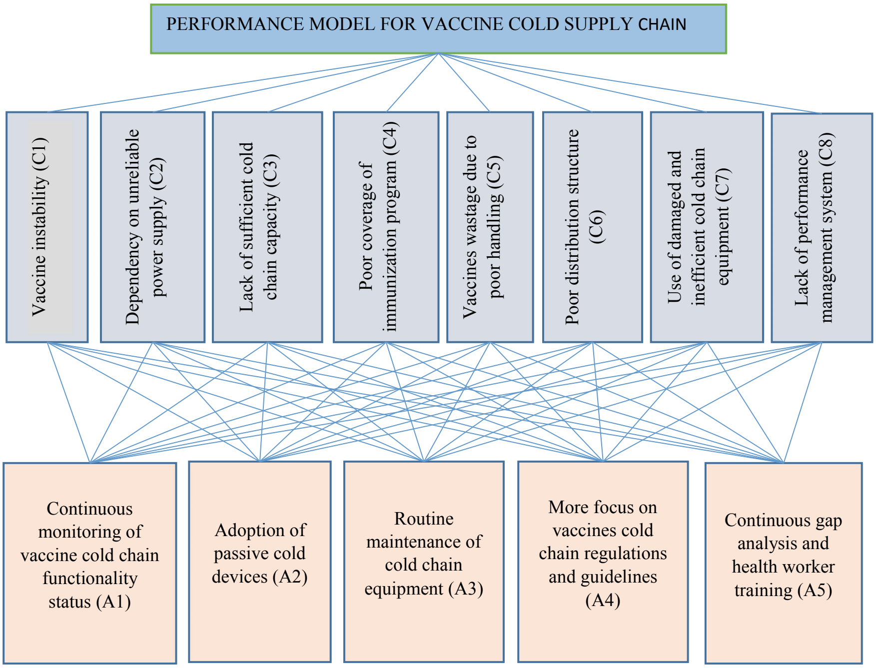

Fig. 22.1 Hierarchal performance measurement model for vaccine cold supply chain

22.3.1 Delphi Approach

Delphi technique was developed by Dalkey and Helmer in the 1950s. The Delphi technique is most widely used and accepted method which is designed as a group communication process or brainstorming interaction which aims to achieve the expert's consensus of opinions by using a questionnaire for a real-world problem [10]. To conduct the Delphi approach initially, a deep study of literatures of past researches of vaccine supply chain has been conducted and the key performance factors of vaccines cold supply chain and to tackle these challenges and for improved performance of the same, possible alternatives were identified. Then, a questionnaire containing challenges and possible alternative was dispatched to the field experts and opinions about their severity of these challenges were obtained. Then, on the basis of opinions of experts about the severity of the identified key performance factors (criteria), eight most severe criteria and five best possible alternatives have been selected.

22.3.2 *The Analytic Hierarchy Process (AHP) Approach*

AHP approach is the most commonly used multi-criteria decision-making technique and is used as a standard tool for multi-criteria decision-making (MCDM) problem because of its simplicity and flexibility to real-world problems. It was introduced by Thomas Saaty in 1980. AHP enables the decision-makers to make decisions depending upon the priority weights obtained from pairwise comparison matrix for criteria. Comparison between the criteria has been made using Saaty's 1–9 scale of relative intensity which is given in Table 22.1.

In this paper, standard AHP approach as explained by Triantaphyllou and Mann, 1995 [11], is used to find the priority weights for selected criteria and then consistency test for priority weights has been conducted. According to Saaty's criteria for consistency check, if the value of consistency ratio (C.R.) is less than or equal to 0.1, then the consistency exist and the priority weights can be selected for making the decision. Stepwise procedure to implement AHP methodology is given in the following section;

Step 1 Construct a pairwise comparison matrix for criteria using a scale of 1–9 for relative importance.

If there are N criteria, then the comparison of criteria i with respect to criteria j will result in a square matrix. The comparison matrix for criteria should satisfy the following criteria

$$a_{ij} = 1,\ \text{when}\ i = j;\ \text{and}\ a_{ji} = \frac{1}{a_{ij}} \tag{22.1}$$

Step 2 Compute the relative normalized weight (wc_i) for each criterion.

Table 22.1 Saaty's scale for intensity of relative importance

Definition	Intensity of relative importance
Equally important/preferred	1
Weakly important/preferred	3
Strongly important/preferred	5
Very strongly more important/preferred	7
Absolutely more important/preferred	9
Intermediate importance between two adjacent judgements	2, 4, 6, 8

Table 22.2 Saaty's R.I. table for the number of criterion N

N	1	2	3	4	5	6	7	8
R.I.	0.00	0.00	0.58	0.90	1.12	1.24	1.32	1.41

$$\mathrm{GM}_i = \left(\prod_{j=1}^{M} a_{ij}\right)^{\frac{1}{M}}; \quad \text{and} \tag{22.2}$$

$$\mathrm{Wc}_i = \frac{\mathrm{GM}_i}{\sum_{j=1}^{N} \mathrm{GM}_i} \tag{22.3}$$

Step 3 Structured matrix A_3 and A_4 such that $A_3 = A_1 \times A_2$ and $A_4 = \frac{\mathrm{A}_3}{\mathrm{A}_2}$;

where

$$A_2 = [W_1, W_2, \ldots W_i, W_N]^T \tag{22.4}$$

Step 4 Obtain maximum eigenvalue ($\gamma_{\max}$) which is the average of matrix A_4.

Step 5 Calculate the consistency index-

$$\mathrm{C.I.} = (\gamma_{\max} - \mathrm{N})/(\mathrm{N} - 1). \tag{22.5}$$

The smaller the value of C.I., the smaller is the deviation from the consistency.

Step 6 Calculate the consistency ratio,

$$\mathrm{C.R.} = \mathrm{C.I.}/\mathrm{R.I.} \tag{22.6}$$

C.R. is an approximate mathematical indicator, of the consistency of pairwise comparisons.

Where R.I. = random index for the number of criteria used in decision making obtained from Saaty's R.I. table for N criterion as given in Table 22.2.

22.3.3 TOPSIS Method

Technique for order preference by similarity to ideal solution (TOPSIS) is a multi-criteria decision-making tool which is most commonly used by the decision-makers to make decisions based on the ranking order obtained from this technique. TOPSIS was first introduced by Huang and Yoon in 1981 [12]. In TOPSIS method, the relative comparison of each alternative with respect to each criterion depends upon the opinions obtained from the experts. TOPSIS method aims to find out the best possible alternative which is nearest to the positive ideal solution (PIS) and farthest to negative ideal solution (NIS). Ranking for the alternatives depends upon the relative closeness coefficient which is the measure of distances of the alternatives from PIS and NIS [13]. The steps for implementing the TOPSIS to obtain the alternative ranking as stated by Joshi, Banwet, and Shankar (8b) are as follow;

Step 1 Construct the comparison matrix, $A = [X_{ij}]_{mn}$, for the alternatives relative to criteria, where m denotes number of alternative and n for criteria and X_{ij} be the score for ith alternative relative to jth criteria.

$$A = \begin{array}{c} \\ X_1 \\ X_2 \\ X_3 \\ . \\ . \\ X_m \end{array} \begin{array}{c} C1 \ldots C2 \ldots\ldots\ldots Cn \\ \begin{bmatrix} x_{11} & x_{12} & \ldots. & x_{1n} \\ x_{21} & x_{22} & \ldots. & x_{2n} \\ x_{31} & x_{32} & \ldots. & x_{3n} \\ . & . & \ldots. & . \\ . & . & \ldots. & . \\ x_{m1} & x_{m2} & \ldots. & x_{mn} \end{bmatrix} \end{array} \tag{22.7}$$

Step 2 Computation of normalized decision matrix which is obtained by dividing the each element of comparison matrix by square root of sum of the square of each element of the decision matrix for the corresponding alternative (row normalization) or criteria (column normalization).

$$r_{ij} = \frac{x_{ij}}{\sqrt{\sum_{i=1}^{m} x_{ij}^2}} \tag{22.8}$$

Step 3 Computation of weightage normalized decision matrix which is obtained by multiplying criteria weight w_j and r_{ij} element of the normalized decision matrix.

$$Z = \left(z_{ij}\right)_{m\times n} = \left(w_j r_{ij}\right)_{m\times n}, \quad i = 1, 2 \ldots, m$$

$$Z = \begin{bmatrix} z_{11} & z_{12} & \cdot\cdot & z_{1j} & \cdot\cdot & z_{1n} \\ \cdot & \cdot & \cdot\cdot & \cdot & \cdot\cdot & \cdot \\ \cdot & \cdot & \cdot\cdot & \cdot & \cdot\cdot & \cdot \\ z_{i1} & z_{i2} & \cdot\cdot & z_{ij} & \cdot\cdot & z_{in} \\ \cdot & \cdot & \cdot\cdot & \cdot & \cdot\cdot & \cdot \\ \cdot & \cdot & \cdot\cdot & \cdot & \cdot\cdot & \cdot \\ z_{m1} & z_{m2} & \cdot\cdot & z_{mj} & \cdot\cdot & z_{mn} \end{bmatrix} \tag{22.9}$$

Step 4 Computation of positive ideal solution (PIS) and negative ideal solution (NIS).

$$\begin{aligned} \mathrm{PIS}(S^{+}) &= \left\{ \left(\max_i z_{ij} / j \in J\right), \left(\max_i z_{ij} / j \in J'\right) \text{ for } i = 1, 2, \ldots m \right\} \\ &= z_1^{+}, z_2^{+}, \ldots z_j^{+}, \ldots z_n^{+} \end{aligned} \tag{22.10}$$

$$\begin{aligned} \mathrm{NIS}(S^{-}) &= \left\{ \left(\min_i z_{ij} | j \in J\right), \left(\max_i z_{ij} | j \in J'\right) \text{ for } i = 1, 2, \ldots m \right\} \\ &= \left\{ z_1^{-}, z_2^{-}, \ldots z_j^{-}, \ldots z_n^{-} \right\} \end{aligned} \tag{22.11}$$

where
{$j = 1, 2\ldots n$, associated with the benefit criteria}
{$j' = 1, 2\ldots n$, associated with the cost criteria}

Step 5 Compute the separation for each alternative from PIS and NIS

Positive ideal separation-

$$D_i^{+} = \sqrt{\sum_{j=1}^{n} \left(z_{ij} - z\right)^2} \quad i = 1, 2, \ldots, m \tag{22.12}$$

Negative ideal separation

$$D_i^{-} = \sqrt{\sum_{j=1}^{n} \left(z_{ij} - z_j^{-}\right)^2} i = 1, 2, \ldots, m \tag{22.13}$$

Step 6 Compute the relative closeness coefficient $\left(\mathrm{CC}_i^{*}\right)$ for each alternative.

Relative closeness coefficient for alternatives can be formed by using the following mathematical expression

$$C_i^{*} = \frac{D_i^{-}}{\left(D_i^{+} + D_i^{-}\right)}, \quad 0 < \mathrm{CC}_i^{*} < 1, \quad i = 1, 2, \ldots, m \tag{22.14}$$

Step 7 Provide the ranking for alternatives based on relative closeness coefficient. The alternative which has the highest value of CC_i^* forms the rank first and which has least forms the rank last. Similarly, other alternatives are provided ranks depending upon their CC_i^* value as calculated from TOPSIS methodology.

22.4 Numerical Illustration

To derive the analysis for priority weights, a questionnaire has been structured using Saaty's scale of relative intensity for pairwise comparison (1–9) on Google Docs and dispatched to the field experts belong to healthcare industry and academies of Punjab, India. Questionnaire contains the questions like which criteria are more important for consideration with regard to desired objective of the research. A deep discussion with the experts of supply chain belong to engineering colleges of Punjab region has also been conducted and their opinions about the severity of issues of vaccines cold chain have been obtained. To find out the priority weights for criteria, AHP has been proposed as mentioned in the above procedure for AHP methodology section. For pairwise comparison between criteria, expert's opinions obtained as result of face-to-face discussion and questionnaire interaction have been used. The criterion which forms the highest priority weights should be taken at first priority for consideration. The pairwise comparison for criteria and their priority weights as obtained from AHP methodology is given in Table 22.3.

22.4.1 Test of Consistency for Pairwise Comparison

The summary of consistency test for the above comparison matrix is given in Table 22.4.

Table 22.3 Pairwise comparison matrix for criteria

C_i	$C1$	$C2$	$C3$	$C4$	$C5$	$C6$	$C7$	$C8$	WC_i
$C1$	1	4	3	2	5	2	3	4	0.26332
$C2$	0.25	1	0.33	0.25	4	0.2	0.2	0.33	0.04147
$C3$	0.33	3	1	3	5	2	1	3	0.17053
$C4$	0.5	4	0.33	1	3	0.25	0.33	2	0.08459
$C5$	0.2	0.25	0.2	0.33	1	0.33	0.25	0.5	0.03197
$C6$	0.5	5	0.5	4	3	1	2	4	0.17699
$C7$	0.33	5	1	3	4	0.5	1	3	0.14865
$C8$	0.25	3	0.33	0.5	2	0.25	0.33	1	0.05982

Table 22.4 Summary of consistency test for pairwise comparison between criteria

Parameter	λ_{max}	C.I.	R.I. (from Table 22.4)	C.R.
Calculated value	8.8155	0.1165	1.41	0.08263

Saaty suggests that if the value of C.R. as calculated from AHP analysis is less than or equal to 0.10, then the consistency exists for the pairwise comparison and the priority weights can be accepted. For above pairwise comparison matrix (Table 22.3), the calculated value of consistency ratio (C.R.) as mentioned in the procedure for AHP methodology is 0.08263 which satisfies Saaty's criteria for existence of consistency, and therefore, the pairwise comparison is consistent and the priority weights are acceptable.

In the next segment, an attempt has been made to provide the ranking for the alternatives with respect to calculated priority weights for criteria. For this purpose, TOPSIS approach has been used. TOPSIS approach aims to find out the best possible alternative which is nearest to positive ideal solution (PIS) and farthest to negative ideal solution (NIS). Ranking for alternatives depends upon the relative closeness coefficient $\left(CC_i^*\right)$ as mentioned in the above procedure for TOPSIS methodology. Step-by-step calculation for providing ranking and selecting best possible alternative is mentioned in Table 22.5.

Next, we calculate normalized comparison matrix for an alternative which can be obtained by using Eq. (22.8) as stated in step 2 for TOPSIS methodology. Normalization of the comparison matrix for alternatives has been done to remove heterogeneity of the data and to form dimensionless parameters for the evaluation intensity. The summary of normalization of the comparison matrix is given in Table 22.6.

Table 22.5 Comparison matrix for alternatives with respect to criteria

	$C1$	$C2$	$C3$	$C4$	$C5$	$C6$	$C7$	$C8$
$A1$	6	5	5	8	8	8	8	7
$A2$	9	8	8	8	6	7	6	6
$A3$	5	7	7	7	7	8	9	8
$A4$	6	6	6	9	8	9	7	8
$A5$	5	8	8	8	9	9	7	5

Table 22.6 Normalized comparison matrix for alternatives

	$C1$	$C2$	$C3$	$C4$	$C5$	$C6$	$C7$	$C8$
$A1$	0.5518	0.4211	0.3241	0.4458	0.4666	0.4345	0.4789	0.4537
$A2$	0.4292	0.6317	0.5186	0.4458	0.3499	0.3802	0.3592	0.3889
$A3$	0.3679	0.3509	0.4537	0.3901	0.4082	0.4345	0.5388	0.5186
$A4$	0.4905	0.4211	0.3889	0.5016	0.4666	0.4888	0.4191	0.5189
$A5$	0.3679	0.3509	0.5186	0.4458	0.5249	0.4888	0.4191	0.3241

Table 22.7 Weightage normalized decision matrix for alternatives relative to criteria weights and calculation of PIS (Si^+) and NIS (Si^-) for the same

WC_i	0.26332	0.04147	0.17053	0.08459	0.03197	0.17699	0.14865	0.05983
	$C1$	$C2$	$C3$	$C4$	$C5$	$C6$	$C7$	$C8$
$A1$	0.1453	0.0175	0.0553	0.0377	0.0149	0.0769	0.0712	0.0271
$A2$	0.1130	0.0262	0.0884	0.0377	0.0112	0.0673	0.0534	0.0233
$A3$	0.0969	0.0146	0.0774	0.0330	0.0131	0.0769	0.0801	0.0310
$A4$	0.1292	0.0175	0.0663	0.0424	0.0149	0.0865	0.0623	0.0310
$A5$	0.0969	0.0146	0.0884	0.0377	0.0168	0.0865	0.0623	0.0194
Si^+	0.1453	0.0262	0.0884	0.0424	0.0168	0.0865	0.0801	0.0310
Si^-	0.0969	0.0146	0.0553	0.0330	0.0112	0.0673	0.0534	0.0194

After obtaining normalized comparison matrix, weightage normalized comparison matrix has been computed by using step 3 of TOPSIS methodology and is given in Table 22.7.

Further, calculate the distance of each alternative from PIS and NIS. For the calculation of distance from PIS and NIS, Eqs. (22.12) and (22.13) (as mentioned above for TOPSIS methodology) have been used. The summary of separation distances from PIS and NIS (Di^+ and Di^-) is given in Table 22.8

After calculating the separation distances from PIS and NIS, next we calculate the relative closeness coefficient $\left(CC_i^*\right)$ for each alternative. The final ranking for alternatives will depend upon the $\left(CC_i^*\right)$ value. The alternative for which the value of $\left(CC_i^*\right)$ has highest provided as rank one and one which has least $\left(CC_i^*\right)$ value provided rank five (Table 22.9).

Table 22.8 Summary of the separation distances from PIS and NIS

	$A1$	$A2$	$A3$	$A4$	$A5$
Di^+	0.0373	0.0473	0.0529	0.0339	0.0544
Di^-	0.0535	0.0392	0.0379	0.0431	0.0400

Table 22.9 Summary of relative closeness coefficient $\left(CC_i^*\right)$ and ranking for alternatives

Alternative	$A1$	$A2$	$A3$	$A4$	$A5$
$CC_i^* = \frac{D_i^-}{(D_i^+ + D_i^-)}$	0.5894	0.4528	0.4171	0.5603	0.4240
Rank for alternative	1	3	5	2	4

22.5 Results and Discussion

Vaccine supply chain is a soul measure of the success of any immunization program and the performance of the vaccine supply chain directly affects the death rate and hazards caused from vaccine-preventable diseases. So in this research work, an attempt has been made to identify and prioritize the most critical factors which reduce the performance of vaccine supply chain and suggest some best possible alternative solutions to tackle these situations so that the performance of the same can be improved. At the start of the research work, Delphi method has been used to select the criteria for the performance measure of vaccine supply chain. Delphi method has been accomplished on the basis of deep study of past researches related to vaccine supply chain and by conducting the brainstorming sessions/discussion with field experts. On the basis of opinions obtained from field experts, eight most critical criteria and five best possible alternatives have been selected. Criteria are namely—vaccine instability ($C1$), dependency on unreliable power supply ($C2$), lack of sufficient cold chain capacity ($C3$), poor coverage of immunization program ($C4$), vaccines wastage due to poor handling ($C5$), poor distribution structure ($C6$), use of damaged and inefficient cold chain equipment ($C7$), and lack of performance management system ($C8$). To find out the priority weights, a questionnaire has been structured which includes the questions like which criterion has more importance over other criteria with regard to desired objective of the research and their opinions have been obtained on a scale of 1–9. On the basis of opinions obtained and desired goal of the research, AHP approach has been proposed. The criteria vaccine instability ($C1$) has the highest value of priority weight (0.26332) and is most critical. The reason behind this high value of priority weight for $C1$ is that since vaccines are biological products therefore are temperature sensitive. A little fluctuation of exposed temperature from recommended sustainable temperature may lead to loss of quality and potency of vaccines and sometimes it may lead to death of the vaccinated person therefore becomes most critical performance factor for the performance measure of vaccines cold supply chain. Therefore, in order to improve the performance of vaccine supply chain, this factor should be given first priority for consideration. The criteria vaccine wastage due to poor handling ($C5$) forms the least value (0.03197). The reason behind the low-value WC_5 that vaccine wastage due to poor handling can be controlled by providing proper training to the handling staff and health workers. Also, $C5$ results in the financial losses and it can be compensated by providing proper funding and executing regulations and laws of vaccines handling. Other criteria $C2$, $C3$, $C4$, $C6$, $C7$, and $C8$ form the priority weights 0.04147, 0.17053, 0.08459, 0.17699, 0.14865, and 0.05982, respectively. The order of priority weights for criteria can be formed as: $C1 > C6 > C3 > C7 > C4 > C8 > C2 > C5$. The graphical representation of criteria weights on pie chart is shown in Fig. 22.2.

In order to tackle these situations, the research work proposed five best possible alternatives which are namely—continuous monitoring of vaccine cold chain functionality status ($A1$), adoption of passive cold devices ($A2$), routine maintenance

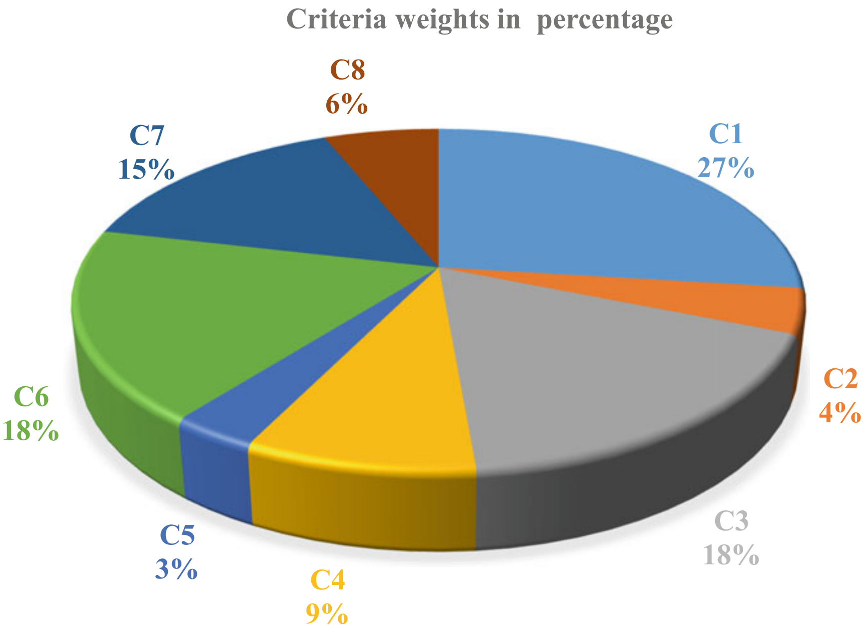

Fig. 22.2 Pie chart representing criteria weights

of cold chain equipment ($A3$), more focus on vaccines cold chain regulations and guidelines ($A4$), and continuous gap analysis and health worker training ($A5$).

To provide the ranking for alternative and to select best among them, we proposed TOPSIS approach to improve the performance of cold supply chain. As discussed above, the ranking of alternatives depends upon the relative closeness coefficient $\left(CC_i^*\right)$ which is a measure of distance from ideal solution, and the alternative $A1$ is provided rank 1 because for $A1$ the value of $\left(CC_i^*\right)$ as calculated from TOPSIS approach is maximum (0.5894) and the alternative $A3$ having least $\left(CC_i^*\right)$ forms the rank 5. Similarly depending upon corresponding $\left(CC_i^*\right)$ values, alternatives $A2$, $A4$, and $A5$ are provided rank 3, 2, and 4, respectively. Therefore, order of preference for proposed alternatives can be obtained as: $A1 > A4 > A2 > A5 > A3$. Figure 22.3 shows the $\left(CC_i^*\right)$ value for each alternative on bar diagram.

22.6 Managerial Implication and Future Scope

This research work provides bright comprehensions for the decision-makers about the factors which are responsible for reduced performance of vaccine supply chain. Research work enlightens the relationships among the various factors such as vaccine instability, dependency on unreliable power supply, cold chain facility, coverage

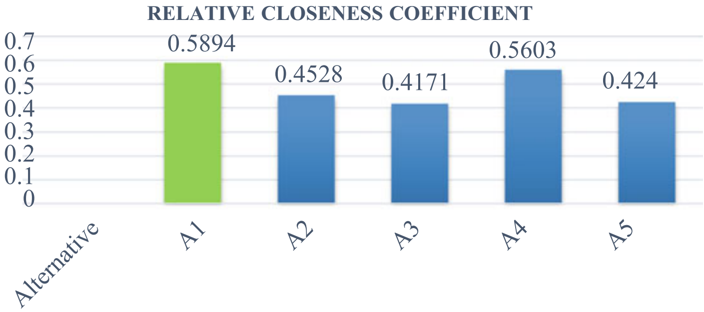

Fig. 22.3 Bar diagram for relative closeness coefficients for alternatives

of immunization program, and poor distribution structure. Further, an attempt has been made to suggest the best possible alternatives and provide ranking for them on the basis of their importance so that the performance of vaccine cold chain can be improved. As discussed earlier, the research provides deep insights toward the issues for the performance of the vaccine cold chain, at the same time it suggests the best possible solutions for them. Therefore, this work provides a good practice for the management and decision-makers to improve their vaccine cold chain performance.

Though from authors' point of view the research work covers most of the factors which are responsible for reduced performance of vaccines cold chain, extensions of this work exist. The interested researchers may consider the subcriteria for the criteria which are responsible for corresponding criteria. In this research work, for prioritizing the criteria and to provide the ranking for alternatives, AHP-TOPSIS hybrid approach has been used. However, in future some other relevant techniques like fuzzy AHP, fuzzy TOPSIS, multi-attribute utility theory, simple multi-attribute rating technique, etc may also be used.

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Chapter 23
Agility in Production Systems: Present Status and Future Prospects

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Abstract In the recent past, the production systems have witnessed paradigm shifts from conventional mass production to lean production and very recently to a state where the products or services need to be designed as per the individual desires of the customers. Due to surge in evolutions and technological advancements in the production systems, the way manufacturing and service sectors have refined is quite evident. At the same time, there has been a significant attitudinal change in the way customers now perceive these systems. The markets have become more volatile, product life has been reduced, and buying power of customers has also gone up due to easy finance options available. As the customer demands more variety in products, so it is the need of the hour that the production systems are designed in such a way that they can be reconfigured to meet the fast-changing demands. In the present work, an attempt has been made to introduce the concept of agility in the light of dynamic market changes with emphasis on need, applicability, enabling technologies, challenges, and future scope of agility by carrying out case studies to validate the relevant aspects of the same.

Keywords Mass production · Lean production · Paradigm shifts · Dynamic market changes · Product variety · Agility

23.1 Introduction

Due to rapidly changing customer demands and increasing competition, manufacturing has undergone many evolutionary stages and paradigm shifts [31] as shown in Fig. 23.1. The journey started from craft production which enabled humankind to produce products in low volume by employing few products. After industrial revolution, as the market demands increased, the production system shifted from craft production to mass production. Mass production enabled humankind to produce

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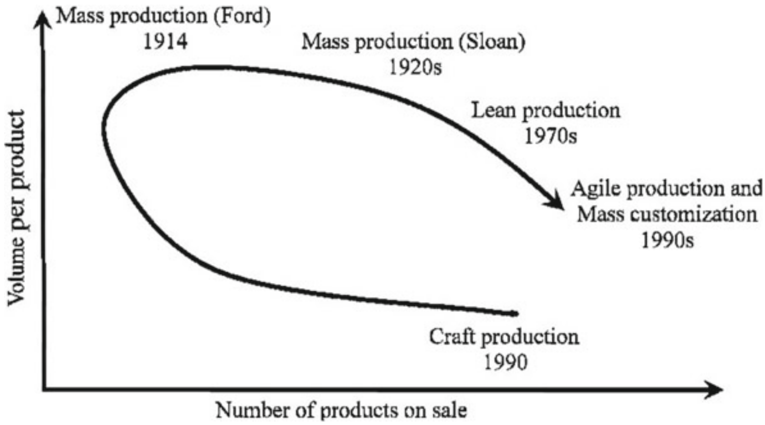

Fig. 23.1 Evolution of production methods [5]

products in large volume by employing many people. As the world began to face the competition, this production technique no longer dominated the production scenario after the 1960s [2]. Thereafter in the 1970s, the world witnesses the emergence of lean production. Lean production is a methodology that focuses on the minimization of waste within production system while maximizing productivity. It worked well where demand was relatively stable and variety was low and predictable [3].

Facing the competitive market, industrial manufacturers are hard pressed to adopt novel strategies and technologies to enhance product quality, to cut manufacturing cost, and to reduce product lead time..Agile manufacturing is an approach to manufacturing which is focused on meeting the needs of customer while maintaining high standards of quality and controlling the overall costs involved in the production of a particular product. It is the capability of surviving and prospering in a competitive environment of continuous and unpredictable change by reacting quickly and effectively to changing markets, driven by customer-designed products and services [4].

23.1.1 Definition of Agility

The ability to be flexible and responsive is called agility [6]. Agile manufacturing which was introduced in the 1990s has witnessed various paradigm shifts in its definition in the past three decades by various researchers. In this section, a variety of definitions given by different authors is presented in Table 23.1 with the objective of developing feasible concept of agile manufacturing.

Table 23.1 Evolution of various definitions for agility

Author	Definition
Nagel and Dove [1]	It is a new post-mass production system for the creation and distribution of goods and services
Dove [7]	Being agile means proficient at change and allows an organization to do anything it wants to do whatever it wants to
Kidd [8]	An agile manufacturing unit is a fast moving, adaptable, and robust business enterprise capable of rapid reconfiguration in response to market opportunities
Goldman et al. [9]	Agility is dynamic aggressively change embracing and growth oriented. It is about winning profits, market shares, and customers in the very center of competitive storms that many companies now fear
Nelson and Harvey [10]	Agility is an organization's capacity to respond rapidly and effectively to unanticipated opportunities and to proactively develop solutions for potential needs
DeVor and Mills [11]	Ability to thrive in a competitive environment of continuous and unanticipated change and to respond quickly to rapidly changing markets driven by customer-based valuing of products and services
Richards [12]	Agility enables enterprises to thrive in an environment of continuous and unanticipated changes
Gupta and Mittal [13]	Agile manufacturing is a business concept that integrates organizations, people, and technology into a meaningful unit by deploying advanced information technologies and flexible organization structures to support highly skilled, knowledgeable, and motivated people
DeVor et al. [14]	Agile manufacturing is an expression that is used to represent the ability of producer of goods and services
Kusiak and He [15]	Agility means a system driven by the need to quickly respond to changing customer requirements
Gould [16]	Agility is a top-down-driven approach designed to respond rapidly to changes in the external world and the forces that a company cannot control. The system is adaptable to rapid changes with the ability to produce small lots
Abair [17]	The concept of agility provides competitiveness to the organizations
Gunasekaran [18]	Agility is the capability to survive and prosper in a competitive environment of continuous and unpredictable change by reacting quickly and effectively to changing markets, driven by customer-designed products and services
Wong and Whitman [19]	Agile enterprise is the one whose processes are able to respond effectively and quickly to rapid and unexpected change
Christopher and Towill [20]	Agility means using market knowledge and virtual corporation to exploit opportunities in a volatile marketplace

(continued)

Table 23.1 (continued)

Author	Definition
Sanchez and Nagi [3]	Agility is characterized by cooperativeness and synergism, by a strategic vision that enables thriving in face of continuous and unpredictable change
Gunasekaran [4]	AM is defined as the capability of surviving and prospering in a competitive environment of continuous and unpredictable change by reacting quickly and effectively to changing markets, driven by customer-designed products and services
Yusuf and Adeleye [21]	AM is encompassed with reprogrammable utilities which are programmed at any time by the knowledge workers
Stratton and Warburton [22]	AM is an approach to manufacturing which is focused on meeting the needs of customers while maintaining high standards of quality and controlling the overall costs involved in the production of a particular product
Wadhwa et al. [23]	Agility can be viewed as a need to encourage the enterprise-wide integration of flexible and core competent resources so as to offer value added products and services in a volatile competitive environment
Bottani [24]	AM is considered a very important and appropriate course of undertakings in a market that demands quick answers to their rapid changes
Vinodh and Kuttalingam [25]	AM is a manufacturing paradigm that enables the industries to respond to the dynamic demands of the customers quickly
Elmoselhy [26]	AM is a manufacturing strategy, which can enable a company to be flexible enough to quickly respond to the dynamic demands of the customers and manufacture products with many varieties and innovative features
Manivelmuralidaran [27]	Agility is a long-term issue for businesses and achieving agility is a journey, not an objective to be attained before moving on to something else
Vyshnavi and Chetan [28]	Agile manufacturing system is most suitable and beneficial than the other manufacturing systems which efficiently and cost-effectively adapts to change in demand
Gunasekaran et al. [29]	Agile manufacturing is indispensable as a means of enhancing competitive advantage

23.1.2 Why Agility?

With the advent of newer technologies, agility has become a key to survive in the present scenario. In today’s market, not only is the change happening quickly but it is forcing businesses themselves to change quickly. New products and services can now be created in a very less time, satisfying the rapidly varying customer demands. The customers are now expecting more value for their money in terms of factors shown in Fig. 23.2. In order to meet ever-increasing demands for quantity and quality at affordable price, manufactures are adopting newer ways to extract maximum out of

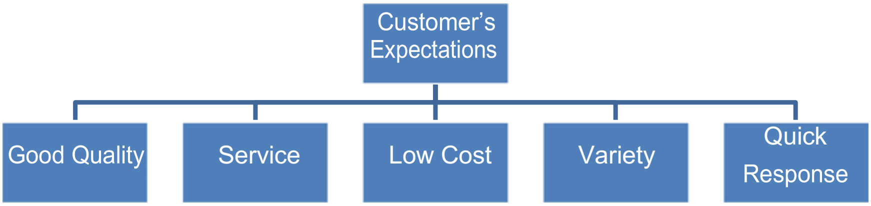

Fig. 23.2 Attributes expected by the customers

the resources they employ. This ensures their survival in the competitive product markets but does not guarantee their growth. Today, many organizations are staring at the danger of getting extinct because of their inability to quickly respond to the changing market needs. Customization therefore seems to be a new buzzword for survival and growth. The effect is taking shape as reflected by the introduction of new models of cars, for example, in quick successions to cater to the rapidly changing taste of the customer. This poses a big challenge for the organization to be always on their toes as far as producing a diversified range of products with new editions every now and then.

The goal of an agile manufacturer is to present a solution to its customer's needs and not just a product. The agile manufacturing firm should be able to respond to [30]:

- Rapidly changing markets;
- Global competitive pressure;
- Decreasing new product time-to-market;
- Increasing inter-enterprise cooperation;
- Interactive supply chain relationships;
- Increasing value of information service.

23.2 Enabling Technologies

As the market is becoming volatile in environment, production systems are turning toward agile systems. In order to shift from the present conventional ways of productions systems to the agile ones, radical changes are required to be made systematically in almost all the segments. Over a period of time, different researchers have dedicatedly put in a lot of efforts to identify various enabling practices required for this transformation. Various enablers are identified by the researchers that would aid the companies in implementing agility. Some of the enabling technologies, categorized into management techniques and technological techniques, have been presented in Fig. 23.3.

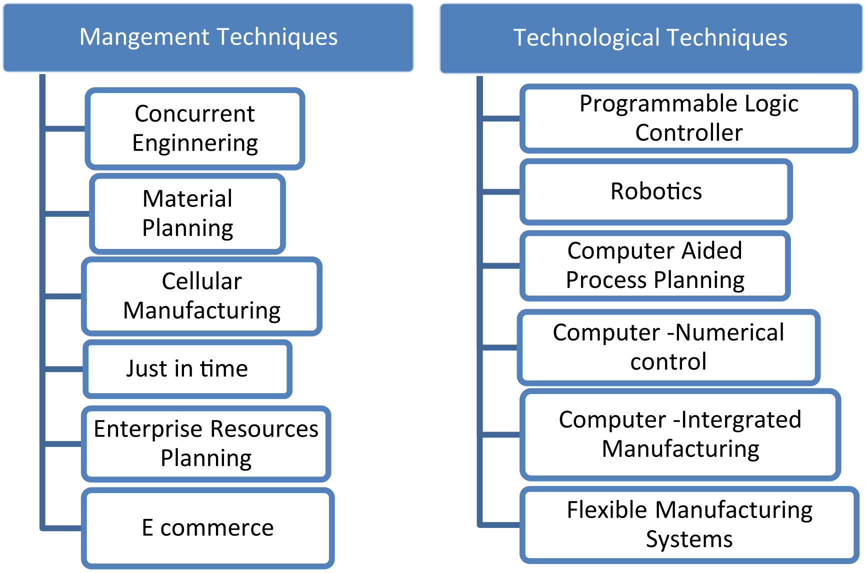

Fig. 23.3 Enabling technologies for agility

23.3 Scopes and Challenges

Agility is a synthesized use of the developed and well-known technologies and methods of manufacturing in a revolutionary new way which sometimes dares to defy the conventional management practices and well-established schools of thoughts. The concept of agile manufacturing was introduced in 1990 and was looked up to as new way of doing business in twenty-first century. Now, after almost three decades, the global industry is realizing the necessity to be agile. But the authors feel that growth made so far in this direction is much on the research side than on the ground. The probable reasons could be that still there is a lack of awareness about this concept in both customers and producers alike. Secondly, the concept asks for radical changes in the current system which can be perceived as risk by many producers.

The implementation of this concept could be highly demanding on resources with uncertainty on the returns. Even if the producer aligns its facilities to being agile, the supporting systems are not designed that way. To bring agility in practice, training of the employees should be emphasized upon to bring a cultural change in the mind-sets of the workforce. Currently, large batch sizes are preferred in the production systems to exploit economy of the scales but it needs to be changed as the mass markets are expected to be converted in niche markets which further are expected to get fragmented into individualistic demands to be catered only by embracing mass customization.

Further reconfigurability of the resources, reduction in the setup, and change over time may lead the organizations from economy of scales to economy of scopes.

In spite of many challenges which exist till date, the authors are of the belief that more and more emphasis on practical aspects will ultimately lead to the evolution of agility in almost all industrial setups because that is the only way going to survive and thrives in times to come.

23.4 Questionnaire Survey

A survey was conducted to evaluate the extent of agility in the present industrial scenario. It consisted of fourteen questions with five options having the following weightage scheme. The results obtained were consolidated in a way that for each question the weighted average scores were calculated (Table 23.2).

Table 23.2 Questionnaire with scores

S.No	Questions	Score obtained
1.	Does your system support variability in your product/service?	0.63
2.	What is the ease of customization of the product/services?	0.61
3.	Rate your technological standing w.r.t. your competitors?	0.72
4.	How would you rate the variation in market trends on your product/services?	0.56
5.	How capable is your organization to handle the market trend variation?	0.67
6.	How effectively and quickly your company responds to the changes in market trends?	0.64
7.	Is the speed of organizational strategic decision making measured in hours (1), days (3/4), weeks (1/2), months (1/4), or years (0)?	0.55
8.	Can you timely re-invent and re-engineer the organization?	0.53
9.	Is change recognized as an opportunity?	0.71
10.	Up to what extent your systems are automated?	0.63
11.	Can your product be easily customized for an individual customer?	0.60
12.	Do you think training of employees will enhance the company's capability of customization?	0.73
13.	How open are you to join hands with your competitors to encash a temporary opportunity in the market requiring expertise of the stake holders?	0.52
14.	Rate the extent of employee's empowerment?	0.71
Total marks obtained out of 14		8.81

23.5 Conclusion

The results obtained revealed that the extent of agility visible in the industrial sectors is not appreciable. The score of the survey, i.e., 8.81 out of 14, indicates that a lot of innovative and radically technological work is still required to be done to meet the scope and challenges posed by the changing demands of the industry. Agility in manufacturing can therefore be looked as a paradigm shift from what is being presently followed in industry to what needs to be done. As the table indicates that the maximum score is given to the need of training in achieving the agility, it reflects the importance of the same as opposite to the common belief that undermines the very existence of training. The minimum score as per the table above however has been received by openness of the organizations to join hands with competitors to encash temporary opportunities in the market. This reveals that this area needs maximum attention and conducive methodologies are required to be evolved to protect the interests of the involved parties, whether it is legal aspects, technological aspects, or profit-sharing aspects.

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Chapter 24
Classification of Diabetes Using Naïve Bayes and Support Vector Machine as a Technique

Smriti Gupta, Harsh Kumar Verma, and Divyansh Bhardwaj

Abstract Diabetes is one of the most common disease in today's life. It is affecting people with a high rate, destroying person's physical, mental, economic and family life. Diabetes is a disease when the normal metabolic process is affected by an increase in the blood sugar level. The disease falls under the chronic category and is said to be the 7th leading cause of death, according to American Diabetes Association (ADA).In this manuscript, Pima India Diabetes Dataset is taken from the UCI Repository for the analysis purpose. The study used Naïve Bayes and Support Vector Machine as classification models along with feature selection for improving the accuracies of the model. Result evaluation is done based on accuracy, precision and recall values. Enhanced performance of the model is calculated using *k*-fold cross-validation technique. Experimental result shows that the performance of Support Vector Machine is better than Naïve Bayes model.

Keywords Naïve Bayes · Support vector machine · *k*-fold cross-validation · Extra tree classifier

24.1 Introduction

Diabetes is a serious condition characterized by increase in the blood sugar (glucose) level over an extended period of time. As of 2015, 30.3 million people in the USA had diabetes. The frequency of the disease is 425 million which is around 8.8% of the world's population. There are 3.2–5.0 million deaths estimated per year. The food we eat gives us energy in the form of glucose. So glucose needs to be circulated to each and every cell of the body. Pancreas produces a hormone, named Insulin which does the job of making glucose reach to our cells to be used up for energy [1].

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Diabetes may be due to two basic reasons: the first one being Pancreas not making sufficient Insulin (Type 1 Diabetes) and the other being the inability of the cells in answering to the Insulin produced (Type 2 Diabetes). As a result of which glucose stays in our blood and does not reach the cells [2].

Mild diabetic cases include uneasiness, sweating and nervousness. Severe cases involve some change in behavior, unconsciousness or death. There are terms like "a touch of sugar" or "borderline diabetes" which represent that the person is less likely to have diabetes or has a less severe type. Having too much glucose in the blood can cause serious health problems.

24.1.1 Type of Diabetes

24.1.1.1 Type 1 Diabetes

Pancreas contains beta cells that are responsible for making Insulin. Insulin's job is to help move glucose in the body tissue. When the immune system demolishes these cells, the body fails to produce Insulin. As Insulin is not produced the glucose is not able to reach these tissue and they starve. Instead, it builds up in the blood and causes high blood sugar which can lead to serious health problems. Type 1 diabetes often starts in childhood or adolescence, but it can occur at any age [2].

24.1.1.2 Type 2 Diabetes

Although Insulin is produced in this type, the cells do not respond as effectively as they should. The body either resists the effects of Insulin or does not produce enough Insulin to maintain normal glucose levels. Type 2 diabetes has no cure. It usually starts after the age of 45 years, although it can appear earlier [2].

24.1.1.3 Gestational Diabetes

It is common in women at the time of pregnancy since the body becomes less sensitive to Insulin at that time. It gets rectified after giving birth. Some lesser popular diabetes is: Cystic fibrosis related diabetes and monogenic diabetes.

24.1.2 Prediabetes

Prediabetes is a condition when the blood sugar level lies in the range of 100–125 milligrams per deciliter (mg/dL) which is above the normal blood sugar level (70–99 mg/dL).

The risk factors of prediabetes and Type 2 diabetes are alike:

- Family background of diabetes
- Being overweight
- Being above 45 years
- Having a high-density lipoprotein (HDL)
- Having a sedentary (sitting for long) lifestyle.

24.1.3 Difficulties Due to Diabetes

Diabetes causes damage to the small blood vessels that indulges some fundamental drawbacks:

- Depreciation to the kidneys (Diabetic Nephropathy)—it involves urine protein loss, tissue scratch and ultimately prolonged kidney disease.
- Depreciation to the eyes (Diabetic Retinopathy)—it involves gradual sight loss and ultimately blindness. It may also cause other eye problems.
- Depreciation to the nerves (Diabetic Neuropathy)—it involves pain, creep and insensitivity in the body which may lead to ulcers and untreated wounds and scratch.
- Diabetes may also lead to stroke, kidney diseases, heart diseases and dental problems.

24.1.4 Symptoms of Diabetes

Some common symptoms of diabetes are mentioned below:

- Polyuria (Frequent Urination)
- Polyphagia (Increased Hunger)
- Polydipsia (Increased Thirst)
- Tiredness
- Sores that do not heal
- Unusual weight loss
- Insensibility in the hands and feet.

24.1.5 Prevention and Treatment

Although Type 2 diabetes has no cure, you can take steps to manage it. Mild and moderate cases can be self-treated but severe cases require injections with glucagon. Some safeguards are listed below:

- Medications and healthy lifestyle
- Standard body weight
- Stay away from tobacco
- Physical exercise in a routine manner.

24.1.6 Medications

The most common medications are Insulin, metformin and self-monitoring. Let us discuss them in sequence.

24.1.6.1 Using Insulin

Insulin is given to regulate the blood sugar level. Whenever the blood sugar level becomes too high people may need to inject Insulin. A person usually checks his/her blood sugar using a finger stick.

24.1.6.2 Metformin

For Type 2 diabetes, a doctor may prescribe metformin in liquid or pill form.

It adds in achieving the following:

- In building Insulin more impressive
- Degrading the blood glucose
- Weight loss.

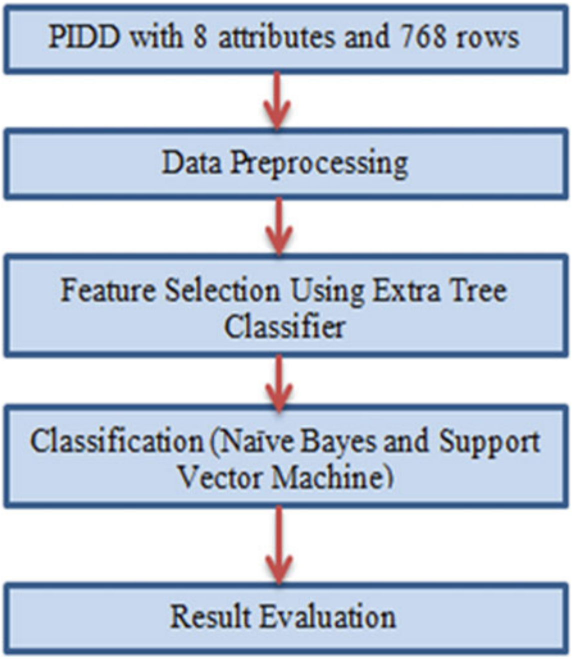
24.1.6.3 Self-monitoring

It is done by using a device called lancet, to pinhole the skin for collecting blood sample. It is significant step in diabetes management as it aids in scheduling the daily activities like exercise, medication, diet and weight.

24.2 Methodologies

Figure 24.1 represents the summarized picture of the methodology used in this manuscript. The dataset is taken from Pima Indian Diabetes Dataset (PIDD) from the UCI Machine Learning Repository [3]. The objective of the paper is to correctly classify if the person has diabetes or not (whether class 0 or 1) from their medical history using techniques and models [3, 4].

Fig. 24.1 Flow chart of the methodology used



24.2.1 Dataset Description and Preprocessing

The dataset is taken from Pima Indian Diabetes Dataset (PIDD) from the UCI Machine Learning Repository which contains number of attributes as 8 and number of rows as 768. The list of attributes is shown in Table 24.1.

Data preprocessing involves handling of missing data, scaling of the attributes value because data can have missing values for a number of reasons. There are many

Table 24.1 List of attributes

S. No.	Attributes	Labels
1.	Number of times pregnant	Preg
2.	Plasma glucose concentration	Plas
3.	Diastolic blood pressure (mm Hg)	Pres
4.	Triceps skinfold thickness (mm)	Skin
5.	2 h Insulin	Insu
6.	Body mass index (kg/m^2)	Mass
7.	Diabetes pedigree function	Pedi
8.	Age (years)	Age
9.	Class variable (0 or 1)	Class

algorithms which do not support missing values and it may also lead to incorrect result; therefore, it is vital to deal with it.

- Imputation—replace the null rows with some relevant values. Here we replaced the rows with the mean of the corresponding attributes. After this step each and every cell will have an entry.
- Scaling—dataset may contain features of varying magnitudes and units. For instance, 1 kg and 1000 g will have a vast impact on the result so we need to bring all attributes (features) to the same level of magnitude in order to suppress the difference.

24.2.2 Feature Selection

Not all the features of the dataset contribute to the result, there are some features which may be irrelevant and decreases the accuracy of the model [7]. So by some feature selection models we choose relevant features which contribute most to the output [8, 9]. Here we used extra tree classifier (ETC) as feature selection technique. The relevant features that were obtained are:

- Plasma glucose concentration
- Body mass index (kg/m^2)
- Diabetes pedigree function
- Age (years).

24.2.3 Classifiers Used in This Methodology

24.2.3.1 Naïve Bayes

A classification technique that is based on Bayes theorem with the belief that the presence of a specific feature in a class is not related to other features presence. It has applications in the area of recommendation system, classification works, predictions and filtering spam. Naïve Bayes is the most common and effective algorithm as it is easy to code and predictions are quick to make [4].

Bayes' theorem states that given hypothesis *h* and data *d*:

$$P(h/d) = (P(d/h) * P(h))/P(d)$$

$P(h/d)$ or posterior probability is the probability of hypothesis *h* given the data *d*.
$P(h)$ is the probability of hypothesis *h* being true, independent of *d*. It is known as prior probability.
$P(h/d)$ is the probability of data *d* being true given hypothesis *h* is true.
$P(d)$ is the probability of data *d*, independent of hypothesis *h*.

As the posterior probability is calculated for n different hypothesis, we can choose the hypothesis with the maximum probability which is known as maximum a posteriori (MAP). This is expressed as:

$$\text{MAP}(h) = \max(P(h|d))$$
Or
$$\text{MAP}(h) = \max((P(d|h) * P(h))/P(d))$$
Or
$$\text{MAP}(h) = \max(P(d|h) * P(h))$$

On an average we will need 2 * ($2^n - 1$) parameters for training the model which is not possible in real scenarios. Therefore, we make an assumption which converts the Bayes algorithm into Naïve Bayes. The assumption states that given random variables *A, B, C* we say *A* is conditionally independent of *B* given *C*, if and only if the probability distribution governing *A* is independent of the value of *B* given *C*. Moreover Naïve Bayes reduces the complexity of Bayes algorithm [5, 6]. Instead of calculating $P(d1, d2, d3|h)$ for every attribute, in Naïve Bayes they are assumed to be conditionally independent and is calculated as $P(d1|h)$ * $P(d2|h)$ and so on. In other words we can say, given *n* different features, the likelihood is written as:

$$P(X1, X2, \ldots, Xn|Y) = \prod P(Xi|Y)$$

where *X* means features and *Y* means response variable. Now $P(X|Y)$ is equal to the product of probability distribution of each attribute *X* given *Y*. Given Naïve Bayes model, we can make predictions for new data using Bayes theorem as:

$$\text{MAP}(h) = \max(P(d|h) * P(h))$$

24.2.3.2 Support Vector Machine (SVM)

It is a supervised learning technique used for classification and regression purpose. The SVM model marks the examples as points in space and is mapped in such a way that the hyperplane clearly differentiates them into separate categories by widening the gap as large as possible [10]. It is suitable for linear as well as non-linear classification (with kernels). Given some training examples (points) that belong to either of the two categories, the SVM classifier constructs a model that assigns new test examples to one of the two categories accurately, making it a binary linear classifier [11].

There are two kinds of SVM classifiers:

- Linear SVM
- Non-linear SVM.

In linear classifier, the training examples (points) are plotted in space where a straight hyperplane divides the points into two classes. The distance between the hyperplane and nearest points of either of the two classes should be maximum, known as maximum margin hyperplane. The data points nearest to the hyperplane are called support vectors.

In non-linear classifier, examples (points) are plotted in a higher dimensional space. There are situations when the data points are not linearly separable in n dimensional space; therefore, they are mapped to a much higher dimensional space using the concept of kernels. There are many standard kernels of which radial basis function kernel is the most common. The SVM classifier and kernel types can be better understood by Fig. 24.2.

Radial Basis Function Kernel (RBF Kernel)—it is used to construct complete non-linear hyperplane. Parameter should be wisely chosen as it could lead to over fitting [12].

$$K(x, x') = \exp\left(\left(-||x - x'||^2\right)/2\sigma^2\right)$$
$$\sigma = \text{free parameter}$$
$$x, x' = \text{vector of feature space}$$

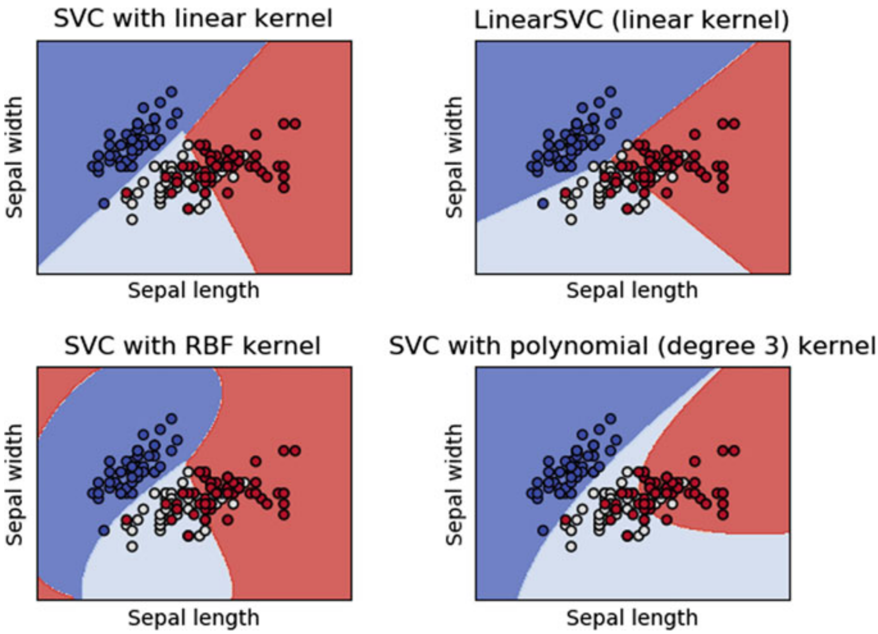


Fig. 24.2 Types of kernels in SVM

Table 24.2 Confusion matrix

	Predicted: YES	Predicted: NO
Actual: YES	TP	FN
Actual: NO	FP	TN

24.2.4 k-Fold Cross-Validation

Since we need to optimize the way to evaluate the model, one way is to split the data into two parts, i.e., test and train data where training is done on train data and testing is done on test data. This is a correct way of evaluating the performance but is not the best way since it causes variance problem. The algorithm to fix variance problem is known as *k*-fold cross-validation where *k* denotes the number of groups in which data is split. Usually $k = 3, 5, 10$. The steps in *k*-fold cross-validation are:

- Shuffle the dataset randomly.
- Split the dataset into *k* groups
- For each unique group:
  - Take the group as a hold out or test dataset
  - Take the remaining groups as a training dataset
  - Fit a model on the training set and evaluate it on the test set
  - Retain the evaluation score and discard the model.
- Summarize the skill of the model using the sample of model evaluation scores.

24.2.5 Evaluation Parameters

24.2.5.1 Confusion Matrix

It is a 2 * 2 table that contains output of a classifier. The values in the cells are TP, FN, FP and TN where, TP = True Positive, FN = False Negative, FP = False Positive and TN = True Negative. A sample of confusion matrix [12] is shown in Table 24.2.

24.2.5.2 Accuracy (ACC)

It is defined as total correct predictions over the entire positive and negative [3, 12].

$$\mathrm{ACC} = \frac{\mathrm{TP} + \mathrm{TN}}{\mathrm{TP} + \mathrm{FP} + \mathrm{TN} + \mathrm{FN}}$$

24.2.5.3 Sensitivity (SN)

It is number of correct predictions over the total number of positives. It is also known as Recall or True Positive Rate. Sensitivity of 1 is said to be best whereas 0 is worst [12].

$$\mathrm{SN} = \frac{\mathrm{TP}}{\mathrm{TP} + \mathrm{FN}}$$

24.2.5.4 Precision (PREC)

It is ratio of correct positive predictions to the total number of positive predictions [12].

$$\mathrm{PREC} = \frac{\mathrm{TP}}{\mathrm{TP} + \mathrm{FP}}$$

24.3 Results and Discussions

In this paper, the dataset was taken from PIDD and divided into 80% and 20% (i.e., 614 and 154 rows) for training and testing sets, respectively. After splitting of the dataset, scaling was done to remove abnormalities that could arise while performing calculation. ETC and CHI 2 both the methods were used initially and ETC was chosen to find the best attributes that could be beneficial in predicting the output. After the feature selection technique, we obtained four prime attributes out of eight attributes which indicates that the cost is reduced by a factor of 0.5 ($x = 4/8$) and improvement in classification is doubled that is increased by a factor of 2. Table 24.3 shows the features that were chosen after feature subset selection:

Once the desired features are selected, both the models, i.e., Naïve Bayes and Support Vector Classifier are applied for the classification of diabetes patient. Confusion matrix for the accuracy of both the models is shown in Tables 24.4 and 24.5. The result obtained from the models is shown in Table 24.6.

Table 24.3 Attributes chosen after feature subset selection

S.No.	Attributes	Labels
1.	Plasma glucose concentration	Plas
2.	Body mass index (kg/m^2)	Mass
3.	Diabetes pedigree function	Pedi
4.	Age (years)	Age

Table 24.4 Confusion matrix for test set using Naïve Bayes

	Predicted: YES	Predicted: NO
Actual: YES	TP = 93	FN = 14
Actual: NO	FP = 18	TN = 29

Table 24.5 Confusion matrix for test set using support vector machine

	Predicted: YES	Predicted: NO
Actual: YES	TP = 97	FN = 10
Actual: NO	FP = 19	TN = 28

Table 24.6 Result analysis of Naïve Bayes and support vector machine

	Naïve Bayes	SVM
Precision	83.78	83.62
Recall	86.92	90.65
Accuracy	79.22	81.17

Table 24.7 Result of Naïve Bayes using *k*-fold cross-validation

	$K = 3$	$K = 5$	$K = 10$
Test data	82.69	86.66	87.5
Training data	80	80.48	81.96

The result of Naïve Bayes and Support Vector Machine along the evaluation parameters of accuracy, precision and recall is listed in the table below.

From the table, it is clear that feature selection has improved the accuracies of both the models to a greater extend. The accuracy of SVC is found to be higher than Naïve Bayes. Also SVC has higher recall value meaning that among the total positive predictions it gives around 91% correct predictions. The precision value of both the models is nearly equal. The result obtained by applying *k*-fold cross-validation to the classification models is listed in Tables 24.7 and 24.8. The highest accuracy was chosen from the list of accuracies obtained by varying $k = 3, 5, 10$.

24.4 Conclusion and Future Work

In this paper, introduction to diabetes is done which states how serious the disease is and what complications it can lead to. Therefore, early diagnosis of whether a

Table 24.8 Result of support vector machine using *k*-fold cross-validation

	$K = 3$	$K = 5$	$K = 10$
Test data	84.61	90.66	92.85
Training data	78.04	81.30	83.60

person is having diabetes or not should be correctly classified. For improving the performance of the models and achieving better result, data preprocessing along with feature selection technique is employed. Later Naïve Bayes and Support Vector Machine are used as classification models for obtaining improved accuracies. To evaluate the model in an efficient way *k*-fold cross-validation technique is also used.

In future, work can be extended to the latest dataset that would contain more number of attributes and rows. An efficient and more precise model can be developed by making improvement in the past models by varying the feature subset selection methods. Other models along with their hybrid can be tested to achieve better accuracy.

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Chapter 25
Three-Stage Joint Economic Lot Size Model for Rice Industry Under Budget and Market Space Constraint in Indian Context

Ajay Kumar Sahare, Vinay Surendra Yadav, and A. R. Singh

Abstract Inventory models play a very important role in improving efficiency of agricultural supply chain. However, each stakeholder of agriculture supply chain makes their own decision about inventory to maximize their profit which results in overall increase in system cost. To this effect, we proposed a novel three-stage joint economic lot size model which would be win - win condition for each stakeholder and also results in reduced overall system cost. To show the applicability of proposed model, we resemble a case of rice industry in Indian context. Further, we modeled some of the real world constraints like processor purchasing budget limitation and market space constraints to the proposed model. The results show that our proposed approach is more beneficial to stakeholders of agricultural supply chain than the traditional approaches.

Keywords Joint economic inventory model · Optimization · Agriculture supply chain · Budget constraint · Market space constraint

25.1 Introduction

In today's globalized market, to compete with other companies, companies are more concerned regarding minimization of total supply chain inventory cost at different levels. Thus, for better supply chain inventory management, organizations are looking toward integration of different stakeholders at each level of supply chain and also collaborations among them. In traditional inventory model, replenishment decisions are taken by companies separately. However, traditional inventory model is beneficial only when single company is considered. Optimal replenishment policy can't be guaranteed when whole supply chain entities are considered. Keeping this in view "Joint Economic Lot Size Model (JELS)" has gained popularity in recent years. Integrated single vendor single buyer inventory model is named as "Joint Economic

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Lot Size Policy", where optimal replenishment policy is determined by taking cost components of both buyer and vendor jointly. The objective of this integrated single vendor single buyer (SVSB) model is to minimize total inventory cost of system. Thus such integration of supply chain results in more monetary benefits, and better customer's satisfaction. JELS model helps to share benefit of coordination among different echelons. First time Goyal [6] proposed a model in which single vendor single buyer has been taken. It assumed that vendor is reseller of product, so it has infinite production rate. Here shipment is made only after production.

In this paper, a three-stage joint economic lot size model in supply chain of rice industry is presented. Previous research work on three-stage JELS model mostly includes model where vendor sends product to buyer in equal size shipment. However, such models fails to address inventory control situations as buyer mayn't wish store more inventory at start as their holding cost increase. Also when buyer holding cost is more than vendor, the overall inventory cost increases. To tackle such circumstances, we propose to ship shipment in geometric progression (G.P.) size and then equal size shipments. Such system would be win-win situation for each echelon as overall inventory cost would be reduced. Such inventory model would be also useful in reducing buffer inventory and average inventory as the number of geometric progression size shipment increases, size of first shipment decreases resulting in overall decrease of inventory and cost. A case study is presented in context of Indian rice industry. Here, procurement center first collects raw material from multiple farmers at finite collection rate during harvesting period. Then this collected raw material is supplied to processor in multiple equal-sized shipments during processing period. Processor has two kinds of inventory, namely raw material inventory and finished product inventory. Processor converts raw material into finished product at fixed conversion rate.

Next section deals with detailed review of literatures related with two and three-stage JELS models in past years and mathematical formulations having assumptions and notations and derivation of objective function is presented in third section. Data for numerical illustration is given Sect. 25.4 and results of various test cases are presented in Sect. 25.5 along with their interpretation. Finally, Sect. 25.6 gives conclusion and future scope of proposed model.

25.2 Literature Review

Researchers around the world have tried to address JELS models where two-stage JELS are more predominant. However multi-stage JELS models are also taken in consideration up to certain extent.

25.2.1 Two-Stage JELS Models

In a two-stage JELS inventory model, the single manufacturer (vendor) and single retailer (buyer) is considered, where the processor aims at finding the optimal production quantity and the buyer seeks to determine the optimal order quantity.

Goyal [6] was first person to address Single Vendor Single Buyer (SVSB) model. The model assumed that vendor was a reseller of product, so it could have infinite production rate. Here shipment is made only after production which makes use of lot for lot shipment policy. The model was extended further by replacing assumption of infinite production rate with finite production rate and production lot is shipped into number of equal-sized shipment [7]. Significant reduction in cost as compared to “lot for lot” inventory model was achieved through this extended inventory model. Agrawal and Raju [1] suggested SVSB JELS model with partial shipment to buyer before entire lot production has been completed. Here, the vendor delivers an integer number of equal-sized shipments to the buyer. The inventory carrying costs of system also decreases, because shipping lots earlier to the buyer results in earlier start of the consumption cycle. Later, Hill [9] developed SVSB integrated inventory model where successive shipment to buyer increased by fixed factor and was indicated as production rate divided by demand rate. Production batch was sent in integer number to buyer. It shows that, If buyer’s holding is slightly more than vendor holding cost, than saving is more in this shipment policy than equal-sized shipment policy. Hoque and Goyal [11] developed two-stage JELS model where the maximum transportation capacity between vendor and buyer was limited. It was assumed that initially the supplier ships unequal- sized batches to the vendor, which increases by the factor production rate/demand rate and after that equal-sized batch shipments is made. Goyal and Nebebe [8] presented a paper where SVSB was considered having shipment to buyer was made through delivering first small size shipment then remaining equal size shipment. It achieved lower cost inventory policy than Hill [9] policy. Hill and Omar [10] presented a SVSB integrated inventory system, where carrying cost of buyer was more than vendor. Shipment policy was followed by first unequal size shipment then equal size shipment is made. It is further extended by Sadjadi et al. [14] where single vendor single buyer JELS model with budget constraints was presented. To make model more practical budget constraints of both buyer and vendor was also considered. K.K.T approach was used to solve the proposed problem. An algorithm was also presented to solve such nonlinear convex total cost function.

25.2.2 Three-Stage JELS Models

In three-stage JELS model, coordination of raw material supplier with SVSB comes into scenario. Banerjee and Kim [3] presented a model in which single raw material supplier in which SVSB was considered. The single supplier delivered equal lots in each production cycle. It resulted in reduction in vendor’s setup cost and batch size. Kim and Burton [2] presented a paper with single supplier, single processor and multiple retailers. For coordination common cycle time was considered. Raw materials are supplied to processor with equally split lot. It suggested a mechanism for integrating the inventory replenishment, production and shipping inventories for a single item in a multi-stage supply chain. Later, Khouja [13] developed a model where a single supplier, supply raw material to multiple processors and multiple customers was taken. Here all stakeholders at same stage has same cycle time and also cycle time of each stage is integer multiple of downstream stage. Ben-Daya and Al-Nassar [5] presented a model having multiple suppliers, processors, and retailers. In this model, produced lot at one stage was sent in equal shipments to the downstream stage and demands for all stages were considered equal. Here, cycle time was integer multiple of downstream stage. Ben-daya and Seliaman [4] developed an inventory model to minimize total cost for make to stock policy supply chain having three-stage JELS Model with single supplier, single processor with multiple retailers. Here, cycle time of supplier was an integer multiplier of processor cycle time and processor cycle time was integer multiplier of retailer cycle time. Later, Islam and Hoque [12] proposed first time a new three-stage JELS inventory model in the field of agro-product supply chain considering single seasonal supplier. Here, a single seasonal supplier, a single processor and multiple retailers was considered. Supplier supplies raw material to processor at equal size shipment and processor made delivery to multiple retailers in number of equal lot size shipment.

25.2.3 Research Gap

Mostly two-stage JELS models are studied in literature wherever few studies exist for three-stage JELS model. Also in case of three-stage JELS, buffer requirement is high which can be reduced by adopting a policy where processor make first Geometric Progression (G.P.) size shipment and then equal size shipment to the market. Such policy has not been addressed in the literature yet. Further these models are subjected to real world constraints like market space and budget constraint which are scarce in literature. To fill these gaps, we aim to develop a three-stage JELS model which considers the former shipment policy having single procurement center, single processor and single market under various real world constraints. The proposed model not only would result in reduction of buffer stock but also average system inventory. We also aim to perform a numerical illustration of the proposed model in Indian context to show the applicability of the model.

25.3 Mathematical Formulation

The objective of proposed three-stage JELS inventory model is to minimize total inventory cost. The schematic for inventory model and on hand inventory level of

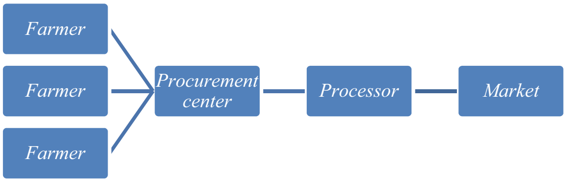

Fig. 25.1 Schematic of proposed inventory model

proposed model is shown in Figs. 25.1 and 25.2 respectively. Total cost is the summation of total cost incurred at procurement center, processing unit and market. The model is also subjected to market space and budget constraints.

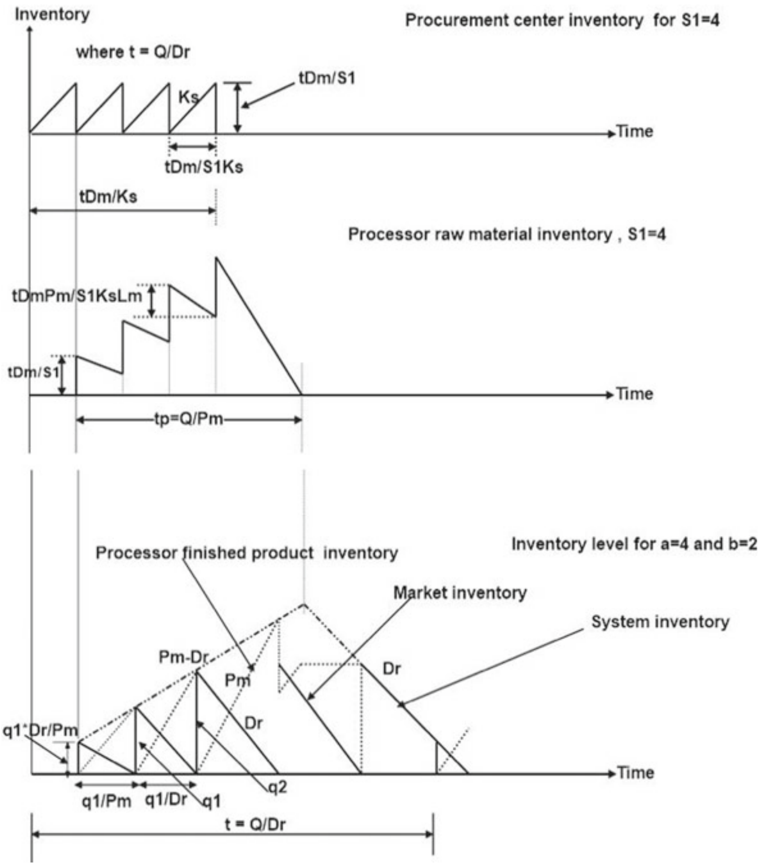

Fig. 25.2 On hand inventory of all echelons

25.3.1 Assumptions

The following assumptions are considered in the proposed model:

1. The demand is assumed to be constant and deterministic.
2. Planning time is based on yearly basis.
3. Shortages are not allowed (i.e., $P_{\mathrm{m}} > D_{\mathrm{r}}$).
4. Lead time (i.e., time between order placed and order received) is assumed zero.
5. Production lot (Q) is delivered from processor to market in total "a" no. of shipments.
6. Delivery of finished product from processor to market involves the first "b" shipments which increase according to a geometric series with factor μ, and then remaining "a–b" shipments are made equal to the last of non-equal shipments.
7. Finished product holding cost of market is greater than processor i.e.$C_{\mathrm{c,r}} > C_{\mathrm{c,mf}}$.

25.3.2 Notations

The notations used in our mathematical model are depicted in Table 25.1.

25.3.3 Objective Function

The objective of proposed three-stage JELS inventory model is to minimize total inventory cost. Here, two types of cost are incurred at procurement center, i.e., purchasing cost and raw material holding cost as denoted by first and second terms in Eq. (25.1). Four types of cost are incurred at processor, i.e., raw material holding cost, ordering cost, finished product holding cost and setup cost as denoted by third, fourth, fifth and sixth terms in Eq. (25.1). Two types of cost are incurred at market, i.e., ordering cost and finished product holding cost as denoted by seventh and eighth terms in Eq. (25.1). Hence, total inventory cost (TC) of three-stage JELS model is summation of total cost incurred at the procurement center, processor and market as computed below:

$$
\begin{aligned}
\text{Minimize TC} &= \text{Cost at procurement center} + \text{cost at processor} + \text{cost at market} \\
\text{Minimize TC} &= D_{\mathrm{m}} \times C_{\mathrm{p,s}} + \frac{tD_{\mathrm{m}}^2}{2S_1K_{\mathrm{s}}} \times C_{\mathrm{c,s}} + \frac{tD_{\mathrm{m}}^2}{2}\left(\frac{1}{P_{\mathrm{m}}} + \frac{1}{S_1K_{\mathrm{s}}} - \frac{1}{L_{\mathrm{m}}K_{\mathrm{s}}}\right) \\
&\quad \times C_{\mathrm{c,mr}} + \frac{S_1}{t} \times C_{\mathrm{o,m}} + \left[\frac{q_1D_{\mathrm{r}}}{P_{\mathrm{m}}} + \frac{(P_{\mathrm{m}} - D_{\mathrm{r}})Q}{2\mathrm{P_m}}\frac{\sum_{i=1}^{a} q_i^2}{2Q}\right] \\
&\quad \times C_{\mathrm{c,mf}} + \left[\frac{D_{\mathrm{r}}}{Q} \times S_{\mathrm{m}}\right] + \left(a \times \frac{D_{\mathrm{r}}}{Q} \times T_{\mathrm{r}}\right) + \left(\frac{\sum_{i=1}^{a} q_i^2}{2Q} \times C_{\mathrm{c,r}}\right)
\end{aligned}
\tag{25.1}
$$

Table 25.1 Notations used in the proposed model

t	Inventory cycle length $= \frac{Q}{D_r}$
t_p	Production cycle length $= \frac{Q}{P_m}$
$C_{p,s}$	Procurement center purchasing cost
D_m	Demand rate of processor $= \frac{D_r}{L_m}$
K_s	Collection rate of the procurement center
$C_{c,s}$	Raw material holding cost of procurement center
P_m	Production rate of processor
L_m	Conversion rate of raw materials to finished product
$C_{c,mr}$	Processor raw material holding cost
D_r	Demand rate of market
$C_{o,r}$	Order cost of market
S_1	Number of shipment delivered to processor
a	Total number of shipment delivered to market
b	Number of G.P. size shipment
T_r	Order cost of market
Q	Production lot size $\left(\sum_{i=1}^{a} q_i\right)$
q_i	Size of ith shipment
$C_{c,r}$	Finished product holding cost of market
S_m	Setup cost of processor
$C_{c,mf}$	Finished product holding cost of processor
q_1	Size of first shipment
$C_{c,r}$	Market storage cost per unit
$C_{o,m}$	Order cost of processor
μ	Common ratio of G.P. series $= \frac{P_m}{D_r}$
W_{bag}	Weight of single rice bag
v_{bag}	Volume of single rice bag
$V_{market\ space}$	Volume of market space
$C_{p,m}$	Processor raw material purchasing cost per unit
B_m	Processor raw material purchasing budget

Subjected to,

$$v_{bag} \times \frac{Q}{W_{bag}} \leq V_{market\ space} \tag{25.2}$$

Constraint 25.2 describes that volume of rice bag supplied to market should not be more than total volume of market space.

$$C_{\mathrm{p,m}} \times t_{\mathrm{p}} \times D_{\mathrm{m}} \le B_{\mathrm{m}} \tag{25.3}$$

Constraint 25.3 describes that purchasing cost of raw material quantity demanded by processor should not exceed budget of raw material purchasing of processor.

25.3.4 Solution Procedure

To simplify Eq. (25.1) following substitution has been made:

$$\begin{aligned}
1.\ Q &= \text{Production batch size} = \sum_{i=1}^{a} q_i \\
&= \sum_{i=1}^{b} \mu^{i-1} q_1 + (a-b)\mu^b q_1 \\
&= \frac{q_1\left(\mu^b - 1\right)}{\mu - 1} + q_1(a-b)\mu^b \\
&= q_1\left[\frac{\left(\mu^b - 1\right)}{\mu - 1} + (a-b)\mu^b\right] \\
&= q_1 \times x
\end{aligned} \tag{a}$$

where

$$x = \left[\frac{\left(\mu^b - 1\right)}{\mu - 1} + (a-b)\mu^b\right]$$

$$2.\ \text{Average market inventory} = \frac{\sum_{i=1}^{a} q_i^2}{2Q} = \frac{q_1 \times y}{2} \tag{b}$$

where

$$y = \left[\frac{\mu^{2b} - 1 + (a-b)\mu^{2b}\left(\mu^2 - 1\right)}{(\mu + 1)\left[\mu^b - 1 + (a-b)\mu^b(\mu - 1)\right]}\right]$$

So, the Eq. 25.1 can be rewritten as follows,

$$\text{Min } Z = D_{\mathrm{m}} \times C_{\mathrm{p,s}} + \frac{tD_{\mathrm{m}}^2}{2S_1K_{\mathrm{s}}} \times C_{\mathrm{c,s}} + \frac{tD_{\mathrm{m}}^2}{2}\left(\frac{1}{P_{\mathrm{m}}} + \frac{1}{S_1K_{\mathrm{s}}} - \frac{1}{L_{\mathrm{m}}K_{\mathrm{s}}}\right)$$

$$\times C_{\mathrm{c,mr}} + \frac{S_1}{t} \times C_{\mathrm{o,m}}$$
$$+ \left[\frac{q_1 D_{\mathrm{r}}}{P_{\mathrm{m}}} + \frac{(P_{\mathrm{m}} - D_{\mathrm{r}}) q_1 x}{2P_{\mathrm{m}}} - \frac{q_1 y}{2}\right] * C_{\mathrm{c,mf}} + \left[\frac{D_{\mathrm{r}}}{q_1 x} \times S_{\mathrm{m}}\right]$$
$$+ \left(a \times \frac{D_{\mathrm{r}}}{q_1 x} \times T_{\mathrm{r}}\right) + \left(\frac{q_{1y}}{2}\right) \times C_{\mathrm{c,r}} \tag{25.4}$$

Here, Eq. (25.4) is nonlinear convex objective function having two variables S_1 and q_1. Therefore for unconstrained problem, it is solved by using partial derivative method of optimization, as illustrated in Islam and Hoque [12] and Sadjadi et al. [14]. If values of "*a*" and "*b*" can be fixed and are known, then optimum value of two variables S_1 and q_1 can be computed by partially differentiating total inventory cost function (i.e., Eq. 25.4) w.r.t. S_1 and q_1 and then equates it to zero. So, optimal values are as given below:

$$q_1 = \sqrt{\frac{\text{L.H.}}{\text{R.H.}}} \tag{25.5}$$

$$S_1 = t D_{\mathrm{m}} \times \sqrt{\frac{C_{\mathrm{c,s}} + C_{\mathrm{c,mr}}}{2K_{\mathrm{s}} C_{\mathrm{o,m}}}} \tag{25.5a}$$

where

$$\text{R.H.} = \left(\frac{x \times D_{\mathrm{m}}^2}{2P_{\mathrm{m}} D_{\mathrm{r}}} - \frac{x \times D_{\mathrm{m}}^2}{2D_{\mathrm{r}} L_{\mathrm{m}} K_{\mathrm{s}}}\right) \times C_{\mathrm{c,mr}} + \left[\frac{D_{\mathrm{r}}}{P_{\mathrm{m}}} + \frac{(P_{\mathrm{m}} - D_{\mathrm{r}})x}{2P_{\mathrm{m}}} - \frac{y}{2}\right]$$
$$\times C_{\mathrm{c,mf}} + \left(\frac{y}{2} \times C_{\mathrm{c,r}}\right) \tag{c}$$

$$\text{L.H.} = \left[\frac{D_{\mathrm{r}}}{x} \times S_{\mathrm{m}}\right] + \left(a \times \frac{D_{\mathrm{r}}}{x} \times T_{\mathrm{r}}\right) \tag{d}$$

$$t = \frac{q_1 x}{D_{\mathrm{r}}} = \text{cycle time} \tag{e}$$

Now for the solving constrained problem we used Lagrangian multiplier. The detailed solution procedure is shown in Fig. 25.3. Under such instances, four cases may arise:

25.3.4.1 Case 1—When Both Market Space Constraint and Processor Raw Material Purchasing Constraint Are Satisfied

When the value of $\boldsymbol{q_1}$ as calculated from Eq. 25.5 satisfies both processor raw materials purchasing budget and market's space constraint, then there is no need to apply

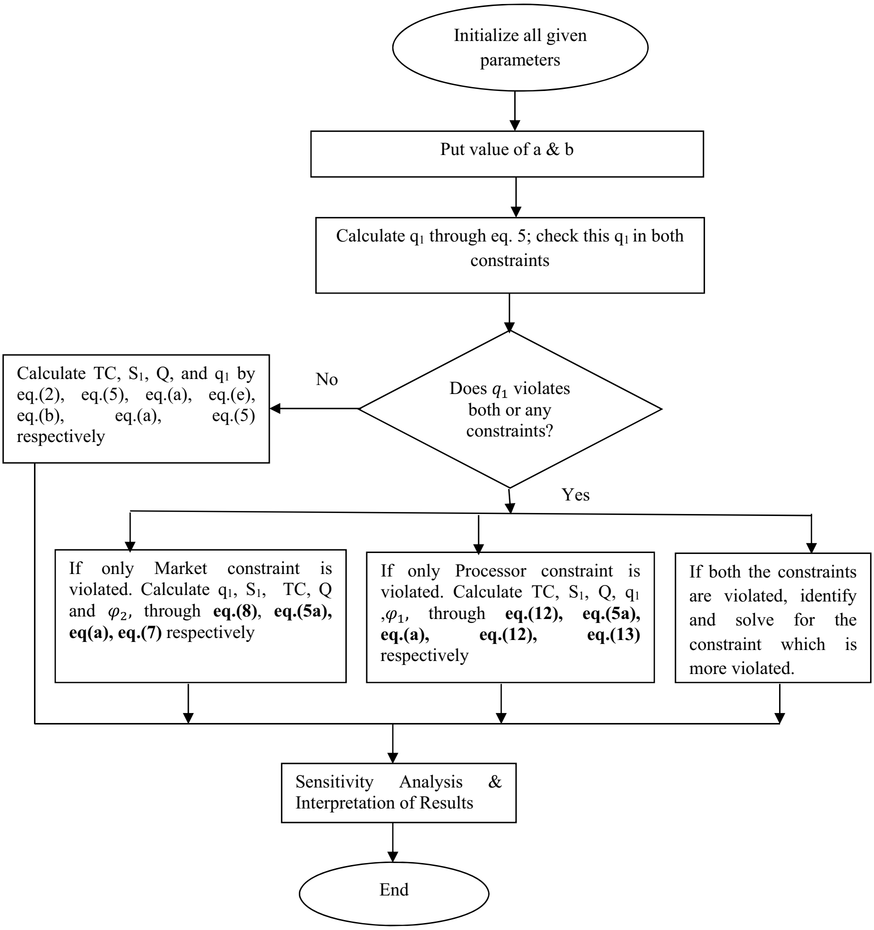

Fig. 25.3 Solution procedure using Lagrangian multiplier

Lagrange multiplier method. So, current value of $\boldsymbol{q_1}$ (Eq. 25.5) gives us **minimum total inventory cost (z).**

25.3.4.2 Case 2—When Only Market Space Constraint Is Violated

When the value of $\boldsymbol{q_1}$ as calculated from Eq. 25.5 satisfy processor raw material purchasing budget constraint (Eq. 25.3) but violates market's space constraint (Eq. 25.2), then Lagrange multiplier method should apply only on Market's space constraint as follows:

$$\text{Minimize } Z = \emptyset + \varphi_2\left(v_{\text{bag}} \times \frac{Q}{W_{\text{bag}}} - V_{\text{market space}}\right) \tag{25.6}$$

In Eq. 25.6 φ_2 is denoting Langrage coefficient for market space constraint. Value of total cost function Ø is same as Eqs. 25.4 in 25.6. Further, Eq. 25.6 can be rewritten as,

$$\text{Minimize } Z = \emptyset + \varphi_2\left(v_{\text{bag}} \times \frac{q_1 x}{W_{\text{bag}}} - V_{\text{market space}}\right) \quad (25.7)$$

Now, partially differentiating Eq. 25.7 w.r.t. q_1, the optimum value of q_1 is found as follows:

$$q_1 = \sqrt{\frac{\text{L.H.}}{\text{R.H.} + \varphi_2\left(v_{\text{bag}} \times \frac{x}{W_{\text{bag}}}\right)}} \quad (25.8)$$

In above Eq. 25.8, the value of R.H. is same as Eq. (c) and L.H. is same as Eq. (d). Again, to get optimum value of φ_2, Partially Differentiating Eq. 25.7 w.r.t. φ_2 and equates it to zero. The value of φ_2 is found to be as follows:

$$\varphi_2 = \left[\frac{W_{\text{bag}}}{v_{\text{bag}} \times x}\right] \times \left[\frac{\text{L.H.} \times v_{\text{bag}}^2 \times x^2}{V_{\text{market space}}^2 \times W_{\text{bag}}^2} - \text{R.H.}\right] \quad (25.9)$$

25.3.4.3 Case 3—When Only Processor Raw Material Purchasing Budget Constraint Is Violated

When value of $\boldsymbol{q_1}$ as calculated from Eq. 25.5 satisfy market space constraint (Eq. 25.2) and violates only processor raw material purchasing budget constraint (Eq. 25.3), Then, Lagrange multiplier method should apply on processor raw material purchasing budget constraint as follows:

$$\text{Minimize} = \emptyset + \varphi_1\left(C_{\text{p,m}} \times t \times D_{\text{m}} - B_{\text{m}}\right) \quad (25.10)$$

In Eq. 25.10 φ_1 is denoting Langrage coefficient for processor raw material purchasing budget constraint. Value of total cost function Ø is same as Eqs. 25.4 into 25.10. Further, Eq. 25.10 can be rewritten as,

$$\text{Minimize } Z = \emptyset + \varphi_1\left(C_{\text{p,m}} \times \frac{q_1 x \times D_{\text{m}}}{D_{\text{r}}} - B_{\text{m}}\right) \quad (25.11)$$

Now, partially differentiating Eq. 25.11 w.r.t. q_1, the optimum value of q_1 is found as follows:

$$q_1 = \sqrt{\frac{\text{L.H.}}{\text{R.H.} + \varphi_1\left(\frac{C_{\text{p,m}} \times x \times D_{\text{m}}}{D_{\text{r}}}\right)}} \quad (25.12)$$

In above Eq. 25.12 value of R.H. is same as Eq. (c) and L.H. is same as ed. (d). Again, to get optimum value of φ_1, Partially Differentiating Eq. 25.11 w.r.t. φ_1 and then equates it to zero.

$$\varphi_1 = \frac{D_{\text{r}}}{C_{\text{p,m}} \times x \times D_{\text{m}}} \times \left[\frac{\text{L.H.} \times x^2 \times C_{\text{p,m}}^2 \times D_m^2}{B_{\text{m}}^2 \times D_{\text{r}}^2} - \text{R.H.}\right] \quad (25.13)$$

25.3.4.4 Case 4—When Both Constraints Are Violated

When the value of $\boldsymbol{q_1}$ as calculated from Eq. 25.5 violates both processor raw material purchasing budget constraint (Eq. 25.3) and market space constraint (Eq. 25.2), then Lagrange method should apply to those constraint which is more violated. Suppose, if processor raw material purchasing budget constraint is more violated than market space constraints, then apply Lagrange method only on processor raw material purchasing budget constraint as shown in **case 3** and vice versa as shown in **case 2**.

The detail solution procedure for these cases is shown in Fig. 25.3.

25.4 Numerical Illustrations and Sensitivity Analysis

In this section, numerical illustrations is presented to show feasibility of our proposed three-stage JELS model having single procurement center, single processor and single market. We have taken case of rice industry situated in Raipur. The name of organization is not mentioned to maintain confidently and any competitive loss to organization. In supply chain network of rice, single procurement center collects paddy from multiple farmers during harvesting period. Procurement center supply collected paddy to single processor in number of equal size shipment for processing of paddy into rice. Then processor supply processed rice to market in multiple shipments. In this model, we have introduced certain limitation often faced by market and processor in agro-product supply chain. From processor perspective, apart from setup cost and inventory holding cost, there is expenditure on purchasing raw material from supplier. So, processor wants to purchase raw material from procurement center within his budget limit. So, here in proposed model we assumed that processor faces budget limitation to purchase from procurement center (B_{m}),as the processor orders ($t D_{\text{m}}$) unit of quantity from procurement center and paying unit raw material purchasing cost ($C_{\text{p,m}}$), it should be within budget limit (B_{m}).

Table 25.2 Various parameter used for numerical illustration

D_r	133,000 ton/year	$C_{p,s}$	600 Rs./ton
D_m	190,000 ton/year	$C_{o,r}$	50 Rs./order
P_m	140,000 ton/year	$C_{c,r}$	5 Rs./ton/year
K_s	399,000 ton/year	S_m	200 Rs./setup
$C_{c,s}$	0.8 Rs./ton/year	μ	1.05
$C_{c,mf}$	2 Rs./ton/year	a	6 shipment
L_m	0.7	$C_{c,mr}$	0.5 Rs./ton/year
$C_{o,m}$	200 Rs./order		

And also from market perspective, there is limited space at market place to store ordered finished product from processor. If production lot size "Q" delivered to market in one cycle is packaged into multiple number of "w" weight of bag to store at market place, if each packaging bag occupy "v_{bag}" space of volume, then total space required by multiple number of packaging bags should be within available space volume at market place. Otherwise market will have to pay extra charges to rent warehouse. Assuming a case when total number of shipment (a) delivered from processor to market in one cycle is 6 and number of G.P. size shipment is varying from 0 to 5 because ($a > b$). The proposed model is solved by using MS-excel. Numerical illustrations of three-stage JELS model when subjected to processor raw material budget and market space constraint on different conditions as described in Sect. 25.3.4.1, 25.3.4.2, 25.3.4.3, and 25.3.4.4 is discussed in Sects. 25.5.1, 25.5.2, 25.5.3, and 25.5.4. For analysis, different artificially generated constraints parameters are introduced in consultation with senior manager of case organization to fit into conditions. The proposed model is also analyzed with and without processor raw material purchasing budget and market space constraint to demonstrate effect on total cost functions (Table 25.2).

25.5 Result and Discussion

25.5.1 Case 1: When Both Processor Raw Material Purchasing Budget and Market Space Constraints Are Satisfied

Parameter introduced for both processor raw material purchasing budget and market space constraints is as follows: (1) for market space constraints: $V_{\text{market space}} = 15{,}000\ \text{m}^3$, $V_{bag} = 0.08118\ \text{m}^3$, $W_{bag} = 0.05$ ton, (2) for processor raw material purchasing budget constraint: $B_m = 500{,}000$ Rs., $C_{pm} = 30$ Rs.

For given data, value of q_1 is calculated from Eq. (25.5). By using presented solution algorithm, the resulted values of TC, Q, buffer stock, average system (processor + market) inventory, and average market inventory is summarized in Table 25.3.

Table 25.3 Numerical result when both constraints are satisfied

a	b	S_1	q_1 (ton)	Q (ton)	Average system inventory (ton)	Buffer stock (ton)	Average market inventory (ton)	TC (Rs.)
6	5	2.00	1314.30	8999.14	1473.56	1248.58	755.67	114,022,680.46
6	4	2.00	1325.08	8987.35	1483.51	1258.83	753.22	114,022,705.01
6	3	2.00	1345.77	8962.46	1502.54	1278.48	749.33	114,022,757.04
6	2	2.00	1376.09	8923.63	1530.38	1307.29	744.73	114,022,838.87
6	1	2.00	1416.25	8870.21	1567.19	1345.44	739.44	114,022,952.71
6	0	2.00	1466.94	8801.66	1613.63	1393.6	733.47	114,023,101.05

According to Table 25.3, when shipment policy is $a^* = 6$, $b^* = 5$ gives us minimum total inventory cost 114,022,680.46 Rs. As number of G.P. size shipment is increasing, size of first shipment (q_1) is getting reduced as we can observe for shipment policy $a = 6$, $b = 1$ value of $q1$ is 1416.25 ton and for shipment policy $a = 6$, $b = 5$ value of q_1 is 1314.3 ton. Here, buffer stock at market level is reducing as number of G.P. size shipment (b) is increasing because size of first shipment also getting smaller. As we can observe for $a = 6$, $b = 1$ value of buffer stock is 1345.44 ton and for $a = 6$, $b = 5$ value of buffer stock is 1248.58 ton. When we increase no. of G.P. size shipment, then average system (i.e., market + processor inventory) is getting reduced. As for $a = 6$, $b = 1$ value of avg. system inventory is 1567.19 ton and for $a = 6$, $b = 5$ value of avg. system inventory is 1473.56 ton. High production lot size "$Q = 8999.14$ ton" is achieved at low total inventory cost 114,022,680.46 Rs. Equal size shipment (i.e., $a = 6$ & $b = 0$) keeps average market's inventory minimum but causing increase in average system (processor + market) inventory.

25.5.2 Case 2: When Only Market Space Constraint Is Violated

Parameters for both constraints is as follows: (1) for market space: Vmarket space = 14,200 m^3, $V_{\text{rice bag}} = 0.08118\ m^3$, $W_{\text{bag}} = 0.05$ ton, (2) for processor raw material purchasing budget $B_m = 500{,}000$ Rs., $C_{pm} = 30$ Rs./ton.

For above given parameter, the value of q_1 calculated from Eq. (25.5) satisfies only processor raw material purchasing budget constraint but market's space constraint is being violated. Hence we have to apply Lagrange multiplier method only on market space constraint. The resulted values of TC, Q, t, φ_2, buffer stock, average system (processor + market) inventory, average market inventory is summarized in Table 25.4.

For given value of "a" (i.e., total no. of shipments delivered to market), model has been tested on different data sets of b (i.e.no. of G.P. size shipment). Here, integer

Table 25.4 Numerical result when an only market space constraint is violated

a	b	$S1$	$q1$	Q	Avg. system inventory (ton)	Buffer stock (ton)	Avg. market inventory (ton)	φ_2	TC (Rs.)
6	5	2	1277.33	8746	1432.11	1213.46	734.41	0.03	114,022,801.62
6	4	2	1289.5	8746	1443.67	1225.02	732.99	0.028	114,022,820.49
6	3	2	1313.27	8746	1466.26	1247.61	731.29	0.026	114,022,860.53
6	2	2	1348.7	8746	1499.91	1281.26	729.90	0.021	114,022,923.69
6	1	2	1396.42	8746	1545.25	1326.60	729.09	0.015	114,023,011.92
6	0	2	1457.67	8746	1603.40	1384.78	728.83	0.007	114,023,127.52

value of "b" is ranging from 0 to $a - 1$ ($a > b$). According to Table 25.4, shipment policy ($a^* = 6$), ($b^* = 5$) gives minimum total inventory cost Rs. 114,022,801.62. As we are observing when we increase G.P. size shipment, then average system (i.e., market + processor inventory) is getting reduced and same production lot size "$Q = 8746$" is achieved at low total inventory cost. Due to constraint production lot size "Q" and no. of cycle "t" is same for all values of a and b. It was also seen that as value of Lagrange coefficient (φ_2) increases system has to pay more additional cost of constraint.

25.5.3 Case 3: When Only Processor Raw Material Purchasing Budget Constraint Is Violated

Parameters for processor raw material purchasing budget and market space constraints is as follows: (1) for market space: $\text{V}_{\text{market space}} = 15{,}000\ \text{m}^3$, $V_{\text{bag}} = 0.08118\ \text{m}^3$, $W_{\text{bag}} = 0.05$ ton (2) for processor: $B_{\text{m}} = 360{,}000$ Rs, $C_{\text{pm}} = 30$ Rs./ton. For above given data, the value of q_1 as calculated from Eq. (25.5) satisfy only market's space constraint but processor raw material purchasing budget constraint is being violated. Hence, we have to apply Lagrange multiplier method only on processor raw material purchasing budget constraint. The resulted values of TC, Q, t, φ_1, buffer stock, average system (processor + market) inventory, average market inventory is summarized in Table 25.5.

For given value of "a" (i.e., total no. of shipments delivered to market), model has been tested on different data sets of b (i.e.no. of G.P. size shipment). Here, integer value of "b" varies from 0 to $a - 1$ ($a > b$). According to Table 25.5, shipment policy ($a^* = 6$), ($b^* = 5$) gives minimum total inventory cost 114,023,004.75 Rs. Increase in Lagrange coefficient (φ_1) causes an additional cost of constraint. When we increase G.P. size shipment, then average system (i.e., market + processor inventory) is getting reduced and same production lot size "Q" is achieved at low total inventory cost.

25.5.4 Case 4: When Both Processors Raw Material Purchasing Budget Constraint and Market Space Constraint Are Violated

Suppose total cost function (z) is subjected to following constraints parameters as follows: (1) for market: Vmarketspace = $14{,}000\ \text{m}^3$, $V_{\text{bag}} = .08118\ \text{m}^3$, $W_{\text{bag}} = 0.05$ ton, (2) for processor: $B_{\text{m}} = 340{,}000$ Rs., $C_{\text{pm}} = 30$ Rs./ton.

For given parameter, value of q_1 as calculated from Eq. (25.5) does not satisfy both processors raw material purchasing budget constraint and market space constraint. So in this condition we have to apply Lagrange multiplier method on that constraint which is more violated. We found that for this data, the processor raw material

Table 25.5 Numerical result when only processor raw material purchasing budget constraint is violated

a	b	$S1$	$q1$	Q	Avg. system inventory (ton)	Buffer stock (ton)	Avg. market inventory (ton)	φ_1	TC (Rs.)
6	5	2	1226.8	8400	1375.46	1165.46	705.36	0.0028	114,023,004.75
6	4	2	1238.48	8400	1386.56	1176.56	704.00	0.0028	114,023,022.87
6	3	2	1261.31	8400	1408.25	1198.25	702.36	0.0027	114,023,061.33
6	2	2	1295.34	8400	1480.59	1264.76	720.50	0.0025	114,023,121.99
6	1	2	1341.18	8400	1484.12	1274.12	700.25	0.0023	114,023,206.73
6	0	2	1400	8400	1540	1330.00	700.00	0.002	114,023,317.76

purchasing budget is more violated. Hence we have to apply Lagrange multiplier method on processor raw material purchasing constraint only. The resulted values of TC, Q, t, φ_1, buffer stock, average system (processor + market) inventory, average market inventory is summarized in Table 25.6.

As the number of G.P. size shipment is increasing (i.e., b), we are getting same $Q = 7933.33$ at low total inventory cost. Lagrange coefficient φ_1 causing increase in total inventory cost. As the value of φ_1 is increases integrated inventory system has to pay more additional cost. Market average inventory increases as we increase no. of G.P. size shipment. For example, for $a = 6$, $b = 1$ value of market avg. inventory is 661.11 ton & for $a = 6$, $b = 5$ value of market avg. inventory is 666.17 ton.

25.6 Conclusion

In this paper, three-stage joint economic lot size models for agro-product (rice) supply chain is presented, which consist of single procurement center, single processor and single market. In real world, processor faces budget limitations to purchase raw material, thus purchasing budget constraint of processor and market space constraint is also discussed. Geometric size then equal size shipment policy is adopted by processor to make delivery to market. Such kind of policy has great advantage as the buffer stock reduces and overall system inventory is also reduced while maintain the same service level. Four different real world cases have been also studied. In first case, both market space and processor purchasing budget case are satisfied. In second case, only market's space constraint is violated while in third case only processor raw material purchasing budget is violated. Finally fourth case considered violation of both market space and processor purchasing budget. A solution methodology is suggested for nonlinear convex cost objective function using partial differentiation method of optimization. The constraints are handled using Lagrange multiplier method. The applicability of model is tested through carrying a case study of rice supply chain in Indian context.

This paper can be extended by considering stochastic demand or stochastic lead time. It can be further extend by considering multiple procurement centers as well as multiple markets. Design of parallel processor for such supply chain could be addressed in future work. This model will help procurement center, processor and market to take replenishment decisions jointly with the help of proposed solution algorithm which can help government and related agencies for efficient distribution of food grains among masses. Other organization having similar condition may apply this model with little alteration.

Table 25.6 Numerical result when both processor raw material purchasing budget constraint and market space constraints are violated

a	b	$S1$	$q1$	Q	Avg. system inventory (ton)	Buffer stock (ton)	Avg. Market inventory (ton)	φ_1	TC (Rs.)
6	5	2	1158.64	7933.33	1299.04	1100.71	666.17	0.0055	114,023,356.61
6	4	2	1169.68	7933.33	1309.53	1111.19	664.89	0.0054	114,023,373.72
6	3	2	1191.24	7933.33	1330.01	1131.68	663.34	0.0053	114,023,410.05
6	2	2	1223.38	7933.33	1360.54	1162.21	662.08	0.0052	114,023,467.34
6	1	2	1266.67	7933.33	1401.67	1203.33	661.34	0.0049	114,023,547.37
6	0	2	1322.22	7933.33	1454.44	1256.11	661.11	0.0046	114,023,652.23

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Chapter 26
Green Supplier Selection Using Statistical Method

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Abstract The effective selection of suppliers is very crucial to the overall success of an industry. The sole objective of this paper is to identify the optimal supplier and rank the supplier organizations in the order of adopting green policies in their supply chain. In this research, an attempt has made to evaluate the consistency of the data interpretation statistically and both scoring model and principal component analysis (PCA) are applied to prioritize and rank the suppliers. The study reveals that all the parameters considered are highly interrelated and contributes to greening supply chain. Also, the survey data set is consistent enough to make a sound decision. Applying the Scoring model and principal component analysis (PCA) separately, it is seen that the pipe fitting industry is the most preferable as a green supplier for both the cases.

Keywords GSCM · Supplier selection · MCDM · Item analysis · Benchmark

Nomenclature

GSCM	Green Supply Chain Management
MCDM	Multi-Criteria Decision-Making
TOC	Theory of Constraints
PCA	Principal Component Analysis
AHP	Analytical Hierarchy Process
St.Dev.	Standard Deviation
Corr	Correlation

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26.1 Introduction

In today's highly competitive market industries necessitates the adoption of green supply chain practices because of facing government regulation on sustainable policies and increasing market pressure. Various industries around the globe have already started implementing green and sustainable practices into their supply chain. With increasing mass awareness and government regulations on sustainability policies, it becomes more important for industries to impose attention to strategic sourcing because the effective selection of suppliers is very crucial to the success of an industry. Sustainable sourcing plays a vital role in the economic development of any organization. Natural resources are depleting at a rapid rate, so sustainable and green thinking can be a preventive measure against this deterioration of resources and harmful environmental impacts. Sustainable supply chain plays a vital role in influencing the total environmental impact of any firm involved in supply chain activities and thus contributing to sustainability performance enhancement. Many organizations have taken a competitive advantage by focusing on the reduction of environmental impacts. Subsequently, organizations have paid attention to sustainable policies based on the traditional approaches it is not enough to select the best supplier due to globalization in business, competitive market situations and the nature of the customer demands. In the present scenario, the complexities of the supply chain become in danger due to globalization or optimal supplier selection which may cause more risk to the environment. The SCM future cannot be truly predicted despite the modern forecasting models followed by various strategies. So, it becomes increasingly clear that greater flexibility and the ability to react rapidly with the global change in the market conditions have the same importance as forecasting skills. In traditional supply chains, the supply chain managers facing problems in purchasing, production, distribution, planning and other logistic functions are handled independently by decision-makers. Due to increasing contemporary competitive and marketing pressures for environmental sustainability, the enterprises have begun to realize the need of implementing the strategies for reducing their environmental impact. As society becomes increasingly concerned about environmental issues, manufacturing companies are bound to adopt green strategies in their bid to achieve the respective goals in an efficient and economical way. The business environment is facing challenges to manage the changing and uncertain future which requires flexibility, i.e., the capacity of any organization to survive, adapt and sustain in the global business environment for the turbulent change. Supplier selection using the statistical process portrays a new paradigm in strategic sourcing methodologies and this provides new approaches in decision-making that can optimize industrial activities. In this research, an attempt has been made to simulate the survey data statistically and found to be consistent. Then scoring model and PCA are applied to rank the supplier organizations.

26.2 Prior Art

Ahi and Searcy [1] developed a framework from which the concepts of GSCM emerged from the realization that isolated implementations of environmental practices by companies are not as effective as collective actions that can make the entire supply chain greener. Ivascu et al. [2] in his research paper, presented research about green supply chain management and highlighted the differences between green supply chain and traditional supply chain management. Then, the paper analyzes the sources of the risk in green supply chain according to sustainable development. Dekker et al. [3] discussed in their research study that the important GSCM practices include the environmental factors in supplier selection, maintenance and development. Soni [4] made an attempt to propose a methodology for internal benchmarking to reduce the variability in performance among supply chains of the same focal firm. Keebler et al. [5] implemented logistics performance measurement in the supply chain to describe the state of logistics performance measurement in corporations based in the USA. Ray et al. [6] in his research paper, developed a model to demonstrate the theory of constraints (TOC) application in which constraints resource prevents the throughput of the organization. Mathi et al. [7] in his research, identified the important pressure, barriers and drivers for GSCM adoption in Indian automotive sector context from the available literature. The important pressure, the hindering barriers and the efficient drivers are then identified using Analytical Hierarchical Process (AHP) approach. Roberto [8] discussed research gaps and the potential applications of analytic hierarchy process (AHP) in an internal benchmarking process used to identify improvement areas when firms attempt to adopt green initiatives with a supply chain perspective. John et al. [9] proposed a study on green supply management practices among large global corporations. The purpose of his work is to understand the status of sustainable supply chain management practices among the world's largest corporations. Kumar et al. [10] emphasized the application of Supply Chain Management and adding the "Green" component to it so as to stress upon the need of environment-friendly systems. Chin et al. [11] focused on environmental collaboration, which has been seen as a key relational capability to facilitate the GSCM strategic formulation and execution. Jamshidi et al. [12] multi-objective green supply chain optimization with a new hybrid mimetic algorithm using the TAGUCHI method. Tamosaitiene et al. [13] proposed a complex assessment model based MCDM methods and used information from decision-makers selecting the supplier company. Gandhi et al. [14] evaluated the important factors associated with the successful implementation of GSCM. The paper represents a decision-making trial and evaluation laboratory (DEMATEL) approach to develop a structural model for evaluating the influential factors among recognized factors. Shaw et al. [15] proposed a research agenda to examine whether green performance measures can be integrated within an existing supply chain performance framework, Ho et al. [16] reviewed the literature of the multi-criteria decision-making approaches for supplier evaluation and selection. Luthra et al. [17] developed a structural model of the barriers to implement GSCM in Indian Automobile Industry. Kang et al. [18] in his research paper elaborated on the managerial and research implications of sustainable supply chain management. Gardas and Narkhede [19] in their research, mainly found the steps required for successful implementation, waste management and challenges in implementing the GSCM. Ying and Li-jun [20] in their study on green supply chain management based on circular economy, analyzed the difference between green supply chain and traditional supply chain and elaborates the content of green supply chain management. Wu et al. [21] used Fuzzy-DEMATEL method to find the influential factors in selecting GSCM criteria and evaluated supplier performance to find key factor criteria to improve performance and provides a novel approach of decision-making information in GSCM implementation. Paul et al. [22] reviewed on green manufacturing, why green manufacturing and why it is needed and methods of green manufacturing that reduces the waste and even pollution. They mainly focused on green design for the environment of green manufacturing systems, energy conservation, development of products with less wastage. Ivascu et al. [2] presented research about GSCM and highlighted the risk in green supply chain according to sustainable development. The study revealed that companies require to take into account both the social and environmental consequences within their activities for sustainable development. Chin et al. [23] proposed a plausible conceptual model to elucidate the relationship between variables in the context of Malaysian manufacturing companies. This research finding is very important for manufacturing firms in developing environmental collaboration with their suppliers in order to achieve sustainability performance. Masoumik et al. [24] developed a conceptual model for strategically prioritizing GSCM initiatives by the combined application of analytical network process (ANP) and structural equation modelling (SEM). The factors that should be considered to make these GSCM initiatives strategically beneficial have been discussed. Agrahari et al. [25] reviewed critically the literature in green processes to understand the process-specific green issues of the supply chain. In their study, 10-year period (2005–2014) is considered to select and analyze relevant studies. Chen et al. [26] conducted a study that designates GSCM strategies to effectively direct business functions and activities in the electronics industry. In their study, a network was proposed to clarify managerial levels and firm-related content. ANP method was applied to evaluate the most important activity in business functions. Case study was taken on Taiwanese electronics company. Sarkis [27] focused on the components and elements of GSCM which explores the applicability of a dynamic non-linear multi-attribute decision model, ANP process. Issues facing the modelling approach are also discussed. Stefanelli and Jabbour [28] presented the result of a survey conducted on 80 micro-, small- and medium-sized firms that are suppliers in the Brazilian bioenergy sector. The result yields that GSCM practices strengthen the environmental performance (EP) of firms. Zhu et al. [29] investigated empirically the construct of and the scale for evaluating green supply chain management practices implementation among manufacturers. They collected data from 341 Chinese manufacturers. Two models of measuring GSCM practices implementation were tested and compared by confirmatory factor analysis. Kafa et al. [30] presented a literature survey on green supply chain management and sustainability performance measurement. They proposed an analytical model to explore the influence of green practices on sustainability performance in supply chain. Uysal [31] applied DEMATEL method to deal with the importance and casual relationship between the sustainable performance measurement criteria by considering the interrelationships among them. MCDM methods of graph theory and matrix approach are used. The proposed framework is tested using data obtained from three different manufacturing companies that take place on the same supply chain. Azfar et al. [32] identified antecedents of existing SC paradigm's practices, as well as antecedents for SC performance measurement to formulate a conceptual framework. This research also presented a set of characteristics and structure that industry as well as academia could use it as a guidance framework to measure SC performance. Butzer et al. [33] made an attempt to develop a performance measurement system to assess international reverse supply chains. The aim of this research was to support the circular economy and the remanufacturing industry with an approach to optimize international reverse supply chains and thus to become more sustainable. Acquaye et al. [34] presented a robust environmental sustainable performance measurement model underpinned by industrial lifecycle thinking. The study assesses the effect of imports and economic growth on carbon footprint and discusses the implications of the study to sustainability transition process in the BRICS nations. Carpinetti et al. [35] made a brief review on supply chain management of various global companies. They discussed various issues and questions like 'What are the scope and principles of the supply chain management of global companies?', 'Why do global companies need to implement supply chain management?', 'How do global companies conduct it?', 'When implementing it, what problems do they encounter?', etc. They concluded that global companies should implement supply chain management, analyze all the enterprises concerned in the supply chain, enter into friendly and close relationships with other enterprises in the chain, enhance close cooperation with them, focusing on the customer, share an interest with them, and undertake risks jointly with them, only by doing so, can all the enterprises in the chain benefit mutually, and can global companies develop successfully and sustainably. Mishra et al. [36] evaluated 653 articles published over 22 years in SCOPUS database and used bibliometric and network analysis as a review technique. They identified top contributing authors, organizations and research topics. Major research areas and potential future directions are identified by conducting network analysis. Olugu et al. [37] aimed to develop a set of measures for evaluating the performance of the automobile green supply chain. They reviewed various literature on green supply chain performance measurement, environment management, traditional supply chain performance measurement and automobile supply chain management. For the development of measures, survey was conducted using questionnaire to experts to establish their importance and applicability. Sharma et al. [38] highlighted environmental protection and sustainability issues in food sector. They aimed to explore the diverse performance indicators and sub-indicators responsible for green supply chain management implementation and to check them using analytical hierarchy process. Quantitative phase was conducted through a survey using questionnaire with various agro-based companies. Internal environmental management, environmental design and regulatory pressure were ranked as the top three performance indicators. Yan et al. [39] made a survey upon a database of over 160 manufacturing facilities in China and explored performance measurement for GSCM. The result revealed that GSCM is strongly complementary with other advanced management practices and the effects on commercial performance are most ambiguous. Espino et al. [40] reviewed the application of multi-criteria decision-making methods in construction. The authors reviewed the application of 22 different methods belonging to various areas of the construction industry clustered in 11 categories. The review highlighted the reliability acquired by the most pragmatic and widespread methods. Scott et al. [41] provided a review of academic works attempting to deal with problems arising within the bioenergy sector using MCDM methods. Authors gathered articles in the international journals from 2000 to 2010 and analyzed to answer questions like 'Which methods are the most popular?', 'Which problems attract the most attention?'. It was found that optimization methods are most popular. Rezaei conducted a systematic reviewed application of different MCDM methods to different MCDM methods to different reverse logistics problems. The result of this research revealed that recycling and AHP are the most researched problem and methodologies. Ageron et al. [42] developed a framework from which the concepts of Green supply chain management (GSCM) emerged from the realization that isolated implementations of environmental practices by companies are not as effective as collective actions that can make the entire supply chain greener. According to Hart et al. [43], the challenges in global SCM are advanced in the decision-making frameworks that provide somewhere to stay diverse concerns of multiple components across the supply chain and sustainable business can effectively achieve using better policies and management of products at lower cost and timely delivery. Substantial efforts have been taken in developing decision models for supply chain problems from the past decades. According to Christopher and Towill [44], suitable collective SCM strategies are developed depending on market distinctiveness to accomplish advanced levels of customer requirements at a lower cost. Truong et al. [45] described that a typical SCM system consists of significant mechanism based on some crucial policies that are interrelated to each component. Hsu et al. [46] and Huang and Keskar [47] expressed that the outline of the degree of arrangement with the buyer is a novel feature in contemporary SCM. Norman and Jansson [48] and Peck [49] emphasized more focus on the concept of supply chain resilience (SCR), risk, vulnerability, logistics, and collaboration. Lin [50] stated that SCR does not involve recovering of anything from any disruption, but it is considered as a crucial aspect of SCM that entails protectiveness, structured and integrated exploration of capabilities, measured to deal the uncertainties. Organization must link the supply chains and sustainable development because implementing internal and external sustainable strategies can improve both economic and environmental performance [51]. Mak and Nebebe [52] used factor analysis for the selection of optimal supplier.

From rigorous literature review, it can be observed that very few researchers have worked upon supplier selection using statistical methods. Statistical methods of supplier selection are very reliable and precise way to identify the optimal supplier. Researchers can make use of various statistical methods and also integrate statistical methods with conventional decision-making methods to evaluate supplier selection problem.

Next section highlights the research design. Section 4 shows the application of proposed research methodology, Sect. 5 shows result and discussion and lastly Sect. 6 draws a conclusion.

26.3 Research Design

The research methodology is based on a survey on Indian manufacturing sectors to assess the extent of adoption of GSCM practices and their impact on firm performance in terms of validating the proposed hypothesis. In this study, a survey questionnaire was developed to measure the degree of greening of supply chain in various manufacturing firms. In this research, multivariate analysis (item analysis) and scoring model have been used. Multivariate analysis is a statistical tool that is used to analyze complex sets of data which contain more than one variable. It is used for quality control, decision-making, process optimization, market research, etc. Item analysis is one kind of multivariate analysis, used to evaluate the characteristics of items. Because an item is the fundamental building unit of any test and its analysis provides necessary information about its performance. Item analysis yields a correlation matrix (Table 26.2) and Cronbach's alpha value which determines the consistency of the data set. Then the scoring model is used to prioritize and rank the alternatives.

26.4 Application of Proposed Research Methodology

Case studies are taken from three West Bengal based manufacturing industries namely pipe fitting industry, automobile sector and IT sector. Few questionnaires about several greenery issues were made and interviews were conducted with the strategic level employees of each organization. By conducting this survey, importance coefficients of variables are derived from expert's subjective viewpoints. Data were collected from the strategic level people and the expert opinion (managerial judgement) was measured against a 9-point linguistic scale (satty's 9-point scale) where the expert's opinion or respondents had to agree on a scale of 1–9. Thirteen greenery parameters (criteria) are considered in this survey and the corresponding data are given in Table 26.1.

26.4.1 Item Analysis

See Tables 26.2, 26.3 and 26.4.

Table 26.1 Survey data

Attributes	Pipe fitting industry	Automobile sector	IT sector
Process parameters (c_1)	7	5	3
Design criteria (c_2)	7	5	3
Manufacturing criteria (c_3)	9	4	5
Process optimization (c_4)	7	5	4
Environmental planning (c_5)	5	3	4
Reuse of material (c_6)	5	6	6
Design for proper utilization of resources (c_7)	7	5	5
Quality (c_8)	7	8	6
Reduce scrap/wastes (c_9)	8	7	8
Adoption of robust environment policy (c_{10})	9	6	5
Green procurement policy (c_{11})	7	6	6
Cooperation with supplier (c_{12})	7	5	4
Cooperation with customer for green initiatives (c_{13})	9	5	5

26.4.2 Principal Component Analysis

See Tables 26.5, 26.6, 26.7, 26.8 and 26.9.

26.5 Results and Discussions

The survey data is represented in Table 26.1. It is also considered as the decision matrix. According to item analysis, if the Cronbach's alpha value is greater than 0.7, then it is considered that the dataset is quite consistent for making strong decision. In the result, the alpha value is 0.9486; therefore, the dataset is consistent and items are highly interrelated. Omitted item statistics is used to assess whether removing an item from the dataset improves the consistency. The 'adjusted total mean' is used to see how the value of total mean changes when an item is omitted from the statistics. In this result, (Table 26.3) the adjusted total mean is 71, when first item is removed from the analysis; that is, the sum of the mean value for rest items is 71. Similarly, 'adjusted total standard deviation' and 'adjusted total correlation' represent adjusted total SD and adjusted total correlation, respectively, when one of the items is omitted. From the above statistics, we can see that removing an item results in no significant change in the alpha value. After removing items, in each case, alpha values remain almost same. Therefore, there is no need to eliminate or add more item in the analysis. As the alpha value for all omitted items is similar, the result suggests that all items measure

Table 26.2 Correlation matrix

	C_1	C_2	C_3	C_4	C_5	C_6	C_7	C_8	C_9	C_{10}	C_{11}	C_{12}
C_2	1.000											
C_3	0.756	0.756										
C_4	0.982	0.982	0.866									
C_5	0.500	0.500	0.945	0.655								
C_6	−0.866	−0.866	−0.982	−0.945	−0.866							
C_7	0.866	0.866	0.982	0.945	0.866	−1.000						
C_8	0.500	0.500	−0.189	0.327	−0.500	0.000	0.000					
C_9	0.000	0.000	0.655	0.189	0.866	−0.500	0.500	−0.866				
C_{10}	0.961	0.961	0.908	0.996	0.721	−0.971	0.971	0.240	0.277			
C_{11}	0.866	0.866	0.982	0.945	0.866	−1.000	1.000	0.000	0.500	0.971		
CC_{12}	0.982	0.982	0.866	1.000	0.655	−0.945	0.945	0.327	0.189	0.996	0.945	
C_{13}	0.866	0.866	0.982	0.945	0.866	−1.000	1.000	0.000	0.500	0.971	1.000	0.945

Cronbach's Alpha value is 0.9486

Table 26.3 Omitted item statistics

Omitted variable	Adj. total mean	Adj. total std. dev.	Item-adj. total corr.	Cronbach's alpha
C_1	71	14	0.9286	0.9258
C_2	71	14	0.9286	0.9258
C_3	70	13.45	0.899	0.9302
C_4	70.67	14.36	0.9875	0.9252
C_5	72	15.13	0.7269	0.9353
C_6	70.33	16.44	−0.9832	0.9464
C_7	70.33	14.74	0.9791	0.9286
C_8	69	15.72	0.1273	0.9466
C_9	68.33	15.7	0.2943	0.9433
C_{10}	69.33	13.8	0.9982	0.9228
C_{11}	69.67	15.31	0.9806	0.9357
C_{12}	70.67	14.36	0.9875	0.9252
C_{13}	69.67	13.61	0.9754	0.9241

Table 26.4 Scoring model ranking

Industries	Scoring value	Ranking
Pipe fitting industry	94	1
Automobile sector	70	2
IT sector	64	3

the same characteristics and also suggest that the dataset is highly consistent. Scoring model (Table 26.4) yields the priority ranking of the three supplier organizations by simply adding the parameter values for each supplier. *Pipe fitting industry gains maximum scoring value hence it is the optimum and mostly preferable supplier*. Figure 26.1 represents the biplot for principal components. The graph mainly shows the dispersion of the parameters according to their nature. From the plot, we can easily make a few clusters according to the relative separation of the items. It can be seen that item C_6 is quite separated from other items, so it can be marked as a single cluster. Similarly, item C_8 and C_9 are a bit differently dispersed hence C_8 and C_9 can separately form another cluster. Item C_1, C_2, C_3, C_4, C_5, C_7, C_{10}, C_{11}, C_{12}, and C_{13} are relatively close to each other and it can be considered that their significance are quite the same and hence they are projected within a single cluster. Thus, according to the nature of the items, they can be grouped in several clusters. The eigenvalues derived from PCA is given in Table 26.5. From the table, it can be noticed that the percentage contribution of first eigenvalue is maximum, i.e. 79%, contribution of second eigenvalue is 21% and contribution of rest eigenvalues are nil. Hence eigenvectors corresponding to first eigenvalue are considered to determine the priority weights for the attributes. Priority weights are determined by squaring and normalizing the said eigenvectors (Table 26.7). Finally, the ranking of the supplier

Table 26.5 Eigen-analysis of the correlation matrix

	C_1	C_2	C_3	C_4	C_5	C_6	C_7	C_8	C_9	C_{10}	C_{11}	C_{12}	C_{13}
Eigenvalue	10.252	2.748	0	0	0	0	0	0	0	0	0	0	0
% Of total variance	78.9	21.1	0	0	0	0	0	0	0	0	0	0	0
Cumulative % of total variance	78.9	100	100	100	100	100	100	100	100	100	100	100	100

Table 26.6 Eigenvectors matrix

	EV1	EV2	EV3	EV4	EV5	EV6	EV7	EV8	EV9	EV10	EV11	EV12	EV13
C_1	0.283	−0.254	−0.099	0.081	0.292	−0.145	−0.707	−0.005	0.14	0.1	−0.242	0.379	0.023
C_2	0.283	−0.254	−0.099	0.081	0.292	−0.145	0.707	−0.005	0.14	0.1	−0.242	0.379	0.023
C_3	0.3	0.166	−0.416	0.008	−0.447	0.001	0	−0.115	0.03	0.235	−0.579	−0.323	0.003
C_4	0.303	−0.146	−0.09	−0.103	0.312	0.426	0	−0.335	0.331	0.106	0.266	−0.365	−0.389
C_5	0.255	0.347	−0.362	0.06	0.181	−0.158	0	−0.281	−0.196	−0.704	0.088	0.044	0.01
C_6	−0.311	−0.054	−0.44	0.204	0.23	0.368	0	0.598	0.053	−0.204	−0.195	−0.071	−0.179
C_7	0.311	0.054	0.287	0.401	−0.168	0.677	0	−0.035	−0.143	−0.105	−0.052	0.211	0.301
C_8	0.028	−0.601	0.092	0.47	−0.297	−0.262	0	−0.027	0.162	−0.359	0.048	−0.303	−0.044
C_9	0.131	0.547	0.086	0.503	0.021	−0.241	0	0.215	0.484	0.18	0.214	−0.008	−0.073
C_{10}	0.309	−0.092	−0.108	0.15	0.319	-0.148	0	0.264	−0.49	0.29	0.24	−0.414	0.34
C_{11}	0.311	0.054	0.363	−0.452	0.09	−0.022	0	0.393	0.328	−0.345	−0.214	−0.26	0.25
C_{12}	0.303	−0.146	−0.374	−0.263	−0.458	0.047	0	0.313	0.104	0.01	0.517	0.297	0.028
C_{13}	0.311	0.054	0.305	0.003	−0.096	−0.084	0	0.261	−0.411	−0.031	−0.097	0.07	−0.734

Table 26.7 Weight vector calculation of parameters using PCA

Variable	Eigenvectors	Priority vectors/weight
C_1	0.283	0.080089
C_2	0.283	0.080089
C_3	0.3	0.09
C_4	0.303	0.091809
C_5	0.255	0.065025
C_6	−0.311	0.096721
C_7	0.311	0.096721
C_8	0.028	0.000784
C_9	0.131	0.017161
C_{10}	0.309	0.095481
C_{11}	0.311	0.096721
C_{12}	0.303	0.091809
C_{13}	0.311	0.096721

Table 26.8 Original decision matrix

	C_1	C_2	C_3	C_4	C_5	C_6	C_7	C_8	C_9	C_{10}	C_{11}	C_{12}	C_{13}
Pipe fitting industry	7	7	9	7	5	5	7	7	8	9	7	7	9
Automobile industry	5	5	4	5	3	6	5	8	7	6	6	5	5
IT industry	3	3	5	4	4	6	5	6	8	5	6	4	5

Table 26.9 PCA ranking

Industries	Priority values	Ranking
Pipe fitting industry	7.25199	1
Automobile sector	5.10120	2
IT sector	4.67236	3

is done by multiplying the priority weight vectors with the decision matrix. Here also, pipe fitting industry gains maximum priority value, therefore, it is the optimal supplier. And the ranking is as follows: Pipe fitting industry > Automobile industry > IT sector. Therefore, we can see, in both the cases (Scoring model and PCA) the ranking yields the same result. *Hence it is justified that pipe fitting industry is the ultimate and benchmarked supplier. Pipe fitting industry has imposed more importance to the greenery issues and it has successfully implemented the sustainable policies in its supply chain. Other companies should follow the strategies, adopted by the benchmarked organization and the firms should strive for implementing green practices continuously for enhancing their both economic, social and environmental performances.*

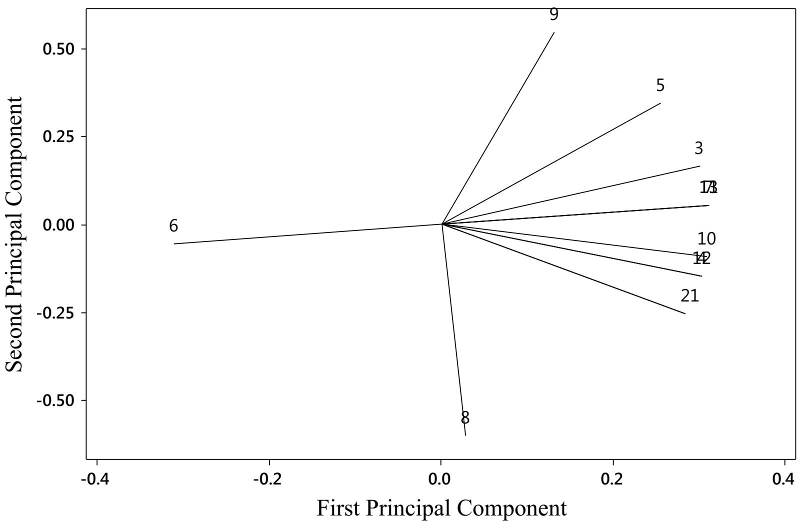

Fig. 26.1 Factor loading plot for first two principal components

26.6 Conclusions

The study finds that the pipe fitting industry is the benchmarked industry and it has adopted sustainable policies more efficiently in its supply chain by imposing more concentration of few criteria like green procurement policies, cooperation with supplier for green initiatives, proper utilization of resources, etc. other industries should follow the policies adopted by the benchmarked industry and the firms should implement green practices continuously for enhancing their both environmental, operational and economical performances. There are also certain limitations in this research, i.e., interviews were carried out with strategic level people only to collect data. But the decision-making process would be more precise and accurate if the expert's opinion is taken into consideration from all the three levels of organizations (i.e., operational level, tactical level and strategic level). This study is purely based on interpretation and expert's opinion, thus sometimes it may be highly subjective. The result may not be always free from bias and errors due to logical elements present in this decision-making process and due to reliance on expert's judgement for collecting data. Few experts were nominated and may be extended to widen the insights to the problem. But this may complicate the process to some extent and would require further justifications.

The proposed model is built on the foundation of expert's opinion from selected manufacturing sectors. The same model can be applied with marginal modifications to other industries like electronics, constructions, etc. in India and in any other developing countries. As a future direction of research, the same methodology may be used to compare the performance measures of GSCM practices among various sectors.

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Chapter 27
Blast Furnace Health Index Based on Historical Data

Arun Kumar, Ashish Agrawal, and Ashok Kumar

Abstract This paper presents a new method for estimation of the health index of blast furnace based on logistic regression analysis. The health status of blast furnace (BF) is important to regulate the smooth operation coupled with the continued production of hot metal and avoid the major danger events to happen. The health index also indicates the performance of BF at an early stage so that the operator can take appropriate actions to avoid before the deterioration in the blast furnace. The health status of blast furnace indicates the stability or instability condition of BF, which might occur during the production process and is used to recognize the fault. The logistic regression analysis techniques have been widely used in various industrial fields due to its various advantages such as it does not require the knowledge of the process and faults. In this paper, based on a past data set collected from a blast furnace with a rated volume, a logistic regression analysis technique using Excel data analysis tool application; that employs logistic regression model for the development of the health index of BF. The health status has been tested with varying process data and is found to be useful in the identification of process abnormality in BF. A similar concept can be extrapolated to other areas of the steel industry where fault diagnosis is a problem.

Keywords Blast furnace · Health status · Health index · Hot metal temperature · Logistic regression analysis

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27.1 Introduction

The blast furnace (BF) is a complex structure and high energy-consuming process where an understanding of the process and process disturbance are of utmost. The blast furnace iron and steel making plays a very important role in the economic development in our country. The hot metal production in the blast furnace process is very complex and it involves the various conversions of energy and matter; therefore, it difficult to better understand all kinds of phenomena in blast furnace [1]. Whenever the BF process diverts from the normal operation, it leads to unplanned outages that result in a reduction of production. With the ever-increasing demand for hot metal, there is a need to operate BF in stable condition. The BF process undergoes abnormality because of innumerable reasons. Therefore, it becomes necessary to identify the causes prevailing and leading to subsequent BF abnormality. The present work deals with the development of a BF health index that logistic regression analysis; a statistical classification model, which can be used to measure the relationship between a categorical dependent variable and several independent variables by using the probability score of predicted values of dependent variables is used to estimate the blast furnace health index [2, 3]. Therefore, the logistic regression analysis and likelihood function are used in the present work for mathematically developing the health index of the model. The data-based approach of modeling the process parameters has been emerging as an important tool to forecast the thermal level in BF, which otherwise would take time. In the recent past, artificial neural networks (ANN) have gained special attention because ANN can model complex non-linear functions. Attempts have been made involving neural networks to predict hot metal Si content of BF. The results of these works show that the use of ANNs has increased the predictive ability of Si content when compared with the conventional models. Although neural networks have been and would continue to be useful in the prediction of hot metal Si content, these models have a drawback that they try to strike a local optimum and the network connection also affects the prediction accuracy. Several attempts have been made to develop such types of models departing from the first principle of thermodynamics and numerically solving the thermodynamic equations that describe the process possible alternatively. These are especially useful in complex systems like BF where the data-based approach is employed.

Binary logistic regression analysis, a multivariate statistical technique, is another data-based approach used to calculate the blast furnace health index and identify the health status of the blast furnace. Therefore, these mathematical models are utmost important to calculate the health index and they are correlated with a prediction of hot metal temperature to estimate the health status of the furnace and ensure about operational stability using several measured parameters of BF since the health index can be developed to detect the instability in the furnace. The logistic regression output health index is used for developing a snake plot between health index Vs predictive hot metal temperature before the occurrence of the actual abnormality (say slip in the furnace). It is demonstrated that the furnace temperature range migrates from the health index range and enters the unstable region which has reduced the severity of slip and thus helped the BF management to reduce the blast volume at an early stage. Further, a health index is derived to provide information about furnace driving behavior. The top gas temperature, gas utilization, gas permeability resistance, differential pressures, and burden descent rate are the various parameters used in logistic regression analysis for developing the health index and thereby a multivariate statistical control chart is formulated. Channeling is a non-homogenous condition of the burden distribution where ascending gases try to preferentially flow, resulting in changes in the gas flow pattern in top gas and subsequently affects the burden movement down the stock line. It is because of these reasons that process parameters are suitably selected for the identification of channeling and slips in BF. Further attempts are made by Gamero et al. [4] to predict the aerodynamic instability in BF using stack pressures. In this paper, the health index of the blast furnace is simply categorized as healthy and unhealthy. Where healthy stands for the blast furnace that has just put into operation and unhealthy stands for the blast furnace in an extremely poor state and it necessary for maintenance or need some modification in process parameter. Logistic regression and likelihood function are preferred to calculate the health index of the blast furnace and it compares with a temperature range of furnace to get the health status of the blast furnace under-rated volume for following reasons.

1. The application of binary logistic regression analysis is widely used in many fields like the medical field and social science. Compare with neural network and support vector machines, the advantage of this method gives a direct estimation of the class probabilities [5, 6]. Therefore, the way doctor analyzes the symptoms to check a human being with or without disease and suggests a cure, similarly can be used to predict the blast furnace health status with different input parameters.
2. It can be used for testing statistical hypothesis to determine whether the independent variable or input parameter in a model is significantly related to the outcome variable [7]. Based on the correct evaluation of the blast furnace health condition, the whole calculation of efficiency is improved since those insignificant input variables can be eliminated and compelling information can be selected with a logistic regression method.

The remainder of this paper consists of five sections. Section 27.2 explains data input and a key parameter representing the health status of the blast furnace. Section 27.3 explains about binary logistic regression model and how to used and calculate the health index of blast furnace. Section 27.4 shows the results and discussions. Section 27.5 concludes the paper.

27.2 Description of Data Set and Data Preprocessing

In this paper, part of the historical data is collected from blast furnace with a rated volume used as a data set. The collected raw data of blast furnace from instrumentation are not consistent enough for direct usage during logistic regression modeling.

It ranges from a problem inherent to the associate data for developing the model, such as missing or very anomalous values or more subtle flaws called outliers, the low-quality data will result in poor quality analysis. Therefore, it not taken into the account in the effects of time lags in the production process of blast furnace [8]. Hence, preprocessing is need on the data set before it used in the logistic regression model. In this model, the outlier's data represent the unhealthy data and normal data represent the healthy data and missing values fill by the average values of the data set. The data set includes 2324 samples (corresponding to 166 days of data with the sampling time of 24 h) for 14 main monitored variables, which are shown in Table 27.1. These variables are used for calculating the health index of the blast furnace by using the logistic regression analysis and likelihood function; these data are collected under a normal working condition of blast furnace and it will be used. Among the input variables, the hot metal temperature is considered as a dependent variable and the other input variables are considered as independent variables because the hot metal temperature is an utmost important thermal state blast furnace indicator parameter and quality of hot metal regulator and it can be predicted easily by the help of predictive model [9]. The logistic regression model for the calculation of health index is as shown in Fig. 27.1.

Table 27.1 Shows the input variable for BF health index calculation

Area	Parameter	Unit
1. Blowing	Hot blast temperature	°C
	Wind volume	K N m^3/h
	Bosh gas volume	K N m^3/h
	Moisture content	g N m ^{3}
	Oxygen enrichment	%
	Tuyere velocity	m/s
2. Output	Hot metal temperature	°C
	Hot metal silicon	%
	Slag viscosity	Poise
	Slag Mgo	%
	Slag Al_2O_3	%
3. Casting	Slag time ratio	Unit less
	Drill diameter	m
	Gutko time	min

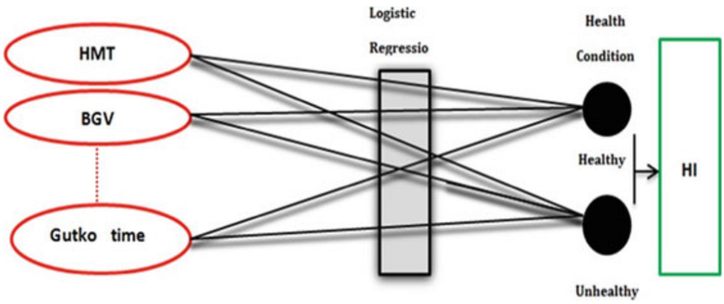


Fig. 27.1 Logistic regression model for health index

27.3 Methodology

27.3.1 Logistic Regression Analysis

Binary logistic regression model is a type of predictive probabilistic statistical classification model which can be used to describe the data and measure the relationship between a categorical dependent variable and several independent variables by using probability scores as the predictive value of the categorical dependent variable that is used to explore the best fitting model to describe the relationship between the blast furnace health index and the set of independent variable like hot blast temperature, wind volume, Bose gas volume, moisture content, oxygen enrichment, Tuyere velocity, hot metal silicon content, slag MgO, slag Al_2O_3, slag time ratio, drill diameter, and Gutko time. Therefore, these input variable parameters are an input parameter for determining the health index of the blast furnace by the logistic regression analysis method.

Assume we have several data set of blast furnace classification samples collected at normal condition monitoring. Each sample can be classified as one in two classes; class 0 (Healthy) and class 1 (Unhealthy). As mention before, healthy means blast furnace just been put into healthy data at good working operation and unhealthy means blast furnace is in extremely abnormal data set; at this point, blast furnace health status is a poor state and in this case, furnace needs to be maintained or aware during production of hot metal by blast furnace controller room operators. Thereby, the health index of a blast furnace is determined by the probability based on binary linear logistic regression and it belongs to one of the two classes. Let health index be a variable indicating the health status of blast furnace: HI = 0 means the health status of sample blast furnace belongs to class 0 (Healthy) and HI = 1 means that the health status of sample blast furnace belongs to class 1 (Unhealthy). Therefore, health index (HI) is the probability that the blast furnace belongs to healthy or unhealthy.

Let us consider the regression model

$$Y = \beta_o + \beta_i X_i + \mathcal{E}$$

Prediction equation line

$$\widehat{Y} = \beta o + \beta i Xi$$

Residual error of the sample

$$e_i = Y - \widehat{Y}$$

Sum of square residual (RSS)

$$\mathrm{RSS} = \sum_{i}^{n} e_i^2$$

where X_i, is the set of independent variables like HBT, WV, BGV, moisture content, oxygen enrichment, Tuyere velocity, hot metal silicon content, slag Mgo, slag Al_2O_3, Slag time ratio, drill diameter, and Gutko time. The blast furnace health index for different values X_i is as shown in flowchart: 1 follows as a binary logistic regression model as calculating the health index.

$$H = \frac{1}{1 + \mathrm{e}^{-\left(\beta 0 + \sum_i^n (\beta i Xi)\right)}} \tag{1}$$

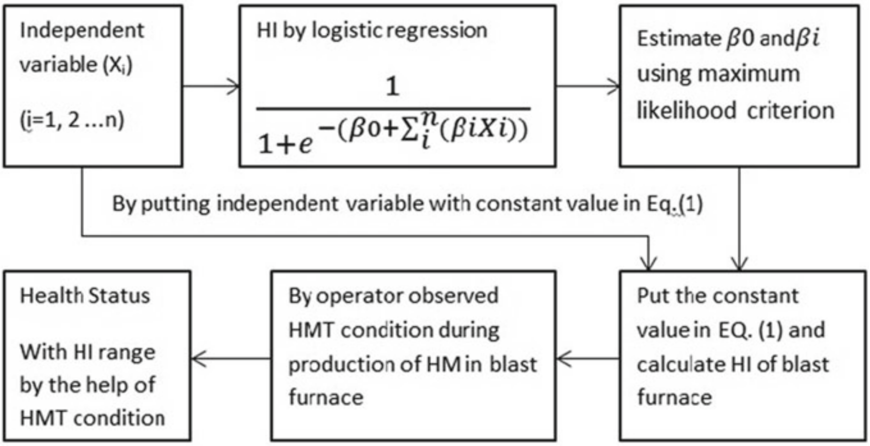
The unknown parameters β_0 and β_i shown in Formula (1) can be estimated by the maximum likelihood criterion. Suppose the total number of sample data is n, $y = 0$ or $y = 1$ represents the health condition of blast furnace raw data being healthy or unhealthy, respectively, and HI represents the health index of the nth data of blast furnace. The likelihood function used to determine the unknown parameters β_0 and β_i is as follows [10, 11].

$$L(\beta) = \prod_{1}^{n} \left[(\mathrm{HI}_n)^{\mathbb{Y}n} \cdot (1 - \mathrm{HI}_n)(1 - Y_n) \right] \tag{2}$$

Maximizing the Formula (2), by differentiating w.r.t Y_n

$$l(\beta) = \prod_{1}^{n} \left\{ \left[Y_n \cdot \ln(\mathrm{HI}_n)^{Yn} \cdot (1 - (1 - \mathrm{HI}_n)(1 - Y_n)) \right] \right\} \tag{3}$$

The Newton–Raphson algorithm can be used to get these values of unknown parameters β_0 and β_i according to the following likelihood equation (Flowchart 27.1).



Flowchart 27.1 shows the step for calculating health index (HI)

Table 27.2 Shows the estimated value of the constant parameter by likelihood maximization (Eqs. 3, 4 and 5)

S. No.	Variable	Symbol	Coefficient value
1.	Hot blast temperature	B_1	−0.5911
2.	Wind volume	B_2	−0.0032
3.	Bose gas volume	B_3	0.1680
4.	Moisture content in blast	B_4	−1.0284
5.	Oxygen enrichment	B_5	−8.6950
6.	Tuyere velocity	B_6	−0.3293
7.	Hot metal silicon	B_7	13.1657
8.	Slag viscosity	B_8	−0.0313
9.	Slag Mgo	B_9	−0.5692
10.	Slag Al2O3	B_{10}	0.1935
11.	Slag time ratio	B_{11}	0.5367
12.	Drill diameter	B_{12}	−0.7861
13.	Gutko time	B_{13}	0.3909
14.	Constant	B_0	2210.5466

$$\bar{l}(\beta) = \frac{\mathrm{d}l(\beta)}{\mathrm{d}\beta} = \sum_{1}^{n}\{[Y_n - \mathrm{HI}_n] \cdot X_{\mathrm{in}}\} = 0 \tag{4}$$

The involving unknown parameter β_0 and β_i in Eq. 1 for calculating the health index of the blast furnace is estimated by the likelihood function (Eqs. 2, 3 and 4). The estimated value of the unknown parameter is calculated as shown in Table 27.2.

27.4 Results and Discussions

The health status plays an important role in the long campaign of life of the blast furnace. In input parameters, the hot metal temperature and silicon content indicate the internal state of the blast furnace as well as the quality of the hot metal. The hot metal temperatures are directly measured by using pyrometer and data directly feed into the server but hot metal silicon content is measured based on chemical analysis of the sample in the laboratory at a certain frequency as there is no such device available to measure it online [12]. Therefore, the hot metal temperature plays an important role in the health status of BF. The health index of BF is varied linearly with a predicted hot metal temperature of the blast furnace as shown in Fig. 27.5. Figure 27.2 shows the scatter plot of the hot metal temperature between actual and predicted values. The r_2 value for the prediction is ~0.5. The error in actual and predicted lies in the range of $\pm 10°$, which is shown in Fig. 27.3. Figure 27.4 shows that the hot metal temperature actual and predicted matches almost with each other. Table 27.2 shows the value of unknown parameters which is estimated by the likelihood maximization function criteria (Eqs. 3, 4). The value of each unknown parameter with independent variable, hot blast temperature, wind volume, Bose gas volume, moisture content, oxygen enrichment, Tuyere velocity, hot metal silicon, slag viscosity, slag Mgo, slag Al_2O_3, slag time ratio, drill diameter, Gutko time, and values are put in Eq. (1) to calculate the blast furnace health index. Therefore, we have to see the linear variation between health index and predicted hot metal temperature after plotting the graph between health index versus predicted HMT as shown in Fig. 27.5.

Table 27.3 shows the health status of a blast furnace with a certain range of health index at a specific hot metal temperature. The blast furnace operator observed that at below 1490 °C temperature, the furnace has indicated the poor health status. The poor health lies between the health index 0–0.63. In this health index range, the furnace faced the random shutdown problem and the need for more maintenance and

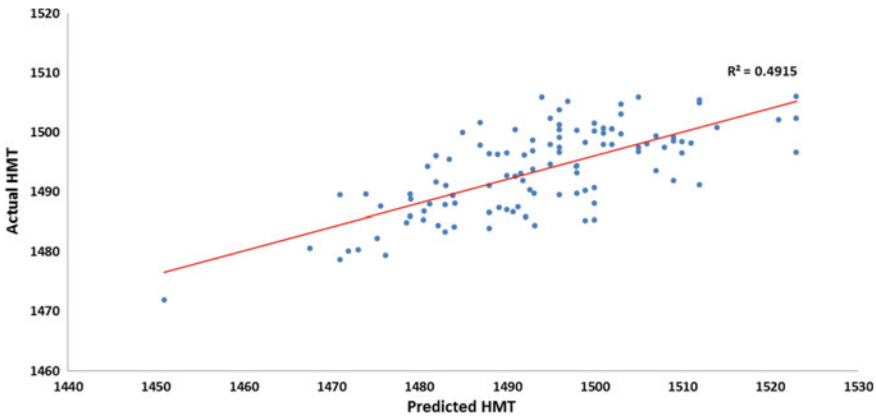


Fig. 27.2 Actual HMT versus predicted HMT

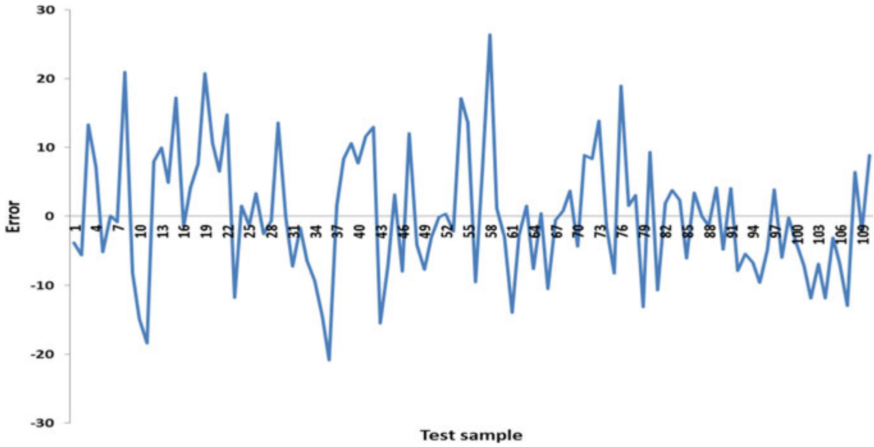


Fig. 27.3 Shows the error in actual HMT versus predicted HMT

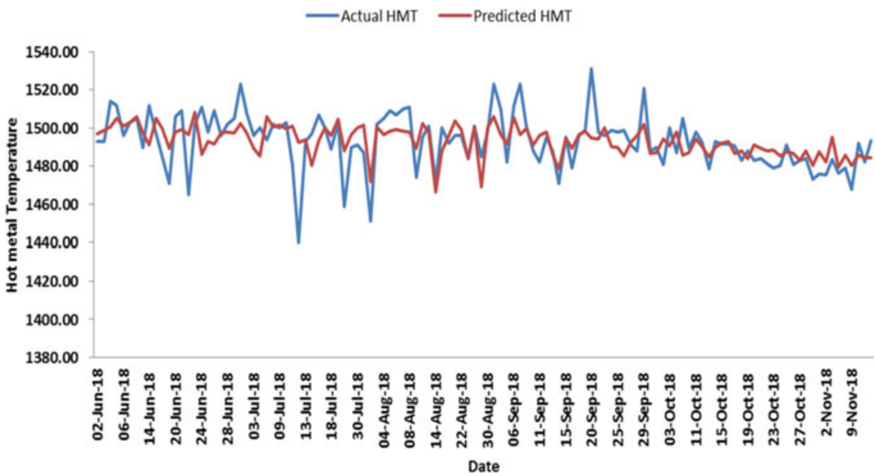


Fig. 27.4 Actual HMT versus predicted HMT

attention to avoid major dangerous events happening during the production of hot metal in the blast furnace and the availability of the furnace is lying below the 70%.

At the temperature range, 1490–1510 °C indicates the very good health status of a blast furnace with a health index of 0.64–0.74. In this case, the furnace production capacity is near to the target value and this is the safe zone; therefore, in this region, availability of the blast furnace lies above 95%.

At temperature above 1510 °C, the furnace has good health status which lies between health index 0.75–1. In this case, furnace has an average production rate and no need for maintenance only need for modification of process parameter for

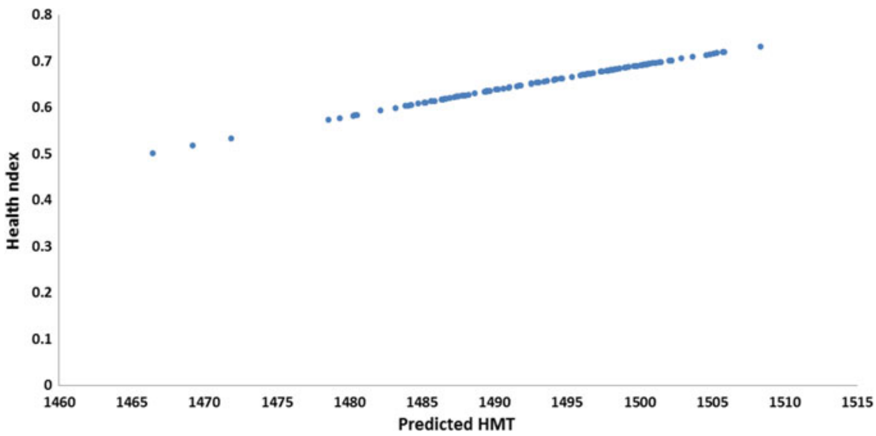


Fig. 27.5 Shows the graph health index versus predicted HMT

Table 27.3 Show the health status with health index range

Hot metal temperature	Health index range	Health status of BF	Colors code	
1490 °C<	0–0.63	Poor	Red	
1490–1510 °C	0.64–0.74	Very good	Green	
1510 °C	0.75–1	Good	Yellow	

achieving near to target value production rate and the availability of the blast furnace lies between above 70% and below 95%.

27.5 Conclusion

This paper focuses on the new method for estimation of the health index and by the help of the health index of blast furnace try to know about the current health status of blast furnace during running conditions based on past recorded data. Feasibility of health index to monitor thermal state of blast furnace is successfully carried out and it has found to be one of the effective ways to monitor the health status of the furnace and it regulates the smooth operation of furnace to indicate the production availability of the furnace and operator ensure about type health status of furnace and need for some modification in process parameter and maintenance for achieving near to target production capacity and avoid major dangerous events during the production of hot metal in blast furnace. The health index is a prior indicating tool of major dangerous events happening during the production of hot metal in a blast furnace. It is based on online parameters from the blast furnace. So the reliability of the instrument and component of a blast furnace is very important. A logistic regression analysis trending may be more useful than the instant value because fluctuation due to electronic signals might cause an erratic change in the instantaneous value of the index, but in a long time trending will be more effective guidance to the operators. The health index indicates the operators to keep temperature range level best for very good or good health status of blast furnace and it results from some excess carbon burning in the blast furnace for stable operation. The advantages of health index (HI) are as follows:

1. It is a health status indicator tool. It can identify the root cause of the change in blast furnace conditions.
2. It changes with change in gas distribution, furnace wall heat losses, carbon input, hot blast temperature, solution loss carbon and humidity in a blast or some other input parameter which contributes to increasing the temperature or heat in the blast furnace.
3. During the production of hot metal in a blast furnace, the problems occur to indicate the early stage such that the operator can take appropriate actions to avoid further deterioration in the blast furnace.
4. To prevent the economic loss of the company, hence increase the profits of the company.
5. It shows the linear relationship between predicted HMT versus HI, hence the more health index of furnace is present at the more thermal stage and vice versa.
6. It shows the health status of the blast furnace like poor, good and very good, where poor health status indicates the need for maintenance and changes in process and process parameters, good health status indicate blast furnace at normal condition therefore no need of maintenances, if only need changing in process and process parameters if we want increase the production rate. The very good health status indicates the working of blast furnace in excellent condition, and in this situation, no need of maintenances and no need of changes in process and process parameter therefore in case the production rate is near to our target values of blast furnace.

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Chapter 28
A Novel Way to Schedule Flexible Manufacturing System

Srushti Bhatt, M. B. Kiran, and Jeetendra A. Vadher

Abstract Modeling and scheduling of flexible manufacturing system problems are yet to be addressed simply to compete in the global manufacture market. Optimizing the performance measure of the available resources of manufacturing systems is a key requirement. Many researchers have proposed techniques for solutions like mathematical programming, heuristic dispatching methods, and artificial intelligence and knowledge base system. In the present work, a combined approach of the Timed Petri Net and genetic algorithm is used for the modeling power and optimization capabilities for scheduling flexible manufacturing system. Petrinet plays a vital role in modeling FMS. The power of Timed Petrinet is used for modeling FMS by using the advantage of its ability to model a complex system with efficient net structure and chromosomal representation along with genetic algorithm for optimal solution needed in scheduling a manufacturing problem. The result obtained by this approach concludes that the proposed method performs much better than the existing methods. The algorithm is developed for minimizing makespan and the simulation run for better performance measures.

Keywords FMS · GA · Petri Nets · SPN

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Nomenclature

FMS Flexible manufacturing system
GA Genetic algorithm
PN Petri nets
TPN Timed Petri nets

28.1 Introduction

In the present market scenario, to stand in a market it is very important for a manufacturing system to accommodate changes quickly as customer demand changes. Many Indian industries have adopted FMS for in time production and quality of the product, but still problems in scheduling still arise. The scheduling problem is nothing but simply a process of resource allocation to accomplish a specified task [1].

Petri nets are a class of modeling tools, which were originated by Petri [2, 3], they have a well-defined mathematical foundation and easy to understand the graphical feature. It is a powerful graphical tool for modeling and analyzing concurrent, parallel, simultaneous, synchronous, distributed, and resource sharing systems with the advantages like an easy visualization of complex systems can model a system hierarchically (a top-down fashion at various levels of abstraction and detail) and can analyze qualitative and quantitative aspects of the system.

The common definition of PNs introduced by Petri is as follows. Petri nets or place/transition net can be defined as a five-tuple: PN = (P, T, I, O, Mo), where P and T are finite non-empty sets of places pictured by circles and transitions pictured by bars, respectively. I: $P \times T \rightarrow \{0, 1\}$ is an input function that defines the set of directed arcs from P to T. O: $P \times T \rightarrow \{0, 1)$ is an output places which are drawn as circles represent possible states or conditions of the system while transition, which is shown in bars or boxes, describe events that may modify the system states. The relationships between places and transitions are represented by a set of arcs that are the only connectors between a place and a transition in either direction. The dynamic behavior of the system can be represented using tokens which graphically appear as black dots in places. A transition can only fire if it is enabled and having one token in that place I to the next transition j. A timed Petri net is associated with places or transitions. Here we consider the time associated with places. The modeling of the problem data takes place using TPN. TPN is a 7 tuple, TPN = (P, T, I, O, $M0$, $Mr0$,) where $M0$ is initial marking, $Mr0$ is initial vector for remaining processes, is set of time delays associated with it. The problem data consist of job-based data, operation-based data, and machine data including processing time or operation time along with the path of the operation for the given jobs. Different researchers have used different approaches of Petri nets for simulation and GA for fine-tuning the parameters [2]. Different researchers have identified different criteria for solving FMS scheduling problem. One of them is performance measures. The list of performance criteria are

Table 28.1 Criteria for performance parameters (Reproduced from Filho et al. [4])

S. No.	Criteria	Code
1	Idle time	T idle
2	Length of the AGVs route	Route length
3	Number of backtrackings of each AGV	Backtrackings
4	Total flow time	F
5	Mean flow time	F medium
6	Maximum lateness	L_{max}
7	Makespan	C_{max}
8	Tardiness	T
9	Maximum tardiness	T_{max}
10	Due date	D_d
11	Cost for tardiness and earliness; production cost, penalty cost	Cost
12	Throughput	T
13	Work in process	WIP
14	Machine utilization	U
15	Maximum utilization of the machines	U_{max}

as stated in Table 28.1. Here, out of all performance parameters attempt is made to address the makespan using a hybrid approach combining Petri nets and GA.

28.2 Problem Definition

The makespan minimization problem of a flexible manufacturing system (FMS) has been recognized as one of the most important planning problems. Job scheduling problems are referred to as NP-hard problems. And to solve such kind of problem there are different four types of representation. They are job-based representation, operation-based representation, priority rule-based, and preference-list-based representation [1].

In this research, a Genetic Algorithm (GA) based heuristic is proposed to solve the makespan of a random type FMS. The objective of the problems is to minimize the system unbalance and maximize the throughput, satisfying the technological constraints such as availability of machining time, and tool slots. The proposed GA-based heuristic determines the part type sequence and the operation-machine allocation that guarantee the optimal solution to the problem, rather than using fixed predetermined part sequencing rules.

The first objective of the research work is to schedule the given FMS, modeling with Petri nets and optimizing using genetic algorithm and obtaining results to conclude with the best option. The makespan minimization problem consists of three types Job shop scheduling (there are *n* jobs and m identical stations. Each job should

Table 28.2 Problem data

Job	Operation time			Operation path		
	M/C 1	M/C 2	M/C 3	M/C 1	M/C 2	M/C 3
1	4	3	2	1	2	3
2	1	4	4	2	1	3
3	3	2	3	3	2	1
4	3	3	1	2	3	1

be executed on a single machine), Open shop scheduling (there are n jobs and m different stations. Each job should spend some time at each station, in a free order), Flow shop scheduling (there are n jobs and m different stations. Each job should spend some time at each station, in a predetermined order). To optimize makespan the system consists of the following:

The system considered is

n = four jobs and m = three machines with the respective operating time. Each job is processed on every machine at the appropriate time.
The machine can operate only one operation at a time.
All machines are available.
Here one job will leave the machine only after completing the operation and scheduling is done in the way that no classes with the same job will assign to two different machines at the same time or vice versa.
Machine setup time is included in the processing time.
The data of n jobs and m machines are as given in Table 28.2.

28.3 Methodology

For the given data will be evaluated into two phases. The first phase gives the system model and the second gives the optimum result.

Step 1: Creating a system model using Petri net tool using MATLAB Environment
Step 2: Identifying the variables (Table 28.3)
Step 3: Simulating the model in the MATLAB environment. Results of system model simulation.

Figures 28.1 and 28.2 shows the FMS modeling for the given 4 job 3 machine problem. Once the modeling is created next phase is to check for the structural and behavioral properties of the net structure. As shown in Fig. 28.1 the model of each job should spend some time at each station, in a predetermined order. Figure 28.3 shows the property check whether is net structure modeled satisfy all the condition of the manufacturing system. Net is bounded means there will be no overflows in the buffer. Liveness shows a complete absence of deadlock in the manufacturing system. Once the property of the net is checked, next step is to analyze the system. There

Table 28.3 Description of timed Petri net model in Fig. 28.2

P1	Job 1 in queue
P2	Operation 2 of Job 1 on machine 2
P3	Operation 3 of Job 1 on machine 3
P4	Job 1 finish
P5	Operation 1 of Job 2 on machine 2
P6	Operation 2 of Job 2 on machine 1
P7	Operation 3 of Job 2 on machine 3
P8	Job 2 finish
P9	Operation 1 of Job 3 on machine 3
P10	Operation 2 of Job 3 on machine 2
P11	Operation 3 of Job 3 on machine 1
P12	Job 3 finish
P13	Operation 1 of Job 4 on machine 2
P14	Operation 2 of Job 4 on machine 3
P15	Operation 3 of Job 4 on machine 1
P16	Job 4 finish
P17	Loop operation 1 for Job 1
P18	Loop operation 2 for Job 1
P19	Loop operation 3 for Job 1
P20	Loop operation 1 for Job 2
P21	Loop operation 2 for Job 2
P22	Loop operation 3 for Job 2
P23	Loop operation 1 for Job 3
P24	Loop operation 2 for Job 3
P25	Loop operation 3 for Job 3
P26	Loop operation 1 for Job 4
P27	Loop operation 2 for Job 4
P28	Loop operation 3 for Job 4

are different ways of analyzing the net-like coverability tree, incidence matrix, and simple reduction rules. Here the net is analyzed using matrix equation that governs the dynamic behavior of the concurrent system as shown in Figs. 28.4, 28.5, and 28.6.

Step 4: Optimizing using GA

GA starts with a set of solutions called population. Chromosomes from the population are occupied and used to form a new population. This is motivated by the desire, that the new population will be better than the old one in terms of a fitness criterion. Solutions that are selected to form new solutions (offspring) are selected according to their fitness—the more suitable they are the more chances they must reproduce. There

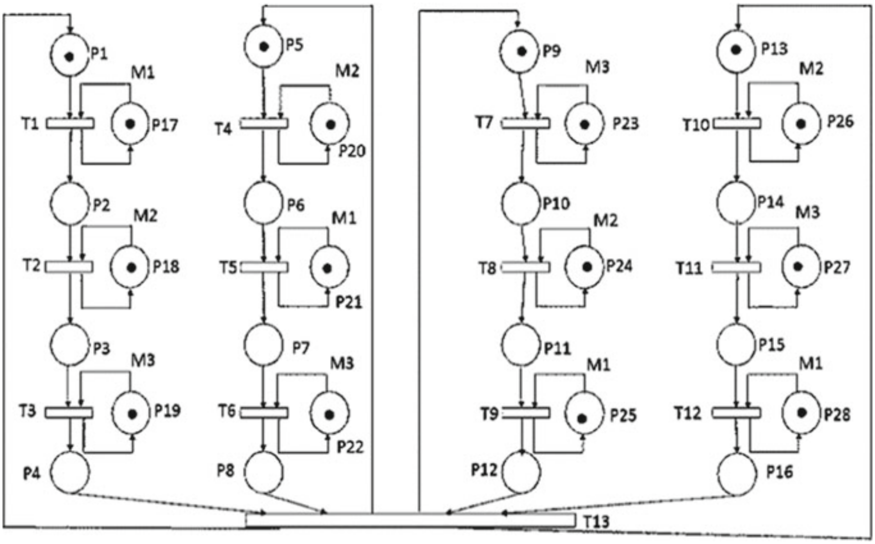

Fig. 28.1 FMS processing of 4 jobs & 3 M/c

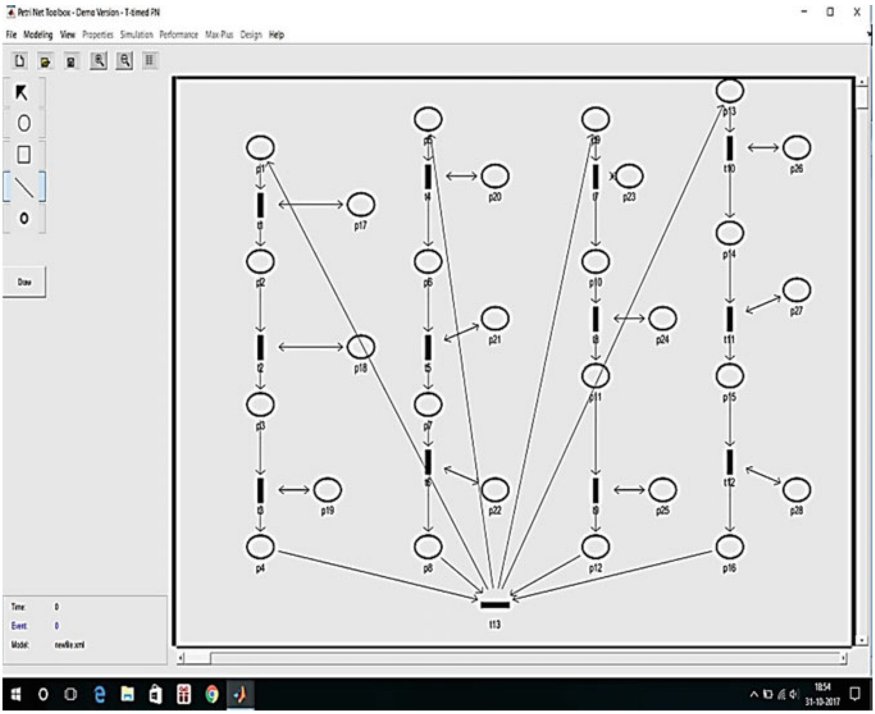

Fig. 28.2 FMS processing of 4 jobs & 3 M/c in MATLAB

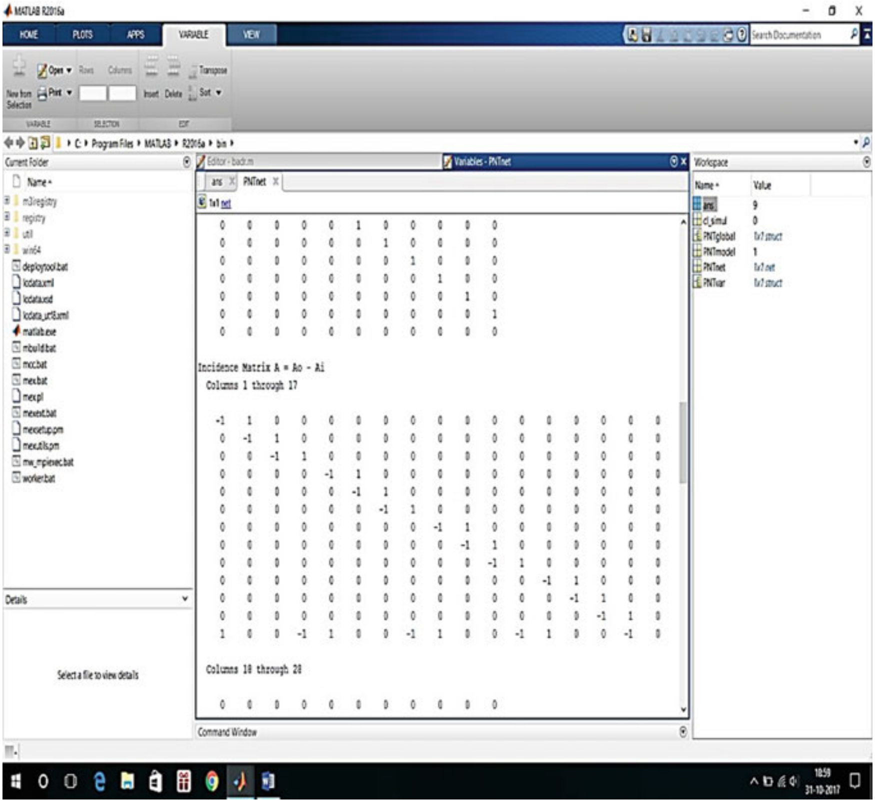

Fig. 28.3 Structural properties

are different representation schemes for evaluation with the makespan objective. They are operation-based representation, job-based representation, preference-list-based representation, priority rule-based representation. In general, GA uses three steps—selection, crossover, and mutation (4). Selection based on the fitness (makespan in our case) is the source of exploitation, and crossover and mutation help us to promote exploration (Fig. 28.7).

A generation of a GA contains a population of individuals, each of which corresponds to a possible solution in the search space. Everyone in the population is evaluated with a fitness function to produce a value which indicates the goodness of a solution. Selection helps in bringing forward certain members from the population to apply crossover and mutation on the given set of problem. Crossover takes pairs of individuals and uses parts of each to produce new individuals. Random mutations swap parts of an individual to prevent the GA from getting caught in a local minimum.

Step 4.1: Creation of First Generation/Initialization:

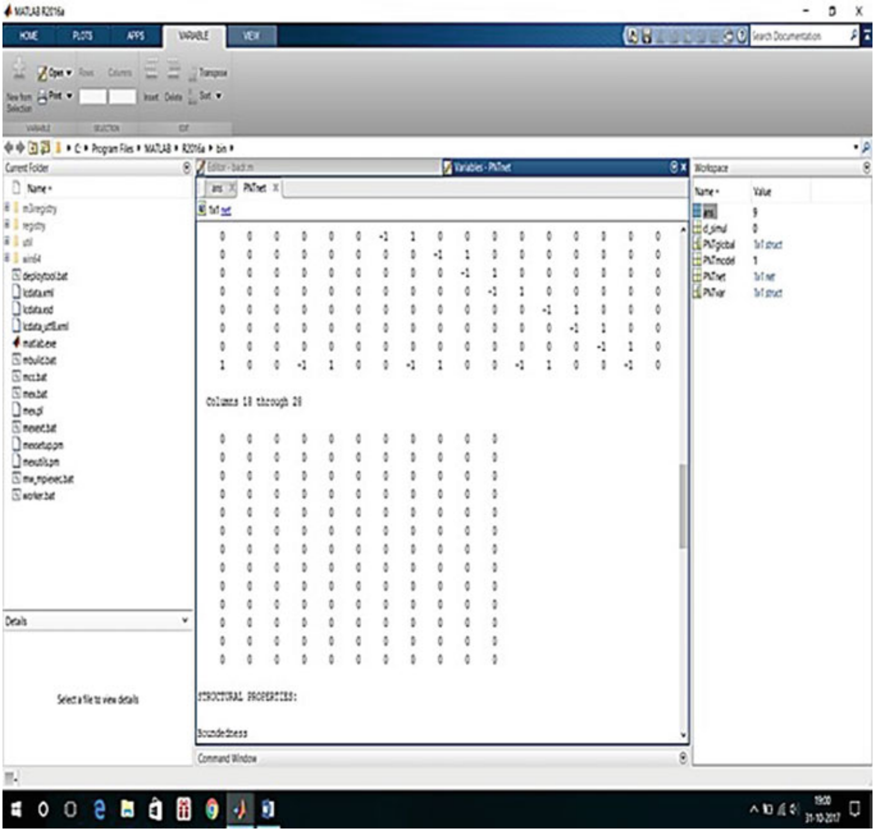

Fig. 28.4 Incidence matrix part 1

In our problem, we are using the datasets that have been taken from Kumar [6]. This data set has initially four jobs and three machines. The term makespan refers to the cumulative time to complete all the operations on all machines [7]. It is the time taken from scheduling the first job submitted until the completion of the last job. The objective of the problem is to find a valid schedule that yields the minimum makespan. The initial population can be generated randomly. Each machine has randomly 3–4 jobs placed on them. The total running time for each machine is then calculated. Here the job-based representation is focused out of four. For the same, the chromosome would be [1 2 0 3]. The first job to be processed is j_1 is m_1, m_2, m_3, and processing time is 4, 3 2 [1]. Similarly, each is processed. The genetic search process starts with a randomly generated set of chromosomes called the initial population. The size of the population (pop_size) depends on the solution space. The chromosome representation of all the representation is as stated in Table 28.4. The outline GA code is as shown in annexure I. The simple GA structure used to evaluate the system

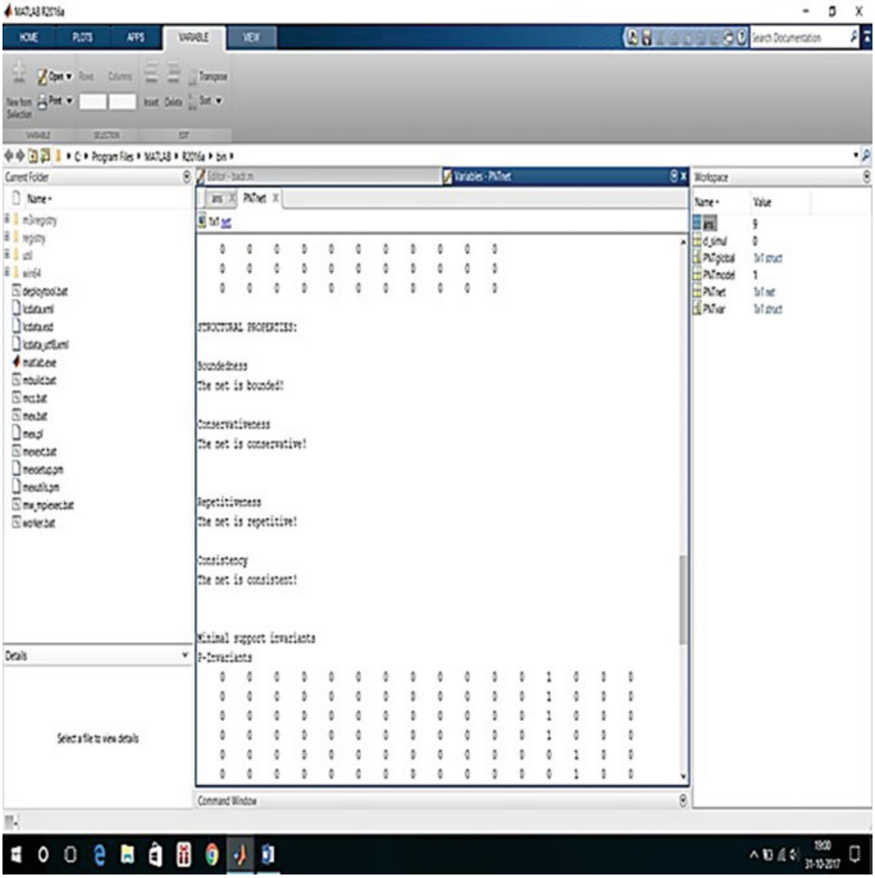

Fig. 28.5 Incidence matrix part 2

is given below. The population at time t is represented by variable s, with the initial population of random estimates as s (0).

Procedure GA

$t = 0$;
initialize $s(t)$;
evaluate $s(t)$;
begin
$t = t + 1$;
select $s(t)$from $s(t-1)$
reproduce pairs in $s(t)$
evaluate $s(t)$;

Step 4.2: Population evaluation

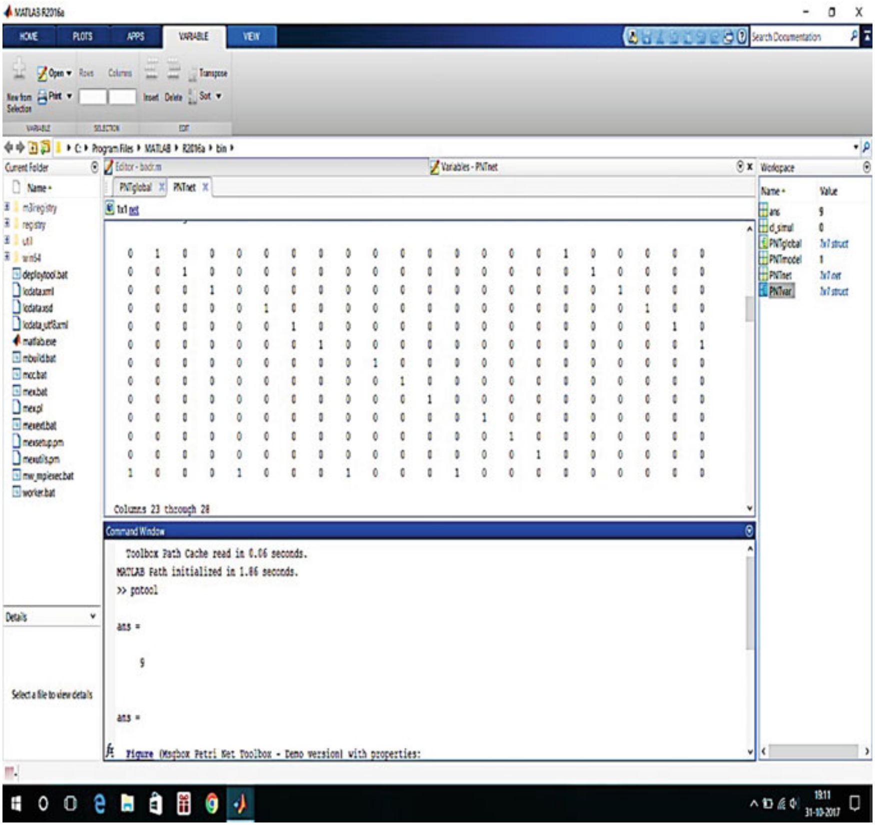

Fig. 28.6 Command window answer

The fitness parameter [fit (*c*)] considered is the makespan time. The initial population is evaluated for makespan.

Step 4.3: Selection of new population

The process of selecting the chromosomes to represent the next generation has the following steps:

1. Conversion of the fitness parameter values to a new fitness value [new_ fit (*c*)]. A fitness function considered here, which is suitable for minimization objective is

$$\text{new fit}(c) = 1 - \text{fit}(c)/F \tag{28.1}$$

where fit (*c*) = makespan time corresponding to chromosome.
   F is the sum of the fitness parameter of all chromosomes.

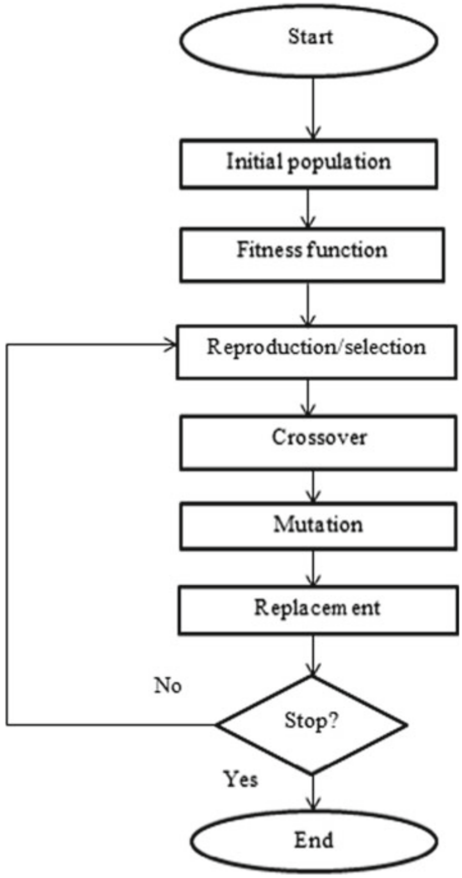

Fig. 28.7 Flow chart for GA. Reproduced from Munibabu et al. [5]

Table 28.4 Chromosome representation for four scheme (Reproduced from [1])

S. No.	Representation	Generation	String length
1	Job-based representation	Job to be processed at a particular instant	Number of jobs
2	Operation-based representation	An operation that is context-dependent	Number of operations
3	Priority rule-based representation	Priority dispatching rule	Number of operations/machine
4	Preference-list-based representation	A string of symbol with length of number of jobs	Number of machines

$$F = \sum_{c=1}^{\text{pop\_size}} \text{fit}(C) \tag{28.2}$$

To have more copies of chromosomes with the smallest objective function value, the ratio fit ©/F is subtracted from 1.

2. Conversion of the new fitness parameter to an expected frequency of selection [$p(c)$].

$$P(c) = \text{new\_fit}(c) / \sum_{c=1}^{\text{pop\_size}} \text{fit}(c) \tag{28.3}$$

3. Calculation of the cumulative probability of survival (cp (c)). A random selection procedure, which is explained below, generates the next population of the same size. A random number between 0 and 1 is obtained and a chromosome c is selected which satisfies the following condition. This selection process is repeated several times equal to the population size. The method used here is more reliable in that it guarantees that the fittest individuals will be selected and that the actual number of times each is selected will be expected frequency ± 1. This procedure enables the first chromosome to have multiple copies and the worst will die off [1, 5].

The fitness function calculated here is the output from the Gantt chart. Expected count, new fitness function is given by, $1 - (13/47)$.

Probability of selection is given by (0.0.7234/2.9999).

The string number here represents the number of job.

Step 4.4: Selection of parents for crossover

Once the makespan is calculated for the different chromosomes, tournament selection is done to filter out those chromosomes which have better makespan values (in this case lesser makespan value) and these chromosomes are then selected to undergo crossover and mutation. In this problem, the tournament size has been taken to be two. Two chromosomes are randomly chosen from the population and their makespan values are compared, whichever chromosome has a lesser makespan value is deemed the winner. After the parents have been chosen, crossover is applied to them.

Chromosomes reproduce among themselves according to a predefined crossover probability. The first child is generated by taking the first portion, from the beginning of the chromosome until the crossover point, of the first parent and the second portion of the second parent, from the crossover point until the end of the chromosome.

Step 4.5: Mutation

Generate the random number, for all chromosomes, if $r \leq \text{pm}$ mutate the chromosome, where pm is the probability of mutation. Mutation is a diversification strategy used mostly to avoid the repetition of chromosomes. The mutation followed in this paper is the order-based mutation (OBM). In this, we pick two loci in the chromosome at random and exchange their genes. For example, 3 0 1 2 is mutated as 3 2 1 0.

Step 4.6: Termination

The above process will be repeated for a fixed number of generations.

The working of the genetic algorithm is explained in Step 4. The GA parameters considered are given in Table 28.5. The parameters used in GA are

Initial population, corresponding fitness values (population evaluation), selection of chromosomes for the next generation, and chromosomes in the mating pool for the considered example are given in Table 28.6. The parents selected for crossover from the mating pool and corresponding offsprings after crossover, chromosomes selected for mutation, new population after mutation, and fitness values for the considered example are given in Table 28.7.

Table 28.5 Parameters used in GA

Parameters	Particulars	Remarks
Population size	A fixed number of individual form the GA population	10
Crossover rate	The probability for an individual to perform crossover	0.8
Mutation rate	The probability for an individual to perform mutation	0.05

Table 28.6 Evaluation and reproduction phase

String No	Initial position	Fitness value	Expected count	Probability of selection	Cumulative probability	Random No	String No.	Mating pool
0	1203	13	0.7234	0.2411	0.2412	0.22	2	3021
1	2130	9	0.8085	0.2695	0.5107	0.02	1	2130
2	3021	14	0.7021	0.234	0.7447	0.36	3	0312
3	0312	11	0.7659	0.2553	1	0.22	2	3021
		47	2.9999					

Table 28.7 Population cross over

Mating pool	Random No.	Selected over crossover	Population after crossover	Random mutation	Population after mutation	Fitness value
3021	0.8900	Yes	3012	0.5000	3210	16
2130	0.7300	No	2130	0.3214	2130	9
0312	0.6200	No	0321	0.2200	0321	11
3021	0.8900	No	3021	0.0300	3021	14

The best makespan and corresponding schedule are given below for the example problem for the job-based representation schemes considered in this example. The best makespan obtained is 9 and Best schedule: 2-1-3-0.

28.4 Conclusions

The scheduling is one of the important aspects of the smooth functioning of flexible manufacturing system. In the present work combined approach of Petrinet and genetic algorithm is used to produce near to optimal result. Here only one performance parameter is considered that is makespan. Due to good modeling power, Petri net is used as this feature is required to model a real manufacturing system. Genetic algorithms are powerful optimization tool and gives better result for combinatorial problems. Out of the four representations scheme the job-based representation is addressed for the optimum makespan. The hybrid approach plays a vital role in scheduling the system and optimizing the makespan.

In the future, the focus must be on a more complex manufacturing system with different representation schemes and with minimum number of constraints. Also, the focus on multi-objective optimization with conflicting objectives/performance measures will be addressed.

Annexure

```
Population population = new Population();
    Individual fittest;
    Individual secondFittest;
    int generationCount = 0;

    public static void main(String[] args) {

        Random rn = new Random();

        GA demo = new GA();

        //Initialize population
        demo.population.initializePopulation(10);

        //Calculate fitness of each individual
        demo.population.calculateFitness();

        System.out.println("Generation: "

+ demo.generationCount + " Fittest: "

+ demo.population.fittest);

        //While population gets an individual with maximum
fitness
```

```
        while (demo.population.fittest < 5) {
      ++demo.generationCount;

            //Do selection
            demo.selection();

            //Do crossover
            demo.crossover();

            //Do mutation under a random probability
            if (rn.nextInt()%7 < 5) {
                demo.mutation();
            }

            //Add fittest offspring to population
            demo.addFittestOffspring();

            //Calculate new fitness value
            demo.population.calculateFitness();

            System.out.println("Generation: "

+       demo.generationCount       +       " Fittest: "       +
demo.population.fittest);
        }

        System.out.println("\nSolution found in generation "  +
demo.generationCount);
        System.out.println("Fitness: "

+ demo.population.getFittest().fitness);
        System.out.print("Genes: ");
        for (int i = 0; i < 5; i ++) {

System.out.print(demo.population.getFittest().genes[i]);
        }

        System.out.println("");

    }

    //Selection
    void selection() {

        //Select the most fittest individual
        fittest = population.getFittest();

        //Select the second most fittest individual
        secondFittest = population.getSecondFittest();
    }

    //Crossover
    void crossover() {
        Random rn = new Random();

        //Select a random crossover point
        int crossOverPoint = rn.nextInt
```

```
(population.individuals[0].geneLength);

        //Swap values among parents
        for (int i = 0; i < crossOverPoint; i ++) {
            int temp = fittest.genes[i];
            fittest.genes[i] = secondFittest.genes[i];
            secondFittest.genes[i] = temp;

        }

    }

    //Mutation
    void mutation() {
        Random rn = new Random();

        //Select a random mutation point
        int mutationPoint

= rn.nextInt(population.individuals[0].geneLength);

        //Flip values at the mutation point
        if (fittest.genes[mutationPoint] == 0) {
            fittest.genes[mutationPoint] = 1;
        } else {
            fittest.genes[mutationPoint] = 0;
        }

        mutationPoint

= rn.nextInt(population.individuals[0].geneLength);

        if (secondFittest.genes[mutationPoint] == 0)

{
            secondFittest.genes[mutationPoint] = 1;
        } else {
            secondFittest.genes[mutationPoint] = 0;
        }
    }

    //Get fittest offspring
    Individual getFittestOffspring() {
        if (fittest.fitness > secondFittest.fitness) {
            return fittest;
        }
        return secondFittest;
    }

    //Replace least fittest individual from most fittest

offspring
    void addFittestOffspring() {

        //Update fitness values of offspring
        fittest.calcFitness();
        secondFittest.calcFitness();
```

```
        //Get index of least fit individual
        int leastFittest

Index = population.getLeastFittestIndex();

        //Replace least fittest individual from most fittest

offspring
        population.individuals[leastFittestIndex]          =
getFittestOffspring();
    }

}

//Individual class
class Individual {

    int fitness = 0;
    int[] genes = new int[5];
    int geneLength = 5;

    public Individual() {
        Random rn = new Random();

        //Set genes randomly for each individual
        for (int i = 0; i < genes.length; i ++) {
            genes[i] = Math.abs(rn.nextInt() % 2);
        }

        fitness = 0;
    }

    //Calculate fitness
    public void calcFitness() {

        fitness = 0;
        for (int i = 0; i < 5; i ++) {
            if (genes[i] == 1) {
      ++fitness;
            }
        }
    }

}

//Population class
class Population {

    int popSize = 10;
    Individual[] individuals = new Individual[10];
    int fittest = 0;

    //Initialize population
    public void initializePopulation(int size) {
        for (int i = 0; i < individuals.length; i ++) {
            individuals[i] = new Individual();
        }
```

```
    }

    //Get the fittest individual
    public Individual getFittest() {
        int maxFit = Integer.MIN_VALUE;
        int maxFitIndex = 0;
        for (int i = 0; i < individuals.length; i ++) {
            if (maxFit <= individuals[i].fitness) {
                maxFit = individuals[i].fitness;
                maxFitIndex = i;
            }
        }
        fittest = individuals[maxFitIndex].fitness;
        return individuals[maxFitIndex];
    }

    //Get the second most fittest individual
    public Individual getSecondFittest() {
        int maxFit1 = 0;
        int maxFit2 = 0;
        for (int i = 0; i < individuals.length; i ++)

{
            if (individuals[i].fitness > individuals[maxFit1].

fitness) {
                maxFit2 = maxFit1;
                maxFit1 = i;
            } else if (individuals[i].fitness                >
individuals[maxFit2].fitness) {
                maxFit2 = i;
            }
        }
        return individuals[maxFit2];
    }

    //Get index of least fittest individual
    public int getLeastFittestIndex() {
        int minFitVal = Integer.MAX_VALUE;
        int minFitIndex = 0;
        for (int i = 0; i < individuals.length; i ++) {
            if (minFitVal >= individuals[i].fitness) {
                minFitVal = individuals[i].fitness;
                minFitIndex = i;
            }
        }
        return minFitIndex;
    }

    //Calculate fitness of each individual
    public void calculateFitness() {

        for (int i = 0; i < individuals.length; i ++) {
            individuals[i].calcFitness();
        }
        getFittest();
    }

}
```

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Chapter 29
Technological Innovativeness and Manufacturing Performance in Indian Manufacturing SMEs: Some Policy Implications

Anup Chawan and Hari Vasudevan

Abstract As the technological innovativeness of firms is one of the major contributors to a country's overall competitiveness, it is important to understand as to how effectively it can influence the manufacturing performance of firms. The primary objective of this research study was to understand the impact of the government initiative "Make in India" in boosting the technological innovativeness of Indian manufacturing small- and medium-scale Enterprises (SMEs), thereby improving the firm's manufacturing performance. The secondary objective of the research study was to understand the role of the government in improving the technological capabilities of Indian manufacturing SMEs. The research methodology adopted in this paper is in the form of an exploratory qualitative interview-based study. Primary data for the study was collected from thirty-eight mold manufacturing SMEs in the plastic injection molded products sector. A detailed literature review was conducted, and accordingly, a conceptual frame work was proposed. It was found that the ease of making technological alliances would play a very important role in making the Indian manufacturing SMEs globally competitive. Technological alliances with special focus on foreign machine manufacturers have been found to be the need of the hour. Some personal interviews conducted as well as few online responses collected revealed that the current Indian Government's initiative is boosting the technological innovativeness of the SMEs, involved in the mold manufacturing sector. The technology adoption rate of Indian mold manufacturers has also been found to have increased considerably. The findings of the study have important implications for the policy makers as well as SMEs, engaged in the manufacturing sector.

Keywords Technological innovativeness · Manufacturing performance · Make in India · SMEs

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Nomenclature

CAD	Computer-aided design
CAM	Computer-aided manufacturing
CAE	Computer-aided engineering
EDM	Electrical discharge machining
CNC	Computer numerical control
VMC	Vertical milling center
OEM	Original equipment manufacturer

29.1 Introduction

Innovativeness is generally defined as a firm's tendency and ability to introduce innovations [1, 2]. Firm innovativeness plays a vital role in enabling the survival, growth, and competitiveness of the firms [3]. However, the nature of firm innovativeness is understood to be quite different in developed and developing countries. Developed countries are more concerned with how innovation networks and knowledge networks boost technological innovations in their country. In developing countries, the nature of technological innovation is considered to be more of incremental rather than radical as reported by various researchers. In this context, many quantitative studies have been conducted by researchers, focusing on factors associated with innovation, firm innovativeness, and their influences on firm performance. However, there have hardly been any studies done on the technological innovativeness to explore its relationship with the manufacturing performance in the SMEs in a country like India.

In India, the business involving SMEs was not given much attention prior to the liberalization started in the 1990s [4]. However, the current Indian Government has admitted this sector in its five-year plan, considering the importance, the SMEs hold in the economy [5]. In this context, four different studies were undertaken, by the Institute of Economic Growth (IEG), Confederation of Indian Industry (CII), Department of Science and Technology (DST), and The Administrative Staff College of India (ASCI), so as to understand the strengths of SMEs and also to upgrade their potential [6]. Two research projects were also carried out at the Indian Institute of Science (IIS), sponsored by the Department of Science and Technology (DST) and Government of India, focusing on innovation in the state of Karnataka [4]. To evolve a framework for the measurement of innovation in the Indian context, the first pilot national innovation survey was conducted in 2009 by the Department of Science and Technology (DST) [7]. Subsequently, the first National Innovation Survey was launched by the Department of Science and Technology (DST), Government of India, in 2010–11 [8]. The work initiated by the present-day government of India has created a keener interest in promoting innovation. Initiatives like Make in India, Cluster Development Program, and Credit Linked Capital Subsidy Scheme have also been getting tremendous response from the Indian manufacturing SMEs [9, 10].

Technological innovativeness strengthens the competitiveness of a nation, thereby securing extended economic growth by reinforcing employment and income generation [6]. Manufacturing is one of the most important sectors in the SMEs segment in India. Competitiveness requires innovations, and many SMEs have realized the importance of innovations and implemented it successfully, while others are working on it. Most of them face problems, while implementing innovations in their perspective areas. There are many SME clusters in India today, and around six thousand different types of products are manufactured in India [11]. It is known that the SMEs play a vital role in the economy of developing and developed countries. SMEs are also known to be the core contributors to the overall process of innovation [12]. It is however found that there is very less information available on the prerequisites of technological innovation among the international SMEs [13]. Researchers around the world have also found that the key issue facing SMEs relates to how they can foster effective innovation [14]. It is also found that the technological innovation has the potential to stimulate growth of SMEs [15].

Industry associations like Tool and Gauge Manufacturers Association (TAGMA) and All India Plastics Manufacturers Association (AIPMA) have played a prominent role in the progress of the Indian plastic industry and most of the plastic industries fall under the SME sector. Tool and Gauge Manufacturers Association (TAGMA) has been dynamic in addressing the issues, challenges, and opportunities for mold and die manufacturers in the context of raw materials, finance, and training [16]. Institutes like Central Institute of Plastics Engineering and Technology (CIPET), Chennai, Nettur Technical Training Foundation (NTTF), Indian Plastic Institute (IPI), and Shri Bhagubhai Mafatlal Polytechnic in Mumbai have also played a significant role in shaping the future of the Indian plastic industries.

29.2 Literature Review

29.2.1 Technological Innovativeness

According to Wang and Ahmed [17], technological innovativeness is incorporated in either the product innovativeness that embodies the unique, novel technological content in new products, or the process innovativeness, that exploits new equipments out of technological advancement. Technological innovativeness in this study is expressed in terms of the extent to which firms invest in developing proprietary technologies and that adopts technologies developed by other organizations as well as firm's emphasis on technological innovation and its intensity on exploring technological development in their industry [18].

29.2.2 Firm Performance

Innovativeness results in better firm performance. This has been confirmed by several scholars. Many scholars have studied different aspects of innovation and innovativeness in relationship to the firm performance, focusing on profitability, sales, etc.

This study focuses on the manufacturing aspect of firm performance. Manufacturing performance is a key determinant of a firm's success [19]. Quality, cost, flexibility, and delivery are the major dimensions of manufacturing performance [20, 21]. Flexibility here refers to the product flexibility and volume flexibility as per customer demands [22]. It has been known from the literature that the manufacturing flexibility has not been much investigated in the SMEs [23]. In this study, these four parameters were considered, as they were found to be the most pertinent in the context of the research [24].

29.2.3 Technological Alliances

Gulati [25] defined strategic alliances as voluntary agreements between firms involving exchange, sharing or co-development of products, technologies, or services. Alliances provide a platform to share capabilities among the partners [26, 27]. Gils and Zwarts [28] found that the strategic alliances help in knowledge acquisition and learning processes of SMEs, thereby improving the firm performance. According to few researchers, technological collaboration improves the firm innovativeness [29]. Moreover, few other researchers have concluded that the research and development alliances enhance the technological innovations [30].

29.3 Research Gap Identification

Technological innovativeness is not a new concept for bigger firms in India, but its relevance in manufacturing SMEs still remains unexplored. A deeper understanding is therefore required to know as to how the SMEs reposition themselves in competitive markets by making changes in their technological capabilities. The proactive role of current government motivates one to study the impact of its initiatives on the firm performance. Moreover, no study has been done so far in exploring the relationship between technological innovativeness and manufacturing performance in the SMEs, especially in the context of the government initiative, "Make in India".

Based on the extant literature review done as part of this study, the following research questions to be put up to the respondents were framed and they are:

[RQ1] Do you think that the "MAKE IN INDIA" initiative will boost the technological innovativeness of Indian manufacturing SMEs, thereby improving the firm's manufacturing performance?

[RQ2] In your opinion, what should be the role of the government in improving the technological capabilities of Indian manufacturing SMEs?

29.4 Research Methodology

29.4.1 Research Approach

This research is based on an exploratory qualitative interview study [31, 32]. "Make in India" initiative is an ongoing movement, and in this regard, a quantitative research approach is not found suitable and also very pertinent to the context. A qualitative research is the right approach in such situations, i.e., to get the questions answered through in-depth interviews, via direct communication [33].

29.4.2 Survey Instrument

A covering letter explaining the significance of research work was communicated to the respondents. A survey questionnaire was developed focusing on the primary and secondary research objectives with the help of relevant literature review and expert's guidance. The questionnaire consisted of demographic information about the SMEs, which included their name, year of establishment, number of employees, and the sector type. The respondent's profile included name, designation, qualification, experience, and the contact information.

The questionnaire consisted of open-ended questions to gain insights on SME's perceptions on the government initiative "Make in India". Technological innovativeness and manufacturing performance were measured using a previously tested standard scales in this study. The details of the scales used are given in the appendix. Technological innovativeness consisted of five measurement items, and manufacturing performance consisted of four measurement items. The survey questionnaire was supplemented with survey related key definitions.

29.4.3 Data Collection

The SMEs selected for this study were randomly taken from the Tool and Gauge Manufacturers Association's (TAGMA) directory and Plast India exhibition directory.

Table 29.1 Respondents' experience in years

Experience range	No.	Percentage
Less than 5	02	5
5–10	03	8
11–20	12	32
21–30	17	45
31–40	03	8
41–50	01	2

Table 29.2 Respondents' qualification

Qualification	No.	Percentage
Post graduate	07	18
Graduate	06	16
Diploma	18	48
Other	07	18

The purpose of the study was explained to the respondents through a telephonic communication. Personal face-to-face interviews were conducted in manufacturing units as per the respondent's availability and time. Personal interviews were conducted in 18 mold manufacturing SMEs. Majority of the surveys were conducted in Andheri and Vasai industrial estates in Mumbai and Palghar district. All the personal interviews lasted for about 30–45 min. Also, the responses were collected by conducting an online survey and they were done in 20 mold manufacturing SMEs. Several follow-ups were done to collect responses through the online medium. Online survey medium gave the respondents the flexibility to answer the questions as per their convenience. Around 50 SMEs were initially selected for the study, out of which 12 refused, because of their other priorities. A total of 38 responses were received from mold manufacturing SMEs, and the response rate was 76%.

Majority of the respondents were directors of the firm, having sound knowledge of manufacturing molds for plastic injection molded products. The respondents' experience ranged in years and is given in Table 29.1. Majority of the respondents had experience in the range of 11–20 and 21–30 years. The respondent's qualification details are given in Table 29.2. Majority of the respondents were diploma holders. Many of them had done their diploma in plastic engineering, tool and die making and mechanical engineering from reputed institutes.

29.4.4 Method of Analyses

There are many approaches to interview analyses. The first step to interview analyses was based on condensation of meaning approach [34]. While conducting personal interviews, key aspects were noted down in short wordings. The most repetitive wordings were further noted. Further codes were generated based on these wordings. Coding was done manually. Coding here refers to labeling the data in the form of a code, which is of potential significance [35]. Code helps to generate categories [36]. The relationships were developed among categories and have resulted in a conceptual framework. Also the discussion in the context of challenges and implications are reported in the secondary research findings.

29.5 Research Findings

29.5.1 Primary Objective

In-depth interviews and online responses revealed that the "Make in India" initiative is boosting the technological innovativeness of the mold manufacturers, thereby improving their manufacturing performance. Out of 38 mold manufacturers, 31 expressed positive perceptions on the government initiative, "Make in India". The government initiative on getting the foreign technological companies set up their manufacturing units in India has created a huge demand for the mold manufacturers from the automobile and electronics industries. To cater to the needs of these industries, SMEs have upgraded in terms of four facilities. The first is using latest CAD, CAM, and CAE software for designing, simulation, and analysis purpose. Secondly, they have upgraded their manufacturing infrastructure in terms of EDM, CNC, VMC, and die spotting machines. The third aspect was in terms of using the mold inspection instruments of different types. The fourth aspect was in terms of trial injection molding machines of different tonnage capacity. This upgradation in all the aspects of manufacturing facilities has improved their manufacturing performance in terms of cost, quality, flexibility, and on-time delivery.

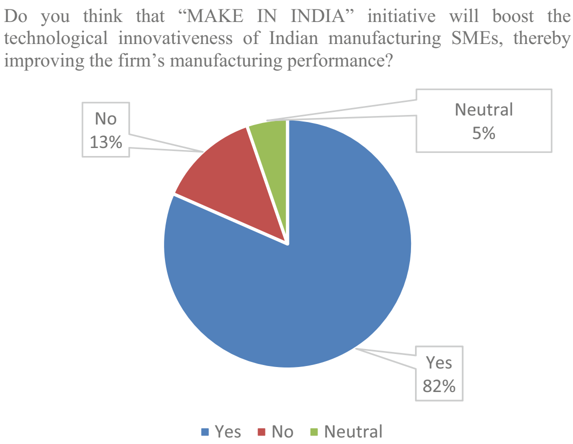
It was found that the "Make in India" drive initiated by the Government of India has helped to accelerate India's manufacturing sector, especially the SMEs, and has become instrumental in shaping the technological innovativeness in manufacturing firms. It has also opened the door for a number of opportunities for the youths of India and has encouraged them for creating start-ups.

The respondent's perception on "Make in India" initiative in the context of the primary research objective is as shown in Fig. 29.1 in the form of a pie chart.

82% of the respondents expressed their positive perceptions on the initiative. 13% of the respondents expressed that still needs to be the ground-level work done to see the impact of the initiative. 5% of the respondents did not answer, which indicated a neutral response.

The government aims to make India a global manufacturing hub for Electric Vehicles (EVs), and in this regard, an effective scheme has been framed [37]. The interior and exterior design of the vehicle is also expected to change effectively. This would create the requirement of new molds for automotive plastic components, and a huge demand is expected in the coming five years.

Fig. 29.1 Perceptions of SMEs on "Make in India Initiative" in the context of primary research objective



Based on the study, a conceptual framework was proposed as shown in Fig. 29.2, explaining the need for government support for ease of forming technological alliances, facilitating the technological know-how and also the training.

Research institutions and industry associations are expected to generate support for the technological alliances. Technological alliances with a special focus on machine manufacturers are required and are expected to make India the largest hub for the mold manufacturers.

Two of the experts closely associated with the molding industry in the context of our primary research objective also observed that:

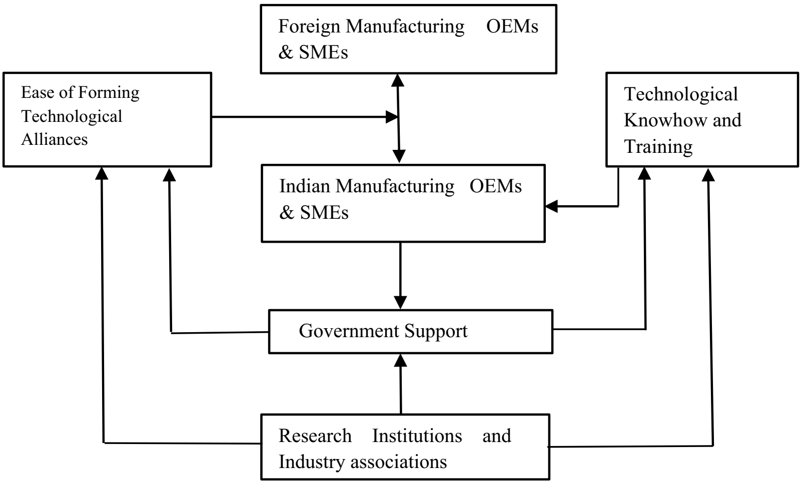


Fig. 29.2 Conceptual framework

According to the first expert, “Government can be a coordinator in the group comprising SMEs, research institutions, institutions of higher learning and society of which SMEs are part of, where the latest technological inputs are made available to SMEs”.

And the second expert concurred with the observation of the first one and added, “Yes, if collaborated with world leaders in manufacturing”.

29.5.2 Secondary Objective

In this study, six important challenges were observed, which included technological alliances, technological awareness, raw material required, quality of machines, training, and financial aspects. The details related to the challenges and implications are represented in Table 29.3. These challenges can be addressed with the following recommendations:

i. **Technological alliances**: It has been observed that the machineries required for precision manufacturing of molds are mostly imported in India. Forming technological alliances with those machine manufacturers could play a very important role in laying the base for internal setup of the machineries for mold manufacturers to be made in India, through alliances like joint ventures technology sharing and research and development contracts.

Table 29.3 Challenges and implications

Sr. No.	Challenges	Implications
1	Technological alliances	Forming key alliances to enhance technological capabilities of Indian machine manufacturers
2	Technological awareness	Giving awareness on latest technologies Exposure to Industry 4.0 practices
3	Raw material	Quality and quantity of steel required of mold steel not available in India, hence imported for which import duty should be less
4	Quality	Improvement in quality of Indian made EDM/CNC machines required
5	Training	Technical education system should be more practical to develop skilled people Emphasis on percentage of turnover invested in training the employees Training calendar for the employees
6	Financial	Import duty on machineries and equipments should be less % of Interest should be low as compared to China Provide direct subsidies to registered SMEs for technological upgradation

ii. **Technological awareness**: Technological awareness on latest technologies related to advanced die polishing machines, high-speed machines, measurement related like, white line scanning system, industry 4.0 practices and advanced hot runner systems, etc., is required. Provision of subsidized tours abroad for technology exposure and more exhibitions focusing on latest technologies would provide the platform for technological awareness among mold manufacturers through government scheme for SMEs.
iii. **Raw material**: The steel of particular grade and quality is hardly available in India, and hence mostly, it is imported. It was recommended by the mold manufacturers to make the import duty reduced for steel imported to make molds.
iv. **Quality**: A technology gap was observed between Indian and foreign machine manufacturers in terms of quality of EDM and CNC machines. Quality can be improved through technological alliances.
v. **Training**: The training-related challenges include the upgradation in syllabus of technical subjects at the high school level. SME owners should emphasize on the percentage of turnover invested in training the employees.
vi. **Financial**: It was seen that the mold manufacturing SMEs require a huge capital investment for the setup. Tax benefits given to the SMEs are seen comparatively less as compared to China. Subsidy must therefore be provided to procure higher technology.

The government should also emphasize on implementing the special technological equipment investment programs. Local software is needed to be developed for the mold manufacturers.

However, these challenges have also been addressed by TAGMA [16]. This increases the validity of the challenges addressed in the study.

Some of the respondents' opinion in the context of our secondary research objective are as follows:

> SMEs first look for making break-even in a competitive environment. Then comes the responsibility of making the firm consistently profitable by upgrading the technologies and skills. But for that, a suitable environment is to be created, whereby the SMEs can collaborate for the benefit of all to remain competitive in their respective fields. Government should sympathetically consider the financial constraints of SMEs to implement technological upgradation and assist them with a very low rate of interest.
>
> Exposure to international onsite visits to world class factories with a very short training (6–12 days) in such environment will be of great help.
>
> Government should reduce taxes on materials, which are not manufactured in India. Mold base material is made in India, but the core and cavity material only as imported material is available. Hence the mold manufacturing industry in India is not considered competitive globally.

One of the experts' comment on the subsidy policy is stated as follows:

List the Indian machinery manufacturers and compare their offered products with international competitors in similar fields. Then, the government can take a call on subsidies and duty free allowance for imports, especially in Tool and Mold making.

29.6 Conclusion

This study explored the current situation of mold manufacturers in India. The "Make in India" initiative has currently created a positive impact on the mindset of the Indian manufacturing SMEs. They have started identifying the products not made in India and the technological know-how required to manufacture them in India. The technology adoption rate has also increased lately.

More than 50% of the molds are being imported in India. But this percentage of imports is expected to decrease soon. The government initiatives have given a driving torque to make India a local hub for mold manufacturing. Increasing the import duty on imported molds and reducing the import duty on raw materials, latest machineries and equipments are required. Target should be to form technological alliances with at least five different machine manufacturers in five years. The conceptual framework developed forms the base for future research.

From this study, some policy implications are identified as follows:

1. Tax breaks to SMEs forming technological alliances with a special focus on research and development contracts and joint development agreements for fostering innovations.
2. Monitoring the number of technological alliances made by the manufacturing SMEs in different manufacturing domains.
3. Monitoring the nature of technological alliances so that further policies can be formulated based on the analysis.
4. Having a separate Web site exclusively for the manufacturing SMEs would be an advantage so that different types of technological alliances can be studied under a single window.
5. Reduction in the import duty on the purchase of steel mold material not available in India must also be emphasized upon.

However, the findings of this study are limited to mold manufacturers. The study does not cover the perceptions of machine manufacturers and OEMs in the context of the primary and secondary research objectives. The questions formulated in this research work can very well be utilized for the other manufacturing sectors too.

Appendix

Measurement Items

1. Technological Innovativeness

Sr. No.	Research questions	Scale type (5-Point Likert scale)	References
1.1	Your investment in developing proprietary technologies	1 = Decreased significantly 5 = Increased significantly	Zahra [38] Antoncic et al. [18]
1.2	Your emphasis on creating proprietary technology	1 = Decreased significantly 5 = Increased significantly	Zahra [38] Antoncic et al. [18]
1.3	Your adoption of technologies developed by other companies or industries	1 = Decreased significantly 5 = Increased significantly	Zahra [38] Antoncic et al. [18]
1.4	Your firm's emphasis on technological innovation	1 = Decreased significantly 5 = Increased significantly	Zahra [38] Antoncic et al. [18]
1.5	Your firm's intensity on exploring technological developments in your industry	1 = Decreased significantly 5 = Increased significantly	Zahra [38] Antoncic et al. [18]

2. Manufacturing performance

Sr. No.	Research questions	Scale type (ordinal scale)	References
2.1	How do you compare the quality of product conformance with that of your competitors	1 = Poor or low end of the industry 5 = Superior than average	Cua et al. [24], Gaur et al. [39]
2.2	How do you compare the cost efficiency with that of your competitors	1 = Poor or low end of the industry 5 = Superior than average	Cua et al. [24], Gaur et al. [39]
2.3	How do you compare the product delivery performance (on-time delivery) with that of your competitors	1 = Poor or low end of the industry 5 = Superior than average	Cua et al. [24], Gaur et al. [39]
2.4	How do you compare your plants volume flexibility and product flexibility with that of your competitors	1 = Poor or low end of the industry 5 = Superior than average	Cua et al. [24], Gaur et al. [39]

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